

**INVESTIGATION OF THE IONIC COMPOSITION OF
ADDIS ABABA DRINKING AND SURFACE WATERS**

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ABRAHA G/KIDAN

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ADDIS ABABA UNIVERSITY
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Abraha G/Kidan

DEPARTMENT OF CHEMISTRY
FACULTY OF SCIENCE

APPROVED BY THE EXAMINING BOARD


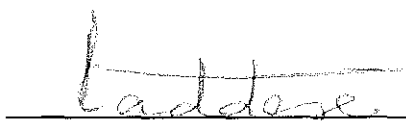
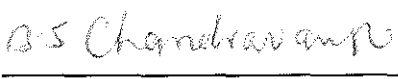
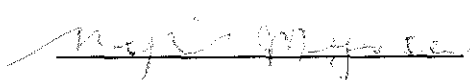
NAME	SIGNATURE
1. <u>Dr. B. HUNDHAMMER</u> RESEARCH ADVISOR	
2. <u>Dr. TADDESE WONDIMU</u> EXAMINER AND COORDINATOR	
3. <u>Dr. B. S. CHANDRAVANSHI</u> EXAMINER	
4. <u>Dr. NEGUSSIE MEGERSA</u> EXAMINER	

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TO MY PARENTS, BROTHERS AND SISTERS

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ABSTRACT

In Addis Ababa there are streams draining north-to-south such as the Tinishu Akaki, Kebena, Kechene, Kurtum and Yeka which receive the uncontrolled domestic sewage and industrial waste water discharges. In addition, intensive human activities are very common on these streams. To assess and characterize the quality of the Addis Ababa's water courses (surface and ground waters) the following parameters are monitored; namely, pH, alkalinity, COD, ammonia (for ground waters), nitrite, nitrate, phosphate, sulphate, chloride, silica, and fluoride for surface and ground waters. The major cations of surface waters and some ground waters are also monitored. The trace elements of surface waters are also detected using standard methods (Li, Be, V, Cr, Mn, Co, Ni, Cu, Zn, As, Rb, Sr, Se, Mo, Cd, Sn, Sb, Cs, Ba, Pb, Bi, Th and U).

The results of this study showed that the surface waters of Addis Ababa are highly contaminated by the nitrate, nitrite, phosphate, organic matter, sulphate and chloride due to the direct and indirect human activities. Springs found in the city are also highly contaminated by nitrates. Most of the ground waters (bore holes) of Addis Ababa are safe for drinking but those found at the southern extreme parts are contaminated .

1. INTRODUCTION

Water has always been vital to man's existence. Its uses for drinking, cooking, agriculture, transport, industry, and recreation show immediately the extent to which it is an integral part of our life. But it has long been recognized that its suitability for that purpose can be affected by other substances dissolved and/or suspended in the water [1, 2]. In the last few decades, a large and steady increase in the importance attaching to many aspects of water quality has been observed for all of the uses to which it is put. The number of impurities of concern has been continually increasing, and smaller and smaller concentrations of many substances are becoming of interest. Hence the concern with water quality is now a topic of importance in virtually all countries.

Many countries [1-3], including Ethiopia, have national legislation stipulating the maximum concentrations for specified impurities in drinking water and, often, other types of water. There has also been growing concern with the need to protect the environment from the various forms of pollution that may be increased by growing populations, industrialization, poor usage of waste disposal mechanisms, modern agricultural methods, etc.

In developing countries, like Ethiopia [4], the advent of industries in the big and small towns is an encouraging phenomenon when seen from the perspectives of economic and social development of the Federal Republic. Such development prospects, however, can be threatening and leading towards a horrifying environmental disaster, unless industrial wastes are avoided or monitored and disposed at recommended safelines.

One of the principal consequences of man's activities is water pollution and consequent deterioration of the aquatic environment. Traditionally, towns and cities are located on the banks

of rivers and streams or in close proximity to them. These water courses serve the needs of town dwellers for domestic water supply and unfortunately as well as waste disposal sites.

Until recently, the deterioration of water courses by pollution was not a serious problem because fairly small populations lived in scattered communities and the wastes dumped into rivers were subject to dilution and natural self-purification [5]. As human population increases and industrialization diversifies, the problem of water pollution becomes more critical. Industrialization leads to urbanization, with people leaving their land to work in the new factories.

Now a days the degree of water pollution in the city of Addis Ababa is threatening the quality of water and the health of the population. Domestic and municipal wastes are dumped untreated into the rivers and streams because the sewage transport system in the city is undeveloped and also industrial effluents are discharged to the streams or the aquatic environments [6].

A study of water pollution, which deteriorates water quality, such as this should begin with the definition of the term. Welber [7] defines water pollution rather philosophical as any influence, whether physical or chemical, that affects the natural conditions or the intended use of water. Similarly, Mara [8] defines a river or stream as polluted when its quality has deteriorated to such a level that it has no longer suitable for its intended purpose in the same way as Welber.

From the above definitions, it is clear that the perceptions of water pollution depends primarily on the ultimate use to which the water in question is to be put. Water which might be considered unpolluted or satisfactory for certain recreational uses might very well be considered polluted or unsatisfactory for drinking purposes. Such definitions are therefore subjective and

probably too broad to be useful. There is no doubt, however, that at present the most serious pollution is the direct result of human activity, i.e. direct discharges of effluent into rivers and streams.

By definition, environmental pollution is the unfavorable alteration of our surroundings, wholly or largely as a by-product of man's activities through direct or indirect effects of changes in energy patterns, radiation levels, chemical and physical constituents and abundance of organisms. These changes may affect man directly through his supplies of water and of agricultural and other biological products. Accordingly, water pollution in particular is defined by Hynes [9] as any impairment of the suitability of water for any of its beneficial uses, actual or potential, by man-caused changes in the quality of water.

According to Mallanby [10] and Bradley [11] impurities resulting from human activities are wastes of animal or human origins which contain bacteria and sometimes viruses, run-off from farms, domestic wastes, industrial wastes and oil pollution such as that resulting from discharging engine oil into rivers, seas and oceans. Sewage effluent is one of the greatest source of the organic materials which enters streams and rivers. A large portion of it is organic in nature, since domestic sewage is waste originating from toilets, wash basins and kitchens [12]. Most of the organic matter from the industry comes from manufacturing process [12]. The industries producing effluent containing substantial amounts of organic wastes are food processing and brewing, dairy, meat processing, tanning, textile and pulp and paper making industries [13]. In cities and towns, the run-off from garages, factories, fuel stations, laundries, offices, houses, and roads can result in sever pollution. Farm effluents are also additional source of organic pollutants to receiving waters [13].

Removal of oxygen is one of the most biologically significant impacts of organic matter

on receiving water. Dissolved oxygen content is known to decline in streams below sewage out falls [9]. Pittet [14] has pointed out that most organic matter both natural and synthetic can serve as food for micro-organisms. When such wastes are discharged to a river, the organic matter they contain is attacked by naturally occurring micro-organisms with oxidation of the material at the expense of oxygen dissolved in the river water. The degree of deoxygenation depends on a number of factors [15] such as the dilution that occurs when the effluents mixes with the streams, the nature of the organic material, the total organic load in the river, temperature, the extent to which reaeration occurs from the atmosphere, the dissolved oxygen in the stream and the number and types of bacteria in the effluent.

Streams polluted by oxidizable organic effluents undergo self-purification, which is manifested by an increased mineralization of the organic matter. The process of mineralization, particularly nitrogen and phosphorus containing compounds, is discussed by Hynes [16]. When organic matter decomposes, ammonia and phosphate are released from it and, as oxidation proceeds, the ammonia is changed first into nitrite and then into nitrate.

Many investigators including Venkateswarlu *et. al* [17] have reported that organic pollution tends to increase the nitrate and phosphate content of a stream. Lemly [18] has also reported similar observations, i.e. rivers with high organic matter are rich in nitrates and phosphates.

Organic pollution carries organisms which are harmful to human health. The possible means of human exposure are through swimming, drinking or eating food such as vegetables, crops irrigated by, or fish obtained from, polluted waters [19]. A water supply with a high nitrate level present yet another potential health risk. According to Mason [13], infants under six months of age may develop methemoglobinemia, a disease involving nitrate which reduces the

oxygen carrying capacity of the blood. The ailment usually occurs when the water may become critical on boiling and, furthermore, cow's milk itself may be the cause when the water drunk by the cow contain a high content of nitrate [20].

The worlds water supply is found in five parts of the hydrologic cycle [21-22]. A large portion of water is found in the oceans. Another fraction is present as water vapor in the atmosphere (clouds). Some water is contained in the solid state as ice and snow. Surface water is found in lakes, streams and reservoirs. Ground water is located in aquifers underground.

The water source that humans use is primarily fresh surface water and ground water. Ground water and surface water have appreciably different characteristics. Many substances either dissolved in surface waters or become suspended in its way to the ocean. Surface water in a lake or reservoir that contains essential mineral nutrients may support a heavy growth of algae. Surface water with a high level of biodegradable organic material, used as food by bacteria, normally contain a large population of bacteria. All these factors have a potential profound effect upon the quality of surface waters. Ground water may dissolve minerals from the formation through which it passes. Most micro-organisms originally present in ground water are gradually filtered out as it seeps through mineral formation. Occasionally, the content of undesirable salts may become excessively high in ground water, although it is superior to surface water as a domestic water resources.

Therefore, the determination of water quality has gained considerable attention in recent times. There is an increasing need for a simple, rapid and reliable method of assessing the degree of purity or contamination of waters. Monitoring of the quality of water for safe use in the case of ground water, spring water and surface water from streams, rivers or lakes for use as drinking, industrial or other purposes requires a wide range of continuous checks on hygienic, physical,

chemical, bacteriological and biological factors.

Addis Ababa is densely populated area. In the city there is a poor waste disposal mechanisms and there is an encouraging phenomenon in the advent of industries. Hence, there is a personal belief that the quality of water in the city and its surroundings is deteriorating. This also threats to the health of population. Therefore, the main objectives of this study are to appreciate the quality of surface and ground waters of Addis Ababa and its surroundings and to develop an environmental awareness of the population as well as institutions and governmental authorities. Putting in more specific manner the following parameters are measured : pH, chemical oxygen demand (COD), alkalinity, ammonia, nitrite, nitrate, phosphate, sulphate, chloride, sulfide, fluoride, major cations and some trace elements (Na, K, Ca, Mg, Li, Be, V, Cr, Mn, Co, Ni, Cu, Zn, As, Rb, Sr, Se, Mo, Cd, Sn, Sb, Cs, Ba, Pb, Bi, Th, and U).

2. DESCRIPTION OF THE STUDY AREA

Addis Ababa is located $9^{\circ}3'$ N latitude and $38^{\circ}43'$ E longitude. The city has an average diameter of 20 km covering a total area of about 400 km² and elevations ranging from 2,700 m in the north to 2,200 m in the south with a population of about 3 million. City development in the north is limited by the steep slopes and rugged topography of the Entoto Range and most new development is now occurring in the south of the city on gently south-ward-sloping, rolling terrain [23-25].

In the city there are streams draining north-to-south such as the Tinishu Akaki, Bantiyketu, Ginfle, Kebena, Kechene, Kurtume, etc. These streams receive the uncontrolled domestic sewage and industrial wastewater discharges. Intensive human activities are very common on these streams. Some of the public toilets around the city are shown in Figure A1. Most of them are concentrated in the central areas and a few in the peripheral part of the city. These public toilets are not connected to the sewer system of the city.

Addis Ababa city is typically a transitional geology between two regional geological blocks [23,25](Figure 1). These are :

- I. The rift valley running NE-SW within about 35 km of the city and,
- II. The Western Ethiopian plateau which ranges from Entoto to the western low lands of Ethiopia along the Sudanese border, and from Omo in the south to Asmara in the north.

The two units are distinctly different in many ways. The main rock types in the rift valley are acidic rock groups while basic rocks dominate in the plateau. Plateau rocks are older tertiary rocks while rift valley rocks are mainly quaternary. However, it should be pointed out that there

are some rock mixtures found away from the main groups. Addis Ababa is exactly on the boundary of the main blocks and therefore all major rocks are found, both acidic and basic. According to Vernier *et. al* [26], there are four major rock units found in Addis Ababa and its surroundings.

Older basic rocks which out crop in the upper part of Entoto ridge and continue north, beyond the water divide, towards the Blue Nile basin. These are the basalts of the western plateau.

Older acidic and intermediate rocks, are mainly occur at the top and in the foot-hills of Entoto. Rydites, trachytes and several episodes of pyroclastic materials are mainly present.

Basic rocks, originate from the same Entoto volcanism, which cover the main part of the city towards the south. Several sequences of different basalts occur for a total thickness of many hundreds of meters as is confirmed by the stratigraphal section.

Younger volcanic rocks, belonging to the recent volcanism of Wechecha, Furi and Yerer over lie the old basalts mostly in the southern and western part of the town.

