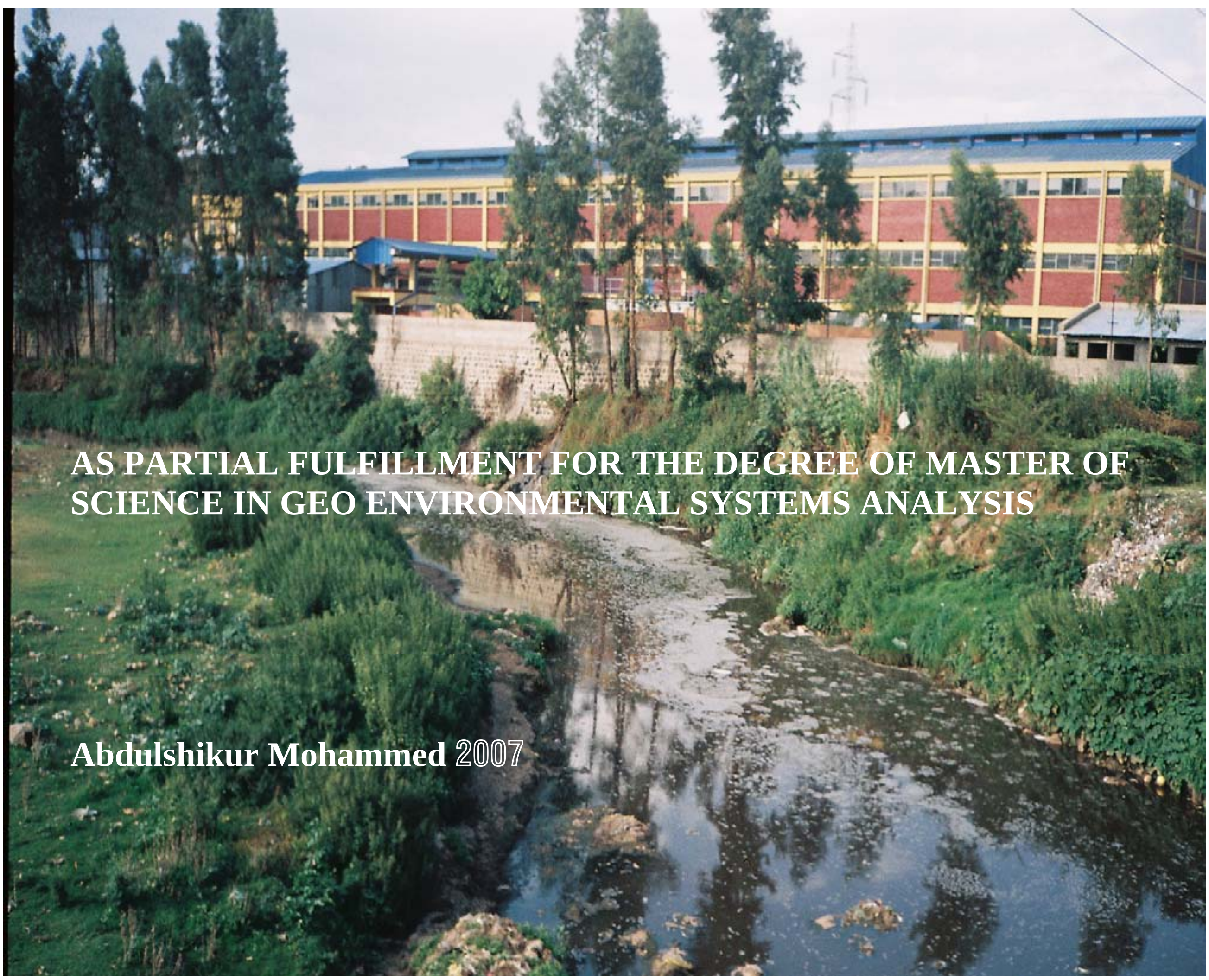
School Of Graduate Studies

Department Of Earth Sciences

ENVIRONMENTAL ANALYSIS OF A HYDROLOGIC SYSTEM THE CASE OF TINISHU AKAKI RIVER, WESTERN ADDIS ABABA, ETHIOPIA.



AS PARTIAL FULFILLMENT FOR THE DEGREE OF MASTER OF SCIENCE IN GEO ENVIRONMENTAL SYSTEMS ANALYSIS

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Abbreviations

AAEPB	Environmental Protection Bureau of Addis Ababa
AAWSA	Addis Ababa Water and Sewerage Authority
BOD	Biochemical Oxygen Demand
BOD_5	Five Days Biochemical Oxygen Demand
CBOD	Carbonaceous Biochemical Oxygen Demand
CSA	Central Statistical Authority
COD	Chemical Oxygen Demand
CUM	Cubic Meter
DO	Dissolved Oxygen
ESDI	Ecologically Sustainable Industrial Development
EC	Electrical Conductivity
EPA	Environmental Protection Authority
EMA	Ethiopian Meteorological Agency
FS	Floatable substances
KN	Kjeldehal Nitrogen
l	Liter
mm	Mili meter
m	Mili gram
MoH	Ministry of Health
MoWR	Ministry of Water Resources
MNP	Most Probable Number
µg/l	Micro gram per liter.
µS/cm @200^{o}c	Micro siemens per centimeter at 200^{o}c.
NBOD	Nitrogenous Biochemical Oxygen Demand
ODWs	Oxygen Demanding Wastes
PoPs	Persistent Organic pollutants
PCBs	Perchlorobiphenyls
SBPDA	Sanitation, Beautification & Parks development Agency
SOD	Sediment Organic Demand
SS	Suspended Solids
Set.S	Settelable Substances
TAR	Tinishu Akaki River
TC	Total Carbon
TDS	Total dissolved Solids
TMDL	Total Maximum Daily Load
TOC	Total Organic Carbon
WHO	World Health Organization
WMO	World Meteorological Organization
WLAs	Waste Load Allocations
WWTPs	Waste Water Treatment Plants

Abstract

Water Quality analysis of the Tinishu Akaki River System has been carried out with the objective of identifying where and when the river's pollution and its consequences are more pronounced. And to determine what factors and / or processes prevail and control the situation spatially and temporally. To do so primary data on conventional water quality parameters; dissolved oxygen (DO), ammonia (NH_3), Nitrate (NO_3), Nitrite (NO_2), PH, temperature(T^o) and total dissolved solids (TDS) was generated. In this study, five water samples were collected and analysed to represent the 2007 moderate flow period, the three spatial domains of the river (i.e. up, mid, and down streams) and the date when industrial effluents discharge is minimal. Besides, secondary data on the same and other physiochemical parameters for the years 1997, 1999, 2000, 2002/03, 2003/04, 2005/06, were collected from EPA monitoring unit and available literatures. After that, the available primary and secondary data were segregated between the three spatial domains, Low, Moderate, and High flow seasons, and Peak and little or No Industrial effluents discharge patterns. Then, by taking dissolved oxygen (DO) depletion as important water quality indicator pollution along the river course and its consequences have been analysed using spread sheet program. Moreover the physicochemical factors such as altitude, atmospheric pressure, temperature, Stream flow velocity, Salinity (TDS), $BOD_{5,}$ NH_3, PO_4, …etc. were used to justify the variation in DO level in the River water column. The results of the analyses depict that the extent of pollution is more severe when industrial effluents load is high and the river's flow is low. Moreover, the midstream spatial domain is found to exhibit the worest situation in terms of pollution and or DO depletion. Above all, the increase in the concentrations of potentially harmful substances; heavy metals (Fe, Mn and Cr), ammonia, hydrogen sulphide, sulphates and phosphates is found to be associated with the generally declining DO level in the down stream direction. So as to abate this problem of water pollution, TMDLs (Total Maximum Daily Loads) and WLAs (Waste Load Allocations) for oxygen demanding wastes of industrial point sources is suggested to be the most cost effective and applicable mechanism of abatement that can assure the attainment of in stream water quality standards.

Key Words: Dissolved Oxygen depletion, Tinishu Akaki River, Conventional Water Quality parameters, Ethiopia.

1. INTRODUCTION

1.1 Water Pollution

The natural physicochemical properties of water render its vital importance to sustain the living planet Earth and every form of life on its face, including human beings. Its vital role in many human activities including agriculture, industry, domestic, electric power generation, transport and recreation shows that to what extent water is an integral part of human's life. The normal functioning of a natural system such as a human body depends entirely on the availability of adequate quantity and quality of water.

Owing to the natural interaction among the earth's subsystems, pure water does not exist by default and its quality can be affected by some dissolved and or suspended substances of natural or anthropogenic origin, and consequently gets polluted. Water pollution is the state of alteration in the natural physical, chemical, biological, bacteriological and radiological properties of water that causes in an impairment of its inherent and or designated uses (Susan & Joy 1998). This also disturbs the biophysical entities of a water body and negatively affects the socio-economic values of water.

This days water pollution resulted from industrialization, urbanization and population explosion has become a global problem. Our country, Ethiopia is also facing the problem of water quality degradation, however, the extent and degree of severity of water pollution is more pronounced in major cities, like Addis Ababa where the problem is at its peak currently. Being the socio political and industrial corner of the country, the capital Addis Ababa and its suburbs are severely affected by the problem of water pollution. Back in time the intermittent and perennial small tributaries and the two major rivers (the Big and Tinishu Akaki) were supposed to be cleaner to a greater or lesser extent. However, the situation has been changed through time, as a consequence of expanding industrialization and extensive population growth. Almost all the tributaries and major rivers draining the city are exposed to different pollution sources.

However, the analysis of a hydrologic system is bound to overlap with the analyses of weather and climate, soil and geology, and the aquatic and terrestrial life. Accordingly, this thesis work will attempt to address the overlaps and interactions among the above environmental components in the subsequent sections.

1.2 Description of the Study Area

1.2.1 Location and Hydrology

Addis Ababa is located on the central highlands at the heart of the country. And the whole of the city lies in the upper Awash river Basin (Tesfaye Chernet 1993, as cited by Solomon Tale 2000) which is comprised of two sub basins namely:

1. The Big Akaki River Basin (The Eastern Subcatchment) &
2. The Tinishu Akaki River Basin (The western Subcatchment)

These subcatchments are separated with a generally N-S trending surface water (hydrographic) divide (Solomon Tale, 2000).Tinishu Akaki River drain the western portion of the city and have a surface area of 950.562 sq.kms (fig.1). It starts from Burayu (Northwest), Gullele and Entoto (North) high lands and flows to the undulating center of the city and then to the flat lying South Western suburbs. After running for about 42.6 kilometers it leaves a dieing Aba Samuel lake that serves as pollutants sink. Many tributaries join Tinishu Akaki River at different localities (Table1). Along its course down to its end, it receives diverse pollution load representative of the areas it and its tributaries drain. Tinishu Akaki River is a third order free flowing river formed from two second order rivers, namely Seko and Gefersa rivers. Seko river formed from two streams (BurayuKera and Welanso) which join at a locality called abay lala south of the Burayu Bridge where as the Gefersa river is a result of two unnamed streams coming from the Gefersa reservoir area. The tributaries and their points of confluence with Tinishu Akaki River are listed in table 1. Moreover larger than 65% of small and medium scale industries in the country reside in the capital Addis. However; most of them are established along either banks of Tinishu Akaki River and are mostly with no or non-functioning waste water treatment facilities. Therefore, discharge untreated waste water to the river and its tributaries. (EPA, 1999).The factories which are closer to and slightly further from the rivers, discharge their effluents to open ditches, municipal drainage which finally ends up in the river. The common contaminants from these industries include solids, oils, detergents, solvents, pesticides, and inorganics such as nitrates, phosphates, sulphates, chloride and others. Besides, heavy metals, acids, alkalis are the most common pollutants generated from industries See (Table 2).

Fig.1 The Study Area (Bounded in Brown Line) Modified after (Tamiru et.al. 2003)

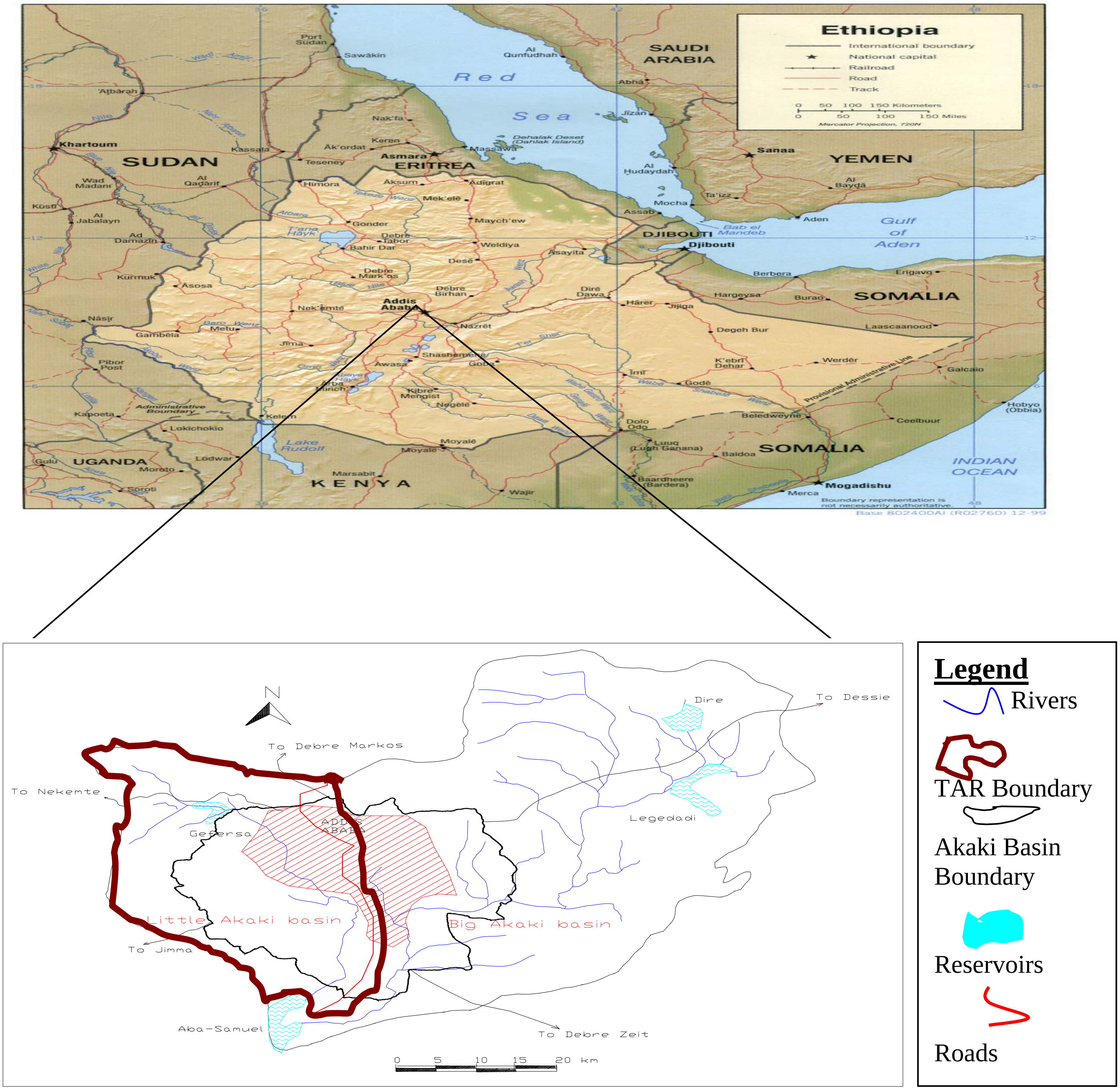


Table 1 Major Tributaries of Tinishu Akaki River and The Types of Areas They Drain.

Name of Tributary	Point of Junction	Drainage area Type
1. Leku	UTM(E) 465683 UTM(N) 1000053	Forest and scattered settlements
2. Soramba	UTM(E) 466367 UTM(N) 999341	Forest, Unplanned settlements,& Markets
3. Gerbaja	UTM(E) 466969 UTM(N) 996936	Residential, Farm plots and forest
4. Likuanda	UTM(E) 467878 UTM(N) 996897	Residential & Market
5. Melka Kurani	UTM(E) 468115 UTM(N) 995560	Residential and agricultural
6. Weira	UTM(E) (Inaccessible) UTM(N)	Residential
7. X	UTM(E) (Inaccessible) UTM(N)	Residential
8. Y	UTM(E) (Inaccessible) UTM(N)	Residential and commercial
9. Zenebworke	UTM(E) 467990 UTM(N) 993300	Residential, commercial and institutional
10. Mekanissa	UTM(E) 470572 UTM(N) 991761	Residential,industrial,commercial and institutional
11. Lafto(Tirbu)	UTM(E) 471490 UTM(N) 990175	Residential and farm lands
12. Jaja	UTM(E) 472305 UTM(N) 990043	Residential,industrial, institutional

Table 2 Major pollutants generated from industries around the river (EPA 1999).

Industrial Sector	Major Pollutants
Food And Beverages	Food preservatives. Cleaning chemicals e.g. NaOH, detergents Air pollution from dust fuel combustion, and organic substances.
Textile, Clothing, Tanning, and Leather goods	Waste water from scouring, Mercerizing, bleaching and dying (NaOH, peroxides, aluminum cpds and dyestuffs) Waste water from tanneries; Chrome, sulphides, ammonium salts, chlorides etc. Solid wastes from deharing, Fleshing and trimming of hides and skins
Wood and Wood Products	Saw dust, Wood Preservatives, paints, and varnishes
Paper, Paper Products & Printing	Printing chemicals, lead in granule form Trimmed papers and inorganic chemical wastes
Chemical, Rubber & Plastic Products	Solid wastes of scorched rubber, scraps of rubber and pvc, plastic and dust. Organic and inorganic chemical wastes
Non metallic mineral products	Dust and particulates, air pollution from fuel combustion.

Basic Iron and steel	Scrap metal, air pollution from combustion
Machinery and equipment	Inorganic waste water, Scrap metal

1.2.2 Climatic Features

The prevailing weather condition of an area observed over a long period of time, usually of over 30 years according to WMO is termed climate. And commonly it governs the physicochemical properties of surface water bodies of an area. Therefore, climatic features are indispensable in any investigation pertaining to a hydrologic system such as a river system. The greater proportion of Tinishu Akaki River Basin is within Addis Ababa City Administration and according to Daniel's (1977 cited in Tamiru et.al. 2003) classification of the Ethiopian rain fall regions; Addis Ababa is located in the region where the rainy months are contiguously distributed. In this classification scheme rain fall coefficients (a ratio of mean monthly rainfall of each month to one twelfth of the annual mean rainfall) were computed for each month so as to determine whether a month is dry or wet. And months October through February are found to be Dry and March to May are small rainy months where as June to September is heavy rainy period. In Addis the mean annual temperature is 16.32 ^{o}C and this categorizes the city under "Woina Dega" Sub tropical climatic conditions (EPA, 2005). Besides, the mean yearly rainfall of the Akaki river basin for the years between 1975 and 2005 is 1039.1 mm (Table 3). Seasonal air temperature variation is not large through out the year (Table 4 and fig.2) in Addis Ababa.

Table 3 Total Annual Rainfall (mm) for the years1975-2005 (**Appendix 1**)

Year	Annual Total Rainfall (mm)	Average (1975-2005)
1975	1301.7	1039.1
1976	1163	
1977	1483	
1978	1110.3	
1979	1095.8	
1980	1167.8	
1981	1197.6	
1982	964.1	
1983	1156.3	
1984	954.9	
1985	1084.9	
1986	1024	
1987	1120.2	
1988	1112.5	
1989	1185.7	
1990	1050.7	
1991	994.1	
1992	855.5	
1993	966.4	
1994	791.9	
1995	903.6	
1996	1112.2	
1997	856.7	
1998	1070.9	
1999	954.5	
2000	837.3	
2001	895.7	
2002	820.7	
2003	1056.9	
2004	812.5	
2005	1112	

Table 4 Mean Monthly Temperature (^{o}c) for the year 2005. (**Appendices 2 and 3**)

	J	F	M	A	M	J	J	A	S	O	N	D	Average
Max.	27.1	29	28.2	27.8	26.8	26.3	23.7	24.6	24.5	26.2	26.3	26.1	26.4
Min.	13.6	15.2	16.5	16.1	16.0	15.4	15.2	15.6	15.6	16.0	14.6	13.7	15.3

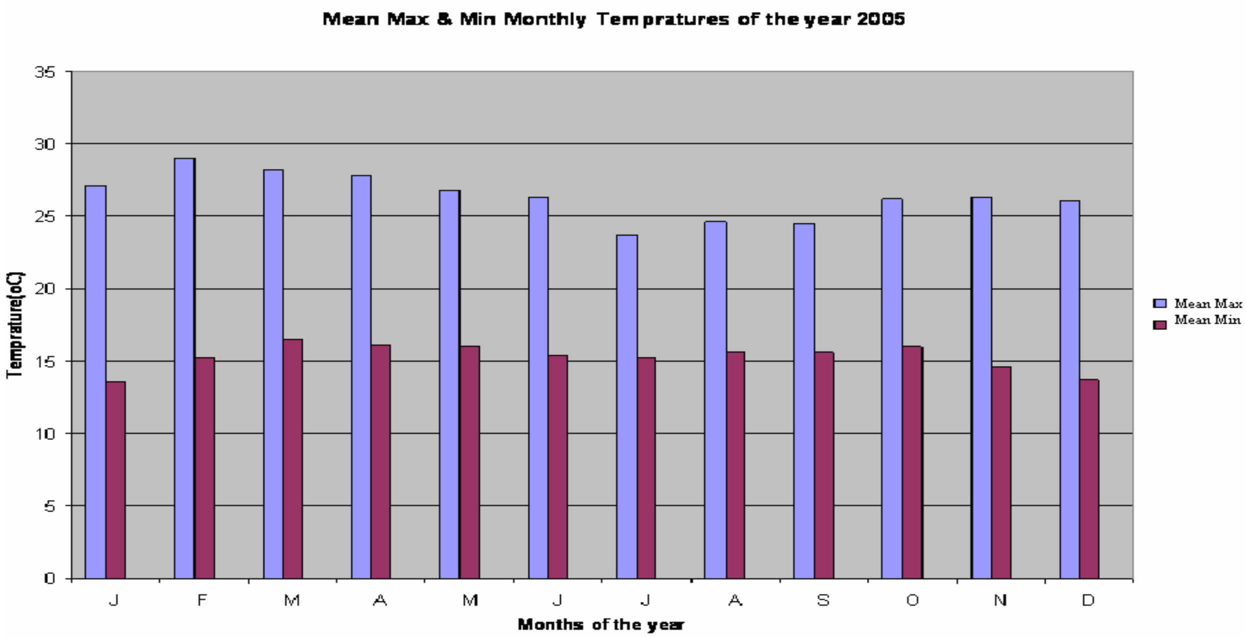


Fig. 2 Mean Max and Min Monthly Temperatures of the Year 2005.

Therefore, the mean annual temperature varies from 13.75 ^{o}C to 26.11 ^{o}C (Table 5).There are two distinct rain fall seasons in a year. During heavy rainy season, that is from mid June to the end of September 71.99% of the annual average rainfall of 1039.1mm is registered. Generally the precipitation is orographic and is characterized by intense rainfall of short durations (EPA, 2005). The spring season, which covers the period from mid February to April is the other rainfall season. The remaining months of the year are generally characterized by having little or no rain. Analysis of the relationships between rainfall and Akaki River flow shows that the highest flow and level in the river corresponds to the rainy season (June–September) (Aynalem Ali 1997) the same is observed in the TAR. Thus flow values for the analysis have been extrapolated from the adjacent stations since TAR is ungauged (Figures 3, 4, 5 and Table 6).

Table 5 Mean Annual Temperature (^{o}c) for the years 2000-2005.

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Average
MeanMax Temp.(^{o}c)	27.9	23.8	26.0	25.9	25.7	25.8	26.2	26.7	26.4	26.4	26.4	26.11
MeanMin Temp.(^{o}c)	12.3	12.1	15.0	14.2	12.8	12.6	13.7	14.2	14.2	14.9	15.3	13.75

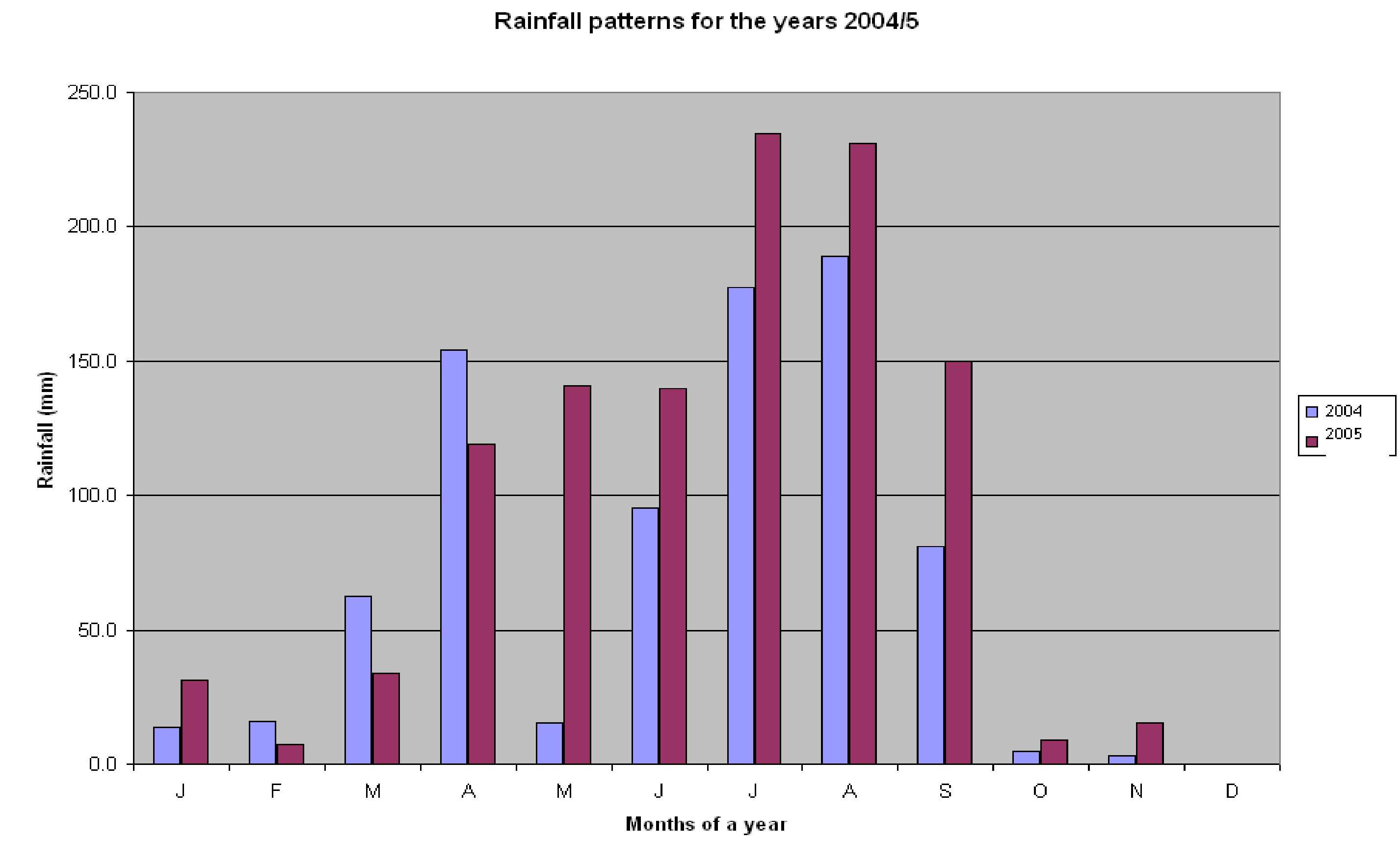


Fig. 3 Rainfall Patterns for Months of the Years 2004/5.

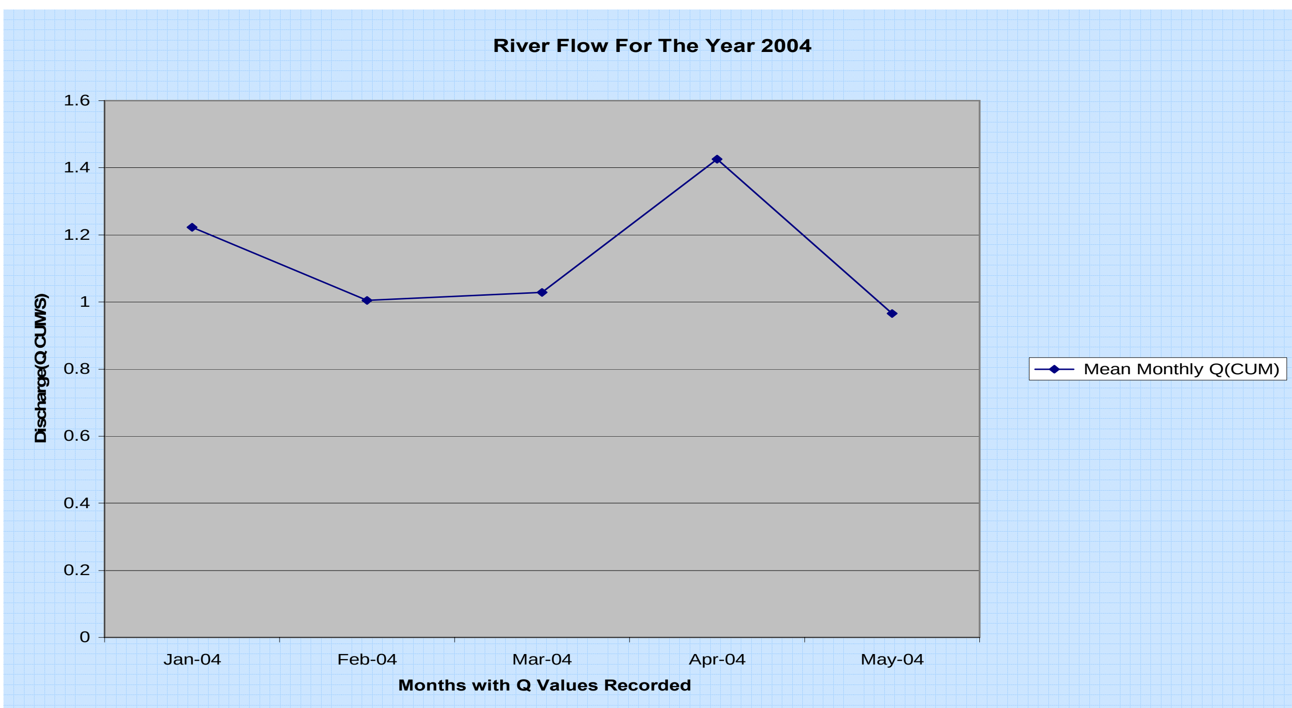


Fig.4 Mean monthly flow of TAR for low & moderate rainy months of the year 2004.

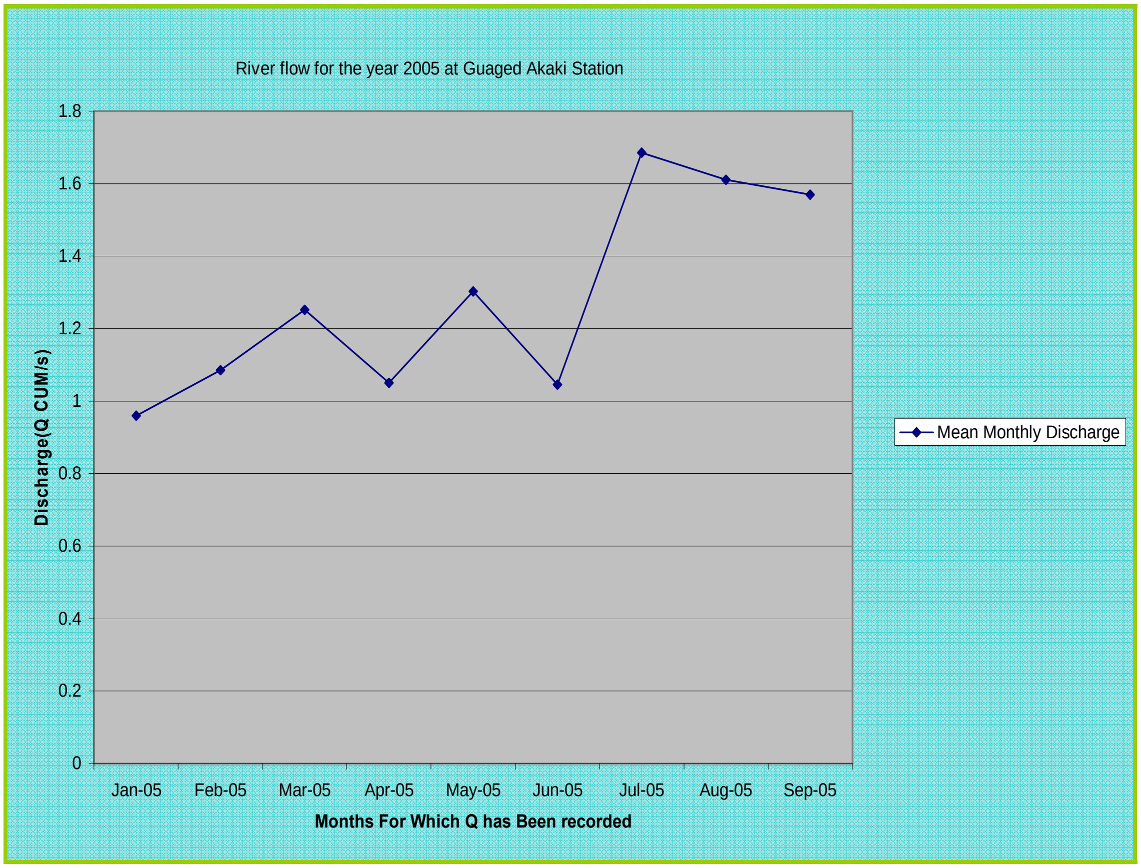


Fig.5 Mean monthly flow of TAR for all rainy months of the year 2005.

Table 6 Monthly Rainfall (mm) for the year 2004/2005 (**Appendix 1**).

	J	F	M	A	M	J	J	A	S	O	N	D	Mean
2004	13.6	15.8	62.4	154.2	15.4	95.2	177.7	189.1	80.9	4.8	3.4	0	67.7
2005	31.4	7.3	33.9	119.0	140.7	139.9	234.8	231.0	149.7	9.1	15.2	0.0	92.7

1.2.3 The Geologic Settings

Geology is one of the most important natural factors that determine the chemistry of natural waters as all of the chemicals in the environment participate in geochemical cycles of some kind, similar to the rock cycle (Carla M.G 2000). The type, distribution, composition, property, and period of contact of a rock mass greatly influences the constituents and their concentrations in a given water body.

And the presence of geologic structures and their density in a rock body highly contributes to the prevailing surface and ground waters interaction. Thus there is a greater chance for a moving surface water body to acquire certain physicochemical properties as a result of its interaction with the surrounding geologic material and the underneath reservoirs. Some dissolved weathering products are carried in to surface water bodies such as rivers. Therefore the geologic setting of the project area will be presented in the following two sections hereunder. And these are:

1.2.3A. The Stratigraphic Sequences, And

1.2.3B. The Geologic Structures.

1.2.3A. The Stratigraphic Sequences

Addis Ababa represents the western escarpment of the main Ethiopian rift system and many researchers systematically proposed its geology and volcanic stratigraphic sequences. The Miocene-Pleistocene volcanic succession in the Addis Ababa area suggested by Haileselassie Girmay and Getaneh Assefa (1989) as cited by Solomon Tale, 2000 and Tamiru et.al. (2003) from bottom to top is:

1.2.3A.1 Alaji Basalts,

1.2.3A.2. Entoto Silicics,

1.2.3A.3. Addis Ababa Basalts,

1.2.3A.4. Nazareth Group, And

1.2.3A.5. Bofa Basalts.

1.2.3A.1 Alaji Basalts

The Alaji group volcanic rocks (Alaji Rhyolite and Basalt) in this part of the escarpment were outpoured from the end of Oligocene until middle Miocene (Zanettin et al., 1974) as stated in Solomon Tale 2000. This unit is composed of basalts, which show variation in texture from highly porphyritic to aphanitic. Within this unit there is an intercalation of gray and glassy welded tuff. This unit outcrops at the crest of Entoto-ridge bordering the northern parts of Addis Ababa (Haileselassie Girmay and Getaneh Assefa, 1989). It is underlain by tuffs and ignimbrites; on the other hand its stratigraphic relationship with the Entoto silicics is difficult to determine as they occur in a fault contact. Mohr (1967); however, proved that the Entoto trachyte overlies the Alaji basalt. The age of the rock is 22.8 M.Y (Morton et. al., 1979).

1.2.3A.2. Entoto Silicics

These early Miocene age silicic volcanics could represent localized terminal episodes to massive Oligocene fissure basalt activity in the Addis Ababa region (Morton et.al. 1979). The thickness of the flow become maximum on the top of Entoto ridge and thin both towards the plateau and the plain east of Addis Ababa. According to Zanettin and Justin-Visentin (1974) these lavas make up a thick pile of flows accumulated along east west fissures (east-west fault running from Kassam River to Ambo) and uplifted northwards. The unit is unconformably overlain by Addis Ababa basalt on the foothill of Entoto and underlain by Alaji basalt. The Entoto silicics composed of rhyolite and trachyte with minor amount of welded tuff and obsidian (Haileselassie Girmay and Getaneh Assefa 1989). The rhyolitic lava flows outcrop on the top and the foothills of the Entoto ridge, predominantly in the western side. The thickness is quite variable as it frequently forms dome structure. In this rock unit flow banding, folding and jointing are common. The rhyolites are overlain by feldspar porphyritic trachyte and underlain by a sequence of tuffs and ignimbrites. Tuffs and ignimbrites are welded and characterized by columnar jointing. The rhyolite made up of phenocrysts of plagioclase and altered rebeekite in a groundmass of glass with iron oxide. The trachytic lava flows outcrop on the top of Entoto ridge and its foothills. It shows a quite uniform texture, and is constituted by phenocrysts of oligoclase, sandine and rebeckite within a groundmass of plagioclase, iron oxide and minor quartz and mafic minerals. The Entoto silicics are dated 21.5my by Morton (1974) and 22 my by Morton et al. (1979). Thus from the general stratigraphy established by Zaneitin et al. (1974) both rhyolite and trachyte of the Entoto silicics belong to the “Miocene

Alaji Rhyolite and Basalt" sequences. The general geology of the study area is given in fig.6 bellow.

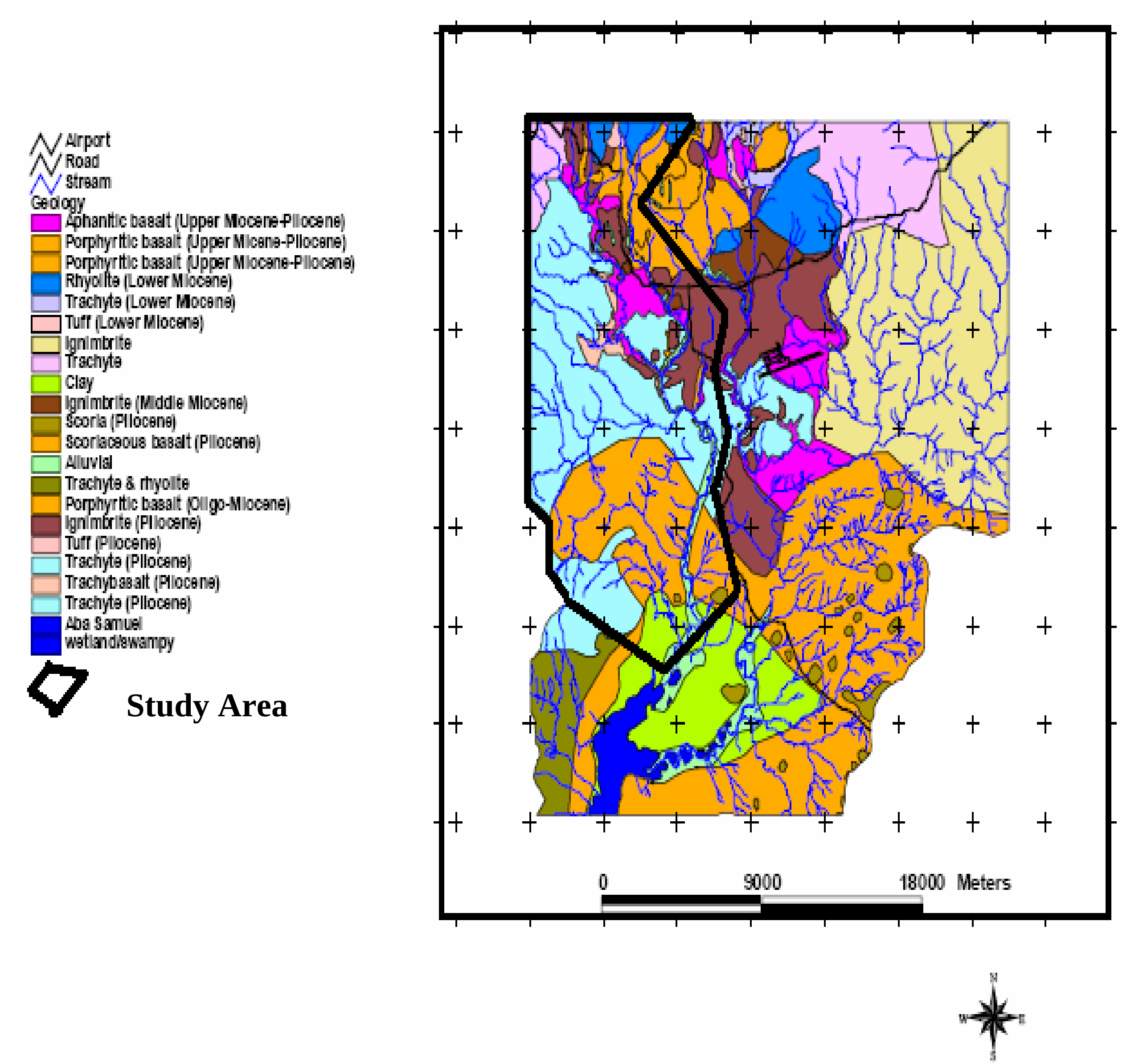


Fig6 The geologic map of Addis Ababa (Modified after Tamiru et.al. 2003).

1.2.3A.3. Addis Ababa Basalts

These units, which are mainly present in the central part of the town, are underlain by the Entoto silicics and overlain by Lower welded Tuff of the Nazareth group. It is porphyritic in texture, composed of labradorite, bytownite, olivine and augite as phenocrysts. The ground mass is made of andesine, labradorite, olivine, magnetite and pyroxene (Haileselassie Girmay and Getaneh Assefa 1989). Olivine porphyritic basalts outcrop in the central part of the town that includes Mercato, Teklehaymanote. The distribution of plagioclase porphyritic basalt is almost the same as that of the olivine prophyritic basalt, but only little more northwards. It outcrops in the study area, arround General Winget School. The thickness of the former varies from 1m or less in the foothills of Entoto, Lideta Airfield and Filwoha to greater than 130 meters at Ketchane stream (Morton, 1974; Varnier et al., 1985). In the project area, the Lower Welded Tuff overlies both types of basalt nearby the Building College, and the Kolfe Police School. The relation ship between olivine and plagioclase poryphyritic basalts is very difficult to determine in the study area except that the former overlays the latter at one place elsewhere (Varnier et al., 1985). Addis Ababa basalt yield ages clustering around 7my and seams to have no time /composition equivalent (Morton et al., 1974).

1.2.3A.4. Nazareth Group

The units identified in this group denoted as Lower Welded Tuff, Aphanitic basalt and Upper Welded Tuff. The group is underlain by Addis Ababa basalt and overlain by Bofa basalts. The rocks outcrop mainly south of Filowha fault and extend towards Nazareth.

1.2.3A.4.1 Lower Welded Tuff

This rock outcrops as small discontinuous body in Filwoha, western parts of Addis Ababa and Sululta. It is glassy with abundant fiamme and has columnar joints. Generally it is overlain by the aphanitic basalt and underlain by the olivine and plagioclase prophyritic basalts. The age of this rock as dated by Morton et al. (1979) at Addis Ababa and Sululta is 5.1 and 5.4 million years respectively. This age overlap with the period of the activity of Wachecha trachyte volcanoes, dated 4.6 million years. Wachecha is located 15 km west of Addis Ababa and probably the sources of the Lower welded tuff at both localities (Morton et al., 1979).

1.2.3A.4.2 Aphanitic Basalt

This basalt covers the southern part of the town, especially the areas of Lideta Airfield. The rock body shows vertically curved columnar jointing together with sub-horizontal sheet jointing. Lenses of Kaolin are present at the contact of this basalt with the younger ignimbrite. This is a sure evidence for the hydrothermal alterations along a NE-SW fracture system, which may affects both the basalt and the Entoto trachyte. Moreover the basalt is overlain by pumeacoues pyroclastic falls and the pyroclastic falls. It is underlain by a soil horizon that covers the plagioclase porphyritic basalt and overlain by soil horizon and tuff layers that lie below the young ignimbrite. It consists of: Labradorite, augite, rarely olivine and magnetite. The crystals of plagioclase show marked flow alignments. The age of the basalt in Addis Ababa ranges from 3.4 to 3.6 million years (Morton, 1974). Trachy-basalt outcrops around Repi and nearby General Wingate School. It is underlain by the plagioclase and olivine porphyritic basalt and overlain by the younger ignimbrite from which it is separated by tuffs and agglomerates. Its relation with the rocks of the group is not clear, but probably younger than the aphanitic basalt (Getaneh et al., 1985). Moreover, phenocrysts that occur mainly in the rock are: sandine, labradorite, magnetite and augite.

1.2.3A.4.3 Upper Welded Tuff

This rock outcrops all over the southern part of the study area including Nefas Silk and Railway station; nevertheless it is also present in the central and northern parts of the town. It is gray colored, vertically and horizontally jointed and composed of sandine, an orthoclase, rebekite, quartz, pumice and unidentified volcanic fragments (Getaneh Assefa et al., 1989). The welded tuff is underlain by aphanitic basalts and overlain by young olivine basalts. An age determinations made on a sample collected near by Haille Gebreselassie road resulted 3.2 million years, that overlap with the activity of Yerer trachytic volcanoes (Morton et.al., 1979).

1.2.3A.4.4 Young Trachyitic Flow

This rock predominates the southwestern parts of the study area, from Dama hotel towards Furi and Repi along the hills and foothills of Hana Mariama and Tulu Iyou. It is porphyritic with phenocrysts of plagioclase (albite-oligoclase) sandine, biotite within a groundmass of microlites of feldspar. Moreover, it is underlain by the tuff that covers the young ignimbrite and overlain by alternating flows of plagioclase porphyritic basalt and rhyolite especially in the Repi hill. Its relation with the young olivine prophyrytic basalt is not clear as they outcrop in different parts of the areas; however, in a small outcrop nearby Aba Samuel Lake south of the project area, the trachyte underlies the olivine porphyritic basalt.

1.2.3A.5 Young Olivine Porphyritic (Bofa) Basalt

They outcrop southward from Akaki River where they appear in the form of boulders reaching a thickness of 10 meter. They are restricted and dominant in the southeast part of the town i.e. Debre Zeit Road. They contain phencorysts of plagioclase, olivine that is partially and completely altered to iddingisite and augite within a groundmass composed of plagioclase, magnetite, pyroxene and olivine. This basalt is underlain by the tuffs, which cover the welded tuff. The age of this basalt is 2.8 My.

1.2.3B. The Geologic Structures

The genetic or post genetic features that appear within or on a geologic material play an important role in controlling the interaction between the surface and ground water systems by facilitating exchange of matter. Instances of ground water contamination with Cr and Cd in the industrial and highly urbanized centers of the has been associated fractures, joints and related preferential flow paths (Demlie et.al. 2006). In the project area the occurrence of faults, joints and other structures within the different Volcanic rocks were reported by different authors. Long fault line running east west via Kassam river, Addis Ababa and Ambo, cut across the western rift escarpment and uplifted its northern block (Zanettin et al., 1978) at about 8 My ago. This fault marks the upper (outer) boundary of the western Ethiopia Rift margin immediately north of Addis Ababa-Ambo road (Zanettin et al., 1974). The Entoto silicics confined along this fault and form a ridge. This ridge bounded the city in the northern direction. The fault has a down throw to the south in the Addis Ababa area (Haileselassie Girmay, 1989). Another prominent normal fault in the city is the Filowha Fault. This fault has a trend of NE-SW (Kundo, 1958; Morton, 1974; Haileselassie Girmay, 1989). The fault has a northwest down thrown side according to Morton (1974). However, Haileselassie (1985) carried out detail mapping of the Filowha Fault using resistivity method and found that the fault has down thrown to the south, shallow depth and covered by very thin soil layer (1-4m).Haileselassie Girmay (1989) found that the fault is not vertical and its throw can be estimated to be about 40m, which is approximately the thickness of the welded glassy ignimbrite. This fault has acted as a dam to the welded glassy ignimbrite, but not to the basalt as it was assumed previously. For this reason there is quite different geology in the south and north parts of the area. Thus, the age of the fault may be bounded by 5.0My (the age of the welded glassy ignimbrite) and 6.4My (the age of plagioclase-poryphyritic basalt). Kundo (1958) proposed that the hot springs in Filowha are controlled by this fault. The presence of hot springs, south of the fault gives resistivity contrast on the either side of the fault.The Filowha fault, having a trend of N55^{O}E (Haileselassie Girmay, 1989) is thought to be a major NE fault that continues up to Debre Berehan (Mohr, 1964). Moreover, Al consult (1996) satellite images interpretation map indicates the continuation of the Filowha fault towards the southwest periphery of the city in the same direction. Morton (1974) map shows four other north-east trending faults, which have south-west or north-west down thrown side. The other major structural features in the study area are joints, which have different spacing, opening and orientation. The dominant preferred orientation of joints occurring in different rock units is NNE-SSW (Kebede et al., 1990), which is sub parallel with the general trend of rifting. They found joint spacing of 15-200 cm (in most basalts), 5-100 cm (in trachy basalt, trachyte and rhyolite) and 2-100 cm (in ignimbrite).

1.3 Water use and supply

The increasing demand and all kinds of use of water have a potential to affect the quantity and quality of the available resource base in an area. Such dual impacts of growing demand and use of water has been observed in the study area. And can be associated with rapid population growth and intense socioeconomic activities. The study area is consisted of six subcities and few peasants associations in the up and down stream peripheries. Each sub city has an average population size of 300,000 people (Tamiru et.al, 2003) and they are, Akaki Kality, Addis Ketema, Kolfe Keraneao, Gullele, Lideta, and Nifas Silk Lafto. The total population in the above sub cities alone comprises more than 53% of the population in the capital Addis Ababa. Projections made excluding immigrations and based on the 1994 census estimated the population size of the city for the year 2005 to be around three million. However, the city currently has a population size of over 3 million.

And according to AAWSA, 80% of the water supply for the city is from the three surface water reservoirs (i.e. Geffersa, Dire, and Legedadi). But, only 80% of the population relies on good quality surface water for drinking, fire fighting and sewage disposal (Girma Tadesse, et.al.2005).This implies that the remaining significant population of the city and the peripheral society is forced to use unsafe river water for various purposes. Moreover, many industries as well as some farmers who irrigate or water livestock all depend on large quantities of good quality surface water (Ijgneh Sime 1998) as cited in Girma et.al 2005. Consequently add to the quality problems in the surface water bodies and thus pose scarcity. The requirement for potable water to satisfy all demands plus unaccountable loses for the year 2010 was estimated to average 1,105,000m^3/day (Table 7). That would increase demands on the existing three dams, springs and Akaki wells with current supplying capacity of 173,000 m3/day, 10,000 m3/day and 30,000 m3/day respectively.

Table 7 Projected potable water demand for Addis Ababa city (Girma Tadesse, et.al.2005).

Year	Population Projection	Potable water Demand (m^3/day)
2004	3060000	380000
2010	3830000	565000
2020	5570000	1105000

1.4 The Importance of Tinishu Akaki River (TAR)

Despite the fact that Tinishu Akaki River is a recipient of unsorted domestic and untreated industrial, municipal, commercial, clinical and other types of wastes (solid and liquid), it is being utilized by a peripheral population for irrigation purposes (Table 8). Moreover a significant number of people use this river and its major tributaries for washing vegetables, clothes, livestock watering, bathing and even for drinking purposes in and around the city Figs (7a-7d).

Fig. 7b People using TAR for bathing.

Figure 7a People Using TAR water for dumping domestic solid waste.

Fig. 7c People Discharge toilet and domestic waste water to TAR.

Fig. 7d Residents using TAR water for Irrigation.

Table 8 Urban Irrigation with Tinishu Akaki and Its Tributaries (extracted From Tadesse et.al. 2004).

Name of scheme	River	Districts	Irrigated Area (ha)
Shankla Ena Kacha Fabrica	Shankla	Coca Cola Fabrica	8.5
Tinshu Akaki Ena Keranio	T. Akaki	Keranyo	7.5
Tinshu Akaki Mekanisa Goffa & Furi Saris	T. Akaki	Goffa Sefer	150
Kolfae Ena Lideta	T. Akaki	Kolfae	51
Total			217

1.5 Land Use and Land Cover

The study area has a mosaic of land features where by the northern and northwestern peripheries exhibit an elevated topography covered with forest. This part also has many agricultural fields along either banks of the rivers and is relatively sparsely settled. Where as the central part exhibits an undulating topography, densely populated unplanned settlements with several, big and small commercial centers, few farm yards and significant number of industrial (**Appendix 4**) and institutional settlements. While the southern down stream portion of the study area has a flat lying topographic feature with large agricultural fields and industrial settlements (Fig. 8).

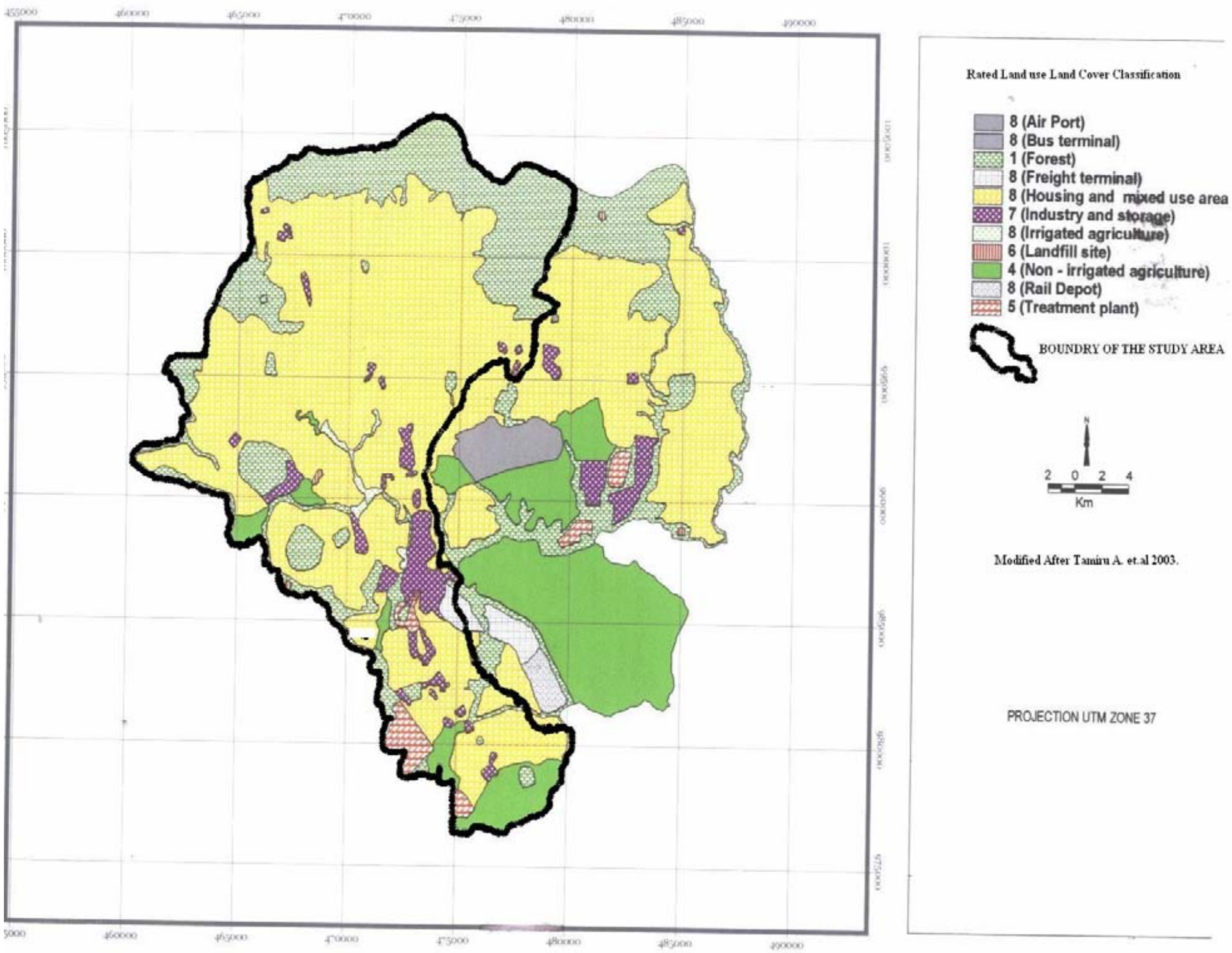


Fig. 8 Land Use and Land Cover Map of the study area (Modified after Tamiru Alemayehu et.al.2003).

1.6 Statements and Justifications of the Problem

Tinishu Akaki River mainly flows in the premises of Addis Ababa city and in the surrounding peasants associations of the Oromia regional and national state. The western, southern and southwestern parts of Addis Ababa are among the highly populated urban as well as industrial centers in the country (Appendix 4). Consequently a considerable amount of waste is generated every day from different sources. Since the city has inadequate and inefficient waste (solid and liquid) management facilities, all point and non point sources in the study area discharge their effluents directly or indirectly to the nearby rivers and streams. In addition to this, wastes dumped on an open ground join the river after a while via surface runoff. On the other hand industries located in the TAR basin discharge their effluents with no treatment. Therefore, the poor sewerage system, uses of old technology, low level of awareness on waste management, weak enforcement mechanisms on pollution prevention and control and low level of income of the city dwellers have aggravated the pollution problem of the TAR. In order to solve the problem, efforts should be directed to wards understanding of **How this riverine system functions? And answering questions like; what factors govern the situation, Is there some kind of spatio-temporal trend? And what can be done?** This thesis work will attempt to answer these questions. Most previous studies in the project area had broad objectives and attempted to assess the potential and quality of water resources in a greater geographic extent and have been dealing with almost all sources of waters including springs, rivers, ground and reservoirs for the whole of the city, giving lesser emphasis to a particular water resource type and commonly end up in shallower discussions of either of a water resource (river, reservoir, …etc.). Moreover, deeper investigation of the hydrogeology unlike the hydrology is the common feature of most previous works. However; in this study an important water quality indicator dissolved oxygen (DO), and conventional parameters such as TDS, NH3, NO2, NO3, BOD along with important physical factors for TAR will be environmentally analyzed and the possible sources and sinks of a particular water quality parameter are utilized to take into account the spatial and temporal variations in DO patterns and its effects.

1.7 Literatures Review

Connell and Miller, 1984 have defined DO as the amount of oxygen contained in water, and as a thing that defines the living conditions for oxygen-requiring (aerobic) aquatic organisms. Moreover, they stated that the solubility of oxygen in water is usually limited, ranging from 6 to 14 mg L^{-1}.

However, Susan and Joy 1998 indicated that temperature, salinity of the water and the partial pressure of the gas in contact with the water to be the common factors by which the Oxygen's inherent solubility in water is affected.

Connell and Miller, 1984 also explained that DO concentrations reflect an equilibrium between oxygen-producing processes (*e.g.* photosynthesis) and oxygen-consuming processes (*e.g*. aerobic respiration, nitrification, chemical oxidation), and the rates at which DO is added to and removed from the system by atmospheric exchange (aeration and degassing) and hydrodynamic processes (*e.g.* accrual/addition from rivers and tides vs. export to ocean).

But, dissolved oxygen consumption and production are found to be subject to diurnal and seasonal variation and are influenced by plant and algal biomass, light intensity and water temperature (because they influence Photosynthesis), as stated by (Connell and Miller, 1984).

And its level in a water supply is indicative of the concentrations of nutrients and organic matter in the water (Susan and Joy 1998).

Besides, Clevland J. 1998, Indicated DO as the best indicator of the health of a water ecosystem.

Additionally (Hem 1989) identified DO as a significant factor in chemical reactions in water and the survival of aquatic organisms.

He also indicated the possibility of its depletion by inorganic oxidation reactions. Or by biological and chemical processes that consume dissolved, suspended, or precipitated organic matter (Hem, 1989).

However, (Mills et. Al.1979) had linked the biologically oxidizable materials that exert an oxygen demand on water resources with many wastes discharged into the waterways.

Mills et. Al.1979 Also associated DO depletions with occurrences of excessive CBOD and NBOD loadings coupled with high temperature and low flow conditions.

Nemerow, 1974; Tchobanoglous and Schroeder, 1985 as cited in (Delzer & McKenzie 2003) defined Oxygen demand as a measure of the amount of oxidizable substances in a water sample that can lower DO concentrations.

Delzer & McKenzie 2003 then defined biochemical or chemical oxygen demand as measure of the decay of organic matter in water. They ((Mills et. Al.1979), (US EPA, 2001) & (Delzer & McKenzie 2003)) also subdivided this biochemical oxygen demand (BOD) into carbonaceous (CBOD) and nitrogenous (NBOD) components.

Besides (Mills et. Al.1979)[25] had approximated the following reaction for CBOD which represents the amount of oxygen required by bacteria to stabilize organic matter under aerobic conditions. And is given as:

$$C_nH_aO_bN_c + (n+a/4-b/2-3/4c)\ O_2 = nCO_2 + (a/2-3/2c)\ H_2O + CNH_3.$$

This reaction assumes that the available organic matter is completely oxidized. However, bacteria might not be able to oxidize all of the available organic matter. That is illustrated by later oxidation of the reduced forms of Nitrogen which are not included in the CBOD (Delzer & McKenzie 2003). The NBOD oxidation under goes in two successive steps as shown bellow:

$2NH_3 + 3O_2 \longrightarrow 2NO_2^- + 2H^+ + 2H_2O$ (Nitrite Forming Bacteria).

$2NO_2^- + O_2 + 2H^+ \longrightarrow 2NO_3^- + 2H+$ (Nitrate Forming Bacteria).