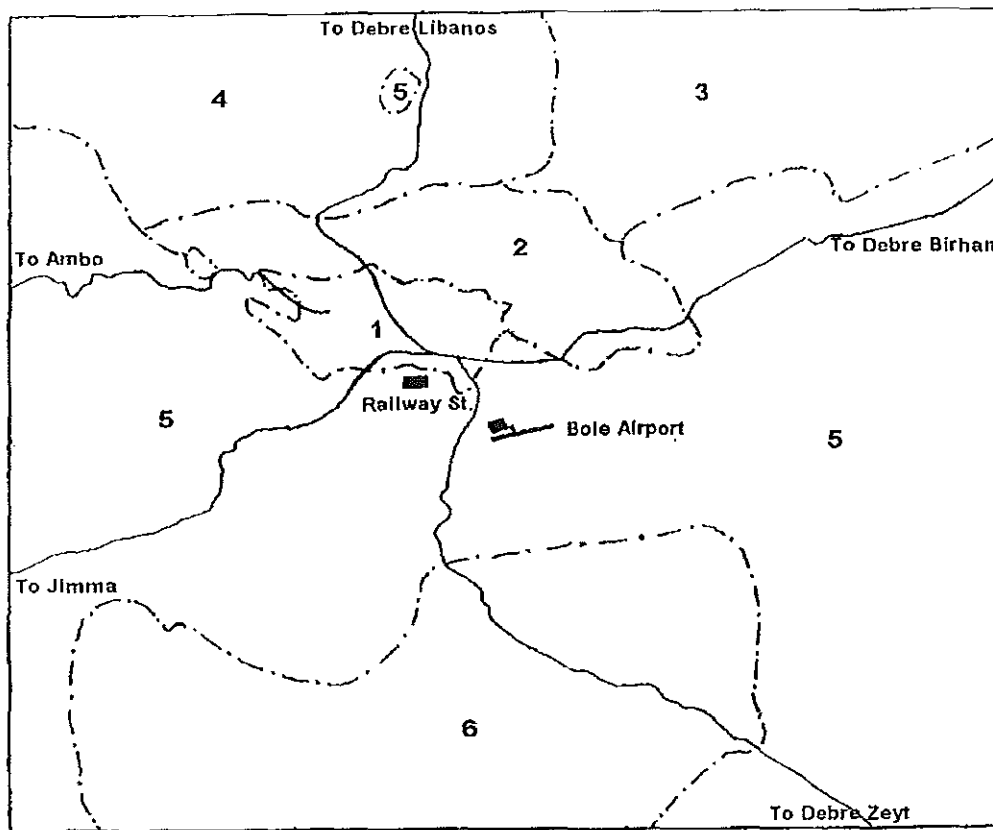


Figure 1. The geological map of Addis Ababa.

- | | |
|--|-------------|
| 1. Basalts of Addis Ababa | Pliocene |
| 2. Silicic lavas and pyroclastics of Entoto | Miocene |
| 3. Basaltic shield volcanoes (Termober Basalts) | Miocene |
| 4. Plateau basalts | Oligocene |
| 5. Silicic lavas and pyroclastics with minor basalts | Pliocene |
| 6. Olivine basalts (Bishoftu basalts) | Pleistocene |

According to Tesahayu *et. al*, cited in BECOM, [25], there are four types of soils identified based on their genetic origin. These are :

- I. Alluvial soils: These are found in southern and south western part of Addis Ababa along Akaki River and also along Kebena River North-West of Bole area. The soils are mainly clays and silts with few fine grained sands. The sands are usually found at the bottom of the soil horizon.
- II. Colluvial soils: These are soils mixed with disintegrated bed rock material in the clay or silty matrix. The disintegrated blocks are randomly oriented and mostly they are unstratified. They are usually deposited after a big mass is moved down the slope of a hill. These are located in the foot-hills of the North-East Entoto mountains in the Yeka areas.
- III. Residual soils: These are formed from the decomposition of rocks. They are insitu soils. These soils are located in central part of Addis Ababa, Gulele and Kolfe regions.
- IV. Lacustrine soils: These are soils commonly called black cotton soils. They are formed as a result of deposition by a lake. It is thought that during Pleistocene, parts of Addis Ababa (Bole, Lideta, Mekanissa and areas along Debrezeit road) were under a water body.

Climate in the area is generally divided into three main seasons [25]- a period of heavy rains between June and September, in which 70% of the mean annual rain fall of 1240 mm occurs; a dry period between October and January; and a period of small rains between February and May. Temperature does not vary much through out the year, with normal maximum and minimum values of 26 °C and 6 °C, around an average of 16 °C. At higher elevations in the city,

night time temperatures may occasionally drop to 0 °C.

The city of Addis Ababa was supplied with water from springs and hand-dug wells in the areas for several decades after its foundation at the end of nineteenth century [3]. Later, water has been provided from the reservoir at Gafarsa which was constructed in 1944 [3] to meet the increasing water demand of the city. In 1955 the storage capacity of the dam was increased to 6.5 million cubic meters. The construction of new Gafarsa dam in 1966 increased the storage capacity to 8.2 million cubic meters and the springs were then taken out of service. In 1970 a second reservoir, Legedadi dam, was constructed as another source of water supply for the city. This brought the total available capacity of water supply to about 180,000 m³/d. At present the city is being supplied from the two dams. Wells are still being used as sources of water by some industries and large number of users. Springs are still used in some areas. During a recent investigations [27], 572 hand-dug wells and 93 springs were identified, most of which are currently used for water supply by near by inhabitants.

The water supply system in Akaki is mainly from a spring located North-East of the town. Future sources of the water supply has been investigated by Addis Ababa Water and Sewage Authority (AAWSA) from the well fields in the Koye area, in Sebeta and Aba-Samuel areas. Another sources of water supply are expected from the Gerbi reservoir and a new reservoir at Sibilu. A new dam Dere is also constructed and at present it is functioning.

3. LITERATURE SURVEY

On the research side, the last few decades witnessed a growing interest in water quality studies. In the Ethiopian environment a good number of works have been carried out during the last few decades and shows the initiation of interest in the studies of water quality.

Pitwell [28], on his theory of secondary ore body formation based on a study of coordination effects associated with Ethiopian and related rivers, have shown that the Little Akaki River was found with negative oxygen values. This river drains the Addis Ketema section of Addis Ababa and resembles rivers in many other large cities through out the world. One or two other rivers in the same area notably the Kebena had also very low oxygen value and one or two areas of high local pollution were found elsewhere but in general the prevalence of rapids and falls soon restores the balance. It is also showed that sulphate occurs as traces all over Ethiopia, but not uniformly. Minute amounts of tellurium have been detected in Awash River just to the south east of Addis Ababa, but this degree of sample concentration has not been attempted elsewhere. Fluoride and chloride are almost universal. Pitwell's [29] work had continued not only on the analyses of extra samples, but also on checking of earlier analyses and this compilation succeeds the earlier results.

Though, more of nature source-based than man induced, Firdu *et. al* [30] and Girma [31] reported the problem of high amount of fluoride in the middle and lower reaches of Awash River, while the Water Resource Development Authority [32] noted that the use of pesticides and fertilizers in the agricultural enterprises of these areas to be the possible causes of the deterioration of the quality of water.

In his attempt to trace out the point sources of industrial wastes, Firdu [33] surveyed twenty six major industrial establishments; such as slaughter house, Mekanissa Wine distillery, United Oil Mills, that discharge their wastes in the Little and Big Akaki Rivers in Addis Ababa and Akaki during the base flow period of February, March and April. His estimate of the amount and types of wastes from the industries, as differentiated from domestic and other sources, tells of a high degree of pollution of the rivers by showing a high value of the biological oxygen demand (BOD).

The other more recent works included Solomon's [34] which assess the wide effects of an environmental pollution caused by tannery effluents. Tesfaye [35] has also examined the variations in biological and chemical characteristics of Abo-Kebena River. His work indicates a significance seasonal variation in the quantity of macro-vertebrates and almost all of the benthic fauna. Furthermore his laboratory analyses shows a clear variation in the content of nitrate-nitrogen, orthophosphate and BOD with respect to space and time.

Melaku [36], on his studies of the seasonal variation of phytoplankton in relation to variation in water quantity in Legedadi Reservoir, showed that rainfall increases the in flow bringing with it chemicals released from rocks and soils into the reservoir and bring about changes in the quality of water. The rise in silicate levels between June and October is probably due to the run-off from the catchment area and other materials brought in the two rivers that drain into the reservoir and that of nitrate is most probably due to the agricultural loading of fertilizers.

Lema [37], on his studies in water quality variations of an urban river systems on Little Akaki, has shown that the Little Akaki River system furnishes with an instance of how the water of streams draining Addis Ababa is getting deteriorated with a sharp increase in the

concentrations of ammonium and phosphate ions.

The Environmental Protection Authority [38] had also made a preliminary survey of pollutant load on Big Akaki, Little Akaki and Kebena Rivers. The work showed that the industries, residential houses and commercial institutions in and around Addis Ababa are seriously polluting the river waters by discharging solid and liquid wastes.

Fisseha [4], on his comparative study on soil pollution with toxic substances on farm lands close to old and new industrial sites in Ethiopia, have shown that the toxic metal build up will reach threshold levels in few years, in particular in areas near Akaki.

The Addis Ababa Water and Sewage Authority (AAWSA) [39] have also made many chemical and biological analyses of surface and ground water. Results showed that most of the streams within Addis Ababa's metropolitan boundaries show a significant degree of pollution. Another environmental impact point is the pollution of ground water. In 1983 AAWSA surveyed fourteen boreholes were identified as polluted by nitrates, sulphate or high concentration of chloride and total dissolved solid (TDS).

In 1989 studies carried out by The Ethiopian Valleys Development Studies Authority (EVDSA) for the development of water resources in the Awash Basin, as cited in reference 39, the dramatic pollution of Big and Little Akaki Rivers are clearly highlighted with a high value of turbidity, suspended solids, biological oxygen demand, coliform and low dissolved oxygen (DO).

4. EXPERIMENTAL

4.1 SAMPLING SITES

Our studies focused on the determination of the ionic composition of the surface and ground waters of Addis Ababa and its surroundings. The selection of the sample sites was, thus, to include most of the Addis Ababa city water courses. The localization of the sample sites are shown in Figure 1, 2 and 3.

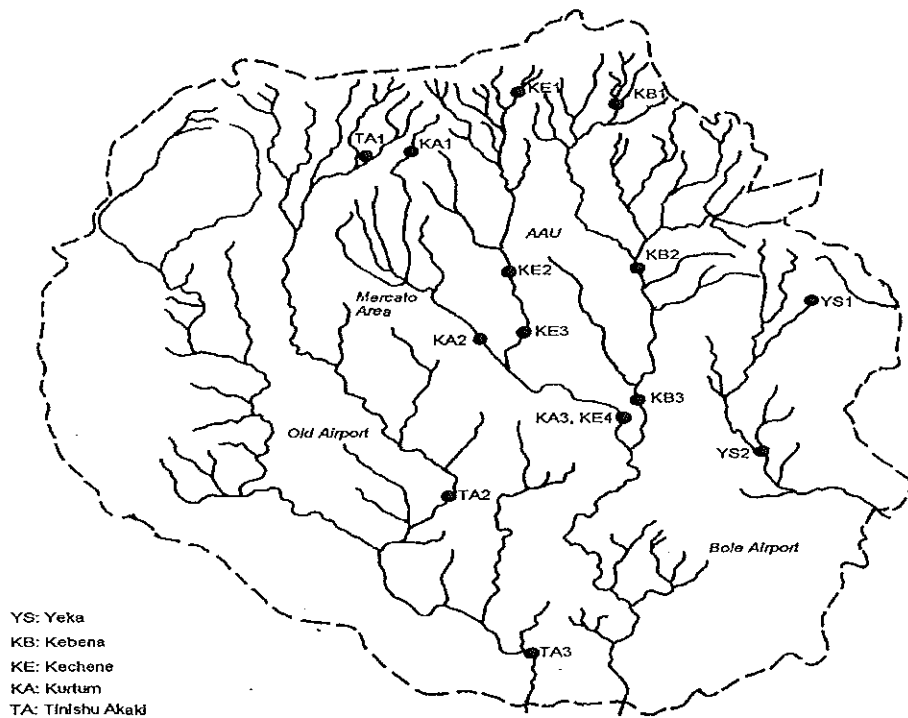


Figure 2. The streams of Addis Ababa and sample sites of surface waters.

S1=up stream Yeka; YS2=stream Yeka; KB1=up stream Kebena; KB2=Kebena German embassy; KB3=Kebena stream Urael; KE1=up stream Kechene; KE2=Ras Mekonnen bridge; KE3=Kechene stream Zewditu; KE4=Bantiyketu stream; KA1=up stream Kurtume; KA2= Near Immigration; KA3=Bantiyketu; TA1=Minch Saloon spring; TA2=Near Kera; TA3=Near Behere Tsige

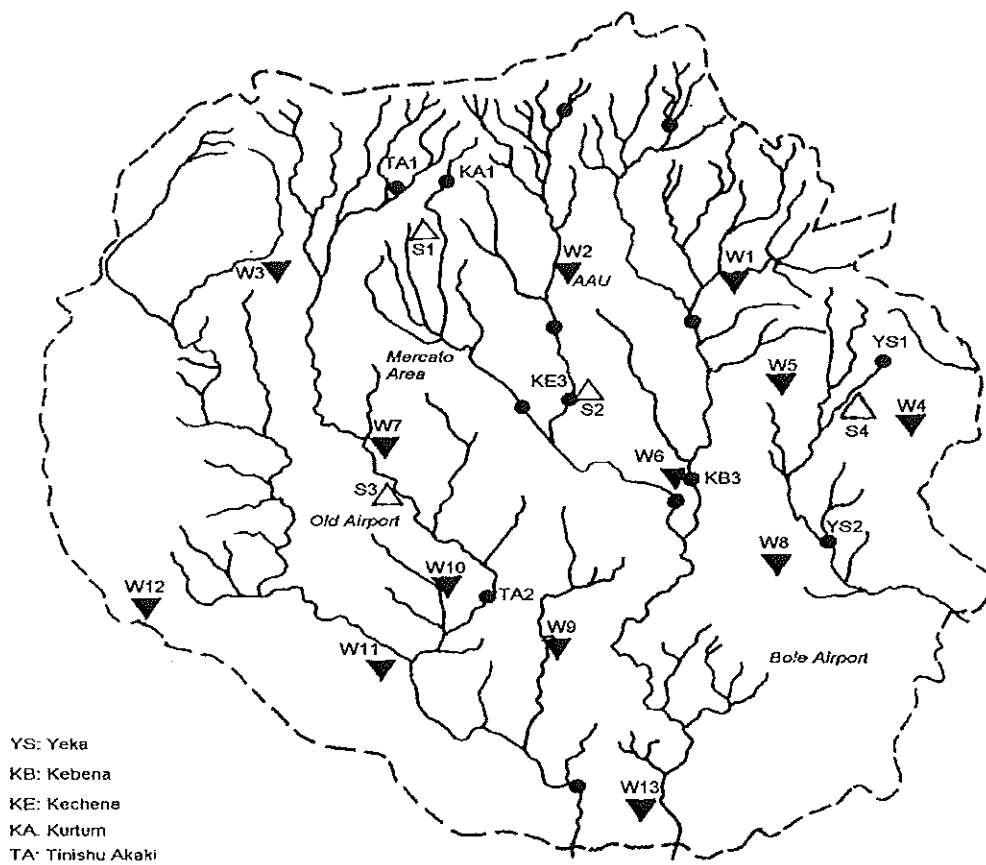


Figure 3. The streams of Addis Ababa and sample locations of ground waters.