Calfed Bay Delta Program, 2000 had also defined ODW as pollutants which reduce the amount of dissolved oxygen in water. Moreover this and several other literatures commonly included the following substances as OD substances. These are:

- Plant nutrients
- Suspended solids
- Toxic chemicals (like benzene, chromium and mercury)
- Dissolved minerals
- Excessive acidity and thermal pollution.

Calfed Bay Delta program, 2000 Also identified a variety of sources from which ODW originate. However, the Common Sources are:

- Sewage treatment plants
- Paper manufacturing, food processing and other industries
- Particulate organic matter from dieing algal blooms
- Confined Animal Operations (Feed lots)
- Untreated Municipal Wastes
- Storm water runoff, and
- Agricultural return flows

ANZECC/ARMCANZ, 2000 has clearly shown the adverse physiological effects of DO concentration changes above or below the range required by most aquatic organisms for respiration and efficient metabolism.

And Washington Department of Ecology, 2002 revealed the significance of oxygen to help Decompose organic matter in the water and bottom sediments in addition to being required by aquatic organisms for respiration.

Delzer & McKenzie 2003 also indicated the importance of determining how organic matter affects the concentration of dissolved oxygen (DO) in a stream or lake to water-quality management.
ANZECC/ARMCANZ, 2000 also depicted the doubling consequence of the toxicity of many toxicants (lead, zinc, copper, cyanide, ammonia, hydrogen sulfide and pentachlorophenol) when DO is reduced by half e.g. from 10 to 5 mg L-1.

Besides, (Kehew A. E., 2001) stated that the mobility and species of most elements in water is also controlled directly or indirectly by the redox condition which in turn is partly a result of the oxic, suboxic, or anoxic nature of the water body.

Connell and Miller, 1984 had also related dissolved oxygen depletion in bottom waters (or sediment) with termination of nitrification, denitrification, and with release of bioavailable orthophosphate and ammonium from the sediment to the water column. Consequently these recycled nutrients reinforce algal blooms.

They did also indicate the toxicity in high concentrations of Ammonia and hydrogen sulfide gas (also the result of anaerobic respiration), to benthic organisms and fish assemblages.

1.8 Previous Works

Gizaw Berehanu, 2000, had environmentally investigated the hydrogeology of the Addis Ababa city and produced an explicit data on few samples from TAR and indicated the pollution of the river.

Then Tamiru Alemayehu (2001) studied the impact of uncontrolled waste disposal on the surface water quality in Addis Ababa and found out higher than background values for pollutants such as Cr and Nitrates and associated it with poor economy and lack of proper waste disposal systems.

Besides, EPA (2002) Assessed the pollution status of the great and little Akaki rives with the objectives to investigate the pollution load of Akaki river and its effect on the surrounding environment and found that the BOD and Total Coli forms load is high and the DO level is low. Moreover, confirmed on the pollution of both rivers and their potential to cause health effects on human and animals in addition to their impact on the aquatic life. In addition, it linked above the limit TDS values with some industries and residential wastes. And also found high chloride concentrations in little Akaki river.

However, few researches pertaining specifically to Tinishu Akaki River basin have been carried out with the objectives of learning about the status, causes and effects of its pollution. In addition few studies relate the pollution in the TAR basin with the contamination of ground water reserves of the vicinity. Thus only the major ones are listed bellow.

Mohammed Ali Mohammed (2002) studied industrial pollution and its impact on the little Akaki River and show that industrial effluents surpass the Ethiopian provisional effluents discharge permit limits. Besides he identified Tanneries as the major polluter industrial sector. And using ANOVA (analysis of variance) he also indicated that the river is grossly polluted in all seasons and through out its course. Above all he concluded that river water can not be used for irrigation, drinking, livestock watering and washing.

Besides, Samuel et.al (2004) had simultaneously determined the trace elements of Tinishu Akaki River Water samples by ICP-MS method and found out that out of the eight elements analyzed except two (Cr and Mn) all fulfill the surface water quality standard of class 2 and 4. Thus he concluded that the water can be used for Irrigation.

Samuel et.al (2005) had carried out multi element analysis of TAR sediments using ICP-MS method and found out that the heavy metals pollution load in the sediments of TAR and its tributaries is alarming. Then he associated this pollution load with untreated domestic, municipal and industrial sources.

Then Demlie et.al. (2006) analyzed soils and ground water samples for trace metal pollution and witnessed Instances of ground water contamination with Cr and Cd in the industrial and highly urbanized centers of the city. And he associated the case with fractures, joints and related preferential flow paths.

Samuel et.al. (2007) evaluated the pollution status of the Tinishu Akaki River and Its tributaries using some physicochemical parameters, major ions and nutrients. And provided data on the physicochemical parameters: PH, temperature, EC, TDS, BOD, COD, DO, Major ions and Nutrients. And assessed the pollution status of the river by comparing values of the parameters with accepted standards and most common natural concentrations (MCNC) and found out that certain parameters violate standards. Besides he also shows the increases in BOD, Nitrate, Ammonia, Phosphates and the decrease in DO downstream of TAR. And he also observed that the average concentrations of the major ions and nutrients surpassing the MCNCs and associated the situation with increasing domestic, industrial and agricultural activities.

2. OBJECTIVES

2.1 General Objective

The over all objective of this study is to environmentally analyze the Tinishu Akaki River system's water quality degradation using an important water quality indicator (Dissolved Oxygen) and other conventional water quality parameters (NH_3, Nitrite, Nitrate, TDS, PH, Temperature, & BOD5).

2.2 Specific Objectives

- To address the spatial and temporal (seasonal) variations in dissolved oxygen depletion (i.e. an important water quality indicator).
- To compare the extent of pollution between spatial domains and temporal periods and identify the relatively worst in terms of DO depletion and its consequences.
- To investigate the level of DO depletion and / or Pollution along Tinishu Akaki River by taking the two extreme industrial effluents discharge scenarios into account.
- To figure out whether industries are major sources Oxygen demanding Wastes (ODWs) or not.
- To show the interplay among the different physicochemical factors and processes responsible for the production (source) and depletion (sinks) of dissolved oxygen in the water column of the TAR along its course.
- To examine the consequences of DO depletion in terms of other pollutants. And
- To suggest cost effective control mechanisms.

2.3 Limitations

Like any other research works, this study has also faced number of limitations in the process of convening the work. The main obstacles were:

- The absence of time series data that could otherwise showed successive trends of TAR's pollution.
- The absecence of centralized environmental data base.
- In sufficiency and non representation of the up and midstreams of TAR in the quarterly EPA monitoring data.
- Severe financial and instrumental constraints that greatly restrict the number of samples that could have been incorporated in the analyses performed for the effluents discharge Scenarios.
- The time bound set for the thesis work (i.e. fourth term of the study) coupled with the financial constraint forced me to incorporate important temporal data form previous works.
- Limited number of literatures specific to the objectives set in this project and the study area.
- Breadth of previous studies objectives resulted in shallow treatment of a specific water body like TAR.

3. METHODOLOGY

In order to achieve the objectives stated before, I devised ways to investigate dissolved oxygen depletion and its consequences in the Tinishu Akaki River system and has the following components:

3.1 Spatial [DO] Pattern Analysis

The three segments of the Tinishu Akaki River are characterized by different topographic features, geographic distribution of point sources and drainage patterns. And are categorized to represent three spatial domains. These are:

3.1.1 The upstream (Head Water)

It covers areas above Geffersa-Seko rivers confluence and is characterized by a relatively high relief and forest covered land features, very few industrial point sources, and a radial drainage pattern. It is also sparsely settled but intensively cultivated spatial domain.

3.1.2 The Midstream (incremental inflow)

Includes areas between Geffersa-Seko confluence and Mekanissa-Tinishu Akaki rivers junction. And it has an undulating topography and a dendritic drainage pattern. Moreover, this spatial domain is congested with several point sources (Industrial, Institutional, and services giving centers) and has highly populated residential areas, many small and big commercial centers (Merkato, Messalemia, Kolfe…etc.), and few agricultural plots (Asteko, Amanuel, Kolfe, & mekanissa). And,

3.1.3 The down Stream (reach)

The area bellow Mekanissa-TAR junction has a relatively low lying (flat) topography. And it is also industrially congested and intensively cultivated especially near the reach; the river in this spatial domain flows in meandering pattern and has almost parallel drainage. Besides, this corner of the city's suburb is characterized by moderate settlement.

Then for all the spatial domains, primary and secondary data on some physicochemical parameters will be used to depict the worst spatial extent of TAR in terms of dissolved oxygen depletion.

3.2 Temporal [DO] Pattern Analysis

Moreover, the physicochemical data generated in this study and other previous studies has been segregated to represent the three flow periods with the aid of the 1977 Daniel's rainfall regions classification and these are:-

3.2.1 The low flow /Dry season

This temporal period includes months from October through February which are characterized by low rainfalls and river flows (fig.3, 4 and 5).

3.2.2 The Moderate flow/ Small rainy season

Months March through may represent this temporal period and are characterized by moderate rainfalls and river flows (fig.3, 4 and 5).

3.2.3 The high flow/ Heavy rainy season

Months from June through September fall in this temporal period and are characterized by heavy rainfalls and high river flows.

Thus data representing these temporal periods has been used to identify the worst temporal period to the pollution of the Tinishu Akaki River.

3.3 [Do] Pattern For Different Effluents Discharge Scenarios

Besides the point sources effluent discharge rates are summarized into two extreme scenarios. Consequently all available data is categorized into two effluents discharge scenarios and are given as:

3.3.1 Peak Discharge Scenario

This scenario stands for the extreme situation assumed to prevail as a result of generally intensive industrial activities. Therefore the river water samples collected and analyzed to represent the dates where the industrial activities were intense are categorized and analyzed for their [DO] pattern under this category.

3.3.2 Little or No Discharge Scenario

Those river water samples collected and analyzed to represent the date for which industrial activities were minimal are categorized under this scenario for the analysis of [DO] trend which is supposed to represent the other extreme situation. Subsequently comparative analysis of the two will be used to confirm whether or not industrial point sources are the major causes of DO depletion or pollution of TAR. Lastly the DO depletion pattern has been environmentally analyzed with the following consideration to the available physicochemical data.

3.4 DO Sources and Sinks

Here under the new and previous works' physicochemical data has been analyzed in terms of the prevailing conditions and or processes that

3.4.1 Produce DO /Sources and

3.4.2 Consume DO/ Sinks.

This will help to determine which processes and or conditions prevail and what kind of interactions (physicochemical and spatiotemporal) are governing the DO depletion along the TAR.

The pollution status of TAR is used to be the concern and work of few individual researchers and organizations. Unlike the whole Akaki river basin not many research papers, reports and documents have dealt with TAR specifically. However, the available information is believed to help in understanding the status, causes and effects of TAR's pollution. And hence generating a primary data on the same physicochemical parameters is not economically feasible and attainable in this limited period of time.

Therefore in this project I strongly rely on the secondary data and tried to extract as much information as possible. And I also generated primary data on few selected physicochemical parameters (**Appendix 5a**).

The sampling was made in such a way that one composite sample comprised of four samples each with 250 ml size, three samples each with one litter size and another one litter sample were collected to represent the upstream (sources) , the Midstream and the down stream portions of TAR and its tributaries respectively (**Appendix 5b**).

These samples also represent the date where there was little or no industrial effluents discharge which is one of the two extreme discharge scenarios.

Moreover, onsite field observations and recording with the aid of PH-Meter, photo camera, topographic map and GPS was made, then compiled and analyzed with a spreadsheet program.

4. MAJOR SOURCES OF POLLUTANTS

The first step in the water quality analysis of a river system is the identification and characterization of wastes emanating from various pollution sources. Both natural and anthropogenic activities can contribute to the pollution of a given water body. However, in a river system that drains an industrial, highly populated and socio economically vibrant urban centers like Tinishu Akaki River, the relative effects of anthropogenic activities in deteriorating the quality of the water exceed by far the natural causes.

The idea of sustainable development urges every socioeconomic activity of a nation to have an environmental consideration. Unfortunately, in most developing countries including Ethiopia, this has not been the concern of the government in its economic progress endeavor until recently. As a result every sector has been involved one way or another in deteriorating the environment, particularly the quality of water bodies. This coupled with little or no environmental management practice worsen the situation in the capital Addis Ababa, the country's socio-political and economic center. Based on field visits, available documents and analytical results the following entities and or activities are identified as potential sources of pollutants in the study area and their typical contaminant characteristics are discussed in the subsequent sections.

- ✓ Industries
- ✓ Agricultural Activities
- ✓ Garages
- ✓ Health and Pharmaceutical centers
- ✓ Municipal Dump sites
- ✓ Fuel stations
- ✓ Market centers
- ✓ Mining quarries and
- ✓ Cemeteries.

4.1 Industrial Sources

The birth and growth of most cities in Ethiopia was associated with the development of infrastructures such as transportation routes and establishment of industries. Thus cities are often the commercial and industrial corners of the country. Addis Ababa too, has been a host for the majority of small and medium scale industries. Consequently they are primary source of water pollution.

4.1.1 Types and Distribution of the Industries in Ethiopia

Of the industrial establishments that are found in the country, more than 65% are situated in Addis Ababa city (EPA, 1999). However, the majorities are food and beverage, Textiles, Tanneries, Chemicals, rubber and plastics, paper and paper products, metallic and non metallic mineral products and wood industries **(Appendix 4).** Most of these industries are established along the course of Tinishu Akaki River and its major tributaries thereby sending their effluents (Table 9).

Table 9 Typical effluent characteristics of the Industries and other anthropogenic activities along TAR (Santra S.C, 2004).

Contaminant Source	Typical Effluent Characteristics
1.Food & Beverage Industries	High BOD&SS, Colloidal and dissolved Organic matter, Oudor.
2.Textile and Clothing Industries	High SS & BOD, Alkaline Effluents
3.Tanneries	High BOD, Total Solids, Hardness, Chlorides, Sulphides & Chromium, Odour
4.Chemicals Industries	
4.1 Acids	Low PH
4.2 Detergents	High BOD
4.3 Pesticides	High TOC, Toxic benzene derivatives, low PH
5. Synthetic Resins and Fibers	High BOD
6. Petroleum & Petrochemical Refining	High BOD, Chloride, Phenols, Sulphur Cpds.

7. Fertilizer Process	High BOD, SS, Chloride, Variable PH.
8. Painting & Metal Finishing	Low PH, High Content of Toxic Metals
9. Engineering Works	High SS, Chlorides, Variable PH
10. Leakage From Storage Tanks & Pipelines	Aqueous solutions, Hydrocarbons, Petrochemicals and Sewage.
11. Mining	High TDS, SS, Possibly High Chloride.
12. Agriculture	
13. Arable Crops	Organo-chlorine compounds from pesticides, Nitrate, Ammonia, Sulphate, Chloride & Phosphates from fertilizers. Bacterial contamination from organic fertilizers.
14. Livestock	SS, BOD, Nitrogen. High faecal Coli forms and Streptococci
15. Silage	High SS, BOD 1-6X10^4 mg/l, Carbohydrates and Phenols.
16. Household Wastes	High Sulphate, Chloride, Ammonia, BOD, TOC, & SS from fresh waste. Bacterial Contamination. Secondary decomposition products from TOC (Mainly Volatile fatty acids- acetic, butyric, propionic acids) change into high molecular weight organics (Humic substances and Carbohydrates).

And almost all industrial wastes are untreated and their pollutant loads (organic and inorganic) are observed to be high (**Appendices 6a-6c and 7**). The principal deleterious effect of these wastes on streams and water courses is their deoxygenation. And the volume of liquid waste generated from the industries ranges from 1 to 1000 cubic meter per day which is summed up to be 4,877,371 cubic meter per annum (CSA 1999), see (Table 10).

Table 10 Volume of waste water annually discharged from industries in Addis Ababa (CSA 1999).

Type Of Industry	Vol. of Waste Water (m^3/yr)
Textiles	1,992,597
Food & Beverages	1, 795, 252
Leather & Foot Wear	547, 860
Rubber	205, 746
Iron and Steel	146, 239
Pharmaceuticals	50,089
Wood	47,805
Paper & Printing	45, 967
Tobacco	31,080
Petrochemicals	11, 421
Non Ferrous Metals	2,217
Soaps & Detergents	1,098
Total	4,877,371

4.1.2 Waste Treatment Status of the Industries

Most of the industries in Addis are concentrated in the southern and western parts (Appendix 4). Among the Industries located in the city 90% of them discharge their wastes without any treatment into the adjoining water coarse and open spaces (EPA, 2001 and EPA, 2002). Moreover in a survey conducted in 2000 by Ghirmy Z., 10 industries out of 25 surveyed dispose their untreated waste water to TAR and 3 to its tributaries, while the rest dispose their liquid waste into open drainage in the city. Similarly during field visit of the study area it has been observed that nearly all industries have no treatment plant and hence they highly contribute to the Akaki river's water pollution.

4.2 Municipal Sources

Ethiopia is one of the developing countries, where urban population growth is very fast. Especially, in Addis Ababa, the growth is faster (Fig.9) than any other cities. It is obvious that when the population increases the municipal solid and liquid wastes generation also increases. In addition the city's municipal waste (solid and liquid) collection coverage is limited to minor proportion of the residents and is less efficient as a result it greatly contributes to the pollution of TAR especially during the rainy seasons when the surface runoff gets higher. And (Table 11) illustrates typical concentrations of organic and nitrogenous wastes in untreated municipal sources.

Fig. 9 Population growth in Addis Ababa City (immigration not considered) (Tamiru et.al. 2003).

Table 11 Typical characteristics of untreated municipal wastes (Omann T. 1972, cited in US EPA 1985)

Variable	Unit	Approximate Average	Normal Range
Average Daily Flow	Gal/cap/day	125	100-200
Solids Total	Mg/l	800	450-1200

Total Volatiles	Mg/l	400	250-800
Total Dissolved	Mg/l	500	300-800
Total Suspended	Mg/l	300	100-400
Volatile Suspended	Mg/l	130	80-200
Settleable	Mg/l	150	-
BOD			
CBOD (5-days)	Mg/l	180	100-450
CBOD Ultimate	Mg/l	220	120-580
Nitrogenous*	Mg/l	220	-
Nitrogen			
Total	Mg/l N	50	15-100
Organic	Mg/l N	20	5-35
Ammonia	Mg/l N	28	10-60
Nitrite + Nitrate	Mg/l N	2	0-6
Phosphate			
Total	Mg/l P	20	10-50
Ortho	Mg/l P	10	5-25
Poly	Mg/l P	10	5-25
Coli forms			
Total	Million Org./100ml	30	2-50
Fecal	Million org./100ml	4	0.3-17

*Ultimate, Nitrogenous oxygen demand, exclusive of CBOD.

4.2.1 Municipal Solid Waste

It includes street sweeping wastes and organic or inorganic materials generated from residential, commercial, industrial establishments, as well as other institutions. TAR commonly receives storm drains and runoff (Fig.10) from areas that include solid waste dumpsites.

Fig.10 Storm Drain Feeding Tributary Shankla at a bridge near Ethiomarble.

This can be attributed to the inadequate and inefficient waste management facilities. According to SBPDA, 2003 the daily waste generation per capita per day for a population size of 3, 0335,138. Was 0.252 kg; However, The daily total waste generation of the city is 2,297 cubic meter i.e. 765 tones currently (EPA 2005). Consequently, the sectoral and compositional contribution of wastes has shown tremendous growth and is given in the Table (12) and Table (13) respectively.

Table 12 Sectoral contributions to the daily total Solid waste generation (EPA, 2005).

Sector	Contribution (%)
House holds	76
Street sweeping	6
Industries	5
Hotels	3
Commercial and other institutions	9
Hospitals	1
Total	100

Table 13 compositional make up of municipal wastes (EPA, 2005).

Municipal solid waste ingredients	Percentages
Organics	60
Recyclable	15
Others	25
Total	100

35% of the solid waste generated in Addis Ababa, is dumped on open sites, drainage channels, rivers, valleys (fig.11), as well as the streets. Besides this, leachates developed in the koshe open municipal dumpsite have been observed joining the TAR.

Fig.11 Solid wastes dumped in the TAR valley.

4.2.2 Municipal Liquid Waste

Domestic liquid waste from overflowing and seeping pit latrines, septic tanks, public and communal toilets, open ground excreta defecation …e.t.c. comprise the municipal liquid waste. Even though the city has a centralized sewerage system (sewer line) and two WWTPs (i.e. the kotebe and kality) plants, they are currently operating bellow their capacities of, 350 and 7500 cubic meters per day respectively due to inefficient waste collection. It is estimated that approximately 100,000 cubic meter waste water is produced in Addis Ababa per day (Mohammed, 2002) from domestic activities such as bathrooms and kitchens alone. In addition to this 30% of the city dwellers have no facility at all to dispose of their liquid waste (EPA, 1999). This adds to the volume of waste water that in one way or another drains to the TAR and contributes to its pollution.

4.3 Medical Waste

Includes, laboratory Cultures, tissues, used dressings, body parts, fluids and needles, blades and broken glasses ((WHO, 1988); cited in EPA, 2005).There are eight specialized and general government hospitals and several higher, medium and small private clinics in the TAR Basin. A study conducted in 2004 by the hygiene and environmental health department, MoH on four selected hospitals, Amanuel, Alert, St. Paul, and St. Peter revealed pollution problems of the Tinishu Akaki River as there are no treatment facilities in those specialized general hospitals and others operating in the study area (Cited in EPA 2005). This class of wastes is the cause for pathogenic pollutants and can be grouped into two namely:

a. General or non clinical wastes

   -consists of (75-90) % of medical center wastes and are resulted from office and kitchen works and

b. Medical (clinical) wastes

   Comprise (10-25) % of medical centers wastes.

4.4 Pharmaceutical Waste

Chemical extraction, modification, and synthesis of organic, inorganic substances are the common processes in this sector. In addition to this purification and packaging are also practiced and together account for pharmaceutical wastes that join the river system via drainage or leachate.

4.5 Miscellaneous Waste Sources

Other activities that are considered in this project work as sources of pollution to the Akaki River are agricultural practices, slaughter houses and fuel stations or garages.

4.5.1 Agricultural Sources

Fertilizers, pesticides and sediments derived from agricultural plots or fields are major polluting agents to TAR. Starting from it's upstream around Asteko to its reach at Aba Samuel abstraction of TAR and it's tributaries for cultivation of vegetables and crops is a common practice (Table 8). Thus during rainy seasons agricultural return flow contributes to pollution.

4.5.2 Slaughter Houses

There are at least two slaughter houses in the study area. These are Burayu kera and Addis Ababa Abattoirs enterprise at the source and midstream areas respectively. The types of wastes produced by the operations are shown bellow:

Source	**Waste**
Stockyard	manure
Killing floor	blood
Dehairing	hair and dirt
Insides removal paunch	manure and liquor
Rendering stick	liquor or press liquor
Carcass dressing	flesh, grease, blood, manure
By-products	grease, offal

The typical characteristics of the effluent coming out from the slaughter Houses (Santra S.C 2004) are as follows:

Parameters	**Characteristic**
1. Total solids	- 4000 to 5000 mg/1
2. BOD	- 4000 mg/1
3. COD	- 8000 mg/1
4. PH	- 6 to 7

4.5.3 Chemicals

PoPs, PCBs, Trace elements such as Cr, As, Cu that are imported and stored by different organizations near TAR and /or its tributaries pose a serious hazard to human beings, animals and the aquatic environment in the basin. Besides their solubility and production is enhanced in the reduced DO levels.

4.5.4 Laundry Chemicals

Dry cleaning chemicals are being threats to TAR as there are several laundries in the basin. One litter out of 10 is being released to open drainage which finally enters a river (EPA 2005).

4.5.5 Fuel Stations and Garages

Sources of oil wastes in Addis Ababa city are fuel stations, private and government Garages. Car washing, Laviajo, are among the activities that cause oil seepage. The battery changing services also contribute to the low p^H or acidic wastes from these centers.

5. DISSOLVED OXYGEN DEPLETION ALONG TAR

Low dissolved oxygen concentration and the presence of oxygen depleting substances (organic and inorganic pollutants) appears to occur along the course of the impaired TAR (**Appendices 7, 8a and 8b**). In addition, Tinishu Akaki River tributaries add oxygen-depleted water. The tributaries also add more of the same oxygen-depleting substances (Fig.12 and **Appendix 9**).

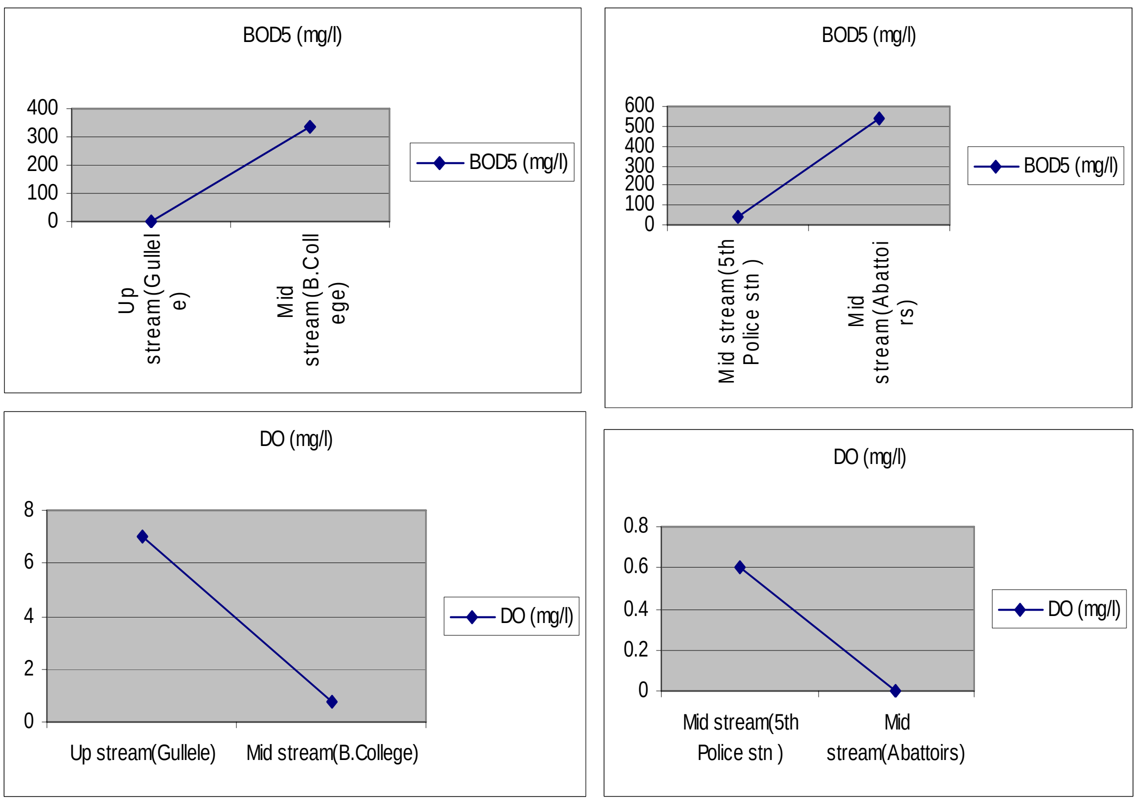


Fig.12 BOD_5 & DO trend along tributaries Shankla and Lideta (ESDI 2001 cited in EPA, 2005).

The fall in DO concentration bellow the Ethiopian draft in-stream water quality standard (i.e. min 6 mg/l) (**Appendix10**) has been observed in all the three flow seasons and in all the spatial domains (figs.13-21). However; the situation is exacerbated during low flow (Dry Seasons) (figs13, 17-19) when high water temperature reduces the oxygen-carrying capacity of the water and increases biotic respiration rates. And the problem is often pronounced in the middle course and seldom at the down and up streams of TAR.

5.1 Spatio-Temporal [DO] Pattern

Hereunder the DO values representing the years 1997, 1999, 2000, 2002/2003, 2003/2004, 2005-2006 and 2007 low, moderate and high flow temporal periods are presented graphically in a way that the three spatial domains are included. Thus sample points S1-S5, S6–S15 and S16-S23 in (figs.13, 14, 15, 18 and 19) and **Appendices (11a-11d)** represent the upstream, midstream and the down stream spatial domains respectively.

The 1997 low flow DO values (**Appendix 11a**) and graph (fig.13) bellow depict that the average [DO] values of the three spatial domains decline to wards the downstream direction. Where the up, mid and down streams spatial extents exhibit an average [DO] values of 7.12 mg/l, 1.54mg/l and 0.86mg/l respectively. However, 68.18 % of the samples have [DO] values lower than 3 mg/l and the majority of them are clustered at the midstream of the river. Therefore, the average [DO] values show only the general down ward declining trend.

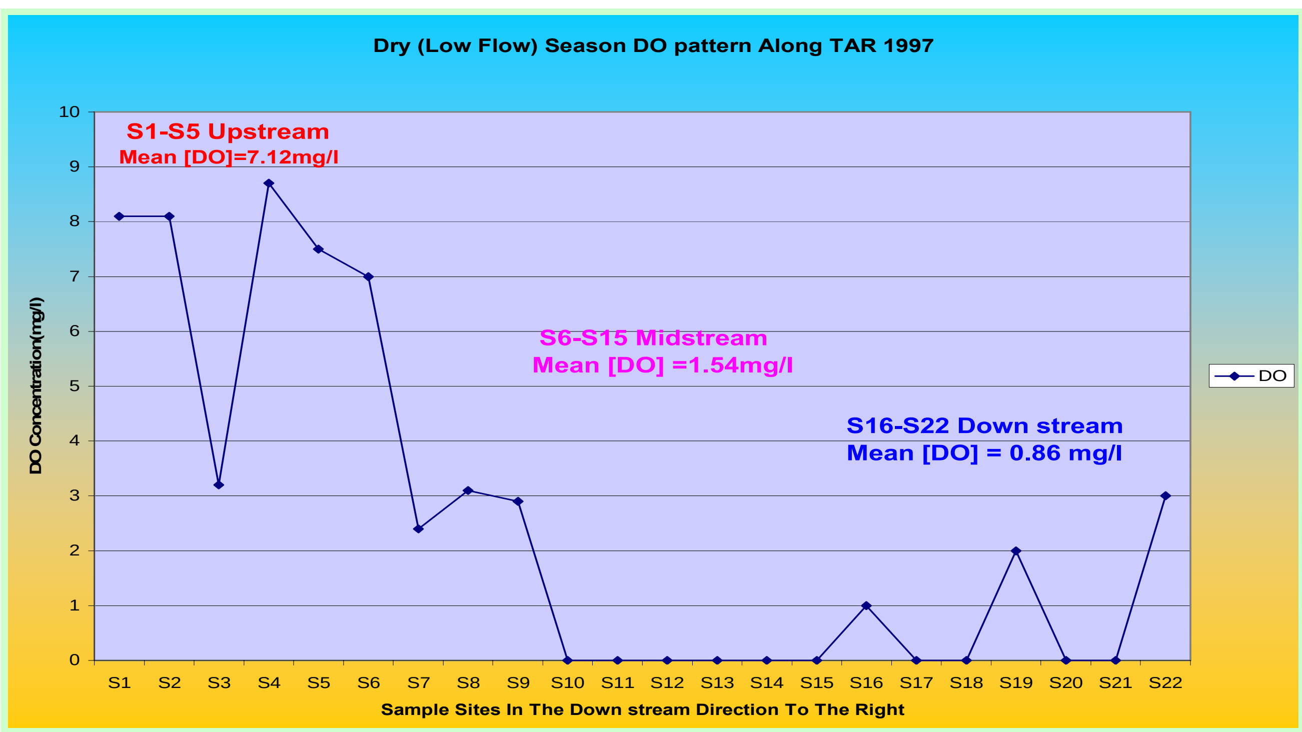


Fig.13 The 1997 Dry (low flow) Season DO pattern along TAR.

Moreover, the 1997 High flow [DO] values (**Appendix 11b**) and trend graph (fig.14) show the generally down stream ward decreasing ternd for average [DO] values. And the up, mid and down stream spatial domains have average values of 7.24 mg/l, 6.1 mg/l, and 6.086 mg/l respectively. In this temporal period many of the samples (86.36%) give DO values greater than 5mg/l indicative of the improving conditions. However, three samples from midstream domain violate the in stream standard and exhibit the lowest values.

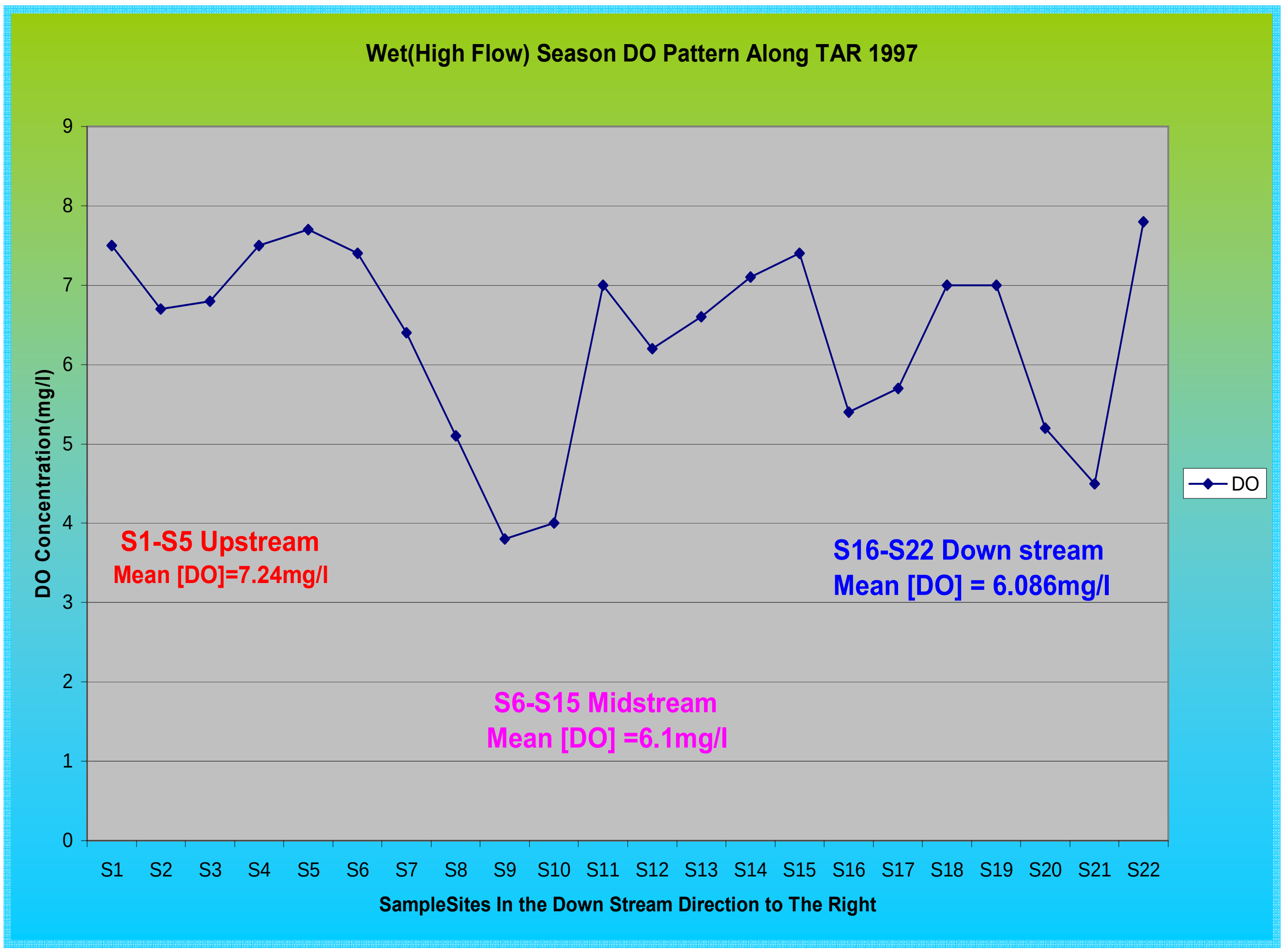
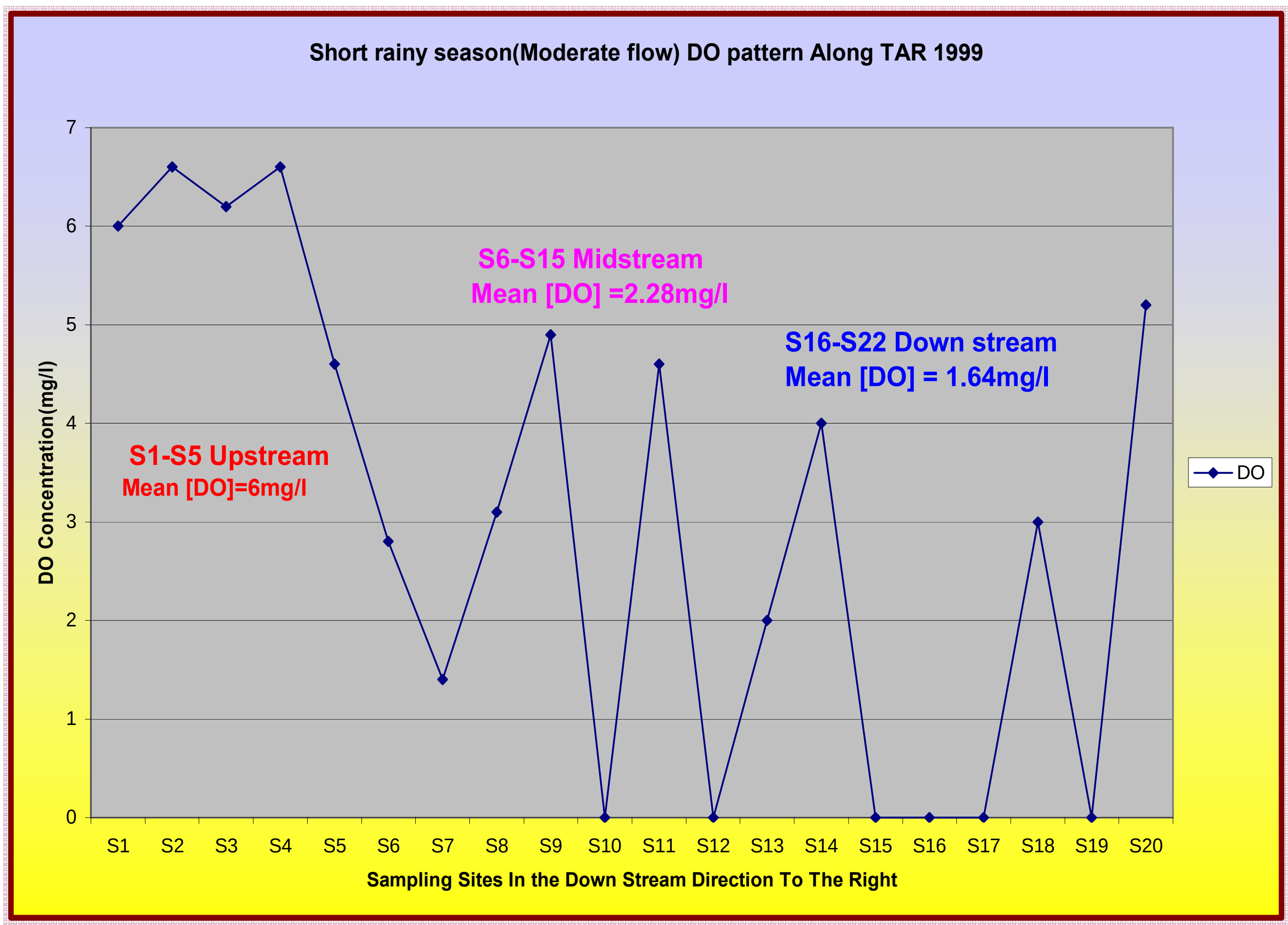


Fig.14 The 1997 Wet (high flow) season DO pattern along TAR.

The 1999 moderate flow period DO values (**Appendix 11c**) and trend graph (fig.15) shows similar declining trend of average [DO] values to wards the downstream of the Tinishu Akaki River. But significant number (75%) of the samples give DO values bellow the in stream standard. And about 45.45% of these give values less than or equal to 3mg/l. Moreover, the majority of these belong to the midstream spatial domain.



. Fig.15 The 1999 Short rainy (moderate flow) season DO pattern along TAR.

The DO values in **Appendix (12)** and the trend shown in fig.16 bellow depict that the lowest DO values are registered for the Midstream spatial extent and all the samples give values 4mg/l. However the general pattern shows a down ward decline. But averages are not involved as the number of samples is small and may give skewed picture of the trend.

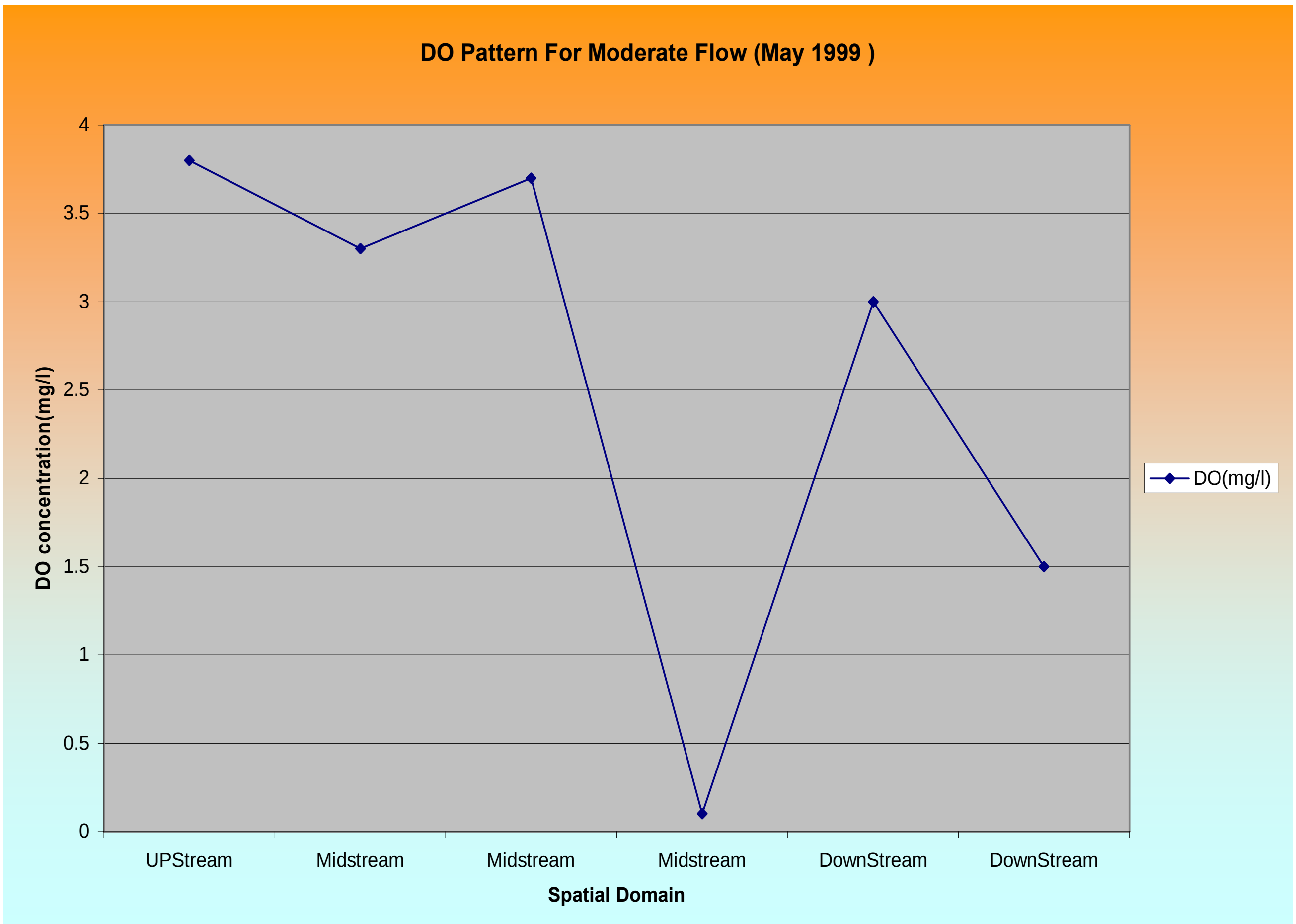


Fig.16 Moderate Flow DO Pattern Along TAR.

This low flow period DO trend is based on the year 2000 data in **Appendix (13)** and the graph (fig.17) clearly shows anomalously high value for the midstream spatial domain. This can be explained with the temperature profile along the course of the river prevalent on the sampling date

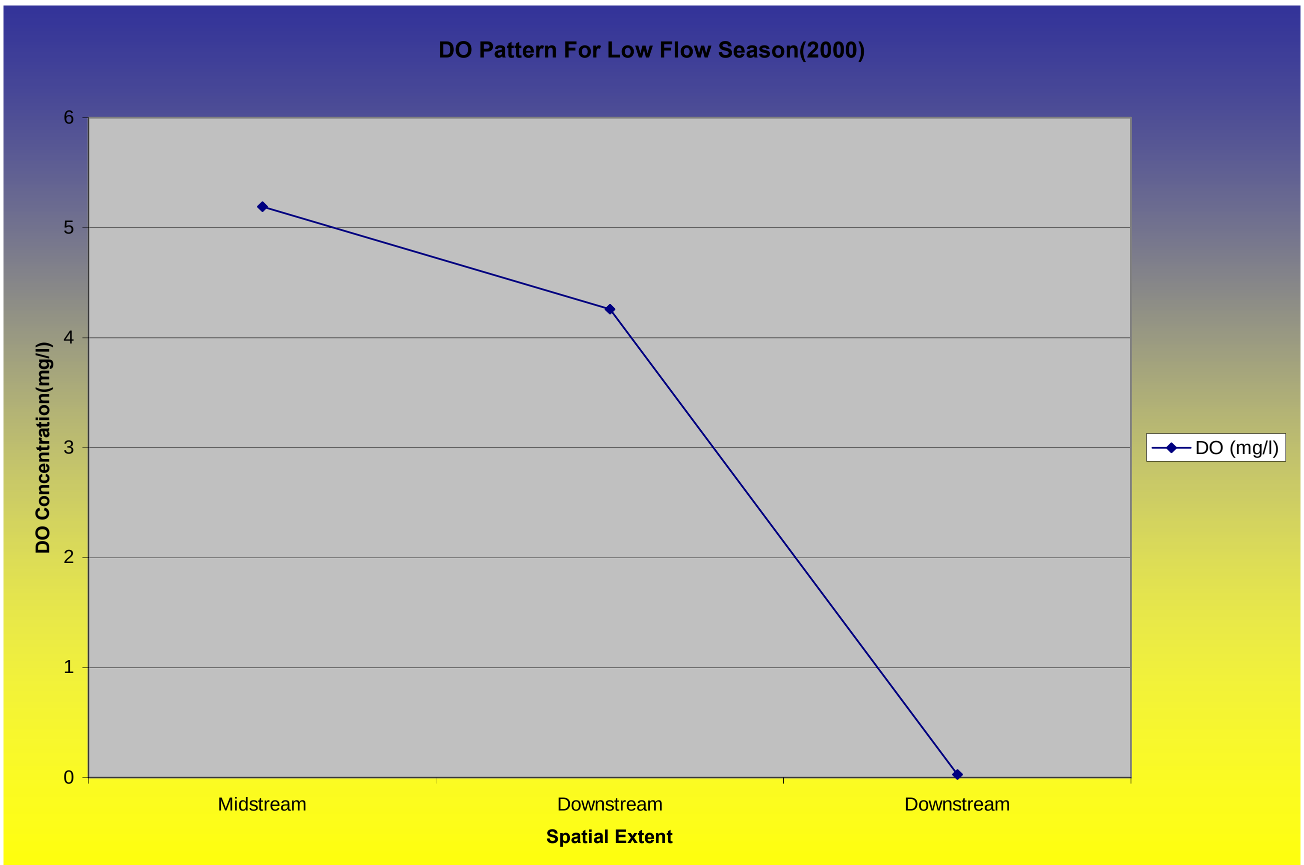


Fig.17 The 2000 Dry (low flow) DO Pattern Along TAR.

The DO depletion patterns for the years 2002/2003 and 2003/2004 low flow temporal periods are shown in figs. 18 and 19 bellow and are based on the data in **Appendix (14)**. And out of the 23 samples analyzed in each year 21 and 15 of them give values bellow 3mg/l for the year 2002/2003 and 2003/2004 respectively. In addition both give a generally decreasing trend for the per spatial domain average [DO] values. (I.e. in both cases the Upstream Average >the Midstream average > the Downstream average).

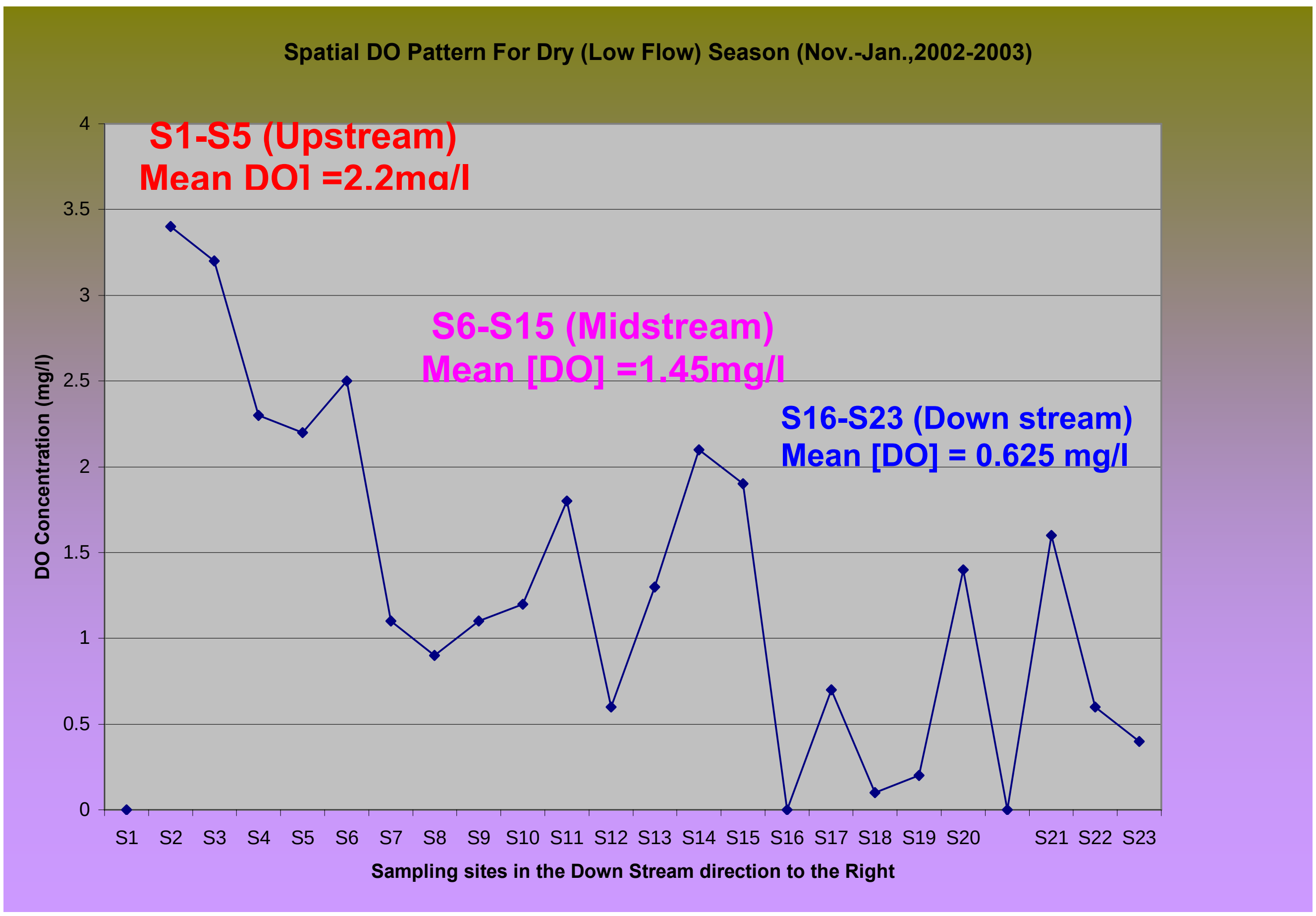


Fig.18 The 2002-2003 Dry (low flow) seasons DO Pattern Along TAR.

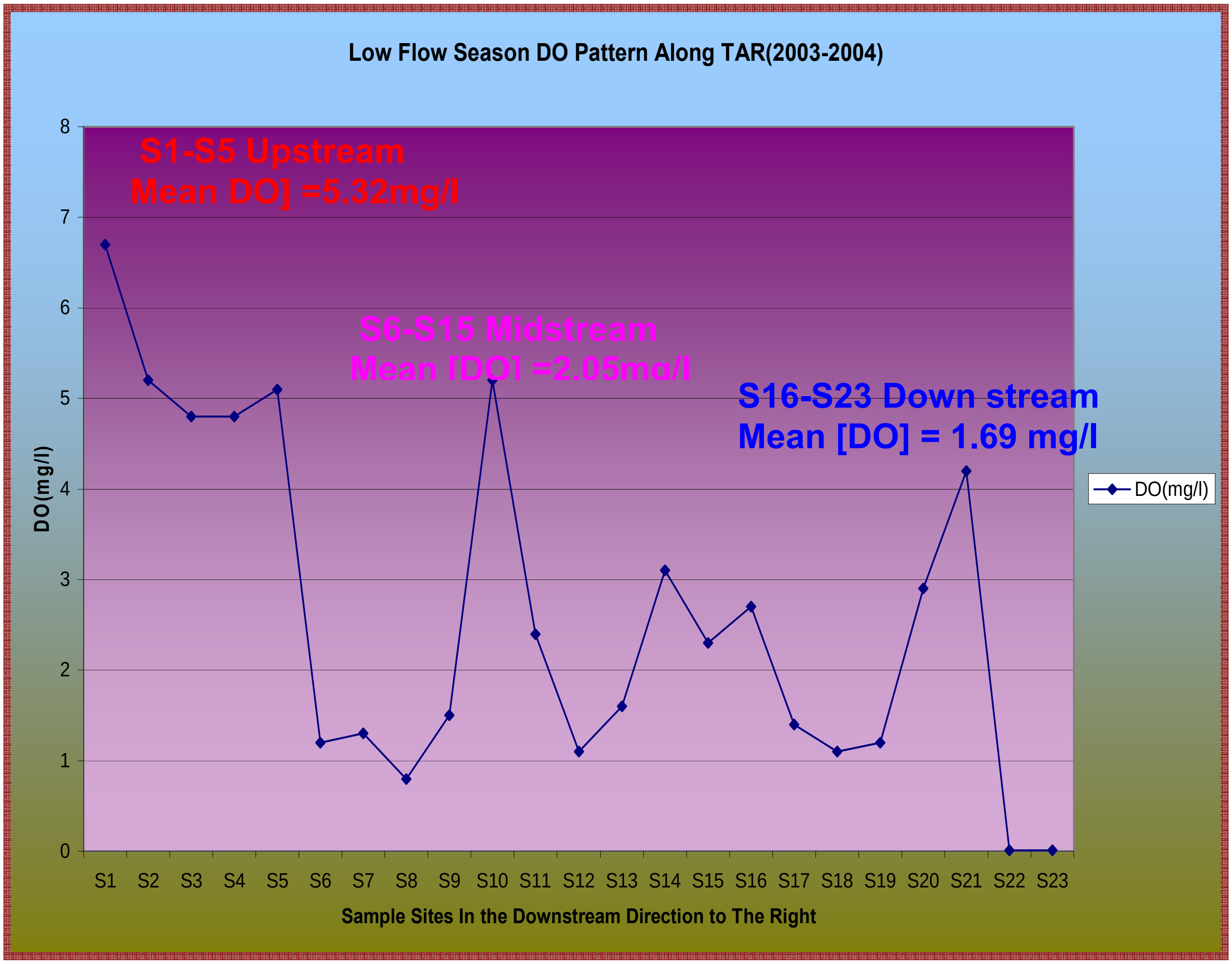


Fig.19 The 2003-2004 Dry (Low Flow) season DO pattern Along TAR.

However, most of the samples with low DO values still belong to the midstream spatial domain, though the general trend is declining downwards.

Both the 2005/2006 high and moderate flow patterns are presented in fig.20 bellow and are based on EPA monitoring data **(Appendix 15 and Appendices 16a-16f)**. And the midstream again exhibits the lowest value in both cases (high and moderate flows).However, in these trends the peculiar down ward declining trend is violated in that the DO values rise up after falling to the lowest in the midstream.

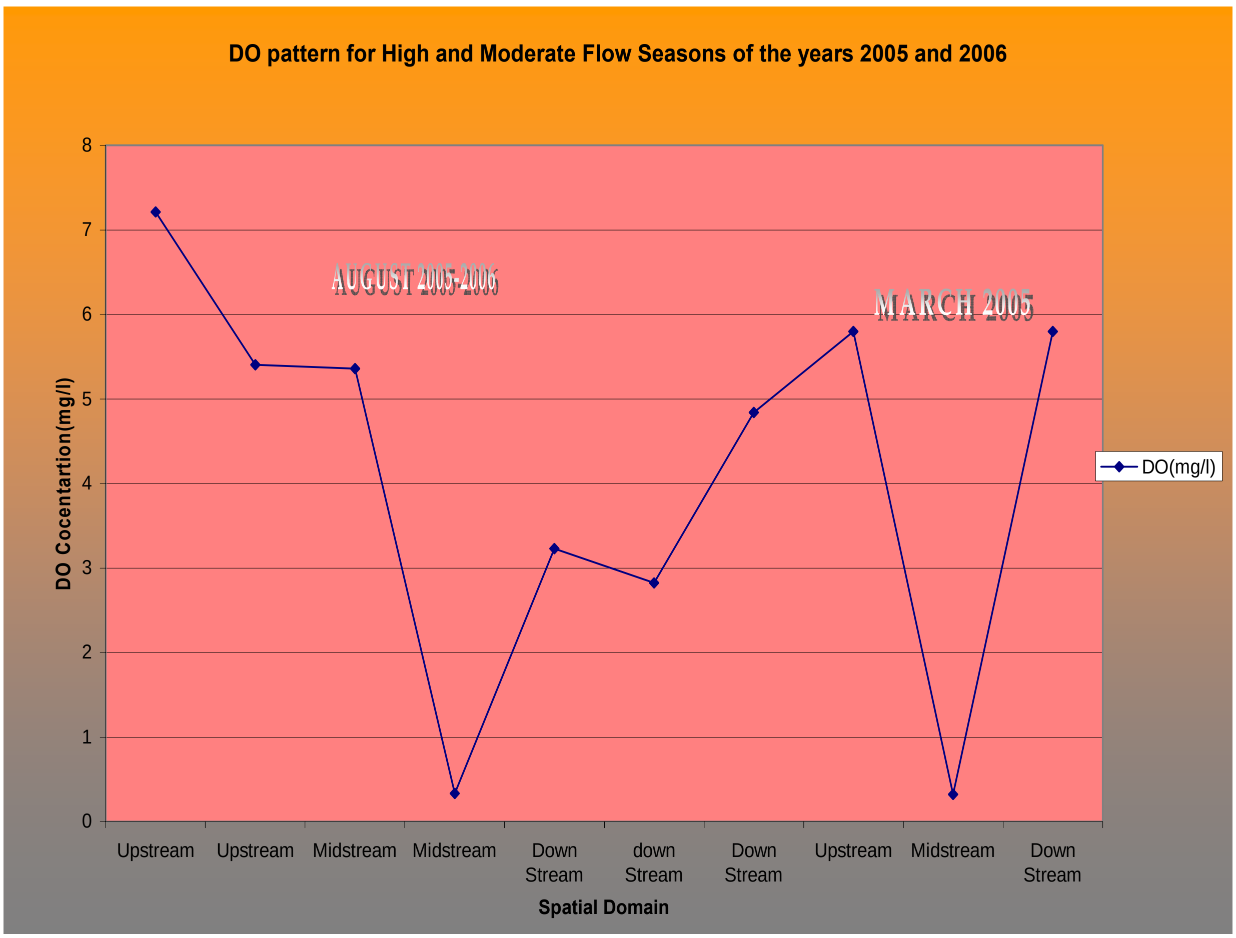


Fig.20 The 2005-2006 high and moderate flow seasons DO patterns along TAR.

This DO pattern has dual purpose and represents both the 2007 moderate flow period and the minimum industrial effluents discharge scenario. Thus it is presented as fig. 21 and 22 which are based on the **Appendices (5a and 5b).**The lowest value (i.e. 3mg/l) is registered for the midstream. But the condition seams improved in the down stream direction. All samples exhibit DO values greater than or equal to 3 mg/l. But non of them achieve the minimum standard (6mg/l) which indicates the presence of ODW sources other than industries that keep the DO level bellow the standard.

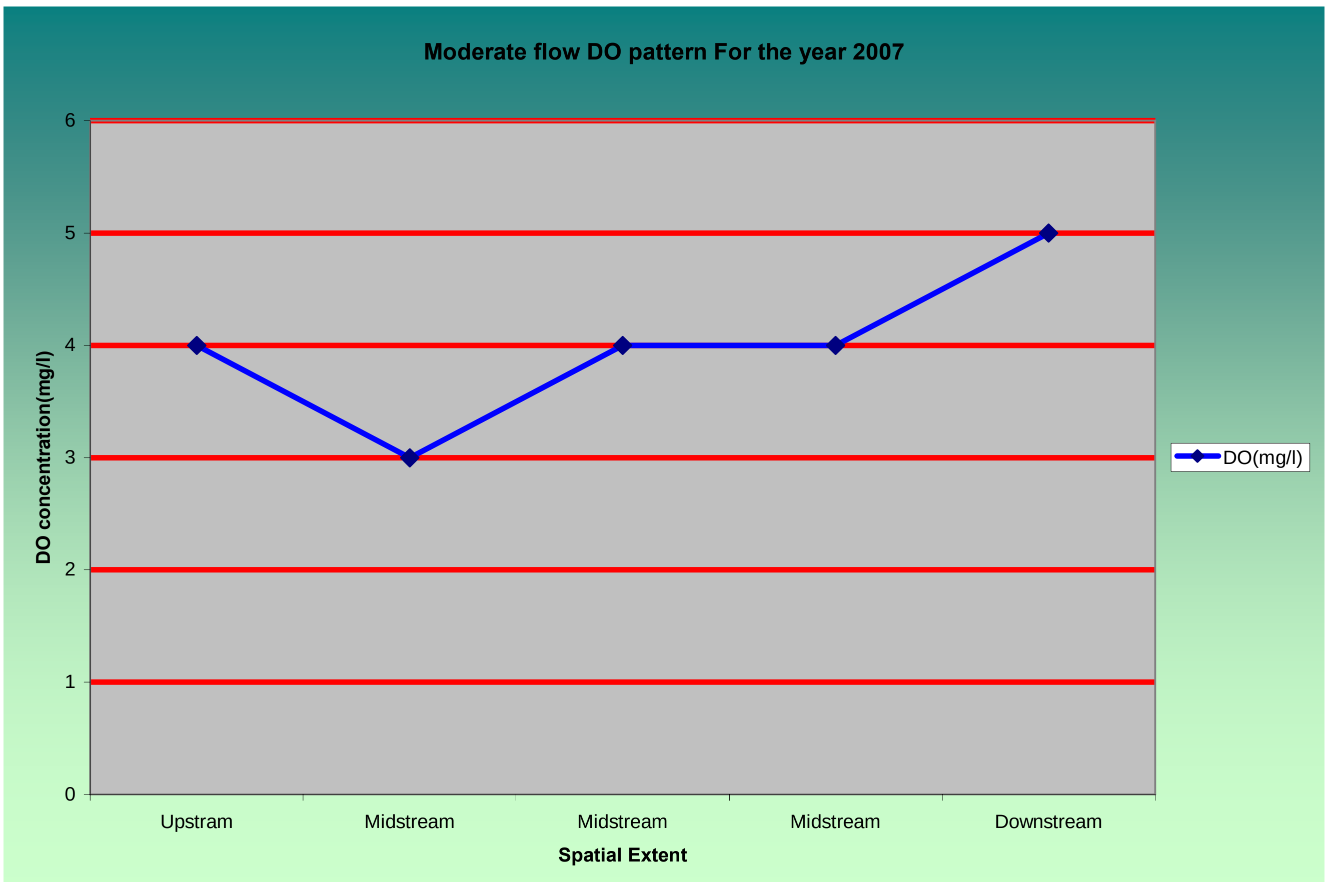


Fig. 21 The 2007 moderate flow DO pattern along TAR.