W1=Italy Embassy; W2= AAU(Sidist kilo); W3=G.Winget School; W4=AA Shola Dairy; W5=St.Michael holly water; W6=St.Urael Holly water; W7=AAU(Building college); W8=St.Medhanealem Holly water; W9=AA Cement factory; W10=St.Gebriel Holly water; W11=Sister Consolodeta; W12=Repi Soap factory; W13=St.Abo Holly water; S1=Sami Spring(Martha); S2=Ras Mekonnen Spring; S3=Lideta Spring; S4=Meganegna Spring

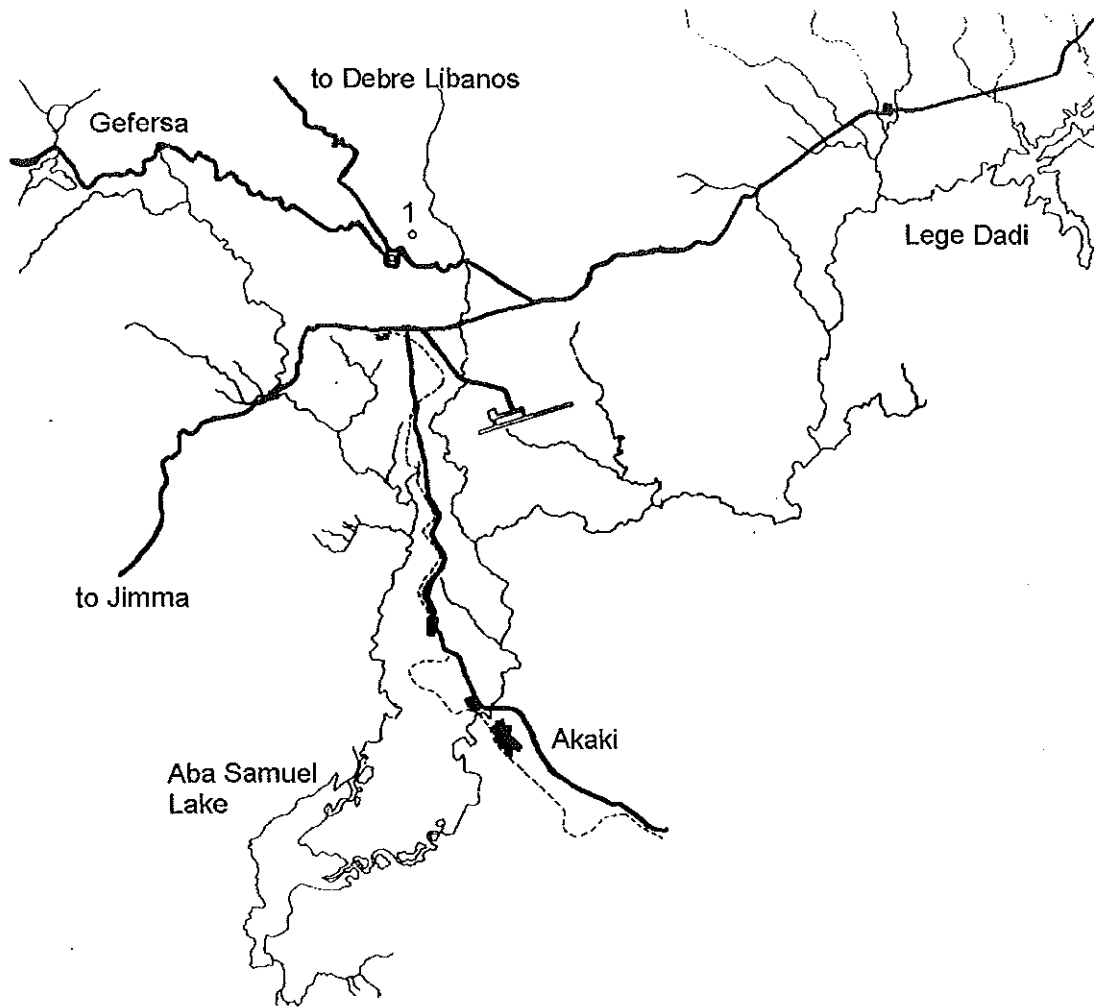


Figure 4. The map of Aba-Samuel Lake, Gefersa and Legedadi water reservoirs.

Table 1 in the appendix shows the utilization and localization of surface waters and some of the ground waters.

Table 1. The utilization and location of surface and ground waters.

Code	Sample sites	Location in UTM*		Utilization
		East (m)	North (m)	
	Tinishu Akaki			
TA1	Minch saloon spring	470690	1002517	Drinking
TA2	Near kera	471973	993418	Irrigation
TA3	Near behere Tsige	472860	989884	Irrigation
	Kurtum Stream			
KA1	Kurtum up stream	471130	1002240	Drinking
KA2	Near Immigration	472646	997370	Natural Sewer
KA3	Bantiyketu	475149	994976	Natural Sewer
	Kebena Stream			
KB1	Up stream Kebena	475144	1003563	Irrigation
KB2	Kebena German Embassy	475578	999342	Natural Sewer
KB3	Kebena stream Urael	475677	995421	Natural Sewer
	Kechene Stream			
KE2	Ras Mekonnen bridge	473113	999195	Natural Sewer
KE3	Kechene stream Zewditu	473136	997222	Natural Sewer

UTM* = Universal Transverse Mercator

.....continued

KE1	UP stream Kechene	473160	1003568	Natural Sewer
KE4	Bantiyketu stream	475149	994976	Natural Sewer
	Yeka Stream			
YS1	Up stream Yeka	478657	998667	Drinking
YS2	Stream Yeka	477888	994481	Natural Sewer
	Big Akaki			
A1	Before Aba-Samuel	473628	975127	Irrigation
A2	Aba-Samuel lake reservoir			Irrigation
A3	Aba-Samuel lake outlet	467775	971387	Irrigation
W2	AAU(sidist killo)	473560	999972	Drinking
W3	G.Wingate school	468491	1000620	Drinking
W11	Sister Consolodeta	470361	991612	Drinking
W7	AAU(Builging college)	470170	996350	Drinking
W4	Shola Dairy	479588	997139	Drinking and other uses
W9	AA Cement Factory	473400	992583	Drinking and factory use
S4	Meganenga spring	478561	997059	Drinking
S1	Sami spring (Martha)	471283	1001160	Irrigation

4.2 SAMPLING

The water samples were collected in polyethylene bottles. The bottles were pre-rinsed three times with water to be sampled. The waters were filled so that a gas bubble of approximately bean size remains in the bottle. The samples were taken into the laboratory as soon as possible and stored in the refrigerator at 5°C for analysis.

4.3 CHEMICALS

All chemicals used for analysis were of analytical grade. Solutions were prepared with distilled water.

4.4 EQUIPMENTS

For the potentiometric determinations a pH-meter (HANNA, HI-9025) and combined fluoride electrode (ORION, Model 96-09) were used. The spectrophotometric determinations were carried out either with a double beam UV/VIS spectrophotometer (PERKIN-ELMER, Lamda 3A UV/VIS) or with atomic absorption spectrophotometer (PERKIN-ELMER,2830A).

4.5 ANALYTICAL PROCEDURE

The surface waters were filtered through a membrane filter (0.45 μm pore size) in order to remove insoluble matter. The pH and the chemical oxygen demand (COD) was determined in the unfiltered samples.

The ions analyzed in the water samples and the methods used for this determinations are compiled in Table 2.

Table 2. The ions detected with their corresponding methods.

Ions/Constituents	Method	Reference	Remarks
Alkalinity	Titrimetric; with HCl	[40] p-278	0.1 N HCl
COD	Titrimetric; with KMnO ₄	[41] p-61	0.1 N KMnO ₄
Ammonium	Indophenol Blue (Spectrophotometric)	[1] p-330	
Nitrite	Diazotization (spectrophotometric)	[40] p-434	
Nitrate	UV	[40] p-420	
Sulphate	Turbidimetric	[42] p-784	
Phosphate	Ascorbic Acid (Spectrophotometric)	[40] p-481	
Chloride	Thiocyanate (spectrophotometric)	[42] p-754	
Sulphide	Methylene Blue (spectrophotometric)	[40] p-503	
Silicate	Molybdenum (spectrophotometric)	[40] p-487	
Fluoride	ISE potentiometric	[40] p-391	Fluoride selective electrode
Sodium	AAS	[43]	Air/C ₂ H ₂ Flame
Potassium	AAS	[43]	Air/C ₂ H ₂ Flame
Calcium	AAS	[43]	Air/C ₂ H ₂ Flame
Magnesium	AAS	[43]	Air/C ₂ H ₂ Flame

The Trace elements: Li, Be, V, Cr, Mn, Co, Ni, Cu, Zn, As, Rb, Sr, Se, Mo, Cd, Sn, Sb, Cs, Ba, Pb, Bi, Th, and U were determined by the Mass Spectroscopy-Inductive Coupled Plasma (MS-ICP) at the University of Caligari (Italy).

5. RESULTS AND DISCUSSIONS

This work is part of a long term project designed to determine the quality of surface and ground waters of Addis Ababa and its surroundings. In this study, a series of tests was carried out on the quality of surface and ground waters. Since this study is a preliminary work of limited scope, an authoritative conclusion may not be drawn. However, the results are indicative of the general water quality trends.

5.1 INVESTIGATION OF SURFACE WATERS (ANIONS)

The study carried out a series of tests on the quality of surface water draining the city. The results of these tests are compiled in the Table A1. The profiles of variation of the parameters at each sampling point are summarized in Figures.

YEKA STREAM

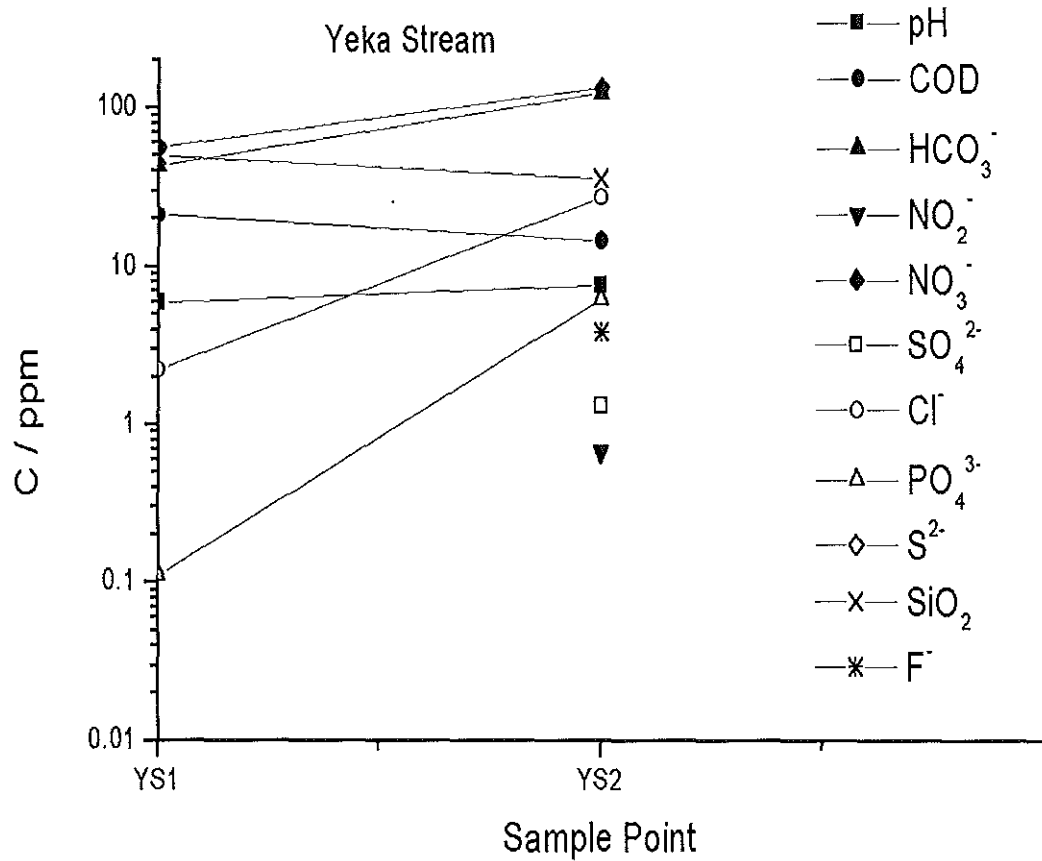


Figure 5. The chemical analysis diagram of Yeka stream.

The analytical results obtained for the Yeka stream is discussed as follows:

pH: The measured pH for Yeka stream showed that up stream Yeka is slightly acidic and down stream Yeka is slightly basic. This variation may indicate that the down stream water course may be contaminated by the substances of basic nature.

COD: As observed from the results of COD, the up stream Yeka has higher COD value than the down stream Yeka. This high value of COD in the up stream may be caused by the polluted flow from the surface water drains to the stream. In addition to the sanitary wastes, the pollution may also be caused by the petrols and oils, and detergents which are either washed into the streams or dumped. The decrease in COD value at the down stream can be due to the bacterial decomposition of the organic matter.

ALKALINITY: The alkalinity of Yeka stream is imparted by the bicarbonate ions of the water. The high alkalinity of down stream Yeka has a high pH value and generally contains elevated levels of dissolved solids.

NUTRIENTS: Experimental results showed that an increase in nitrate-nitrogen is observed down stream. This increase may be due to the marked effect of domestic and municipal wastes dumped into the stream. The results also showed that down the stream an increased nitrite-nitrogen is observed indicating pollution down the stream. In addition, down stream an increase in phosphate is obtained. This increase in phosphate concentration may be due to the inorganic phosphate compounds used in various house hold detergents and decomposition of some organic pollutants that are dumped into the stream.

KEBENA STREAM

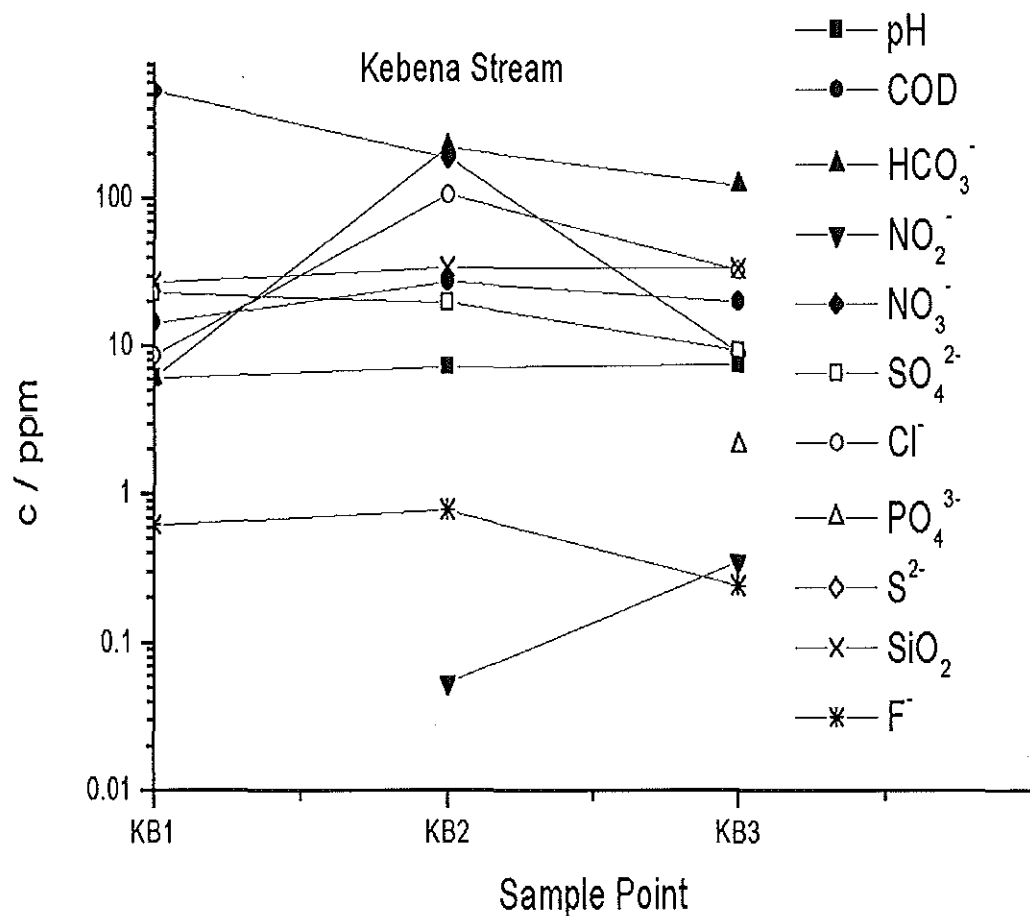


Figure 6. The chemical analysis diagram of Kebena stream.

The analytical results obtained for the Kebena stream are also discussed as follows:

pH: The measured pH for the Kebena stream indicates an increase in pH value down stream due to the pollution of the water courses down stream.

COD: From the results of COD obtained, in the middle streams of Kebena (near German

Embassy) a high value of COD is observed. This high value of COD is due to the polluted flow of surface water drains and ditches into which the septate and sullage of the city flows or other organic pollutants enter into the stream.

ALKALINITY: The alkalinity of Kebena stream is also imparted by the bicarbonate ions of the water. It has been observed that water with high alkalinity has a greater complement of most ions than water of low alkalinity. The results showed that a large alkalinity is obtained in the middle stream of Kebena near German Embassy due to pollution of the stream by domestic and municipal wastes and some natural processes.

NUTRIENTS: Experimental results revealed that a high value of nitrate-nitrogen is obtained in the up stream of Kebena. This high value of nitrate-nitrogen in the up stream of Kebena is due to the nitrogen loading of agricultural areas or originate by the conversion of organic nitrogen or ammonia which occur naturally or from the animal wastes. The decrease in nitrate-nitrogen down stream is due to biological activities. The results obtained for nitrite-nitrogen also showed that an increase in nitrite-nitrogen down the stream is seen. This may also indicate that the down stream part is highly polluted by organic matter derived from domestic or municipal wastes dumped in the stream. In the up and middle stream of Kebena no phosphate concentration is observed. But in the down stream of Kebena near Urael a high value of phosphate is obtained. This high value of phosphate near Urael is due to the organic pollutants that are discharged into the stream as it passes through the city or inorganic phosphate compounds used in the various household detergents dumped into the stream. In addition, a high concentration of chloride is obtained in the middle of Kebena due to domestic wastes dumped into the water course. The decrease in sulphate concentration down the stream may be attributed to some of the bacteria and associated processes that are responsible for the transformations of organic pollutants.

KECHENE STREAM

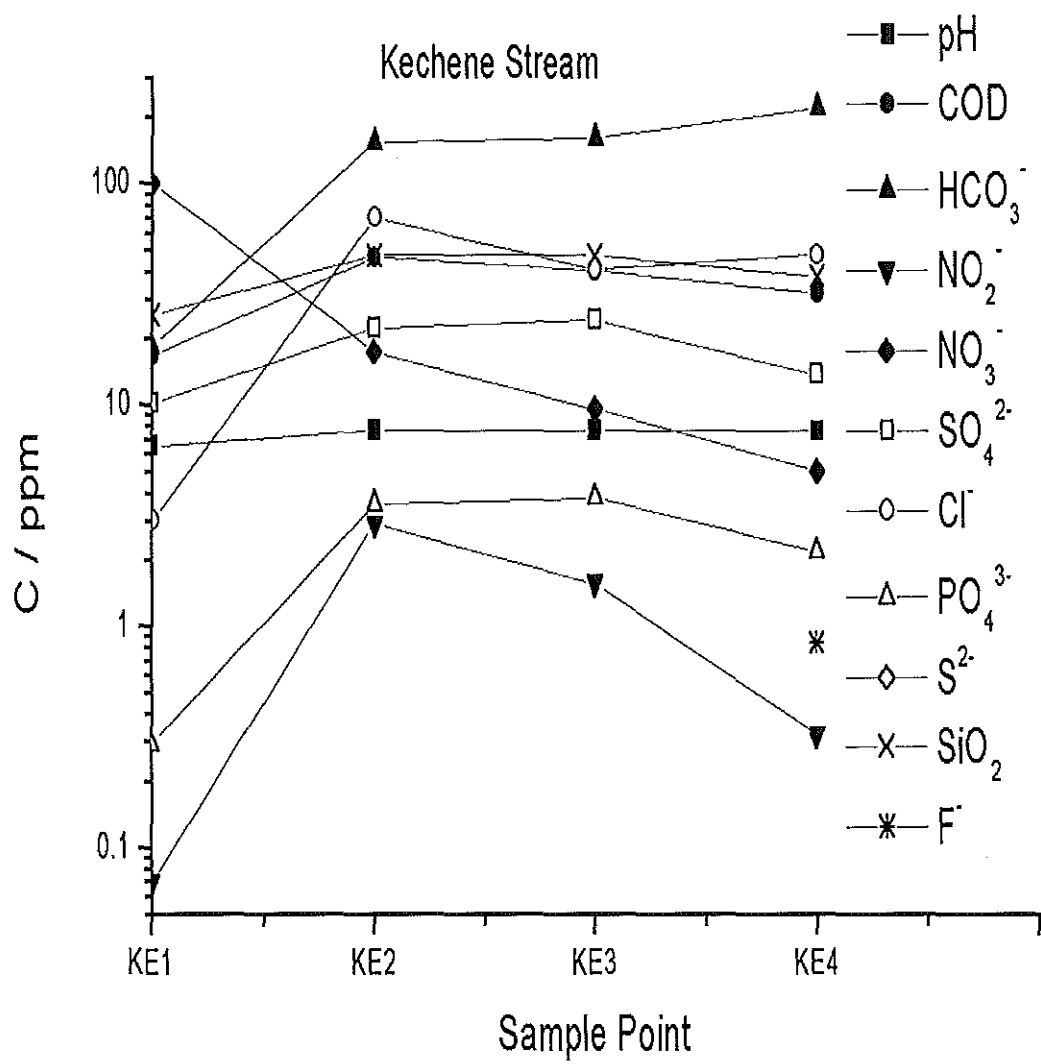


Figure 7. The chemical analysis diagram of Kechene stream.

The analytical results obtained for Kechene stream are also discussed as follows:

pH: The measured pH for the Kechene stream indicates that down the stream a slight increase in pH value is obtained. This variation may show the pollution of water courses down the stream.

COD: As can be seen by the results obtained the COD value of the up stream Kechene is lower than that of the middle and down stream. This high value of COD in the central part is mainly caused by the polluted flow from the surface water drains and ditches into which the septate and sullage of the city flows. In addition there is also pollution caused by the petrols and oils, acids and detergents which are either washed into the stream or dumped. The dark color of flow in the different water courses indicate a high rate of sewage which is characteristic of effluents from septic tanks and pit latrines (Figure A1).

ALKALINITY: The alkalinity of Kechene stream is also imparted by the bicarbonate ions of the water. The results showed that an increase in alkalinity is seen down stream due to the pollution of the stream by domestic and municipal wastes and some natural processes.

NUTRIENTS: In the up stream part a high value of nitrate-nitrogen is measured. This can be attributed from the nitrogen loading of agricultural areas. But down stream a decrease in nitrate is observed. This decrease is also attributed to the biological activities taking place in the stream such as eutrophication and denitrification. The results also showed that streams passed through the central part of the city are highly contaminated by nitrite-nitrogen and phosphate than the up streams. This is also an indication of pollution in the central part of the city due to domestic and municipal wastes dumped into the stream. The same pattern is also observed for chloride and sulphate.

KURTUME STREAM

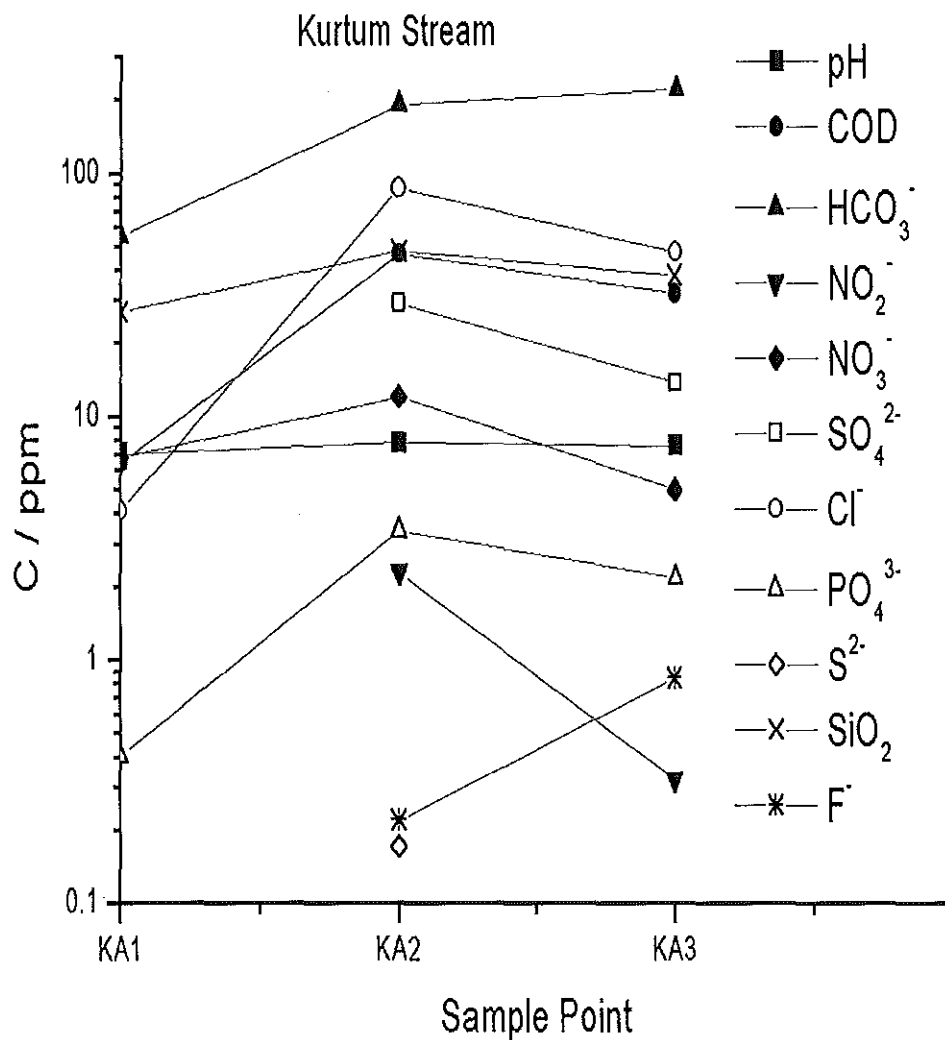


Figure 8. The chemical analysis diagram of Kurtume stream.

The analytical results obtained for Kurtume stream are also discussed as follows:

pH: The measured pH shows that the up stream of Kurtume is slightly acidic and the middle and down streams are slightly basic. This may indicate the water course is polluted down stream.

COD: The COD value obtained indicates that the up stream portion is less polluted by organic matter than the middle and down stream part. The high COD value of the stream in the middle and down part is attributed to the polluted flow of the surface water that drains from the Mercato area and pollution caused by the petrol and oils, and domestic sullage which are washed or dumped to the streams.

ALKALINITY: The alkalinity of the Kurtume stream is imparted by the bicarbonate ions of the water. The increase in alkalinity down stream is due to the pollution of the stream by municipal and domestic wastes and some other natural processes.

NUTRIENTS: Experimental results showed that a relative high value of nitrate-nitrogen is obtained in the middle stream than up and down stream. This is may be due to effluents flowing from septic tanks and pit latrines which are concentrated in the Mercato area and some other wastes dumped into the stream. In addition, a high value of nitrite-nitrogen and phosphate is also observed in the middle stream which is an indication of contamination of the stream. The same pattern is also observed for chloride and sulphate in the middle stream due to municipal and domestic wastes which are dumped into the stream.