5.2 Industrial Discharge Scenarios and DO Patterns of TAR

5.2.1 DO trend With Little or No Industrial effluents Discharge

The DO trend presented in fig.22 bellow stands for the samples collected to represent the date when there was little or no industrial activity thereby the effluents discharge was assumed to be minimal. As a result the DO values obtained in this analysis (>=3mg/l) exceed by far those that represent relatively peak effluent discharge scenario which will be discussed in the next pages.

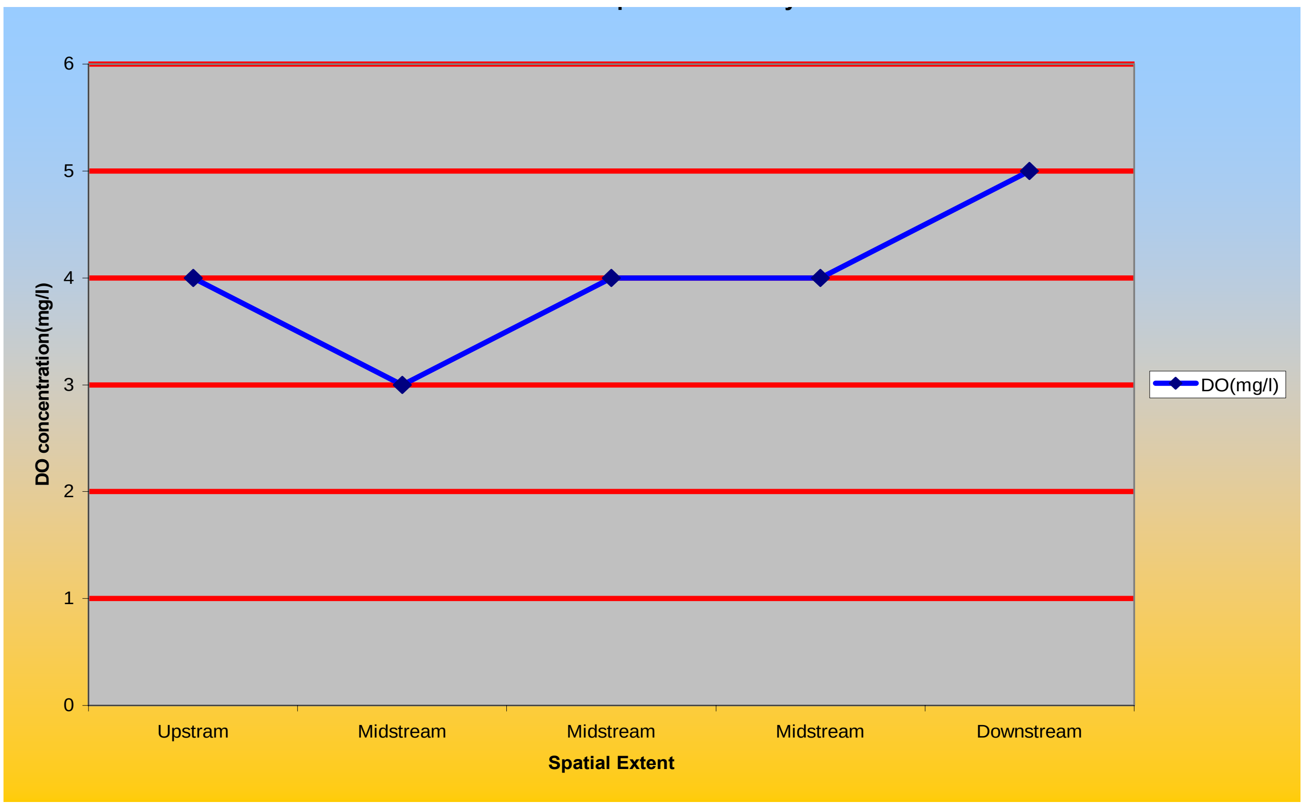


Fig.22 Little or No Industrial effluents discharge Scenario DO pattern along TAR.

5.2.2 DO Trend With Peak Effluents Discharge Scenario

The DO values in these trends (fig.23 and 24) represent the peak industrial effluents discharge as the samples were collected on the dates when the industries were intensively active discharging there effluents. Moreover the data for these analyses are based on **Appendices (8b and 9)** respectively. And in both the graphs the DO levels are severely impaired (Very low) occasionally reaching zero which clearly depicts that how deleterious industrial effluents are to the quality of TAR.

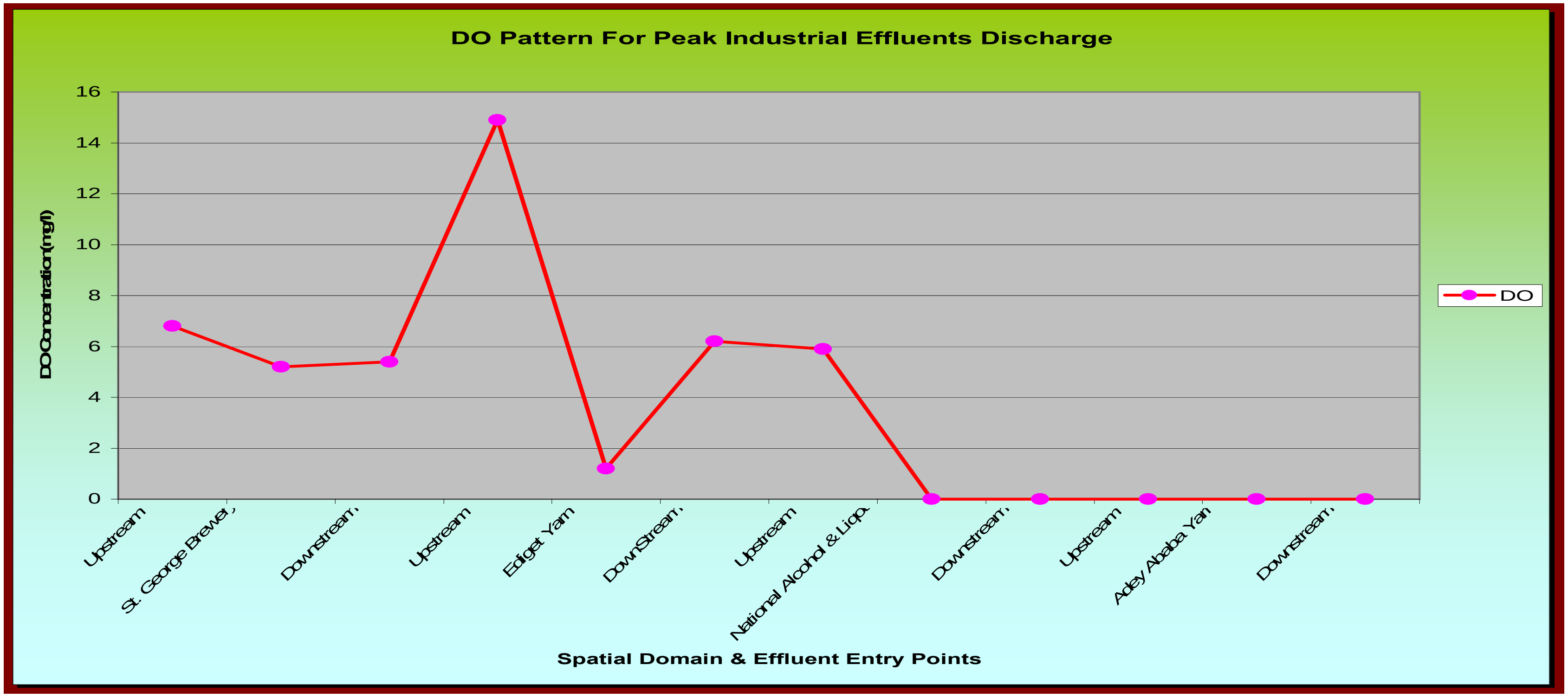


Fig.23 DO pattern along TAR before and after Industrial effluents release

Here all of the mid and down stream samples give [DO] values bellow 1mg/l as the industrial organic and inorganic loads were great.

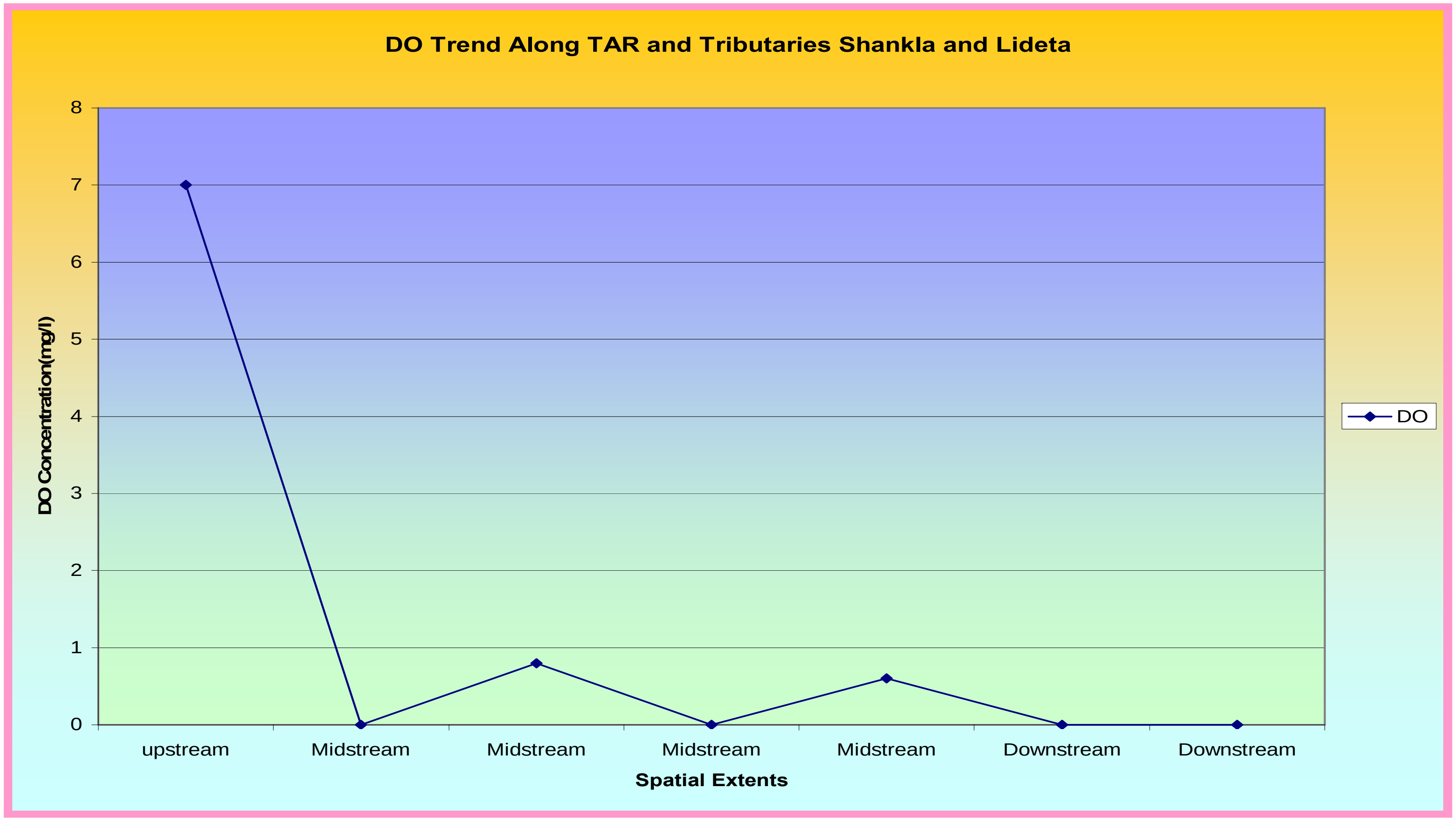


Fig.24 Peak industrial effluents discharge scenario DO pattern along TAR.

5.3 Processes and Conditions Based Account For DO Patterns Along TAR

A river is not a self-contained system, but naturally it interacts with its surrounding environment, hence many of its features are highly influenced by the nature of the out side environment, the prevailing conditions and the extent of its interaction. And here under the general trends of factors and processes that increase or decrease [DO] along TAR are displayed graphically. However, since the number of factors and processes that can be involved in such account are many only instances of them will be discussed and presented bellow.

5.3.1. The Increase In Temperature, Salinity, And Microbial Population along TAR

The increase in the above factors along the course of a river can be associated with the decrease in the DO holding capacity of the water and the general trend of each factor along TAR are shown bellow with data representing the early and recent years only. Therefore, the 1999 and 2007 data is used to show the downward increment in TDS and Temperature in figs. 25-28 which are based on **Appendices (5a and 11c.a).**

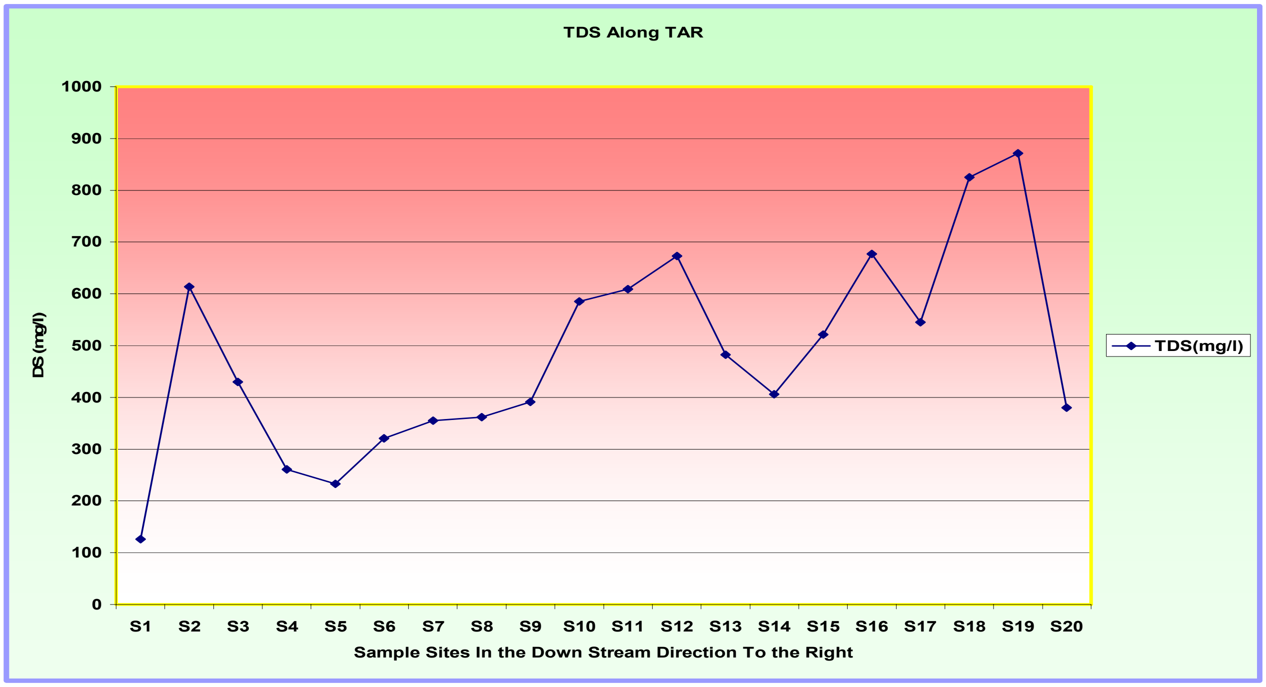


Fig.25 TDS Increment in the downstream direction (Based on1999 data Appendix 11c.a)

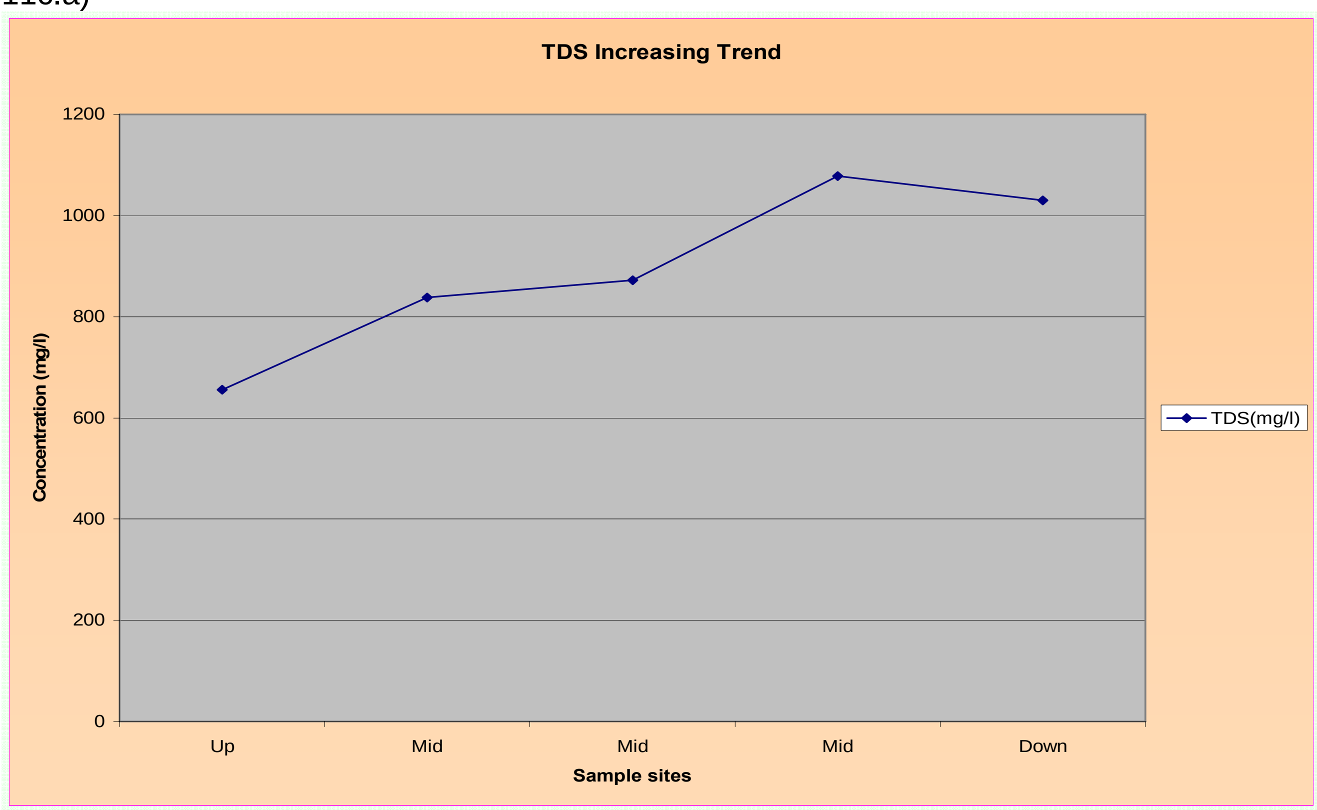


Fig.26 TDS Increment in the downstream direction. (Based on 2007 Data Appendix 5a).

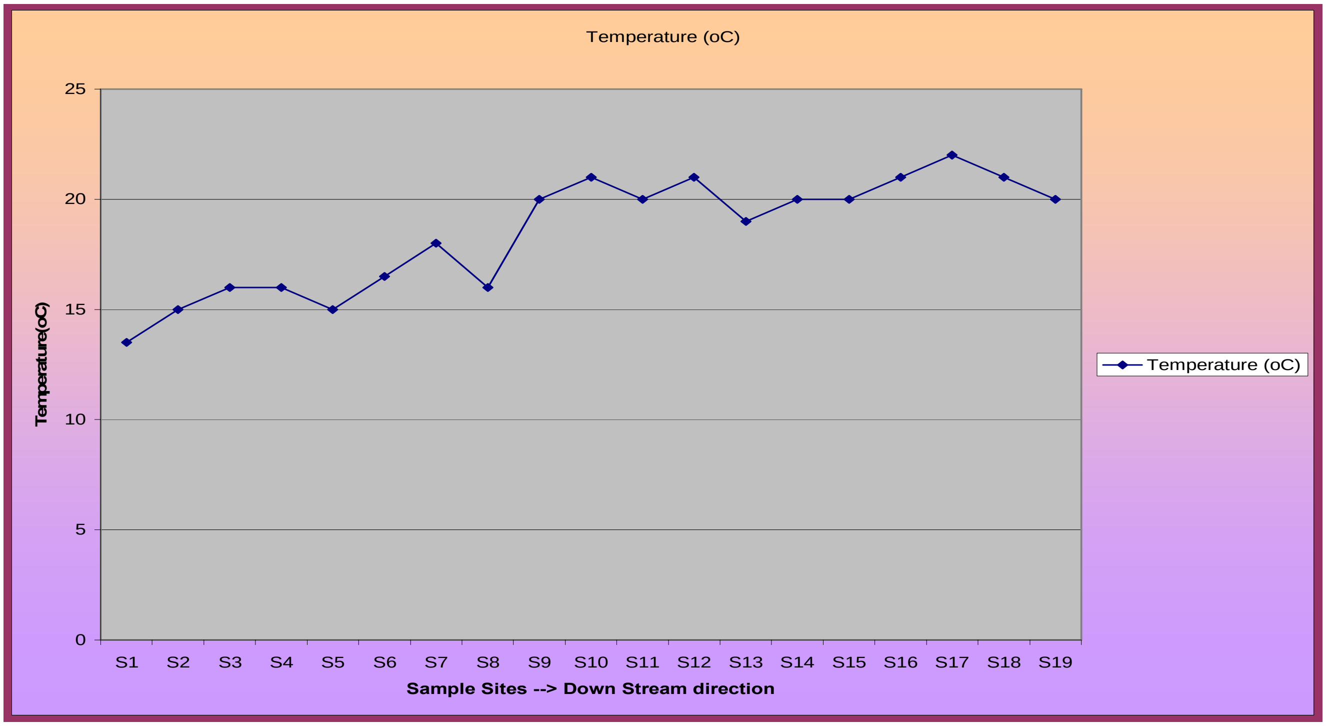


Fig.27 Downward increasing temperature (Based on 1999 data)

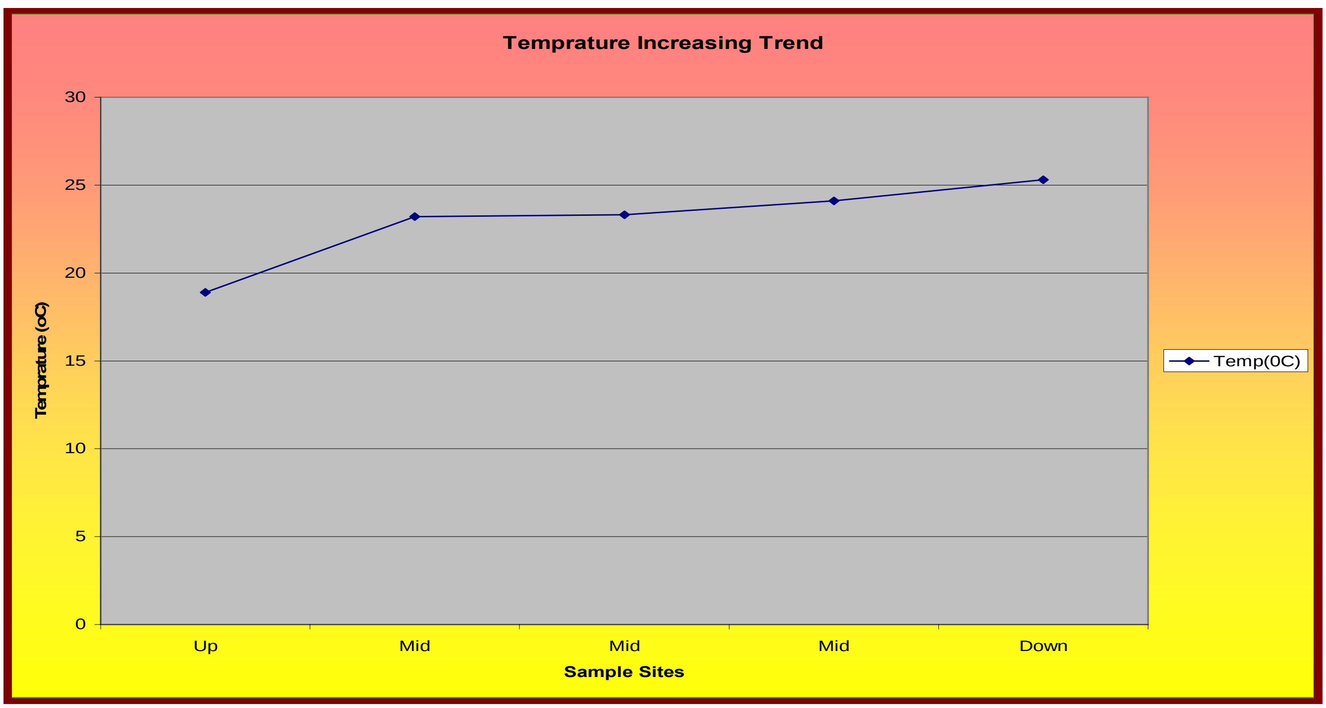


Fig.28 Downward increasing temperature (Based on 2007 data)

Such trends for the above factors have been observed for the years 1999, 2000, 2002-2003, 2003-2004, and 2005-2006 **(Appendices 12-14, & 16a -16f).**

Moreover, the greater microbial population in the mid and down streams of the Tinishu Akaki river and its tributaries have been detected in many analyses. Fore instance the 1999 low flow (fig.28) shows the peaking of microbial population in the midstream, the fall at its end and then starting to rise in the down stream direction. (Gizaw Berehanu 2000) had also found greater numbers for bacteriological ananlyses of the samples of the TAR and its tributaries.

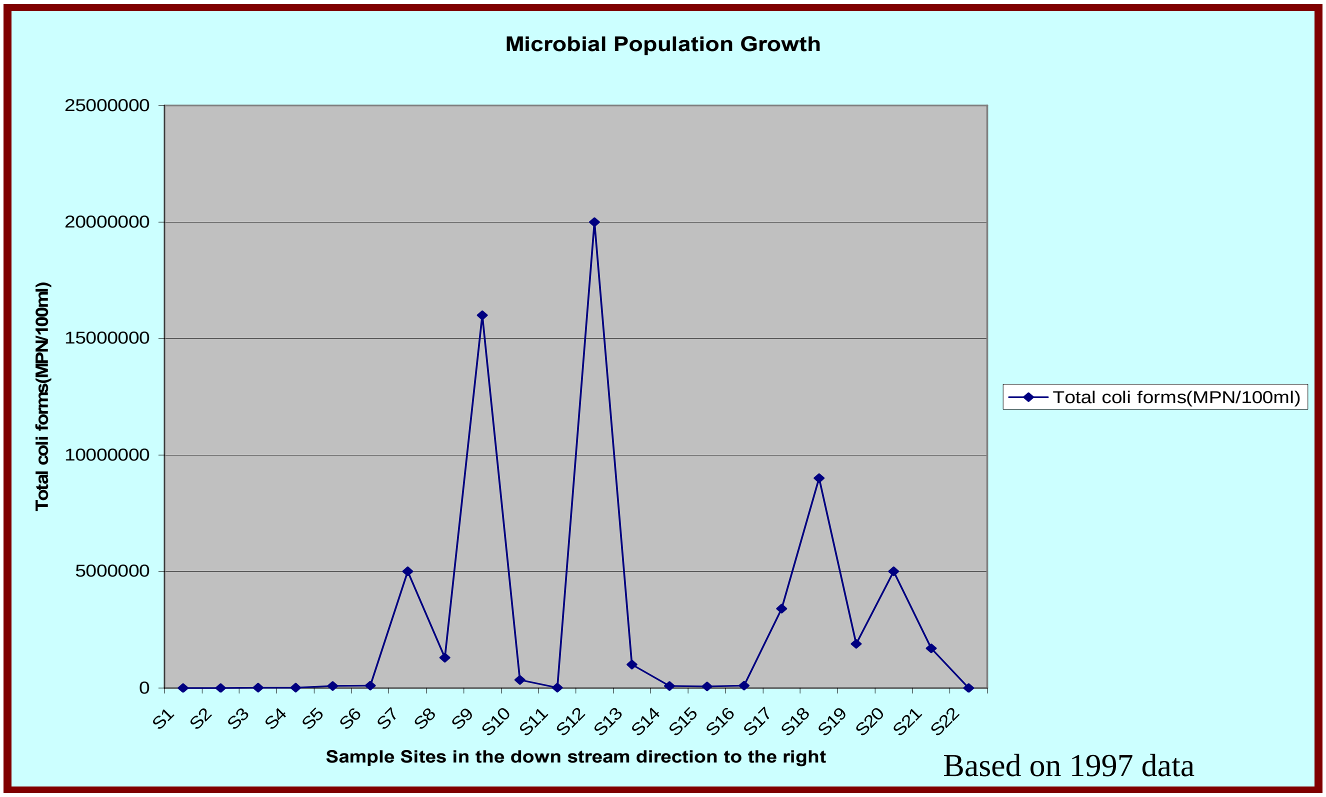


Fig.29 Microbial Population growth. (Appendix 11b.a)

5.3.2. The Increase in Chloride and Heavy Metals and the Decrease Along TAR

The increase in the chloride and heavy metals concentration (Nitrification inhibitors) coupled with an increase in the atmospheric pressure and a decrease in the BOD in the down stream direction of TAR counter acts to the deteriorating factors and processes thus attempt to improve the DO level. Thus figures 29, 30 and 31 bellow show instances of such trends. However, [DO] have been observed to fall where ever these parameters rise and vice versa.