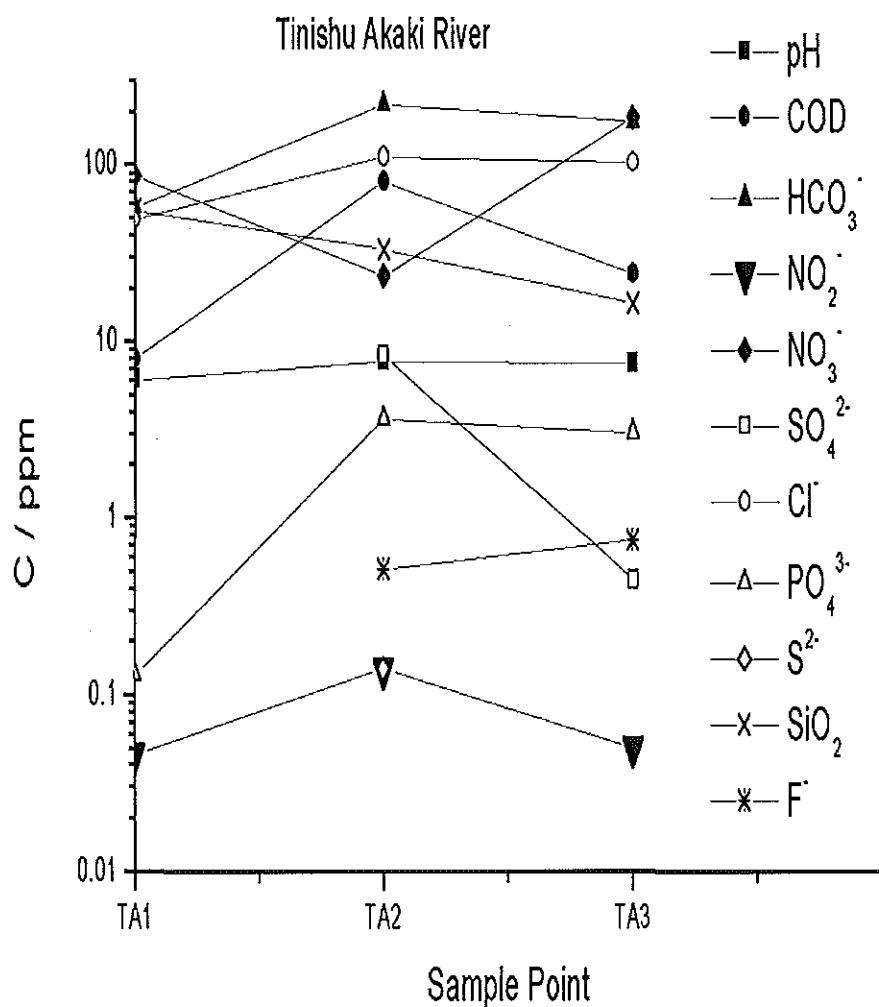


Figure 9. The chemical analysis diagram of Tinishu Akaki.

The analytical results obtained for the Tinishu Akaki river are also discussed as follows:

pH: Like the other streams, the pH in the up stream part is slightly acidic and that of the middle and up stream is slightly basic. This variation may indicate the pollution of the water down

stream.

COD: From the results of COD value obtained, in the middle river of Tinishu Akaki near Kera a high value of COD is obtained. This high value of COD near Kera is mainly attributed to the organic effluents from the slaughterhouses that are discharged into the river.

ALKALINITY: Like the other streams that are passing through the city, the alkalinity of Tinishu Akaki is also imparted by the bicarbonate ions of the water. In this river, the same pattern is also observed like other streams where a high value of alkalinity is obtained in the middle stream.

NUTRIENTS: The results obtained also show that a high value of nitrate is obtained in the up and down stream due to the nitrogen load from agricultural areas or other pollutants; and due to the biological activities a decrease in nitrate is seen in the middle stream. In addition, a high phosphate concentration is obtained in the middle and down stream due to the bacterial decomposition of organic matters or domestic sullage that are dumped into the river. The same pattern is also observed for chloride and sulphate due to domestic and municipal wastes that are washed into the river.

BIG AKAKI

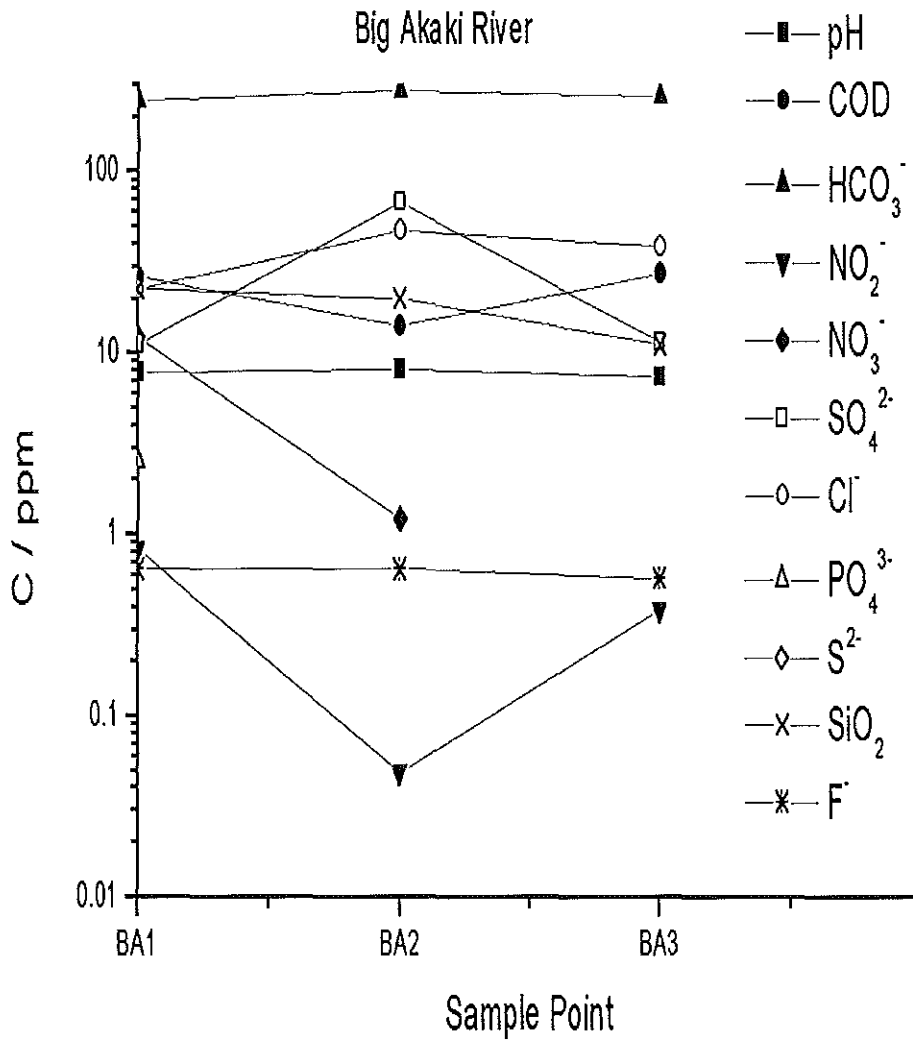


Figure 10. The chemical analysis diagram of the Big Akaki river.

The analytical results of the Big Akaki River are also discussed as follows:

pH: The measured pH for the Aba-Samuel Lake at the inlet, reservoir and outlet indicates that

it is slightly basic. This is because all pollution sources of the city, i.e industrial effluents, municipal and domestic wastes, enter into the lake through Big Akaki Rivers.

COD: The COD value of the Big Akaki before and after Aba-Samuel Lake is some what higher than the lake reservoir. Comparing the COD value of the Lake reservoir with other streams near the central part of the city, it is lower in value. This is, may be, because of the self-purification of water or the bacterial decomposition of organic matter.

ALKALINITY: Alkalinity of water is the capacity of that water to accept protons. It is usually imparted by the bicarbonate, carbonate and hydroxide components of natural waters. It has been observed that water with high alkalinity has greater complement of most ions than water of low alkalinity. Highly alkaline water often has a high pH and generally contains elevated levels of dissolved solids. Hence, a high alkalinity which is imparted by the bicarbonate ions of the water is obtained in the Aba-Samuel Lake inlet, reservoir and outlet due to the concentration of wastes in the Lake.

NUTRIENTS: Experimental results showed that the Big Akaki before Aba-Samuel has higher nitrate due to the nitrogen loading of agricultural areas near to the river and other organic pollutants loaded into the river. But going to the lake reservoir and its outlet the nitrate becomes very low in the reservoir and absent in the outlet. This is most probably due to biological activities, i.e denitrification and eutrophication of the Lake. The same pattern of phosphate is also observed in the Lake reservoir and the decrease in nitrite through the inlet to the outlet of the Lake reservoir is due to the self-purification of the water. In addition, an increase in chloride is observed in the Lake reservoir because chloride is not affected by bacteria and the decrease in silica is probably associated with biological activities.

In undisturbed, free-flowing streams the nitrate and phosphate levels are usually low. In a river where inputs are absent not only all nutrient levels are low, but also their concentrations tend to decrease down streams [44-46]. Therefore, nitrate and phosphate concentrations along a stream are widely used in the determination of water pollution. Hence, the correlation of the anions of nitrate and phosphate with other parameters is also shown in the figure attached below using a triangular diagram that can show the percentage composition of the three ions. In this triangular diagram, the concentration of the three ions in ppm is summed up and considered as hundred percent. From this, the percentage of the ions is calculated.

YEKA STREAM

The correlation of nitrate and phosphate of Yeka stream with sulphate, chloride and COD is shown in Figure 11.

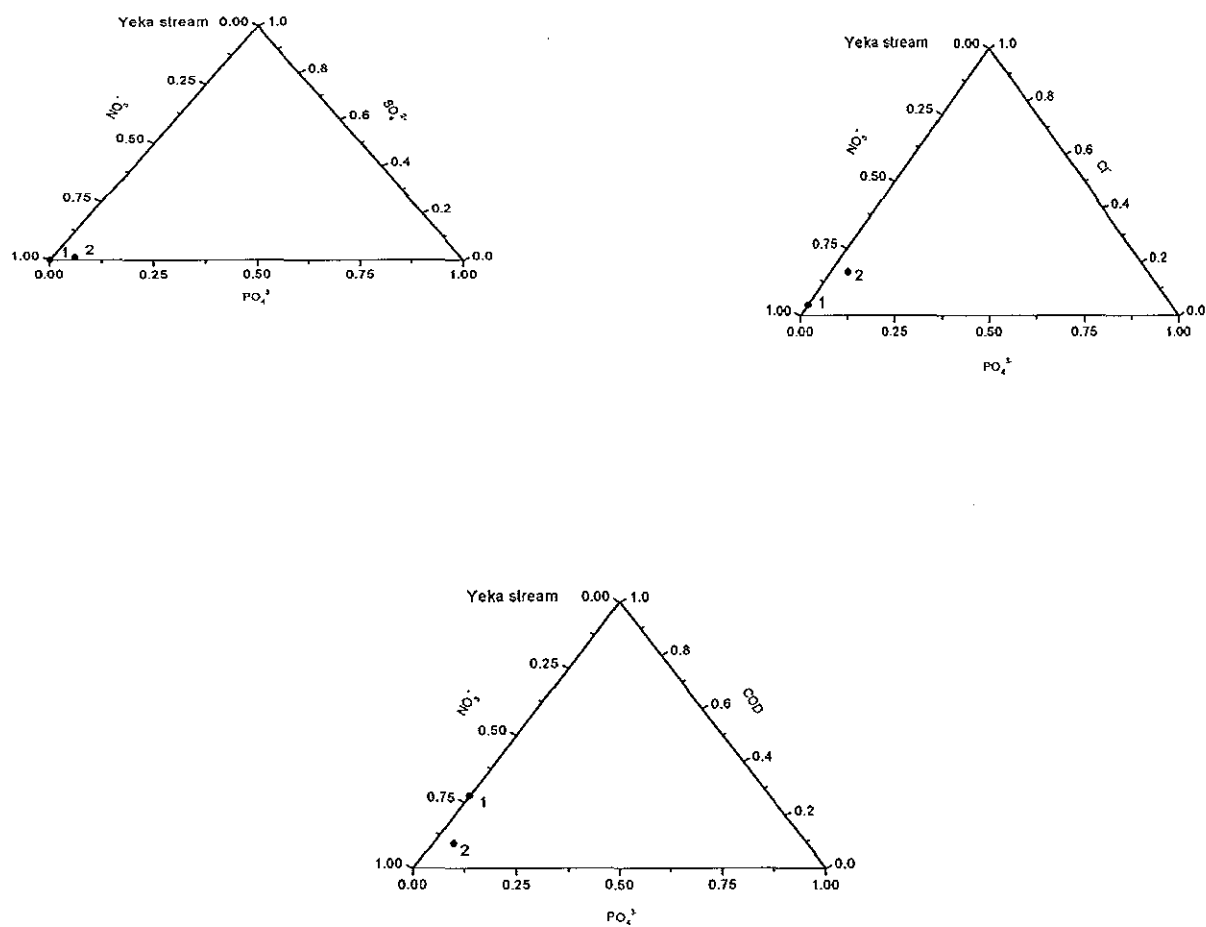


Figure 11. The correlation of anions of NO_3^- , PO_4^{3-} with SO_4^{2-} , Cl^- and COD of Yeka stream.

This correlation shows that down stream, a decrease in percentage of nitrate and COD, and an increase in percentage of phosphate, sulphate and chloride is observed. The decrease in nitrate is due to biological activities and that of COD is probably due to the self purification of the water. The increase in phosphate, chloride and sulphate is due to the input of pollutants on the stream.

KEBENA STREAM

The correlation of nitrate and phosphate of Kebena stream with sulphate, chloride and COD is also shown in Figure 12.

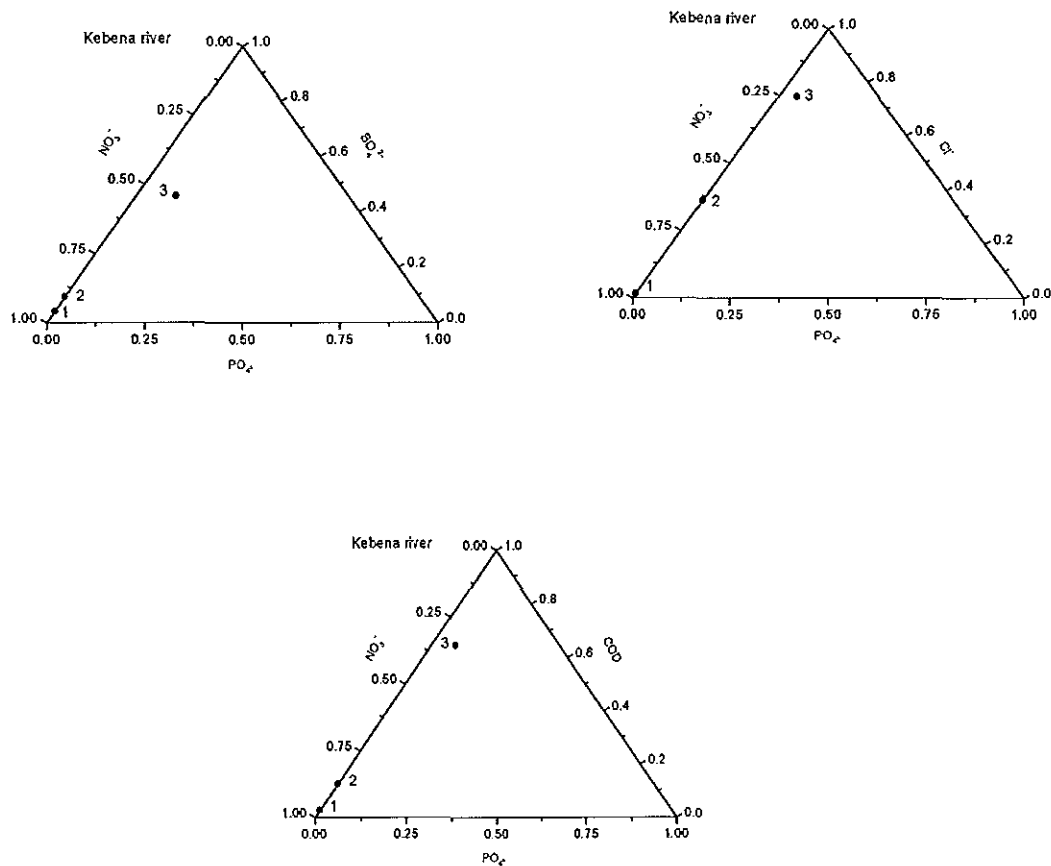


Figure 12. The correlation of anions of NO₃⁻, PO₄³⁻ with SO₄²⁻, Cl⁻ and COD of Kebena stream.

This correlation clearly indicates that a decrease in the percentage of nitrate due to biological activities and an increase in the percentage of sulphate, chloride and COD down the stream is observed. This shows how the water is deteriorated down stream due to the input of domestic and municipal wastes into the stream.

KECHENE STREAM

The correlation of nitrate and phosphate of Kechene stream with sulphate, chloride and COD is shown in Figure 13.

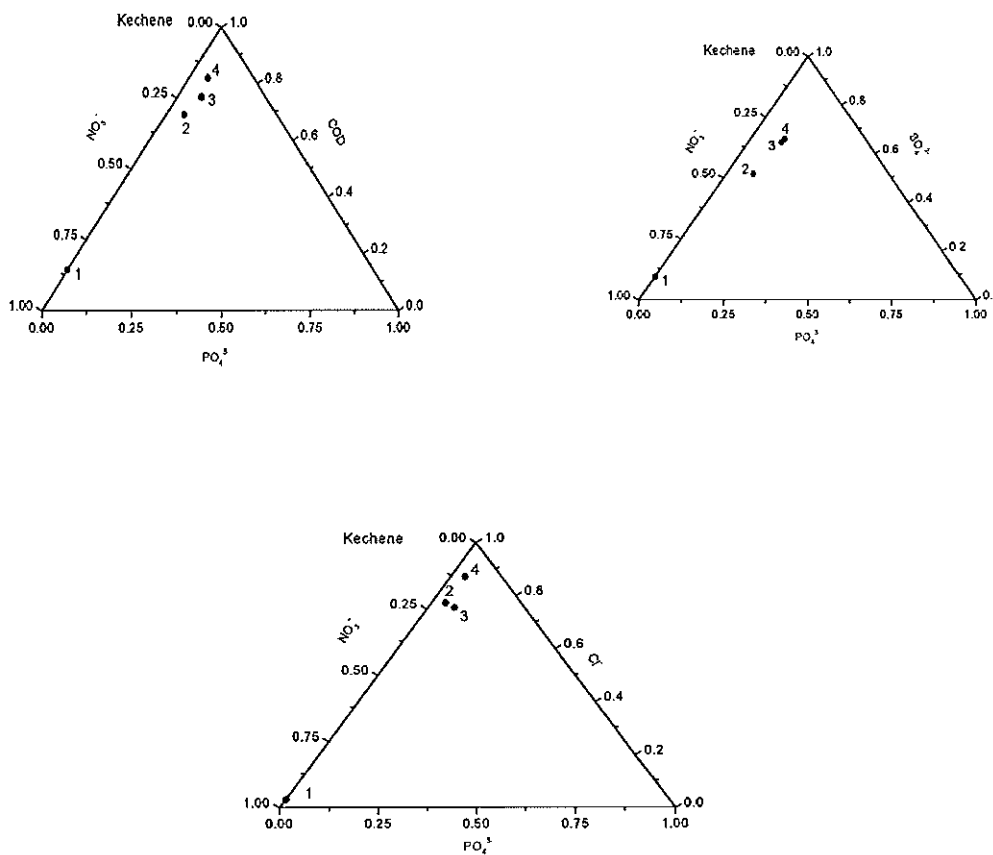


Figure 13. The correlation of anions of NO₃⁻, PO₄³⁻ with SO₄²⁻, Cl⁻ and COD Kechene stream.

This correlation also showed an increase in the percentage of COD value indicating an increase in pollution; and a decrease in the percentage of nitrate most probably due to biological activities. In addition an increase in percentage of sulphate and chloride is also observed down stream.

KURTUME STREAM

The correlation of nitrate and phosphate of Kurtume stream with COD, sulphate and chloride is shown in Figure 14 below.

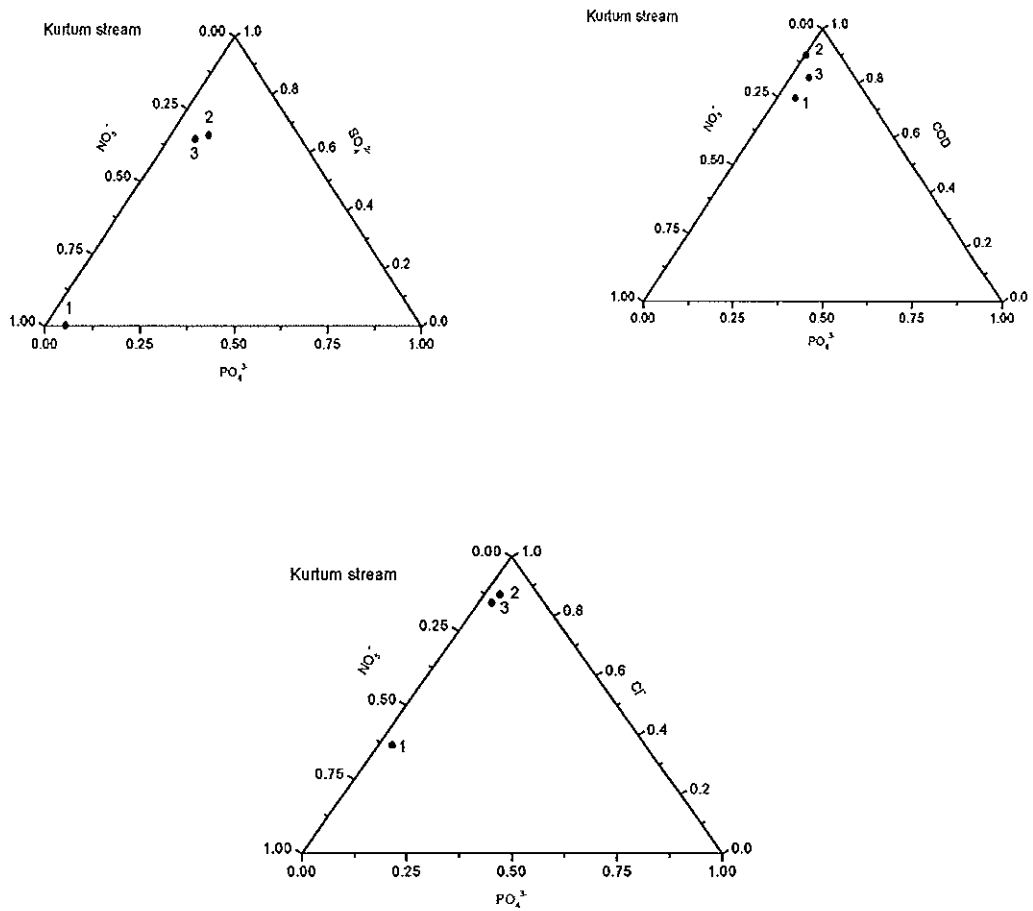


Figure 14. The correlation of anions of NO_3^- , PO_4^{3-} with SO_4^{2-} , Cl⁻ and COD of Kurtume stream.

This correlation shows that in the central part of the city, down Mercato areas a high degree of pollution obtaining a high percentage of COD, chloride and sulphate is observed; and like the other streams a decrease in percentage of nitrate is seen.

TINISHU AKAKI

The correlation of nitrate and phosphate of Tinishu Akaki river with COD, sulphate and chloride is shown in Figure 15.

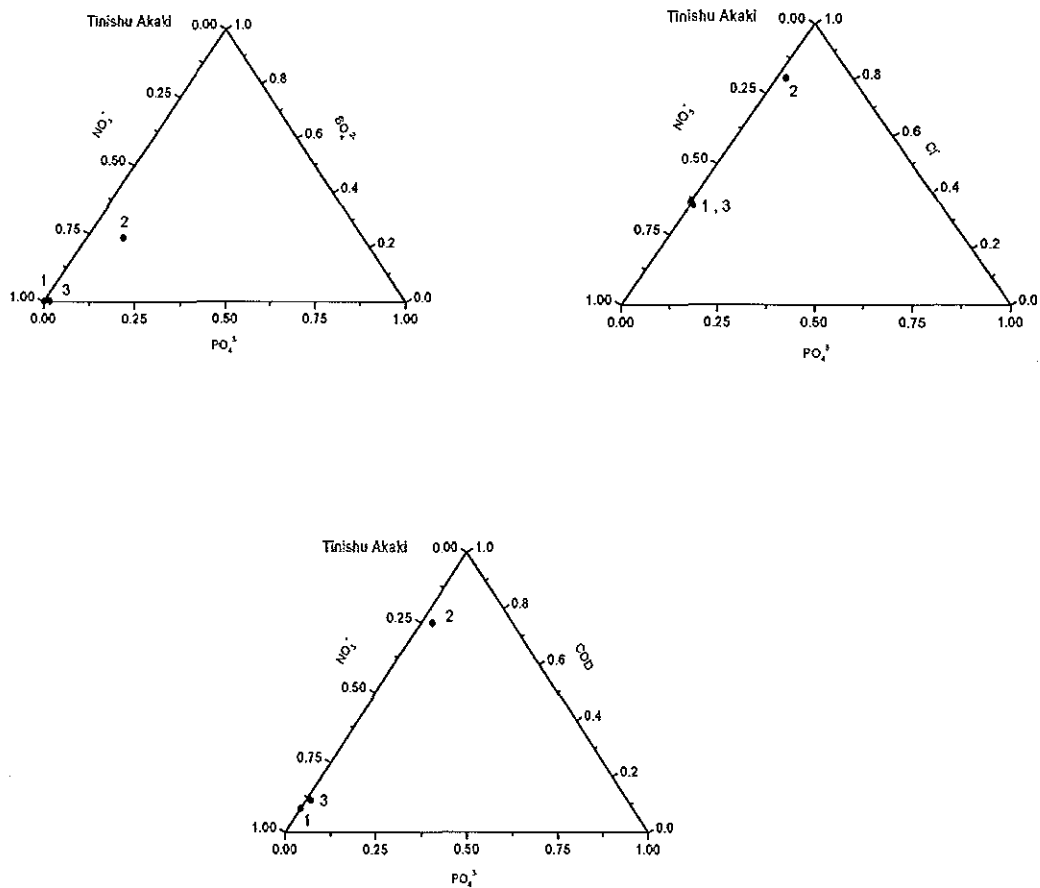


Figure 15. The correlation of anions of NO₃⁻, PO₄³⁻ with SO₄²⁻, Cl⁻ and COD of Tinishu Akaki River.

This shows that a high percentage of COD, sulphate and chloride is observed at the middle stream of the river near Kera indicating a high degree of pollution in that area; the decrease in percentage of COD, sulphate and chloride at the bottom of the stream near Behere Tsige is due to the self-purification of the water.

BIG AKAKI RIVER

The correlation of nitrate and phosphate of the Big Akaki near Aba-Samuel Lake reservoir is shown in Figure 16.