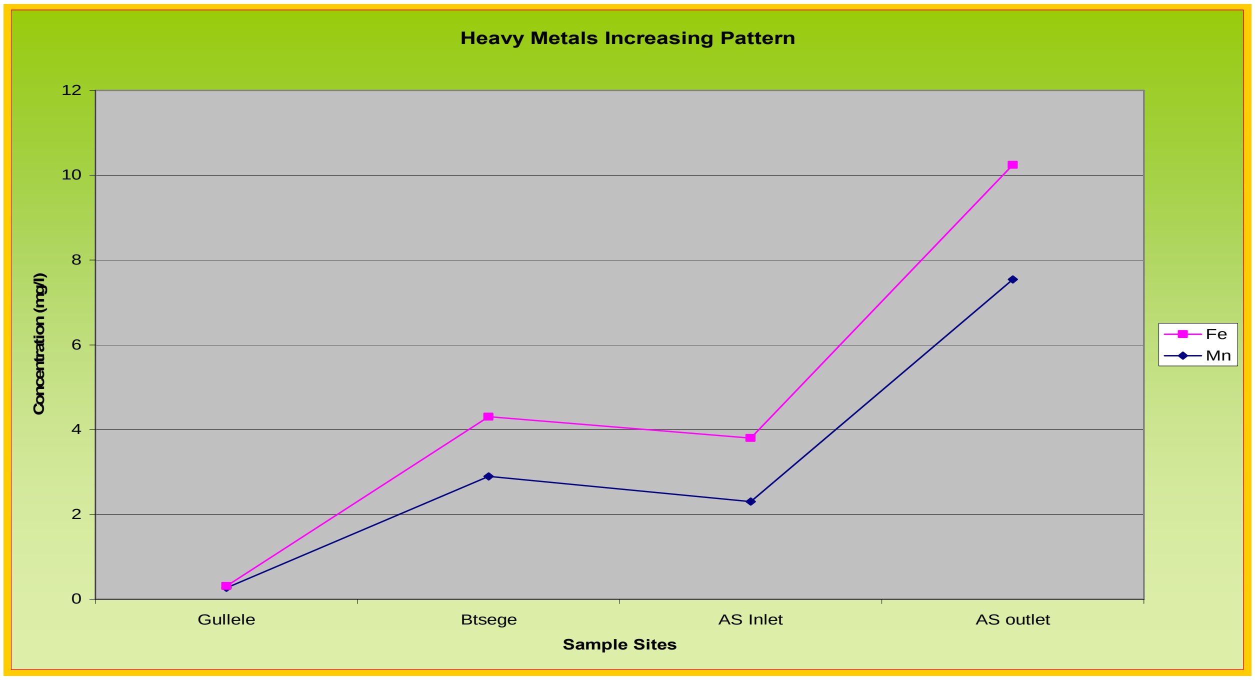


Fig.30 increasing metals concentration (Based on EPA 2006 data)

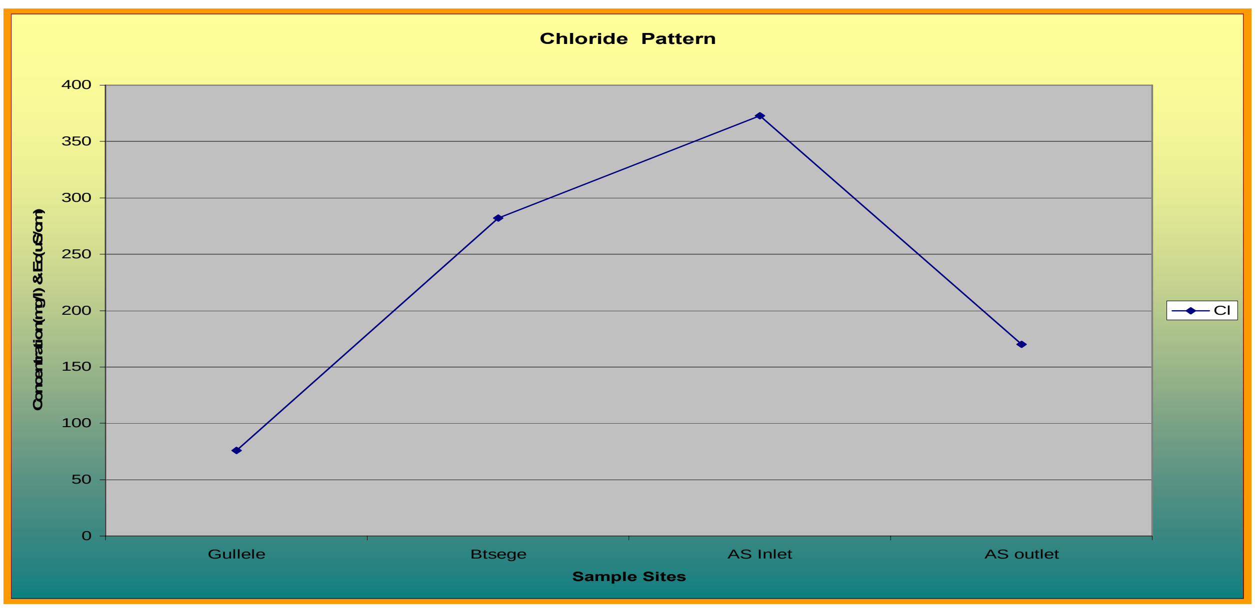


Fig.31 A generally increasing chloride concentration (Based on EPA 2006 data).

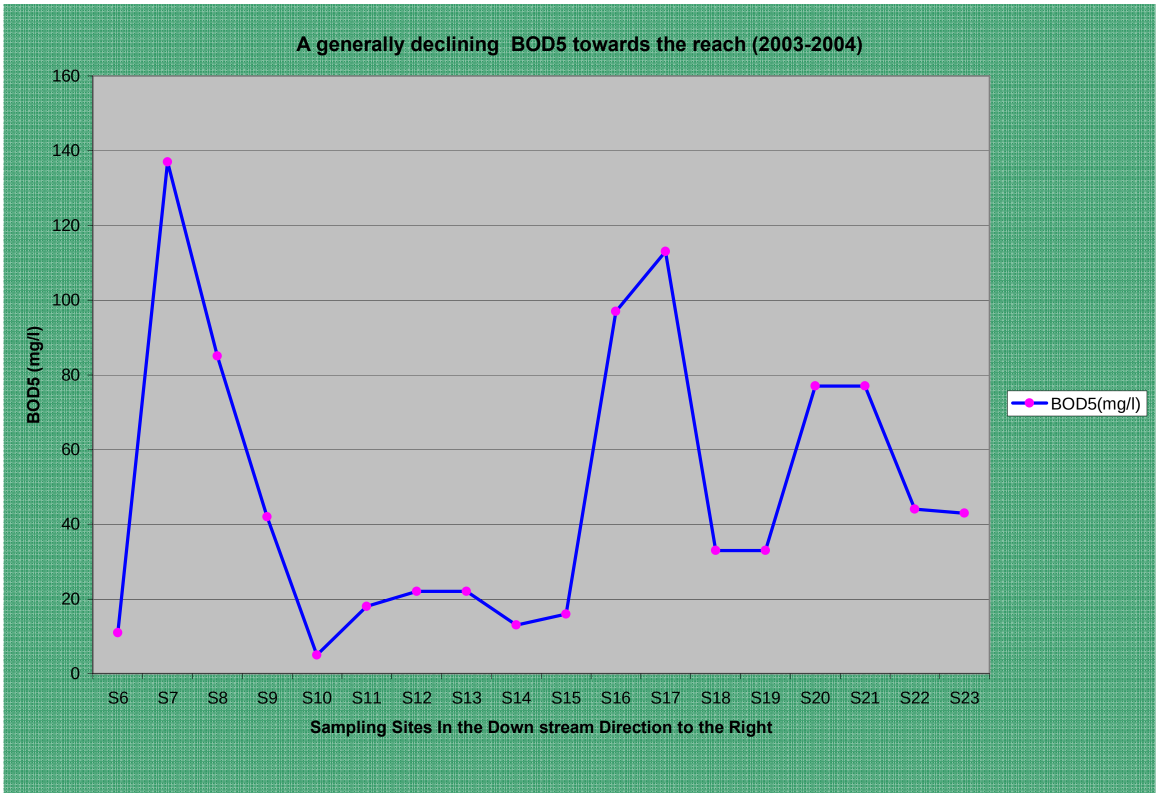


Fig. 32 A declining BOD5 trend to wards the downstream (based on 2003-04 data)

The pattern of the above parameters is also similar with 1997, 1999, 2000, 2002-2003, and the rest except that some stations are unsampled in some of the years and only few samples are analyzed in the others.

In addition to the above factors the interactions among the biophysical processes and the river system also determine the relative concentration of dissolved oxygen and other pollutants in the water column at various spatial domains. Therefore the conceptual models of interactions between a river system and the other environmental subcomponents along with the biophysical processes are shown in the figures 32 and 33 bellow.

The interacting components within a river system include the water column, the gaseous substances (volatiles), and the sediments or bed rocks. Precipitation, dissolution, adsorption and desorption of materials are the common processes which occur among the components within the river system itself. This together with interactions between the river and other subsystems determine the relative concentration of matter (e.g. DO, heavy metals, and other pollutants) in the water column. Instance of such interactions has been observed in TAR sediments trace elements analyses data of Samuel et.al. 2004 that shows a generally declining trend for the concentration of trace elements (e.g. Cr, Mn) in the downstream direction. Incontrast to this however, their concentration in the water column have an increasing trend down wards as depicted in the data by Samuel et.al.2005 and EPA, 2005/6.

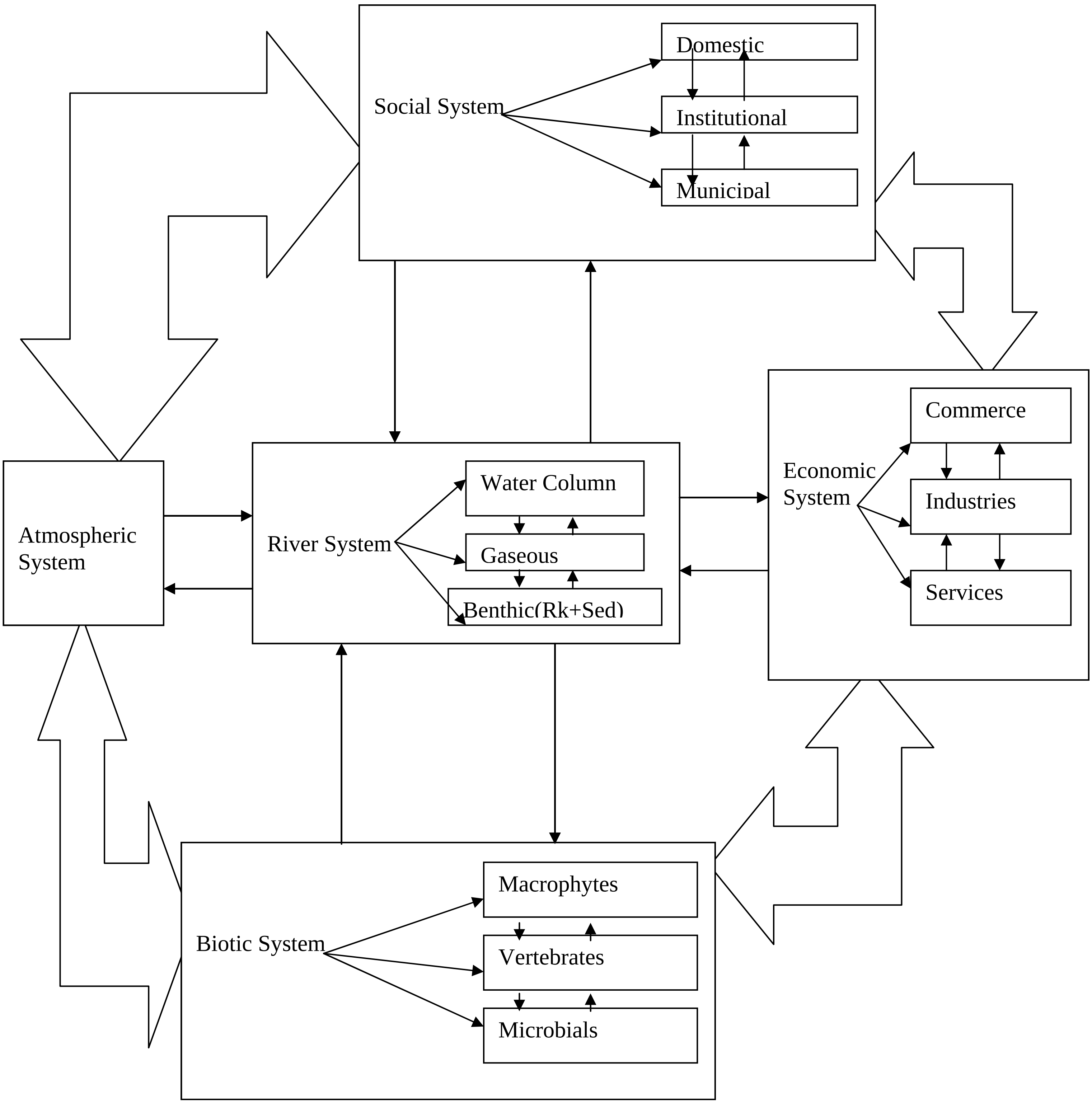
Moreover the river system also interacts with the atmospheric system though exchange of gaseous (volatile) substances, precipitation and evaporation, wet and dry deposition of atmospheric pollutants (e.g. nitrogen and sulphur oxides). This has also been revealed in the temporal variations of the TAR flow, level, and DO concentrations.

Besides, it also interacts with the economic system and serves as a recipient of production wastes that are rich in BOD and COD and in some production and commercial activities the river water is abstracted and used as input. Such interactions of the TAR is observed in pollutants load which have typical characteristics of their sources.

Moreover it receives all sorts of consumption wastes from the social system (domestics, institutions and municipalities) and gives off recreational, domestic and other services. However if impaired only diseases causing agents will the society receive.

In addition the river system also interacts with the life systems that occur within the river (e.g. microorganisms, fish, algae and weeds) and also gets shelter from pollutants runoff. And the vegetation cover in the riparian areas also shade the river from solar radiation. Here the interaction can be considered as symbiotic. The river serves as habitat and gives of nutrients for the life system. And the microbial community attempts to purify it from organic contaminants. Moreover, the riparian vegetation filters the pollutants load from runoffs and gets its mineral and water demands from the nearby river water. Therefore, the full skeleton of interaction among the environmental systems is presented bellow (fig.32).

Fig.33 Skeleton Of the interactions among the Environmental Subsystems



The oxygen producing processes are termed sources and the ones that consume are called sinks. These interacting processes are presented pictorially in fig 33 bellow: Atmspheric reaeration

Photosynthesis and

DO from tributaries or effluents are considered to be sources.

Reaeration refers to the dissolution of atmospheric oxygen gas as a result of its contact with the exposed river water and this phenomenon is usually enhanced when the river moves in greater turbulence. In addition photosynthesis by aquatic plants also releases oxygen as byproduct and replenish the river water. Besides unpolluted and cold tributaries and effluents also add some DO to the river thereby rise its level.

In contrast to this however, the oxidation of Carbonaceous BOD and Nitrogenous BOD plus the demand from sediment organics and aerobic respiration of aquatic organisms lowers the DO level in a river water column. However, the DO level at any time and place in river water is a reflection of the balance between contrasting processes and prevailing conditions. Therefore, the case of TAR has been evaluated in light of those processes and prevailing conditions and the followings seams to prevail at each spatial domain and these are:

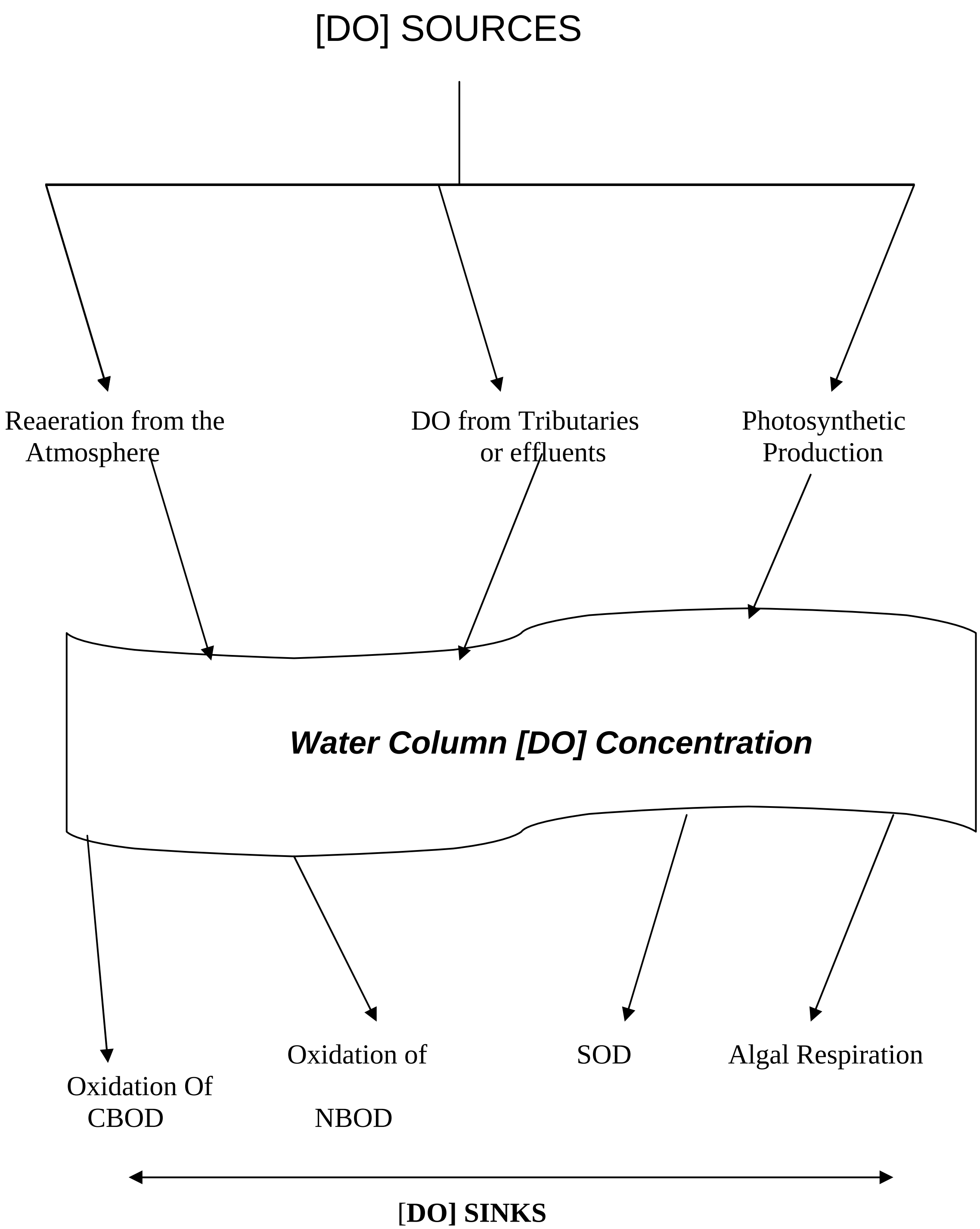
Table 14 [DO] Sinks and Sources along TAR.

Spatial domain	Prevailing Conditions	Over-balancing Process
1. Upstream	Sloppy river beds and few falls, high velocity, Reaeration, High altitude, low Temperature, Relatively less polluted tributaries and low BOD and COD loads. Erosional- low sediment Oxygen demand (SOD)	DO Production (SOURCES)
2.Mid and Down streams	Gentle to Flat slope- Low Reaeration Altitude lowers- High Temperature Many industries- high BOD and COD Loads. Congested residentials- Bacterial load. Large farm fields- high nutrients load	DO consumption (SINKS)

	Depositional- High Sediment Oxygen Demand (SOD)	

These interactions are also displayed in the conceptual model in fig.33.

Fig.34 Sources and Sinks of DO in the river



5.3.3 Instances Of Biochemical and Physical Factors In Control of [DO] Patterns

Every rise in BOD5, COD and Temperature is observed to be accompanied with a fall in DO level and vice versa.

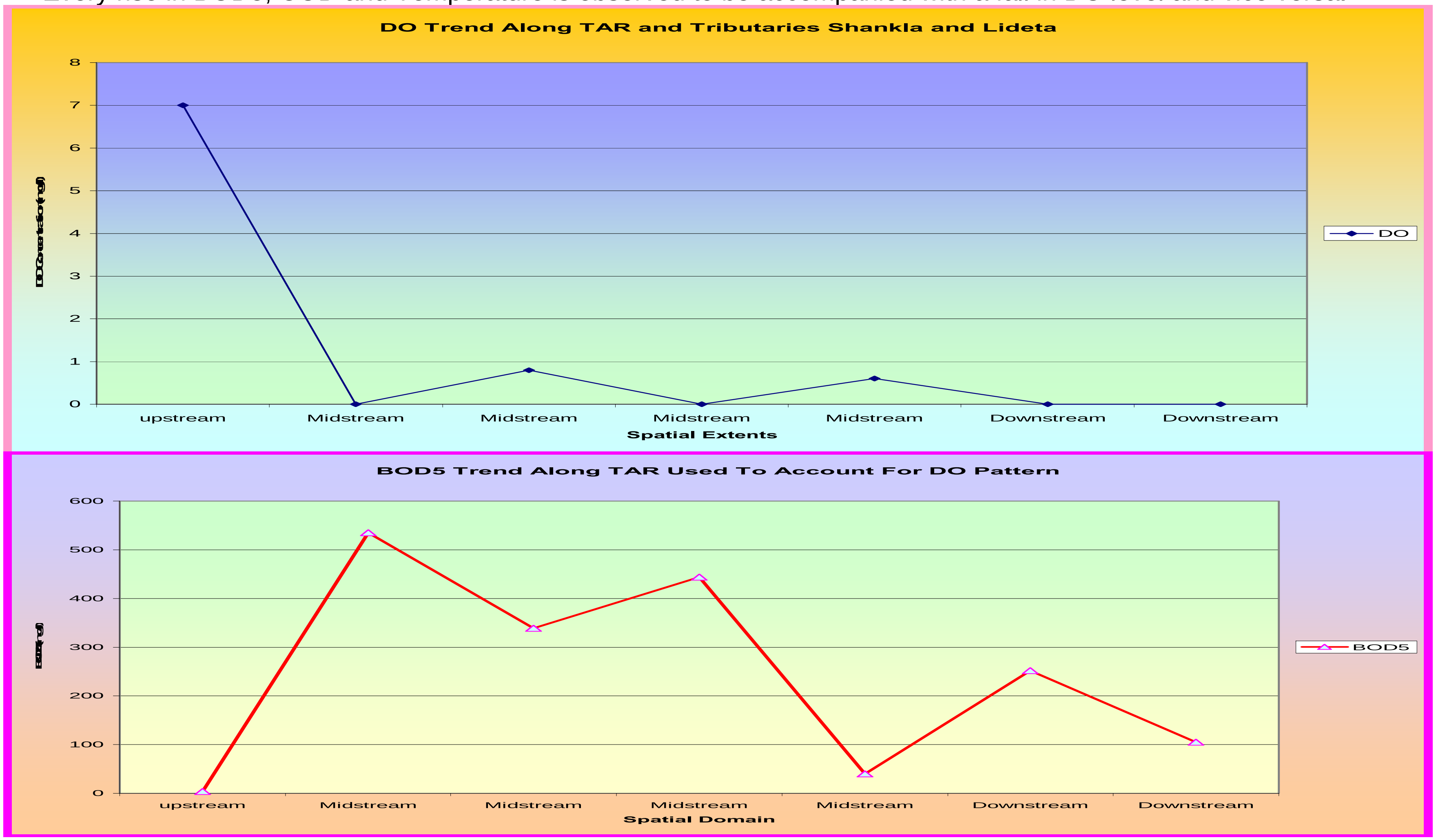


Fig.35 BOD_5 in control of the peak effluents discharge DO pattern along TAR and tributaries Shankla and Lideta.

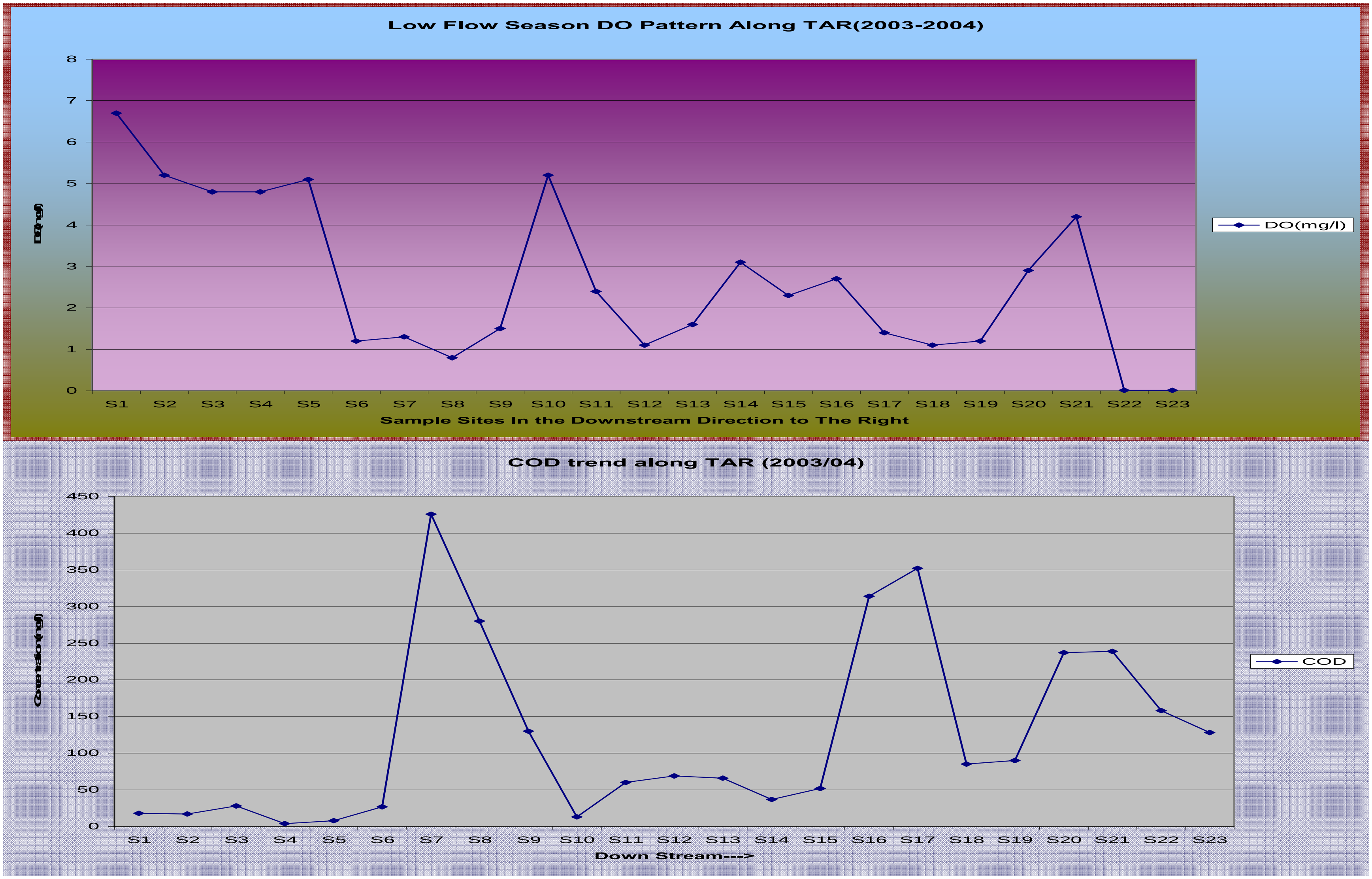


Figure 36 COD In control of the DO pattern along TAR

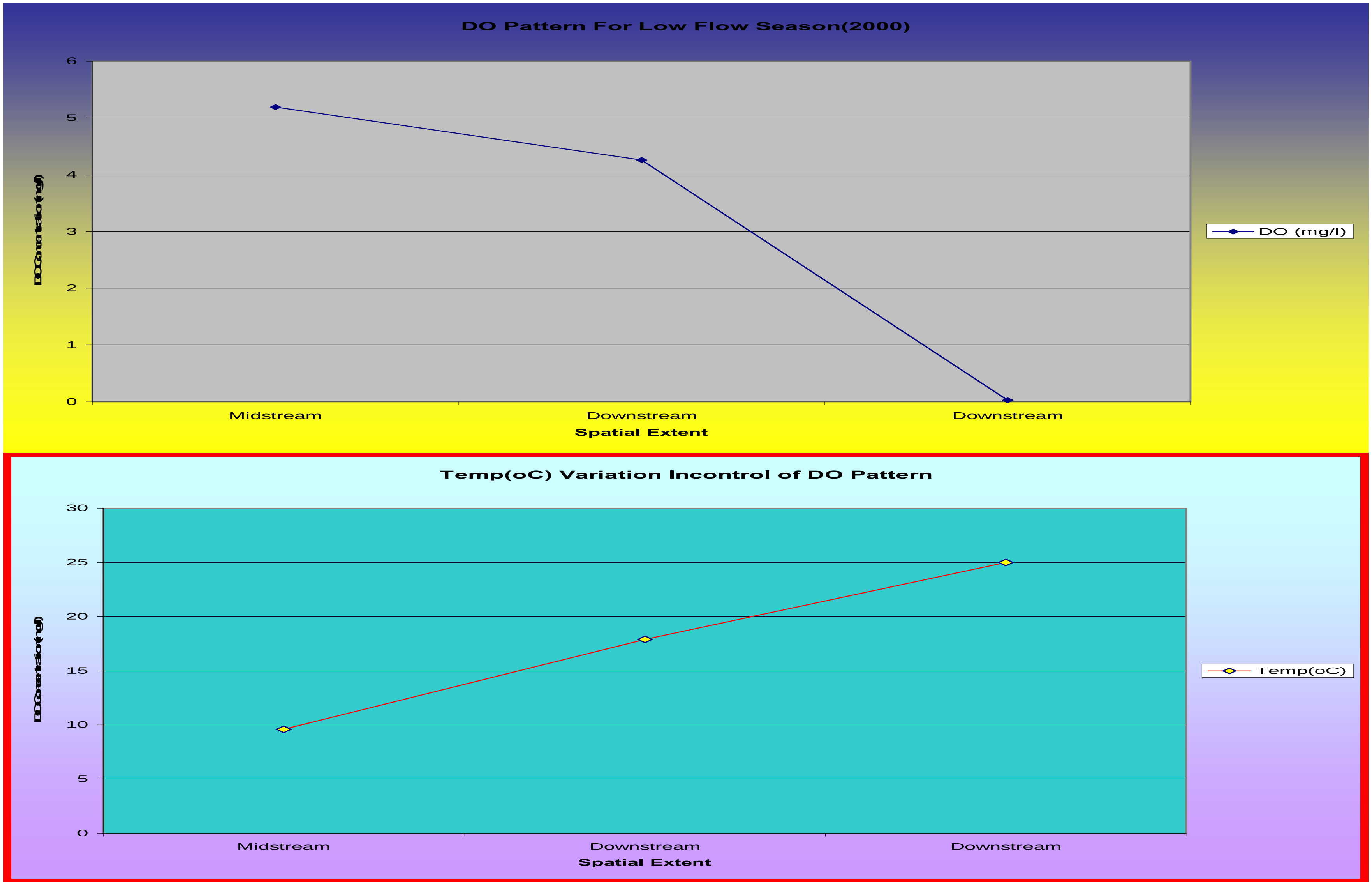


Fig.37 Temperature in control of DO along TAR.

5.4 Consequences of Reduced [DO] Levels Along TAR

The fall in [DO] level towards the down stream of TAR is observed to be accompanied with an increase in the production, mobility and toxicity of potentially harmful substances such as ammonia, heavy metals (Cr, Mn, and Fe etc), sulphates, hydrogen sulfide, methane and phosphates .Moreover the increase in Chloride & heavy metals inhibit further depletion of dissolved oxygen towards the end of the river.

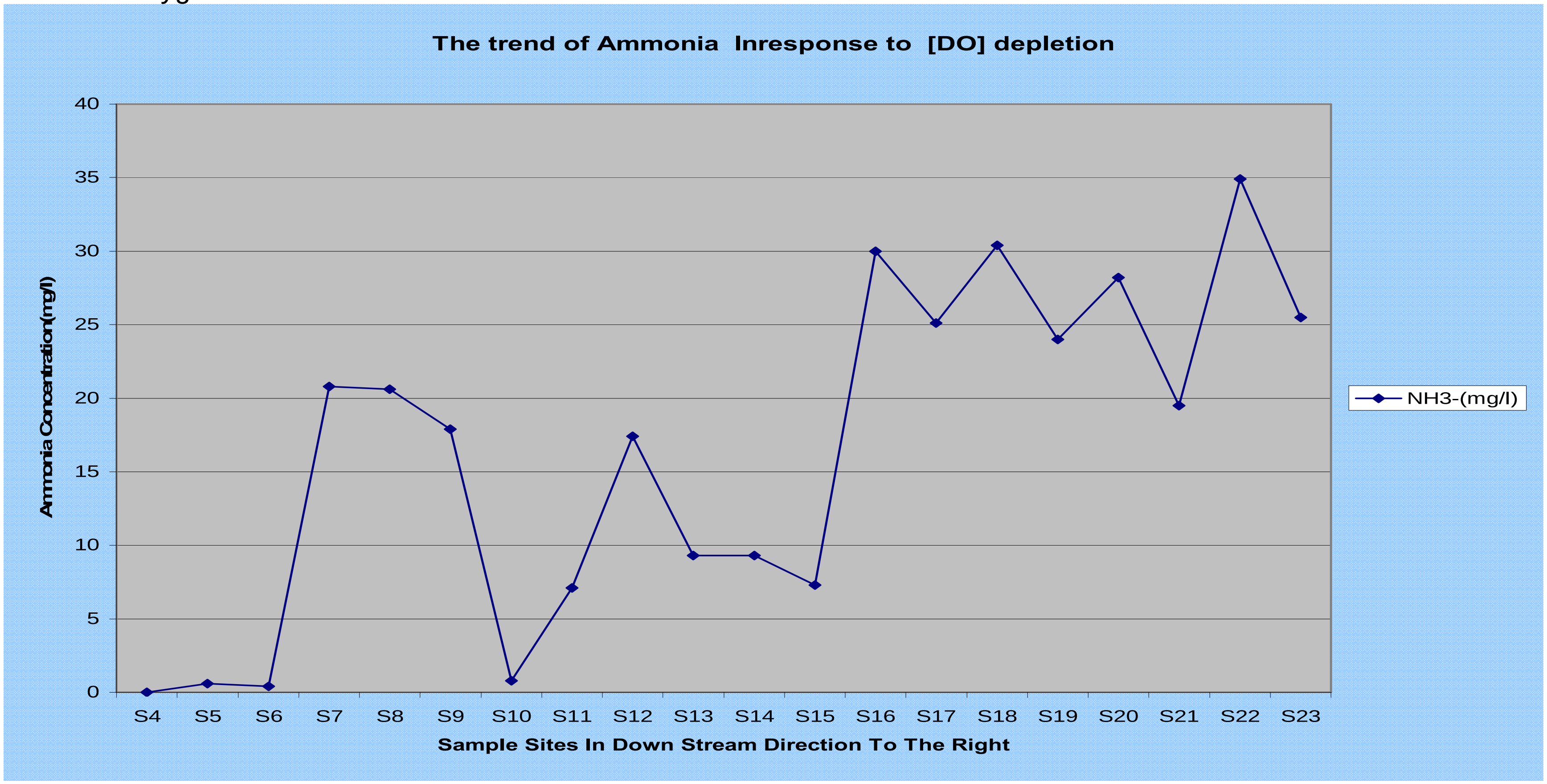


Fig.38 Ammonia in response to [DO] pattern along TAR.

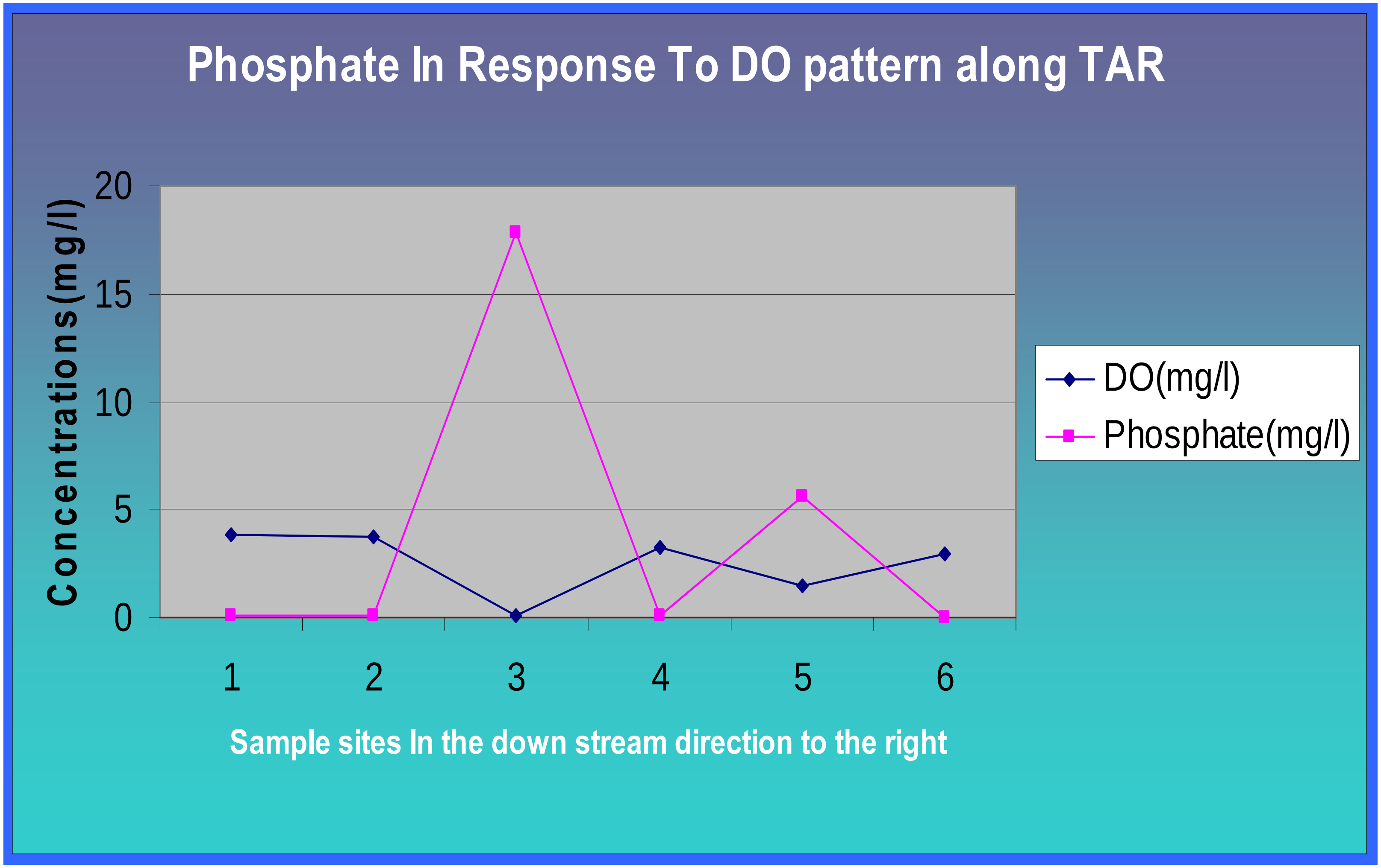


Fig. 39 Phosphate in response to [DO] depletion along TAR.

6. DISCUSSION AND INTERPRETATION

The graph for the year 1997 low flow period depicts that more than 68% of the samples representative of the three spatial domains had <= 3mg/l DO values as a result the greater portion of the river suffers from DO depletion despite the fact that the midstream case is the worst, where the majority of the 68% impaired samples are congested. And this can be attributed to the rise in the atmospheric and water temperatures and then microbial or chemical activities, the fall in the volume and velocity of the river water and to the closely spaced industrial establishments that gave the river lesser time to maintain its assimilative capacity and greatly declined its oxygen holding capacity. Moreover, the average [DO] value for the up stream domain is greater than the midstream which in turn exceeds the down stream.

But the trend is almost similar for the years 2002/03, and 2003/04 low flow periods and the only exception is the year 2000 low flow period which shows an anomalous DO value in the midstream that is 7mg/l which can be justified with the prevailing low temperature (i.e. 9.6 ^{0}C) in the same location and with possible thermal pollution (high temperature) in the down stream.

However, the condition got better in the 1999 Moderate flow temporal period and only slightly greater than 45% of the samples exhibit the critical DO value(i.e. < 3mg/l) and this can be associated with the relative increase in the streams flow velocity and volume of water in the rivers. But still in this temporal period the mid and down streams were the hotspots in terms of DO depletion as all of the 45% spoiled samples were from these spatial extents. And the trend is more or less similar with the 2005 and 2007 moderate flow seasons.

Moreover, in the 1997 high flow period the situation was much better than any other temporal period, consequently more than 86% of the samples collected to represent the whole of the river's spatial extents, had DO values greater than 5mg/l. But the minimum DO values still correspond to the midstream spatial domain and again the pattern is almost similar with the year 2005/06 high flow period; however, the general improvement in DO level pertaining to this temporal period can be accounted by the high amount and rate of precipitation that causes in an increase in surface runoff and stream velocity which improves the rates of atmospheric reaeration and mixing at the surface of rapidly moving or turbulent river water. Besides, the decline in the daily temperature values in this season, which reduced the chemical and microbial activities also greatly, improves the DO level in the river water. Therefore, low flow temporal period and the Midstream are found to be the critical temporal and spatial extents in terms of DO depletion along Tinishu Akaki River.

Besides, the analysis of the physicochemical data have shown that the DO level for the samples collected and analyzed to represent the date where there was little or no industrial activities, every thing else taken as control is much better than the DO values of the samples associated with the intense industrial activities. Four out of the five samples analyzed for little discharge scenario exhibit DO values greater than 3mg/l; however, among the six samples that represent the peak industrial discharge scenario five of them have DO values below 1mg/l. Therefore, it has become evident from the above discussion that unpermitted industrial waste waters are the major contributors of oxygen demanding wastes in particular and the pollution of TAR in general.

Besides, the temporal and spatial variation in the extent of DO depletion and or pollution along the TAR was accounted for with the analysis of factors that control the production (Sources) and consumption (sinks) of dissolved oxygen (DO) in the river water column. As a result it has become possible to detect differences in the kind of processes and factors that prevail and control the DO depletion and or production at various spatial domains along the river. And for the majority of the temporal periods and till the end of the mid streams spatial extents, BOD and COD (Biochemical Oxygen Demand and Chemical Oxygen Demand) are in control of the DO trend along the river.

However, BOD and anaerobic chemical reactions along with increasing atmospheric pressure play an important role in determining the level of DO in the downstream spatial domain i.e. clearly shown in the exactly contrasting BOD_5, COD, PO_4 Vs DO trends and generally Matching NH_3 Vs DO patterns respectively. Generally the Salinity (TDS), temperature, microbial population and atmospheric pressure, profiles along the river show an increasing trend in the down stream direction parallel to the decreasing elevation and BOD. But they have a contrasting effect on the solubility of the air (oxygen) at the surface of the river water, the former three act negatively while the latter operates positively.

Moreover, the slope of the river bed becomes gentler in the down stream direction resulting in a decline of the turbulent flow of the river which in turn negatively affects the DO input that would otherwise be made available via reaeration and mixing.

In contrast to this, the year 2000 low flow DO sag curve shows an anomalous pattern and that can be associated to the anomalously low temperature in the midstream and the possible thermal pollution in the down stream hence the trend can be better accounted with temperature profile. Above all the reduced [DO] level is observed to be accompanied with the downward increment in the concentrations of harmful substances such as NH_3, H_2S, PO_4, SO_4 and heavy metals like, Cr, Mn and Fe. And increasing chloride concentrations have also been observed in all the years **(Appendices 11a, 11b, 11c, 16a- 16f)**.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The environment has not been featured on the development agenda in the past since the project evaluation and decision making mechanisms have focused on short-term technical feasibility and economic benefits. Past development practices have not anticipated, eliminated or mitigated potential environmental problems early in the planning process. This has resulted in a situation where the city experiences a serious degraded natural environment.

DO depletion or water pollution along TAR is prevalent in all the three spatial domains (i.e. the up, mid & down Streams) and temporal periods (i.e. the high flow, Moderate Flow, and Low Flow periods).

In most cases DO levels are bellow the in stream water quality standard and occasionally become zero.

But the mid stream and low flow period are the worst in terms of dissolved oxygen depletion and or pollution.

Moreover the DO depletion is found to be severe with intense industrial activities and therefore industries are the major sources of pollutants in general and ODW in particular. The Industrial effluents also violated the Ethiopian provisional effluents discharge limits **(Appendix 18).**

Industries are followed by the domestic and other nonpoint sources in their role of polluting the TAR as shown clearly in the effluent discharge scenarios analyses.

Besides the increase in temperature, Atmospheric pressure, Salinity, River water Volume, microbial population, (Oxidation-Reduction), the number of industrial establishments, the size and number of farm lands coupled with the decreasing elevation, forest cover and stream velocity interact govern the spatio-temporal DO trends along the course of Tinishu Akaki River.

In addition to this the exceptionally high concentrations of the industrial, commercial, residential, institutional and service centers in the midstream spatial domain are attributed to exacerbate the problem at this particular spatial extent by giving lesser time for the river and its tributaries to remaintain their assimilative capacities

It is also possible to conclude that the dominant causes of DO depletion and pollution of TAR water are BOD and COD rather than the nutrients.

Moreover, the rise in the concentrations above the in-stream, drinking water standards of the potentially harmful substances such as ammonia, sulphates, phosphates, hydrogen sulfides, and heavy metals (Cr, Mn and Fe…etc.) to wards the downstream is associated to a generally declining [DO] level.

In addition the increase in the toxic substances downstream ward is believed to pose potential public health problems to the residents.

However the relatively improved DO levels near the reach of the river can be a result of inhibition of microbial nitrification due to increasing concentration of chlorides and heavy metals in the same direction.

Lastly it is also possible to conclude that further development has the potential to exacerbate the damage of fragile riverine systems. Thus proper and cost effective mitigation measures must be sought.

7.2 Recommendations

Environmental assessment and management have been recognized as effective tools for facilitating the inclusion of the principles of sustainable development into development proposals. Thus to ensure that the existing situations get improved and future developments in Addis are sustainable it is essential to integrate environmental concerns into development activities.

In line with this and knowing that Biochemical (i.e. CBOD and NBOD) and Chemical Oxygen demands as, the dominant impairing substances in the TAR and industries as the largest contributors;

- Total Maximum Daily Loads (TMDLs) for Oxygen Demanding Wastes (ODW) must be designed to implement applicable water quality standards that enable the maintenance of DO standards. And the design should include and consider the followings:

- A total allowable load as well as individual waste load allocations for point sources.
- The impacts of background pollutant contributions.
- Critical environmental conditions.
- Seasonal environmental variations.
- A margin of safety (MOS) and
- Public participation.

- Besides Industrial effluents discharges must be regulated and monitored regularly by the concerned environmental bureaus.
- And industries must be forced by law to comply with provisional discharge permit limits whenever they violate.
- The waste water collection capacity of the city must be improved and Proper waste disposal or sewage treatment prior to discharge to surface waters has to be practiced by the municipal WWTPs and industries so as to minimize the BOD and bacteriological pollution loads emanating from domestic and other sources.
- Moreover, Vegetation cover alongside streams has to be maintained and enhanced so as to shade the water and filter pollutants from the runoff or nonpoint sources.
- Anthropogenic activities such as, Agricultural practices, Livestock rearing, Construction, Chemicals storage and handling and waste disposal in the project areas should be carried out in such away that impacts to the riverine system and or the whole environment is minimal.

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9. APPENDICES

Appendix 1 Monthly Rainfall Data for the Years (1975-2005) at Akaki mission Station.

			NATIONAL METEOROLOGICAL SERVICES AGENCY									
Element:	Monthly Rainfall				Lat	08°.52'		Altitude	2120mt			
Region:	SHOA				Long.	38°.48'						
Station:	AKAKI MISSION											
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1975	0.0	0.0	3.8	107.2	58.5	175.2	347.2	308.3	281.6	19.9	0.0	0.0
1976	0.0	17.0	19.5	92.0	93.8	195.3	282.4	325.3	83.6	7.0	46.6	0.5
1977	80.5	29.9	80.8	67.4	108.2	158.0	289.7	329.4	108.4	225.7	5.0	0.0
1978	2.4	84.4	60.7	50.4	39.7	153.8	150.6	328.2	194.6	45.5	0.0	0.0
1979	106.4	28.2	107.6	57.6	122.0	75.9	243.2	241.4	96.5	13.0	0.0	4.0
1980	28.5	36.8	54.7	55.8	56.8	111.8	381.5	364.4	64.4	13.1	0.0	0.0
1981	0.0	13.3	179.8	143.9	1.3	46.2	402.6	186.5	219.0	5.0	0.0	0.0
1982	12.1	35.4	39.5	94.6	75.2	63.5	199.6	275.1	124.2	25.8	11.0	8.1
1983	1.8	33.3	15.0	147.3	175.0	83.0	278.0	275.0	138.7	9.2	0.0	0.0
1984	0.0	0.0	40.4	5.1	130.0	215.3	277.9	227.1	57.2	0.0	0.0	1.9
1985	3.6	0.0	32.4	71.8	96.6	96.5	294.0	324.1	164.3	1.6	0.0	0.0
1986	0.0	95.4	66.9	148.7	68.2	143.4	189.4	216.5	86.1	9.4	0.0	0.0
1987	0.0	65.6	181.9	80.7	187.7	69.3	202.0	246.9	81.7	4.4	0.0	0.0
1988	0.0	44.5	0.0	96.0	23.8	124.6	255.9	278.1	254.2	35.4	0.0	0.0
1989	2.1	63.8	53.8	226.3	7.1	58.6	264.2	301.0	170.9	37.9	0.0	0.0
1990	7.7	120.6	48.4	129.4	37.8	78.9	280.7	222.9	117.3	5.8	1.2	0.0
1991	0.0	37.6	62.4	11.6	45.6	90.4	263.7	308.5	113.4	4.4	0.0	56.5
1992	34.7	24.2	30.5	15.5	25.6	100.4	218.4	276.0	86.7	43.3	0.2	0.0
1993	1.2	53.9	5.6	118.4	62.5	116.5	218.0	251.5	118.3	20.5	0.0	0.0
1994	0.0	0.0	62.7	72.2	20.2	125.0	225.1	168.9	106.8	X	11.0	0.0
1995	0.0	25.4	63.7	102.1	20.9	95.7	269.2	242.3	79.5	0.0	0.0	4.8
1996	15.3	0.3	79.7	38.8	90.5	240.1	292.5	234.1	119.0	1.9	0.0	0.0
1997	27.6	0.0	29.5	102.7	25.2	57.0	203.6	203.4	82.5	114.9	10.3	0.0

1998	32.7	30.2	19.6	69.3	159.9	116.9	207.8	280.0	118.5	36.0	0.0	0.0
1999	1.3	1.8	91.8	12.1	44.7	92.8	282.6	300.7	61.7	65.0	0.0	0.0
2000	0.0	0.0	29.1	93.0	64.9	100.1	188.9	210.0	124.1	X	23.4	3.8
2001	0.0	20.7	121.2	23.6	118.0	142.6	257.5	145.0	64.9	2.2	0.0	0.0
2002	31.1	10.5	87.1	82.4	76.6	108.0	167.3	187.0	52.4	0.6	0.0	17.7
2003	19.6	24.3	23.9	114.0	2.9	125.4	325.1	307.4	112.4	0.0	1.9	0.0
2004	13.6	15.8	62.4	154.2	15.4	95.2	177.7	189.1	80.9	4.8	3.4	0
2005	31.4	7.3	33.9	119.0	140.7	139.9	234.8	231.0	149.7	9.1	15.2	0.0

Appendix 2 Monthly Mean Min. Temp.(°c)

NATIONAL METEOROLOGICAL SERVICES AGENCY												
Element						Alt.	2120mt					
Region	Shoa					Long.	38°.48'					
Station	Akaki					Lat.	8°.52'					
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1951	5.8	9.5	12.2	11.3	11.4	10.3	12.0	12.5	11.2	11.1	8.3	8.5
1952	6.1	9.7	11.5	12.6	11.6	11.1	12.2	12.5	11.4	8.9	6.5	7.0
1953	7.4	9.3	10.6	12.8	11.2	11.9	12.5	12.0	10.9	8.3	6.8	8.1
1954	4.5	9.1	10.7	10.4	10.9	10.7	11.6	11.6	10.9	8.0	5.9	5.9
1955	9.5	6.5	9.4	10.7	10.0	9.8	11.0	11.5	11.1	7.5	6.6	
1956			9.8	11.0	9.2	9.1	10.8	11.7	11.7	10.9	6.6	7.6
1957	8.8	12.8	15.0	14.7	14.4	13.6	15.8	15.1	9.5	2.8		
1996												12.1
1997	15.0	14.4	15.9	18.0	16.6	15.5	14.8	14.8	14.5	14.5	14.8	11.5
1998	14.0	14.4	16.0	16.2	15.8	14.9	14.9	14.6	14.5	14.3	11.3	9.4
1999	10.5	10.5	13.8	14.5	15.1	14.2	13.7	13.3	14.4	13.2	10.8	9.4
2000	9.2	10.0	12.9	15.0	15.0	13.0	13.9	14.1	14.1	X	11.4	10.3

2001	10.1	11.8	13.4	15.3	15.4	13.9	13.9	14.6	13.5	13.0	14.4	15.1
2002	X	16.3	14.2	12.6	15.7	15.0	14.5	14.1	13.8	13.8	12.6	13.7
2003	11.8	13.2	14.2	15.1	15.0	15.0	14.2	14.1	15.0	14.9	14.9	12.8
2004	14.6	14.2	14.6	15.9	16.2	15.6	14.7	14.6	14.9	14.6	14.2	14.4
2005	13.6	15.2	16.5	16.1	16.0	15.4	15.2	15.6	15.6	16.0	14.6	13.7

Appendix 3 Monthly mean Max Temp. (^{o} C)

Element	NATIONAL METEOROLOGICAL SERVICES AGENCY					Alt.	2120mt					
Region	Shoa					Long.	38^{o}.48'					
Station	Akaki					Lat.	8^{o}.52'					
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1951	27.6	28.5	29.1	28.5	27.8	27.3	23.9	24.4	25.8	26.4	27.8	28.2
1952	29.4	30.4	30.5	26.5	29.5	27.0	24.2	23.3	25.8	27.4	28.8	28.8
1953	29.6	29.9	30.5	28.5	30.7	26.9	21.7	24.1	25.6	28.9	29.4	28.5
1954	29.2	30.4	30.4	30.6	30.4	25.9	22.4	22.5	23.8	27.5	29.4	29.5
1955	29.0	30.2	31.1	29.9	30.5	26.2	23.9	23.0	23.4	28.4	30.4	x
1956			32.2	28.7	29.0	26.2	22.5	23.6	25.4	26.5	28.5	30.2
1957	29.5	28.8	28.3	28.7	28.9	27.9	24.4	25.1	26.7	30.5		
1996												23.8
1997	25.8	26.3	28.1	26.3	28.6	27.2	24.2	24.3	25.8	24.9	24.9	25.7
1998	25.8	27.3	27.5	29.1	27.6	26.6	24.1	23.0	24.4	25.0	25.3	24.9
1999	25.9	27.2	26.5	27.3	28.0	26.4	23.4	23.6	25.1	24.6	25.0	25.2
2000	26.2	27.0	27.6	27.2	27.0	25.0	24.5	23.7	24.6	X	25.7	25.7
2001	26.3	27.2	26.1	27.6	26.9	25.6	24.6	24.7	25.8	26.9	26.4	26.4
2002	X	27.5	27.4	26.9	28.5	27.0	25.8	24.6	26.1	26.9	26.5	26.2
2003	26.6	28.3	27.9	27.3	28.9	27.1	23.7	23.6	24.9	26.6	26.6	25.7

2004	27.5	27.5	27.9	26.5	28.6	26.3	23.9	24.3	25.6	25.9	26.6	26.7
2005	27.1	29.0	28.2	27.8	26.8	26.3	23.7	24.6	24.5	26.2	26.3	26.1

Appendix (4) Main Industrial Point Sources in the Study Area and Its Surroundings.

Serial No.	Name of factory	Major Chemicals Used	Waste generation Rate(Cubic Meter/Day)
1.	Addis Tannery	Cr, $CaOH_2$, NaCl, Na_2S…	350
2.	Gullele Soap Factory	NaOH, NaCl,…	64
3.	Tikur Abay Shoe	Plastics, Rubbers,…	275
4.	Ethio Marble Factory		16
5.	Shegate State Garage	Oils, lubricants, detergents, paints…	20
6.	Idget Edible oil	Detergents,	42
7.	Research Institute Lab		135
8.	Kolfe Oil factory		35
9.	Edible Oil Factory	Different seeds, NaOH	100
10.	Gullele Oil Factory	‘’	25
11.	Anbessa Flour		35
12.	Addis Soft Drinks	NaOH, Phosphoric Acid	34.5-51.5
13.	Ethiopian Tyre And Rubber	S, CaCO3, ZnO…	45
14.	Awash Wine Factory	Na- Meta Bisulphate, Grapes	178
15.	Anbessa Shoe Factory	Glue	25
16.	A.A Foam and Plastic Factory	Dyes, Tin, Silicon	17
18.	Beer Factory	NaOH, Glyc., Antifoam	900
19.	National Distiled Liqour Factory		175
20.	Yekatit Paper Factory	Inks	30
21.	Bole Printing Press(Nifas Silk)	Ink,	16
22.	Paint Factory(Lideta)	TiO_2 Resin	40
23.	Ethiopian Pharmaceutical Factory		200
24.	Cotton Yarn Factory	Dye stuffs, Salt, detergents	440
25.	Fait Diaboaco Anbessa		20
26.	Addis Ababa Abattoirs Ent.		750

27.	Ethiopia Spices Extraction fact	Hex.Metha Acetone	50
28.	United Abilities	$ZnCl_2$, ZnO, Cr, H_2SO_4	210
29.	National Alcohol & Liqour	Aldehydes, Glycerole	75
30.	Misrak Flour	Ascrobic Acid	30
31.	Adie Ababa Yarn factory	NaCl, Sodaash, Dye Stuff, Acetic Acid, NaOH, Detergents, Furnance Oil	549
32.	Addis Ababa Car Battery	Pb, Sb, H_2SO_4,PbO_2	4
33.	Akaki Oil Mills Factory	NaOH	47
34.	Kokeb Flour & Spaghetti		100
35.	National Distiled &Liqour Fact.	H_2SO_4	40
36.	Canvas and Rubber Factory	ZnO, S, FeO, Antioxide.	60
37.	Matador Addis Tyre		375
38.	Awash Tannery	$CaOH_2$, Cr, Na_2S, …	800
39.	National Tobacco and Matches		139
40.	Universal Leather Articles		14
41.	Commercial Printing Press(Nifas Silk)	HNO_3	39
42.	EthioThread Factory	Acetic Acid, Salt, Dyestuffs, Alcohol…	3.5-4
43.	Ethiopickling and Tanning	Cr, H_2 $SO_{4,}$ Na_2S, $Ca(OH)_2$	450
44.	Walia Tannery	Cr, Na_2S, $Ca(OH)_2$, Salts	510
45.	Kadisco Paints Factory		165
46.	Batu Tannery	Cr, $NaCl_,$ Na_2S, $Ca(OH)_2$	430
47.	Leather & Leather Products Technology Institute	Cr, H_2 $SO_{4,}$ Na_2S, $Ca(OH)_2$	86 (Woks Five days a week) Treat before discharge
48.	Prefab Housing		165
49.	Kality Animal Feed		5
50.	Ethiopian Iron & Steel Foundry	Paint Products	925
51.	OCFA Sh.CO		10
52	Adwa Flour Mills Factory		22
53.	Akaki Spare Parts		121
54.	Pumps Factory		34

55.	Yerkesem Factory		12
56.	Meher Fiber Factory		110
57.	Nifas Silk Paint Factory		175
58.	East Africa Bottling Ltd.		-
59.	St. George Brewery		-
60.	Ediget Yarn And Sewing Thread		-
61.	Addis Ababa Bottel and Glass		-
62.	East Africa Soap And Detergents		-
63.	MOHA Soft Drinks		-
64.	Dil Edible Oil		-
65.	Chora Oxygen And Acetylen		-

Appendix (5a) Selected Physico-Chemical Water Analysis Results (AMS 13-05-2007)

Sample ID	Date	Sampled From	Physical Parameters					Chemical Parameter				
			Altitude (m)	UTM(E)	UTM(N)	P^H	T^o	DO (mg/l)	NH_3 (mg/l)	NO_2(mg/l)	NO_3(mg/l)	TDS(mg/l)
1.Composite- US_1GRRA US_2ShRFA US_3WKMR US_4BRKA	13-05-07	TAR upstream	2600-2554	470104	1001129	6.55-7.13	23-17.9	4	56.98	0.15	0.50	656
2.MS_5TSRTS	‘’	Mid Stream	2316	470676	995220	7.24	23.2	3	38.36	0.02	0.29	838
3.MS_6TR(sh+l) Bu.A	‘’	‘’	2296	470997	994579	7.26	23.3	4	51.66	0.1	0.2	872

4.MS_7TAKMRC	“”	“”	2210	470565	991743	7.34	24.1	4	27.26	0.17	0.19	1078
5.$TAKS_8$L&LPTI	‘’	Down Stream	2132	472944	986521	7.63	25.3	5	43.68	0.2	0.34	1030

Appendix (5b) Sampling Sites and Sample Id abbreviations (AMS 2007 Data)

1. Composite-four samples of 250 ml each were collected to represent upstream (head water) condition for TAR and Its tributaries Namely:-

US_1GRRA –Upstream sample #1 Gullele River Rufael Area

US_2ShRFA- Upstream Sample #2 shegole river Filance Area

US_3WKMR- Upstream Sample #3 Wingete Kidanemihret River

US_4BRKA- Upstream Sample #4 Burayu Kera River

2.MS_5TSRTS- Midstream Sample # 5 Tributary Shankla River Toslosa sefer

3.MS_6TR(sh+l) Bu.A- Midstream sample # 6 tributaries (Shankla and Lideta) Rivers at Buchare Meda area.

4.MS_7TAKMRC- Midstream Sample # 7 TAR and Tributary Mekanisa River Confluence near national Alcohol and Liquor factory

5.$TAKS_8$L&LPTI- Tinishu Akaki River Sample # 8 bellow Leather and leather products technology Institute.