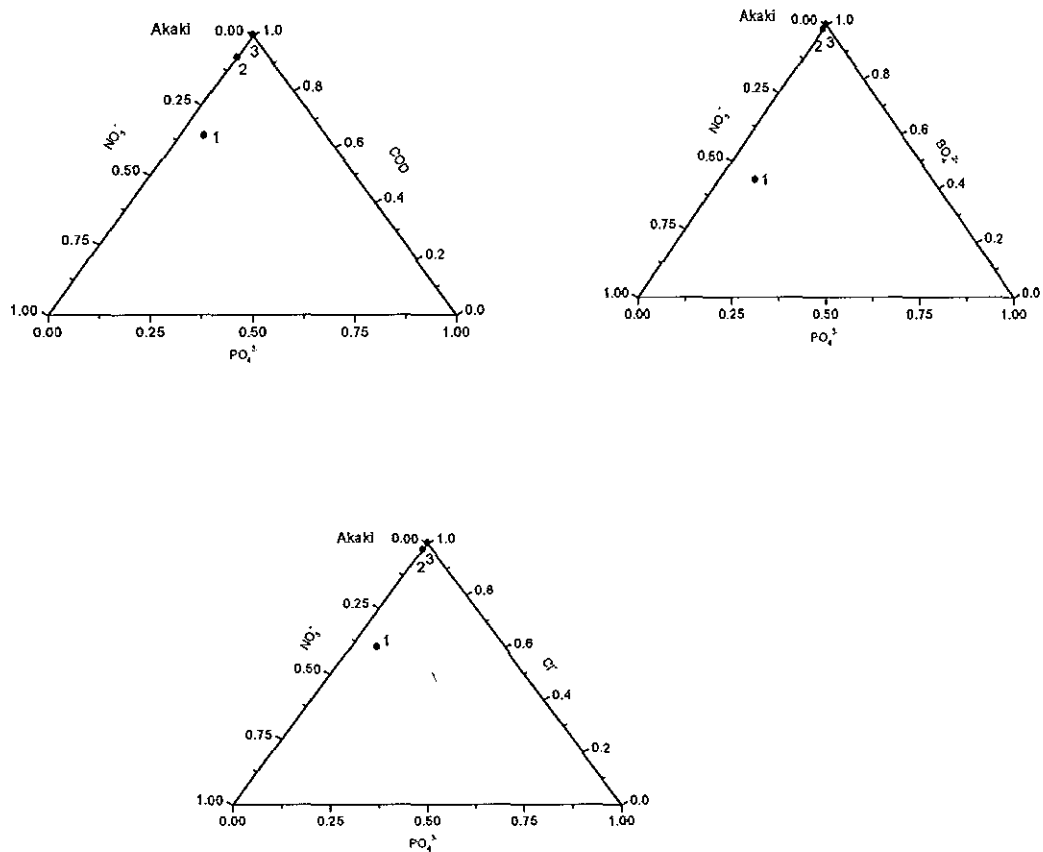


Figure 16. The correlation of anions of NO₃⁻, PO₄³⁻ with SO₄²⁻, Cl⁻ and COD of Big Akaki River.

This correlation clearly shows that a decrease in the percentage of nitrate and phosphate may be due to biological activities; and an increase in the percentage of COD, sulphate and chloride is observed. This is because of all the wastes of the city is finally dumped or enter into the reservoir and signifies high degree of pollution.

5.2 INVESTIGATION OF GROUNDWATER (anions)

The study also carried out a series of tests on the quality of ground waters of the city. The results of these tests are compiled in the Table A2.

5.2.1 BORE HOLES

pH: The most commonly measured chemical parameter in natural waters is the pH value. The value of pH measured has been considered as an important water feature, because it is an indicator of the presence of acidity or alkalinity in the water. Thus the studied water samples have pH values in range of 6.4-8.0 which falls with the recommended values of WHO as well as the Ethiopian standard regulations [1-3].

COD: As can be seen from the experimental results of COD obtained, most of the groundwater samples have lower COD values ranging from 6.4-11.6 ppm with the exception of high COD value of the Dewera Gudo well (near Aba-Samuel), 40.8 ppm. This high COD value of the well may be due to pollution from the highly polluted Akaki River infiltrated through porous aquifers.

ALKALINITY: The alkalinity of groundwater is also detected. The bicarbonate ion is the most

predominant anion and this may be derived from carbon dioxide that occurs in the soil horizon and from the dissolution of soil and mineral strata that are alkaline.

NUTRIENTS: The most common contaminant identified in groundwater is dissolved nitrogen in the form of nitrate. This contaminant is becoming widespread because of agricultural activities and disposal of sewage on or beneath the land surface. Experimental results show that most of the water samples have nitrate-nitrogen concentrations less than the recommended values of the WHO and the Ethiopian standards. But in some of the water samples the presence of nitrate is observed. For example, the Building College bore hole contains 35 ppm, Repi Soap Factory bore hole contains 10.2 ppm, AA Cement Factory bore hole contains 11.3 ppm and St. Gabriel holly water contains 16.5 ppm. This contamination may be due to direct leakage of sewage into the ground waters, or nitrate originated by the conversion of organic nitrogen or ammonium which occur naturally or are introduced to the soil zone by human activities. In all ground waters no nitrite is detected. This may be, because denitrification in the groundwater zone is a process about which little is known. It appears that a lack of suitable type or amounts of organic matter in the groundwater zone commonly inhibit the growth of denitrifying bacteria in groundwater. However, since groundwater commonly flows at a low velocity, a slow rate of denitrification may nevertheless be significant and hence a small amount of ammonium is detected in some ground waters such as AAU (Sidist kilo) (0.12 ppm), Repi Soap Factory (0.07 ppm) and St. Urael holly water (0.04 ppm).

The occurrence and mobility of phosphorus in groundwater is important in situations where there is a potential for groundwater to feed phosphorus. Through the widespread use of chemicals and disposal of sewage on land, the potential for phosphorus contamination of groundwater may take place. Hence, experimental works showed that some of the ground waters

are contaminated by phosphate-phosphorus such as Sister Consolodata (0.1 ppm), Repi Soap Factory (0.1 ppm) and AA Cement Factory (0.1 ppm).

In addition, experimental results show that all of these tested ground waters are less mineralized by sulphate, chloride, silica and fluoride ions and no sulphide is detected. Although a high concentration of sulphate in Dewera Gudo well (near Aba-Samuel) is obtained (82.4 ppm), it is below the recommended value of WHO and Ethiopian standards. But this high concentration of sulphate, may be due to pollution from the near by polluted Akaki River.

5.2.2 SPRINGS

In addition to such boreholes, springs that are found in Addis Ababa and its surroundings have pH values that are slightly acidic, ranging from 5.9-6.9; have COD values in the range of 5.2-17.6 indicating less polluted by organic matter; and have sulphate, chloride, silica and fluoride concentrations less than the recommended values by the WHO as well as the Ethiopian standards. No sulphide is detected. But in most of the springs such as Ras Mekonnen spring, Lideta spring, Sami spring (Martha) and Meganegna spring a high concentration of nitrate is recorded. This is most probably from the leakage of septic tanks and pit-latrines (Figure A1). In addition to nitrate-nitrogen, in most of these springs nitrite and phosphate ions are also detected.

5.3 ANALYSIS OF MAJOR CATIONS AND TRACE ELEMENTS

The major cations of all surface waters and some ground waters are analyzed. In addition to this, the trace elements of the surface waters are also analyzed. The results are compiled in

Table A3, A4 and A5.

5.3.1 MAJOR CATIONS OF SURFACE AND SOME GROUND WATERS

The analytical results of major cations, such as sodium, calcium, potassium and magnesium in ppm, revealed that in the middle and down streams a high value is obtained than up stream. The high value of such cations is probably due to the leaching of minerals or some domestic wastes that are dumped into the streams. The results obtained for the ground water are related more to geological sources.

5.3.2 TRACE ELEMENTS OF SURFACE WATERS

The measured analytical results of trace elements in $\mu\text{g/l}$ show that in all of the middle and up streams no chromium is detected except in the stream of Tinishu Akaki, i.e. near Kera and Behere Tsigie. This is most probably from the effluents of industry discharged into the rivers. In all of the streams no cadmium is detected. Most of them are free of lead except in Kurtume up stream may be from battery, Bantiyketu and Yeka stream due to domestic or from metal works some lead was detected. In addition, in most of the streams, middle and down stream, some arsenic was also detected. In most of the streams high concentration of manganese was also detected due to industrial effluents and leaching of natural minerals. The other trace elements are located in Table A5 of the Appendix and their sources is more of geological.

5.4 COMPARISON OF THE PRESENT WITH PREVIOUS RESULTS

MEASURED BY AAWSA

A comparison of some parameters such as COD, nitrite, nitrate, phosphate, sulphate and chloride is made with the samples of the surface and ground waters measured in our laboratory (code 1) and measured by AAWSA (code 2). The results are compiled in Table A6 and A7.

The comparison of some surface waters revealed that the samples have more or less the same pH and chloride values. But in the case of COD value, the potassium dichromate test which is made by AAWSA gives a higher COD value with a more thorough oxidation of organic matter including the oxidation of different inorganic materials such as chlorides than the potassium permanganate test made in our laboratory which is a very incomplete oxidation of organic matter but used to give a good picture of the total content of organic matter as pollution sources.

In the other cases, an increase in the concentration of nitrate and sulphate was observed in most of the samples analyzed. This may also indicate the increase of pollution from day to day. This can also be confirmed by the increase of nitrite in some of the sample which are shown in Table A6.

The comparison of some of the ground waters (Boreholes) which is shown in Table A7 reveals that there is no significant variation in the parameters measured such as pH, nitrite and phosphate. But in some of these samples a certain variation is observed in nitrate, sulphate, chloride and alkalinity.

6. CONCLUSIONS

The study reveals that in most of the streams/ivers, on their upper reaches, before they enter the city of Addis Ababa are high in nitrate due to the nitrogen load of agricultural areas and low in the other parameters measured showing the cleanliness of the water. It becomes polluted as it passes through the city. The degree of pollution varies in relation to the amount of organic matter and other domestic wastes introduced. In general, a decrease in nitrate-nitrogen due to biological activities showing the streams are contaminated by bacteria such as coli and coliform and an increase in phosphate, COD, sulphate, chloride and nitrite-nitrogen is observed in the middle and down streams/ivers indicating the deterioration of the waters. Therefore, this pollution of surface waters is severe enough to threat the health of population by causing a disease such as calorie, etc. In addition, the springs found in the city are also highly contaminated by nitrates. But most of the ground waters of Addis Ababa (bore holes) are safe for drinking and those found in the southern extreme part of the city are contaminated.

It is, therefore, concluded from the chemical analysis that the streams/ivers of Addis Ababa are heavily polluted and the water is unfit for personal, domestic and recreational purposes. Based on the present investigations the following recommendations are forwarded:

1. Because of its contamination, people who depend on the streams for any purpose should be informed of the potential danger of using the water.
2. It has been observed that the polluted water e.g., the Akaki River, is used for irrigation to grow some crops and vegetables for commercial purpose of the city. Therefore, the quality of those food will be under risk and before the use of such foods some investigation is

required.

3. As the number of population of Addis Ababa is sky rocketing from year to year the water pollution becomes more serious in the city. Therefore, peoples need to be advised regularly not to dump waste materials into the streams/rivers.
4. Groundwater found in the southern extreme part of the city are susceptible to contamination. Hence, a continuous check up of chemical and biological of such groundwater is highly recommended.
5. In order to minimize the water pollution there should be a direct interrelation between governmental, non-governmental officials with the population through an extension of the waste collecting and disposal facilities entrusted with the task of waste removal of the city.
6. The open sewer of Addis Ababa should be changed to closed, under ground sewers and discharged direct to the central plant where treatment of sewage may be under taken; and the direct connection of public toilets to the streams/rivers should be condemned.
7. The proper planning of industrial and selection of appropriate disposal sites are very important considerations. In addition, the treatment of industrial sewage before discharging into the streams/rivers is also recommended.
8. Finally, as it is seen practically no organized research carried out in this city about water quality and it is time to expand much further; and more investigation of chemical analysis is also required upon which important water use planning may be based in order to preserve the water quality for different purposes.

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APPENDIX

.....Continued

KE1	UP stream Kechene	6.5	16.5	18	0.07	100	10.0	3.0	0.30	ND	25	ND
KE2	Ras Mekonnen bridge	7.6	46.1	153	2.90	17	22.0	70.0	3.50	ND	47	ND
KE3	Kechene stream Zewditu	7.6	40.0	159	1.60	10	24.0	41.0	3.80	ND	47	ND
KE4	Bantiyketu stream	7.6	32.0	220	0.30	5	14.0	47.0	2.20	ND	38	0.80
	Yeka Stream											
YS1	Up stream Yeka	5.9	21.0	43	ND	55	ND	2.2	0.10	ND	49	ND
YS2	Stream Yeka	7.5	14.0	122	0.70	133	1.0	27.0	6.10	ND	36	3.80
	Big Akaki											
A1	Before Aba-Samuel	7.8	26.0	244	0.80	12	11.0	22.0	2.50	ND	22	0.60
A2	Aba-Samuel lake reservoir	8.0	14.0	275	0.05	1	67.0	47.0	ND	ND	20	0.60
A3	Aba-Samuel lake outlet	7.3	27.0	256	0.50	ND	11.0	38.0	ND	ND	11	0.06

Table A2: The analytical results of ground waters (Bore holes and springs)

Co de	Ground Waters	in ppm											
		pH	COD	HCO ₃ ⁻	NH ₄ ⁺	NO ₂ ⁻	NO ₃ ⁻	SO ₄ ²⁻	Cl ⁻	PO ₄ ³⁻	S ²⁻	SiO ₂	F ⁻
W1	Italy Embassy	8.0	7.6	165	ND	ND	ND	8.0	7	ND	ND	41	1
W3	General Winget School	7.6	11.2	159	ND	ND	2.0	11.0	2	ND	ND	34	0.2
W2	AAU (sidist killo)	7.6	6.8	232	0.10	ND	0.7	6.0	7	ND	ND	24	0.2
W1 1	Sister Consolodata	7.5	7.2	201	ND	ND	6.8	3.3	4	0.1	ND	25	0.2
W7	AAU (Building College)	8.0	8.1	153	ND	ND	35.0	5.0	17	ND	ND	23	0.1
W4	AA Shola Dairy	6.4	7.2	110	ND	ND	9.0	3.0	2	ND	ND	21	0.3
W1 2	Repi Soap Factory	7.4	7.6	171	0.10	ND	10.0	ND	5	0.1	ND	21	0.4
W1 3	St. Abo Holly water	7.6	11.6	49	ND	ND	3.0	2.0	7	ND	ND	8	0.2
W9	AA Cement Factory	7.0	9.2	152	ND	ND	11.0	13.0	12	0.1	ND	20	0.7
W5	St. Michael Holly Water	7.4	10.8	43	ND	ND	4.0	1.0	5	ND	ND	9	0.2

.....Continued

Code	Spring Waters	p ^H	COD	HCO ₃ ⁻	NO ₂ ⁻	NO ₃ ⁻	SO ₄ ²⁻	Cl ⁻	PO ₄ ³⁻	S ²⁻	SiO ₂	F ⁻
W8	St. Medhanealem Holly Water (Bole)	7.3	10.8	49	ND	ND	4.0	ND	8	ND	ND	22
W14	Dewera Gudo Well (near Aba-Samuel)	7.7	40.8	256	ND	ND	9.0	82.4	28	ND	ND	24
W15	Ato Tessema House(Burayu oromia)	6.9	9.2	195	ND	ND	0.5	3.0	1	0.03	ND	24
W10	St.Gebreal Holly Water (near Mekanisa)	7.2	8.8	73	ND	ND	17.0	2.9	21	0.1	ND	17
W6	St. Urael Holly Water	6.9	6.4	55	0.04	ND	9.0	31.0	5	ND	ND	13
S2	Ras Mekonnen Spring	6.3	6.4	61	0.03	481	19.0	57	0.1	ND	70	ND
S3	Lideta Spring	6.5	11.2	146	0.07	728	23.0	194	0.2	ND	88	0.3
S1	Sami spring (Martha)	6.3	17.6	31	0.13	185	7.0	34	0.9	ND	30	ND
S4	Meganagna Spring	6.3	5.2	92	ND	56	12.0	18	ND	ND	24	0.3
S5	Kore Spring near Legedadi	6.9	9.6	159	ND	3	0.6	2	0.2	ND	26	0.4
S6	Kera Spring	5.9	9.2	61	0.03	ND	7.0	10	0.1	ND	22	0.1

Table A3: The analytical results of major cations for surface waters(ppm)

Code	Sampling Area	Na	K	Ca	Mg
	Tinishu Akaki				
TA1	Minch saloon spring	31	3	25	12
TA2	Near kera	76	28	53	26
TA3	Near behere Tsige	90	24	50	23
	Kurtum Stream				
KA1	Kurtum up stream	30	4	10	5
KA2	Near Immigration	76	27	49	28
KA3	Bantiyketu	63	22	41	19
	Kebena Stream				
KB1	Up stream Kebena	15	6	15	5
KB2	Kebena German Embassy	74	21	67	35
KB3	Kebena stream Urael	28	17	36	15
	Kechene Stream				
KE1	UP stream Kechene	12	7	7	3.6
KE2	Ras Mekonnen bridge	45	24	43	24
KE3	Kechene stream Zewditu	44	23	44	23
KE4	Bantiyketu stream	63	22	41	19
	Yeka Stream				
YS1	Up stream Yeka	8	6	6	21
YS2	Stream Yeka	41	17	29	10
	Big Akaki				
A1	Before Aba-Samuel	14	13	54	8
A2	Aba-Samuel lake reservoir	14	15	56	9
A3	Aba-Samuel lake outlet	14	14	51	9

Table A4: Analytical results of major cations for some ground waters(ppm)

Code	Samlpe point	Na	K	Ca	Mg
W14	Dewera Gudo Well (near Aba-Samuel)	15	17	29	7
W15	Ato Tessema House(Burayu oromia)	6	5	62	5
S5	Kore Spring near Legedadi	9	4	27	6
S6	Kera Spring	5	ND	14	4

Table A5: Analytical results of the trace elements of surface waters($\mu\text{g/l}$)

Code	Sampling Area	Li	Be	V	Cr	Mn	Co	Ni	Cu	Zn	As	Rb	Sr	Se	Mo	Cd	Sn	Sb	Cs	Ba	Pb	Bi	Th	U
	Tinishu Akaki																							
TA1	Minch saloon Spring	2.0	ND	7.0	ND	34	2.5	44.0	ND	ND	ND	1.8	182	5.5	1.2	ND	ND	1.6	1.2	80	ND	0.2	0.8	1.6
TA2	Near kera	0.6	0.6	ND	5.5	1230	3.3	9.2	ND	ND	ND	21.0	278	7.9	15.5	ND	ND	0.5	1.4	91	ND	ND	0.1	ND
TA3	Near Behere Tsige	1.1	ND	ND	14.0	1757	4.0	4.8	ND	ND	2.3	20.1	299	ND	2.1	ND	ND	0.2	1.0	132	ND	ND	ND	0.2
	Kurtum Stream																							
KA1	Kurtum up stream	4.4	ND	9.2	ND	6	ND	ND	ND	ND	ND	15.5	90	2.7	0.8	ND	ND	0.2	0.5	27	5.3	ND	0.1	0.4
KA2	Near Immigration	0.2	ND	5.4	ND	1203	3.6	ND	ND	ND	3.6	22.9	298	ND	8.1	ND	ND	0.6	1.9	80	ND	ND	0.1	0.2
KA3	Bantiyketu	7.5	ND	11.1	ND	171	1.6	ND	ND	0.2	2.7	16.6	237	5.0	7.4	ND	ND	0.4	2.7	58	91	ND	0.1	0.4
	Kebena Stream																							
KB1	Up stream Kebena	ND	ND	2.3	ND	12	ND	ND	ND	ND	1.2	3.2	76	ND	3.4	ND	ND	ND	0.4	47	ND	ND	ND	0.1
KB2	Kebena German Embassy	ND	ND	12.0	ND	6532	11	ND	ND	ND	ND	24.0	600	1.8	5.2	ND	ND	ND	0.5	410	ND	ND	ND	1.0
KB3	Kebena stream Urael	0.5	ND	6.5	ND	1219	2.4	ND	ND	ND	0.6	13.0	234	ND	4.7	ND	0.6	0.5	1.7	70	ND	ND	0.5	0.6
	Kechene Stream																							
KE1	UP stream Kechene	0.2	ND	ND	5.8	63	ND	ND	ND	54	1.0	3.6	31	11.0	1.7	ND	ND	0.1	0.5	27	7.9	ND	ND	0.1

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KE1	UP stream Kechene	0.2	ND	ND	5.8	63	ND	ND	ND	54	1.0	3.6	31	11.0	1.7	ND	ND	0.1	0.5	27	7.9	ND	ND	0.1
KE2	Ras Mekonnen bridge	ND	ND	3.6	ND	1142	2.8	ND	ND	ND	0.1	18.2	294	ND	11.0	ND	ND	0.3	ND	101	ND	ND	0.2	0.4
KE3	Kechene stream Zewditu	ND	ND	1.5	ND	1551	3.2	ND	ND	82	0.1	18.0	297	1.0	12.0	ND	ND	0.7	0.4	98	ND	ND	0.2	0.6
KE4	Bantiyketu stream	7.5	ND	11.0	ND	171	1.6	ND	ND	0.2	2.7	16.5	237	4.9	7.4	ND	ND	0.4	2.7	58	91	ND	0.1	0.4
	Yeka Stream																							
YS1	Up stream Yeka	0.2	ND	13.0	ND	23	ND	ND	ND	ND	ND	19.0	42	6.5	2.6	ND	ND	ND	ND	2196	ND	ND	ND	0.2
YS2	Stream Yeka	1.6	1.6	7.7	ND	28	2.5	ND	ND	ND	3.5	13.0	145	11.0	14.0	ND	1.4	2.8	4.0	83	11	1.0	1.0	1.6
	Big Akaki																							
A1	Before Aba-Samuel	5.0	ND	4.3	2.3	1190	2.7	5.1	ND	ND	0.4	8.8	235	ND	4.7	ND	ND	0.2	0.5	107	ND	ND	0.1	0.7
A3	Aba-Samuel lake outlet	1.3	ND	6.3	ND	2944	2.4	8.9	ND	ND	2.2	12.4	242	ND	06.2	ND	ND	0.1	0.6	153	ND	ND	0.1	0.6

Table A6: Comparion of surface waters(ppm)

No	Sampling Area	Measured Parameter													
		COD		NO ₂ ⁻		NO ₃ ⁻		PO ₄ ³⁻		SO ₄ ²⁻		Cl ⁻		pH	
		1	2	1	2	1	2	1	2	1	2	1	2	1	2
1	Kechene stream,Zewditu	40	127	1.60	0.05	9.5	ND	3.8	10.0	24.0	15.0	41	65	7.6	7.6
2	Tinishu Akaki,B.Tsige	24	68	0.05	0.05	9.7	1.3	3.03	7.6	0.4	ND	103	22	7.5	7.7
3	Bantyeketu stream	32	410	0.32	0.03	5.0	0.8	2.2	10.0	13.7	4.0	47	48	7.6	7.7
4	Kebena stream, Urael	20	127	0.35	1.19	9.0	0.8	2.1	10.0	9.3	6.0	34	46	7.5	7.7
5	Kechene, near university	46	40	2.90	0.59	17	3.5	3.5	9.0	22.0	9.0	70	70	7.6	7.8
6	Aba-Samuel lake outlet	27	7	0.05	0.10	ND	1.3	1.3	1.8	2.2	3.8	31	50	7.3	7.3
7	Aba-Samuel lake reservoir	14	7	0.40	0.07	1.2	1.3	ND	1.8	67.0	3.5	47	48	8.0	7.0

Table A7: Comparison of ground waters(ppm)

No.	Sample Point	Measured Parameter													
		HCO ₃ ⁻		NO ₂ ⁻		NO ₃ ⁻		PO ₄ ³⁻		SO ₄ ²⁻		Cl ⁻		pH	
		1	2	1	2	1	2	1	2	1	2	1	2	1	2
1	AAU,Sidist kilo	232	188	ND	0.02	0.72	0.88	ND	0.10	6.4	20	6.80	6.0	7.6	7.3
2	AA cement Factory	152	186	ND	0.005	11.3	44.0	0.1	0.30	12.7	20	11.9	5.0	7.0	7.2
3	General Winget School	232	126	ND	0.01	0.72	3.08	ND	0.10	6.4	ND	6.80	0.1	7.6	7.8
4	Shola Dairy	110	50	ND	0.05	8.8	13.2	ND	0.36	2.5	31	1.70	16 0	6.4	6.8
5	Repi Soap Factory	171	140	ND	ND	10.2	7.90	0.1	0.20	ND	ND	4.82	2.0	7.4	7.2

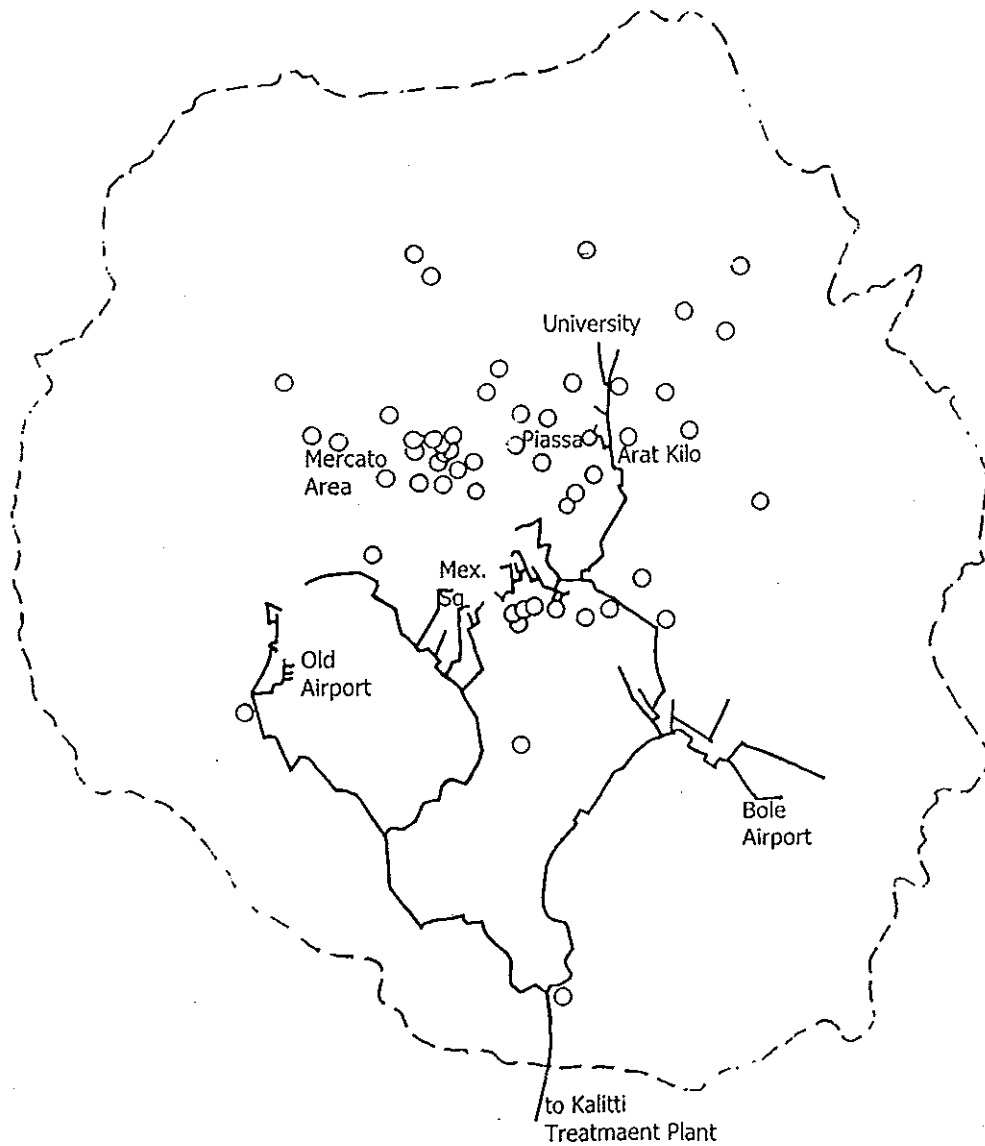



Figure A1. The sewers and public toilets of Addis Ababa.

DECLARATION

I, the undersigned, declare that this thesis is my work and all sources of materials used for the thesis have been duly acknowledged.

Name: ABRAHA G/KIDAN

Signature: 

Place and date of submission: Department of Chemistry
Addis Ababa University
June 2000

This thesis has been submitted for examination with my approval as university advisor.

Dr. B. HUNDHAMMER 