Appendix (6a) Industrial effluents discharged into the Tinishu Akaki River (Random Sampling) chemical test

Industry	Date	BOD	COD	NH_3	NO_3^-	NO_2^-	SO_42^-	PO_43^-	Cl^-	Alkalinity	Acidity	H_2S
Ediget Yarn	09-11-2000	153	266	1.55	0.9	0.24	34.1	2.96	8	150	0	0
Ediget Yarn	06-11-2000	10	94	0.95	9.1	0.075	25.5	1.56	10	176	0	0
Average		81.5	180	1.25	5	0.16	29.8	2.26	9	163	0	0
Nifas silk Thread	09-11-2000	8	20	0.295	1.7	0.03	29.6	2.1	23	258	0	0
Nifas Silk Thread	06-11-2000	12	74	0.01	4.5	0.034	5.5	1.28	25	254	0	0
Average		10	47	0.15	3.1	0.03	17.55	1.69	24	256	0	0
Addis Tannery	27-01-2001	4575	9920	57	10	1.6	95	18.9	0	250	0	208
Addis Tannery	24-01-2001	282	496	284	117.5	0.275	2945	41.25	300	288	48	158
Average		2428.5	5208	170.5	63.75	0.94	1520	30.1	150	269	24	183
Awash Tannery	05-01-2001	1485	9216	75.3	7.5	4.65	3100	5.25	8000	0	186	186
Awash Tannery	03-01-2001	343	1664	30	5	0.225	52.5	7.1	15000	0	63	178
Average		914	5440	52.65	6.25	2.44	1576	6.18	11500	0	124.5	0
Dire Tannery	03-02-2001	951	2760	1375	0	0.025	4875	0	28500	0	248	0
Dire Tannery	03-02-2001	4613	44160	432.5	375	0.035	1678	34.78	9000	438	0	150.6
Average		2782	23460	903.75	187.5	0.03	3277	17.39	18750	219	124	75.3
Walia Tannery	14-02-2001	1361	3948	74.75	35	0.8	144.6	6.575	150	288	0	33.5
Walia Tannery	14-02-2001	1928	7934	72.25	0.28	0.18	144.8	15.95	200	1400	0	41.5
Average		1644.5	5941	73.5	17.64	0.49	144.7	11.26	175	844	0	37.5

Source EPA, 2001 Unit= all are in mg/l.

Appendix (6a.1) Chemical test Continued

Industry	Date	BOD	COD	NH_3	NO_3^-	NO_2^-	SO_42^-	PO_43^-	Cl^-	Alkalinity	Acidity	H_2S
Gullele Soap	03-02-2001	346	644	20.25	400	1.035	0	48.78	0	368	0	0
Gullele Soap	03-02-2001	790	1472	22.25	0	0	160	29.75	3.5	836	0	0
Average		568	1058	21.25	200	0.52	80	39.27	1.75	602	0	0
Nifas Silk Paint	30-12-2000	322	1920	31.8	0	0	300	5.9	15	130	42	5.9
Nifas Slik Paint	27-12-2000	135	2576	12	47.5	2.4	400	8.5	0	340	14	19.6
Average		228.5	2248	21.9	23.75	1.2	350	7.2	7.5	235	28	12.75
Addis Mojo Edible Oil	30-12-2000	169	422	12.5	60	.18	113	18.5	30	200	54	6.7
Addis Mojo Edible Oil	27-12-2000	464	763	13	0	9.6	925	85	7.5	1400	0	22.3
Average		316.5	592.5	12.75	30	4.89	519	51.75	18.75	800	27	14.5
Addis Soft Drinks	23-12-2000	369	1088	2.25	0	0.09	42.4	5.04	0	1200	0	0.095
Addis Soft Drinks	27-12-2000	794	1208	1.69	0	0.078	38.9	5.178	0	1600	0	0
Average		581.5	1148	1.97	0	0.08	40.65	5.11	0	1400	0	0.05
Awash Winery	14-02-2001	4457	6016	0.29	4	0.3	12	4.425	0	1860	0	0.4
Awash Winery	14-02-2001	2211	2632	106.5	14	0.3	69	27.575	50	0	345	4
Average		3334	4324	53.40	9	0.3	40.5	16	25	930	172.5	2.2
Moha Soft Drinks	30-12-2000	787	3328	10.3	27	0.098	390	29	0	20000	0	0.18
Moha Soft Drinks	27-12-2000	28	74	7.5	0	0.02	165	10.3	65	1540	0	0.06
Average		407.5	1701	8.9	13.5	0.06	277.5	19.65	32.5	1770	0	0.12

Appendix (6a.2) Chemical test Continued

Industry	Date	BOD	COD	NH_3	NO_3^-	NO_2^-	SO_42^-	PO_43^-	Cl^-	Alkalinity	Acidity	H_2S
EthioMarble	27-01-2001		198	0.759	1.5	0.08	22.4	3.5	5	280	0	0
EthioMarble	24-01-2001		661	0.657	5.25	0.05	18.5	1.6	5	60	0	0
Average		23.5	429.5	0.708	3.375	0.065	20.45	2.55	5	170	0	0
Addis Machine	13-01-2001	31	124	0.58	4.5	0.001	204	0.1	95	230	0	0
Addis Machine	10-01-2001	2.2	27	0.24	8.9	2.1	22	0.1	45	236	0	0
Average		16.6	75.5	0.41	6.7	1.051	113	0.1	70	233	0	0
United Abilities	23-12-2000	3.3	12.4	0.26	1.5	0.005	0.15	0.472	2	170	95	0.012
United Abilities	20-12-2000	4	12.4	0.4	0.9	0.007	1.5	0.243	6	32	0	0
Average		3.65	12.4	0.33	1.2	0.01	0.83	0.36	4	101	47.5	0.01
Addis Gas & Plastics	23-12-2000	14	111	0.35	2.9	0.12	10.9	0.5	27.5	836	0	0
Addis Gas & Plastics	16-12-2000	13	51	4.04	0.3	0.07	15	0.6	1543	3600	0	0
Average		13.5	81	2.20	1.6	0.10	12.95	0.55	785.25	2218	0	0
Matador Addis Tyre	05-01-2001	41	85	14	3.5	1.95	42.5	14.45	600	100	48	8
Matador Addis Tyre	03-01-2001	8.3	58	1.98	1.9	0.013	5250	1.5	750	270	0	0
Average		24.65	71.5	7.99	2.7	0.98	2646	7.98	675	185	24	4
Chora Gas & Chemicals	16-12-2000	82	744	0.1	0	0	7.5	0.7	5.5	258	0	0
Chora Gas & chemicals	13-12-2000	88	832	0.85	0	0	10.23	5.1	26.5	84	0	0
Average		85	788	0.48	0	0	8.87	2.9	16	171	0	0
Equatorial Paint	23-12-2000	574	2480	4.75	0	0.091	0	0.325	25	327	13.6	3.75
Equatorial paint	20-12-2000	577	2870	26	0	0.09	625	0.234	80	368	0	258
Average		575.5	2675	15.38	0	0.09	312.5	0.28	52.5	347.5	6.8	130.8

Appendix (6a.3) Chemical test Continued

Industry	Date	BOD	COD	NH_3	NO_3^-	NO_2^-	SO_42^-	PO_43^-	Cl^-	Alkalinity	Acidity	H_2S
National Alcohol & Liqour	16-12-2000	100	930	308	0.4	0.06	5	3.75	2.5	496	0	0
National Alcohol & Liqour	13-12-2000	270	1648	0	0	0		96	5.5	0	136	0
Average		185	1289	154	0.2	0.03	5	49.88	4	248	68	0
St. George Brewery	13-01-2001		39	21.8	1.7	0.006	8	1.99	5	21.5	16.4	0
St. George Brewery	10-01-2001	55	154	2.9	0.4	0	3.9	2.1	5	16	75	0
Average			96.5	12.35	1.05	0.003	5.95	2.045	5	18.75	45.7	0
Addis Ababa Abattoirs	05-01-2001	436	3924	52	4.5	3.5	40	3.45	750	280	0	48
Addis Ababa Abattoirs	03-01-2001	1193	2880	100	3.8	0.71	312.5	16.95	1000	270	0	0
Average		814.5	3402	76	4.15	2.11	176.3	10.2	875	275	0	24

Appendix (6b) Physical test

Industry	Date	Temp	PH	SS	FS	Set.S	DS	VS	EC
Akaki Textile	06-11-2000	-	7.98	54	0	0	922	48	1882
Akaki Textile	09-11-2000	-	10.16	265	32	212	1010	174	2050
Average		-	9.07	159.5	16	106	966	111	1966
Ediget Yarn	09-11-2000	-	10.23	96	0	0	17	87	372
Ediget Yarn	06-11-2000	-	10.3	13	0	0	237	12	498
Average		-	10.27	54.5	0.00	0.00	127.00	49.5	435
Nifas Silk Thread	09-11-2000	-	8.2	76	0	0	302	30	631
Nifas Silk Thread	06-11-2000	-	7.82	96	0	0	304	51	633
Average		-	8.01	86	0	0	303	40.5	632
Addis Tannery	27-01-2001	21.1	12.01	2678	219	2089	7220	1878	12740
Addis Tannery	24-01-2001	15.5	6.89	23	0	0	959	22	1905
Average		18.3	9.45	1350.5	109.5	1045	4090	950	7322.5
Awash Tannery	05-01-2001	22	3.45	773	58	487	12400	447	22000
Awash Tannery	03-01-2001	26	4.16	556	257		22450	551	44900
Average		24	3.805	664.5	157.5	487	17425	499	33450
Dire Tannery	03-02-2001	21.1	3.78	1480	357	1025	10000	523	10850
Dire Tannery	03-02-2001	16.1	8.14	1750	198	14.56	13900	1208	25400
Average		18.6	5.96	1615	277.5	519.8	11950	865.5	66950
Walia Tannery	14-02-2001	21.1	9.52	202	0	0	4250	136	7900
Walia Tannery	14-02-2001	25.5	11.38	1792	212	1479	6250	1262	11210
Average		23.3	10.45	997	106	739.5	5250	699	9555
EthioMarble	27-01-2001	20	8.85	998	0	728	134	55	286
EthioMarble	24-01-2001	18.8	8.63	271	0	156	84	103	174
Average		19.4	8.74	634.5	0	442	109	79	230

Appendix (6b.1) Physical test results Continued

Industry	Date	Temp	PH	SS	FS	Set.S	DS	VS	EC
Addis Mojo edible Oil	30-12-2000	18	6.8	1023	447	358	275	400	485
Addis Mojo edible Oil	27-12-2000	55	10.05	6390	3190	2360	495	6320	1020
Average		36.5	8.425	3706.5	1819	1359	385	3360	752.5
Addis Soft Drinks	23-12-2000	28	1.32	70	0	0	2240	61	4350
Addis Soft Drinks	27-12-2000	28	12.07	118	0	38	3520	42	6780
Average		28	6.695	94	0	19	2880	51.5	5565
Awash winery	14-02-2001	54.4	11.85	253	0	112	5240	178	9570
Awash winery	14-02-2001	22.2	3.08	6245	0	3132	606	6209	1250
Average		38.3	7.465	3249	0	1622	2923	3193.5	5410
Moha Soft Drinks	30-12-2000	54	12.57	584	0	112	1603	135	16130
Moha Soft Drinks	27-12-2000	52	12.06	89	0	0	2790	84	5370
Average		53	12.315	336.5	0	56	2197	109.5	10750
National Alcohol & Liqour	16-12-2000	21	11.3	35	0	0	777	11	1595
National Alcohol & Liqour	13-12-2000	47	4.52	4655	0	1725	1990	4164	3920
Average		34	7.91	2345	0	862.5	1384	2087.5	2757.5
St. George Brewery	13-01-2001	31	6.52	13	0	0	34	7	70.5
St. George Brewery	10-01-2001	36	6.75	59	0	0	28	26	62.3
Average		33.5	6.635	36	0	0	31	16.5	66.4
Addis Ababa Abattoirs	05-01-2001	55	8.65	40	0	0	322	38	676
Addis Ababa Abattoirs	03-01-2001	80	8.35	672	0	273	404	656	838
Average		67.5	8.5	356	0	136.5	363	347	757

Appendix (6b.2) Physical Test Result Continued.

Industry	Date	Temp	PH3	SS	FS	Set.S	DS	VS	EC
Addis Machine	13-01-2001	15	7.85	3	0	0	603	3	1248
Addis Machine	10-01-2001	17	8.63	60	0	0	688	51	1464
Average		16	8.24	31.5	0	0	645.5	27	1356
United Abilities	23-12-2000	25	6.73	0.2	0	0	162	0.2	341
United Abilities	16-12-2000	22	7.43	2.0	0	0	39	1	83
Average		23.5	7.08	1.1	0	0	100.5	0.6	212
Addis Gas & Plastic	16-02-2001	42	7.64	5	0	0	17900	4	31300
Addis Gas & Plastic	13-02-2001	22	8.9	21	0	0	272	8	537
Average		32	8.27	13	0	0	9088	6	15919
Addis Tyre	05-01-2001	43	6.59	87	0	0	181	55	381
Addis Tyre	03-01-2001	28	11.19	458	0	0	1610	435	3180
Average		35.5	8.89	272.5	0	0	895.5	245	1780.5
Chora Gas & Chemicals	16-12-2000	25	12.5	2491	0	2127	5430	180	9890
Chora Gas & Chemicals	13-12-2000	23	7.7	52850	0	50736	2110	9991	3890
Average		24	10.1	27670.5	0	26432	3770	5085.5	6890
Equatorial Paint	23-12-2000	20	7.51	6829	5196	368	61	4857	129
Equatorial Paint	20-12-2000	25	9.1	493	318	68	22	303	48
Average		22.5	8.305	3661	2757	218	41.5	2580	88.5
Gullele Soap	03-02-2001	21.1	13.54	242	46	92	16300	131	145500
Gullele Soap	03-02-2001	21.1	13.45	169	114	52	2E+05	75	248200
Average		21.1	13.495	205.5	80	72	89650	103	196850
Nifas Silk Paint	30-12-2000	17	6.58	4305	4201	106	214	400	485
Nifas Silk Paint	27-12-2000	18	6.58	2920	2300	610	117	2840	245
Average		17.5	6.58	3612.5	3251	358	165.5	1620	365

EPA 2002, EC in micro siemens per centimeter. Temp. ^{o}C and others in mg/l.

Appendix (6c) Continued on selected Heavy Metals

Industry	Date	Cr	Fe	Mn
Ediget Yarn	09-11-2000	<0.1	0.7	<0.1
Nifas Silk Thread	09-11-2000	<0.1	0.8	<0.1
Addis tannery	27-01-2001	0.5	0.7	<0.1
Awash Tannery	05-01-2001	700	4.5	0.6
Dire tannery	03-02-2001	1.5	18	1.7
Walia Tannery	14-02-2001	0.1	0.5	<0.1
Marble Industry	27-01-2001	<0.1	0.5	<0.1
Addis Machine	13-01-2001	<0.1	0.4	<0.1
United Abilities	23-12-2000	<0.1	<0.1	<0.1
Addis Gas & Palstic	23-12-2000	<0.1	0.3	<0.1
Addis Tyre	05-01-2001	<0.1	0.2	0.1
Chora Gas & Chemical	16-12-2000	0.2	3.2	0.1
Equatorial paint	23-12-2000	ND	ND	ND
Gullele Soap	03-02-01	0.2	116	0.1
Nifas Silk	30-12-2000	<0.1	1	0.2
Addis Mojo Edible Oil	30-12-200	<0.1	4.9	0.2
Addis Soft Drinks	23-12-2000	<0.1	1.1	<0.1
Awash Winnery	14-02-2001	<0.1	2.5	0.1
Moha Soft Drinks	30-12-2000	<0.1	0.3	<0.1
National Alcohol & Liqour	16-12-2000	<0.1	0.9	0.2
St. George Brewery	13-01-2001	<0.1	0.4	<0.1
Addis Ababa Abattoirs	05-01-2001	0.1	68	5.1

Source EPA 2001, ND not determined, All units are in mg/l

Appendix (7) Some of the Selected Industrial Effluents Physico-Chemical Characteristics (Source ESDI JUNE 2001)**.**

Beverage Industries

Name Of Industries	PH	SS	DS	BOD5	Nitrates	Sulphate	Chloride
Standard	6_9	50	_	60	_	_	_
Addis Soft Drinks	11.7	94	2880	581.5	nil	40.65	nil
Awash Winnery	7.46	3249	2923	112,768	9	40.5	25
MoHA Soft Drinks	12.3	157.5	4393	407.5	13.5	277.5	32.5
National Alcohol & Liqour	7.91	2345	1383.5	13,550	0.2	2.5	4
St. George Brewery	6.64	36	62	55	1.05	5.95	5
Source ESDI JUNE 2001							

Chemical Industries

Name Of Industries	PH	SS	DS	BOD5	Nitrates	Sulphate	Chloride
Standard	6_9	100	3000	80	_	_	_
Addis Gas & Plastics	8.27	13	9087.5	13.5	1.6	12.95	785.25
Matador Addis Tyre	8.89	272.5	895.5	24.65	2.7	2646.25	675
Chora Gas & Chemical	10.1	27670	3720	85	nil	8.86	16
Equatorial Paint	8.3	3616	41.5	575.5	nil	312.5	52.5
Gullele Soap	13.5	205.5	89650	57231.5	200	80	3.5
Nifas Silk Paint	6.58	3612.5	165.5	228.5	23.75	350	7.5
Repi Soap	9	321.5	1990	1034	7	25	52

Tanneries

Name Of Industries	PH	SS	DS	BOD5	Nitrates	Sulphate	Chloride
Standard	6_9	50	_	200	_	_	1000
Addis tannery	9.45	1350.5	4089.5	2428.5	113.75	1529	150
Awash Tannery??	3.8	664.5	17425	914	6.25	1576.25	11500
Dire Tannery	5.96	1615	11950	2782	375	3276.5	18750
Walia Tanneries	10.5	997	5250	1648	17.64	1447	175
L&LPTI	7.51	4850	4671	901.2(ave. COD)	75.6(TKN)	Ave.(Na_2S) 25.1	1600(ave.)

Textile Industries

Name Of Industries	PH	SS	DS	BOD5	Nitrates	Sulphate	Chloride
Standard	6_9	30	_	50	_	_	_
Akaki Textile	9.07	159.5	966	259.5	50	57.85	116.5
Ediget Yarn	10.3	54.5	251.5	81.5	5	29.8	9
Nefas Silk Thread	8.01	86	303	10	3.1	17.55	24
Adie Ababa yarn							

Metal Products

Name Of Industries	PH	SS	DS	BOD5	Nitrates	Sulphate	Chloride
Standard	5.5_9.5	25	_	25	_	_	_
Addis Machine Tools	8.24	31.5	645.5	16.6	6.7	213	70
Akaki Spare Parts	6.74	262	411.5	11	7.65	25.95	57.5
Akaki Metal Products	2.75	93.5	3540	73	11	20.3	1220
Ethiopian Metal Fooundary	7.51	40.5	292	13	11.12	24.5	12.5
Kality Metal Products	8.64	157	304.5	165	7	87.8	27.6
United Abilities	7.1	1.1	100.5	3.65	1.2	0.825	4

Appendix (8a) EPB 2002 Industrial effluents Discharged in to the little Akaki River (Systematic Samples)

Sample Points	Temp	P^H	SS (mg/l)	DS (mg/l)	VS (mg/l)	Turbidity(ETU)	EC µS/cm
Ediget Yarn							
Effluent		12.2	66.4	1880	36		3600
Upstream		7.2	22	236	12.3		1178
Down Stream		11.32	58	572	40.5		2600
National Alcohol & Liqour							
Effluent		4.39	4261	14700	4522		26
Upstream		7.32	23	405	6.5		844
Downstream		4.95	1423	1603	883		3220
Adiey Ababa Yarn							
Effluents		6.52	396	1300	372		2610
Upstream		6.84	108.7	543	65.2		1121

Down Stream		6.18	222.1	544	123.5		1120
St. George Brewery							
Effluents	25	4.8	156	740		156	
Upstream	20	5.6	218	1794		420	
Downstream	21	5.2	338	1624		540	

Appendix (8b) Continued Chemical parameters in mg/l

Sampling Point	DO	BOD	COD	H_2S	NH_3	NO_3^-	NO_2-	SO_4^{2-}	PO_4^{3-}	Cl^-
Ediget Yarn										
Effluent	1.2	36	103	0.018	2.3	0.3	-	-	1.96	9
Upstream	14.9	22	46	0.018	13.7	3.5	-	-	6	25
DownStream	6.2	31	90	0.019	7.9	2.1	-	-	6	21
National Alcohol & Liqour										
Effluent	0	81072	216300	-	315	350	-	-	455	5300
Upstream	5.9	6.9	24.72	-	33.6	2.6	-	-	0.85	111
Downstream	0	4350	11124	-	83.4	350	-	-	455	5300
Adey Ababa Yarn										
Effluent	0	103.4	284.2	-	4.2	1.6	-	-	6.9	130
Upstream	0	72.66	284.2	-	23.2	1.2	-	-	10.2	105
Downstream	0	67.6	223	-	21	1.7	-	-	7.75	120
St. George Brewery										
Effluent	5.2	642	348	-	12.8	154	1.23	-	5.2	31
Upstream	6.8	420	890	0.8	36.4	221	2.29	0.2	15.51	79
Downstream	5.4	561	970	0.8	20.9	176	2.05	0.2	3.9	46

Source EPB 2002

Appendix (9) Pollution Load on Tinishu Akaki River and Its Tributaries (source ESDI 2001)

Tributary & Major River	Spatial Domain	BOD_5 (mg/l)	DO (mg/l)	NH_3 (mg/l)	Cl (mg/l)
Lideta	Mid stream(5th Police stn)	40	0.6	8.8	50
	Mid stream(Abattoirs)	535	0	63	83
Tinishu Akaki	Mid stream(zenebwork)	40	0.6	8.8	50
	Down stream(Behere Tsege)	252	0	52.5	65
	Down stream(kality)	105	0	80.6	235
Shankla	Up stream(Gullele)	3.5	7	0.53	5
	Mid stream(B.College)	339	0.8	32.3	110

Appendix (10) The in stream Water Quality Standard for selected parameters.

Parameters	**PH**	**DO**	**BOD**	**NO3**	**SO4**	**CI**	**NH3**	**KN**	**Conductivity**	**T.C**
Standard Values	**6-9**	**min6mg/l**	**<5mg/l**	**50mg/l**	**200mg/l**	**250mg/l**	**20 µg/l**	**2mg/l**	**1000 µS/cm a@200oc**	**10 MNP(WHO)**

Appendix (11a) Dry Season Chemical Analysis Results (EPB, 2002)

Sample sites	Date	COD	BOD	DO	Alkalinity	Total Hardness	Cl	SO_4	PO_4	NH_3	NO_3	NO_2	H_2S
S1	28-02-1997	12	4	8.1	118	116	11.5	0.7	0.085	0.166	0.01	1.3	0.013
S2	‘’	22	8	8.1	139	177	40.5	Nil	0.395	0.297	0.281	15.9	0.015
S3	03-03-1997	7	3	3.2	182	214	45	Nil	1.54	2.98	0.0456	2.5	0.017
S4	‘’	21	10	8.7	148	215.4	42.5	0.6	1.285	4.556	0.0652	20.8	Nil
S5	07-03-1997	18	8	7.5	105	166.25	33	5.8	0.55	12.26	0.438	22	0.018
S6	‘’	42	16	7	154	155	41.5	5	4.4	9.4	0.518	8	0.021
Mean		20	8	7	141	174	36	3	1	5	0	12	0
S7	10-03-1997	212	76	2.4	243	202	63	10	13.3	24.12	0.0712	6.5	Nil
S8	‘’	289	110	3.1	236	234	69	6	10.5	17.65	0.465	20.7	0.011
S9	14-03-1997	96	30	2.9	160	280	85	2.5	4.55	0.44	0.013	79.1	Nil
S10	‘’	626	402	Nil	368	290	75	8.1	24.02	49.33	Nil	Nil	0.078
S11	17-03-1997	314	266	Nil	392	274	112	Nil	27.75	56.28	Nil	Nil	0.35
S12	‘’	419	399	Nil	384	276	216	Nil	4.55	67.88	Nil	Nil	0.843
S13	21-03-1997	393	394	Nil	402	244	117	Nil	3.262	64.8	Nil	Nil	0.4
S14	‘’	49	22	3	176	218	106	33.4	4.01	1.9	1.813	18.2	0.015
S15	24-03-1997	61	19	Nil	320	260	100	15.1	13.21	30.73	0.181	0.3	0.025
S16	‘’	58	32	1.2	340	260	97	15.5	11	32.2	0.15	0.2	0.018
S17	28-03-1997	233	84	3	232	224	125	52.5	5.65	19.1	Nil	0.8	0.073
Mean		250	167	3	296	251	106	18	11	33	0	18	0
S18	28-03-1997	522	205	Nil	386	140	226	49.3	31.25	55	Nil	Nil	0.003
S19	31-03-1997	366	298	Nil	482	262	178	38.4	40	73.1	Nil	Nil	0.003
S20	‘’	213	171	Nil	380	248	159	30.2	32.5	48.3	0.05	Nil	0.007
S21	04-04-1997	209	32	Nil	382	258	142.5	40	21.2	57	Nil	Nil	0.07
S22	‘’	17	20	6.7	226	204	57.5	Nil	0.624	0.662	Nil	Nil	0.004
Mean		265	145	1.3	371	222	153	39	25	47	0	Nil	0

Appendix (11a.a) Seasonal Water quality Analysis results of Little Akaki River Dry Season Physical Analysis Results (EPB 2002)

Sample sites	Date	Temp(oC)	PH	SS	DS	Odour
S1	28-02-1997	19	8.2	5.4	179	Non objectionable
S2	28-02-1997	21	8.1	78.4	272	‘’
S3	03-03-1997	15	7.7	11.8	329	‘’
S4	‘’	15.5	8.3	322.2	295	Objectionable
S5	07-03-1997	15	8.2	25.8	231	‘’
S6	‘’	15.5	7.7	49.8	259	‘’
Mean		17	8	82	261	‘’
S7	10-03-1997	18	7.6	159.3	378	‘’
S8	10-03-1997	17	8.2	46.3	410	‘’
S9	14-03-1997	17	8.2	26.4	463	‘’
S10	‘’	20	8	370	660	‘’
S11	17-03-1997	19	7.9	295	760	‘’
S12	‘’	19	7.6	224	793	‘’
S13	21-03-1997	18.5	7.6	348	832	‘’
S14	‘’	22	7.5	40	478	‘’
S15	24-03-1997	20	7.7	35	447	‘
S16	‘’	21	7.9	24	643	‘’
S17	28-03-1997	24	7.8	260	658	‘’
Mean		20	8	166	593	‘’
S18	28-03-1997	21	7.8	360	936	‘’
S19	31-03-1997	23	8	212	1103	‘’
S20	‘’	23	7.8	187	870	‘’
S21	04-04-1997	23.5	8	219	899	‘’
S22	‘’	16	7.8	9.8	410	‘’
Mean		21	8	169	844	

Appendix (11a.b) Dry season bacteriological Analysis Results. (EPB 2002)

Sample	Sampling Date	Total coli forms(MPN/100ml)	Ecoli (MPN/100ml)
S1	28-02-1997	4	2
S2	‘’	50	8
S3	03-03-1997	1.8×10^{4}	1.6×10^{4}
S4	‘’	1.7×10^{4}	1.7×10^{3}
S5	07-03-1997	9×10^{4}	1.1×10^{4}
S6	‘’	1×10^{5}	3.4×10^{4}
S7	10-03-1997	5×10^{6}	3.3×10^{5}
S8	‘’	13×10^{5}	3×10^{5}
S9	14-03-1997	1.6×10^{7}	Nil
S10	‘’	3.4×10^{5}	Nil
S11	17-03-1997	1.7×10^{4}	Nil
S12	‘’	2×10^{7}	Nil
S13	21-03-1997	1×10^{6}	Nil
S14	‘’	8×10^{4}	2×10^{4}
S15	24-03-1997	7×10^{4}	Nil
S16	‘’	1×10^{5}	Nil
S17	28-03-1997	3.4×10^{6}	Nil
S18	‘’	9×10^{6}	Nil
S19	31-03-1997	1.9×10^{6}	Nil
S20	‘’	5×10^{6}	Nil
S21	04-04-1997	1.7×10^{6}	Nil
S22	‘’	5×10^{3}	Nil

Appendix (11b) Wet Season Chemical Analysis results of TAR.

Sample sites	Date	COD	BOD	DO	Alkalinity	Total Hardness	Cl	SO_4	PO_4	NH_3	NO_3	NO_2	H_2S
S1	10-07-97	16	2.6	7.5	20	30	7.5	0.1	0.127	0.92	0.04	6.4	Nil
S2	15-07-97	48	1	6.7	68	114	7.4	1.4	0.24	1.7	0.466	35	Nil
S3	‘’	48	16	6.8	88	128	7.6	12.6	0.572	2.16	0.4	35	Nil
S4	‘’	130	45	7.5	82	120	6.8	16.8	0.435	2.01	0.476	33	Nil
S5	17-07-97	46	16	7.7	60	16	30	16.3	0.257	1.55	0.456	48.4	Nil
S6	‘’	82	22	7.4	100	166	45	28.3	1.956	3.73	1.1	54.4	Nil
Mean		62	17	7	70	96	17	13	1	2	0	35	
S7	‘’	139	60	6.4	160	230	72.5	34.4	2.431	10.8	1.93	52.7	Nil
S8	21-07-97	323	75	5.1	98	18	39	24.1	2.5	8.05	0.421	37.5	Nil
S9	‘’	267	65	3.8	108	121	36	5.6	2.67	9	0.49	33.5	Nil
S10	‘’	395	100	4	12	130	38	30	3.98	13.95	0.815	40.5	Nil
S11	28-07-97	138	26	7	116	152	52.5	24.8	2.11	9.12	0.754	37.6	Nil
S12	‘’	229	43	6.2	12	128	45	23.7	1.88	8.24	0.699	29.9	Nil
S13	‘’	244	58	6.6	120	140	45	25.1	2.07	8.54	0.675	25.6	Nil
S14	31-07-97	33	7	7.1	60	90	20	18.8	0.33	1.79	0.268	15.9	Nil
S15	‘’	57	12	7.4	94	108	30	16.8	0.36	3.54	2.92	16.7	Nil
S16	‘’	84	15	5.4	114	10	35	22.9	0.41	4.04	0.296	15.8	Nil
S17	04-08-97	320	49	5.7	104	120	35	16	0.67	3.54	2.92	16.7	Nil
Mean		209	45	6	84	102	38	21	2	7	1	27	
S18	‘’	264	43	7	98	130	38	19	0.67	2.21	0.48	20	Nil
S19	07-08-97	128	17	7	110	130	41	17.6	0.81	3.05	0.9	23.3	Nil
S20	‘’	144	19	5.2	106	138	37	21	0.82	3.32	0.62	23	Nil
S21	14-07-97	39	6	4.5	108	140	27	28.1	0.22	3.2	1.466	13.4	Nil
S22	01-08-97	4	1	7.8	108	14	25	15	0.69	0.86	0.261	4.7	Nil
Mean		116	17	6	106	110	34	20	1	3	1	17	

Appendix (11b.a) Wet Season Physical Analysis Results (EPB 2002)

Sample Sites	Date	Temp (oC)	P^H	SS	DS	Odour	VS
S1	10-07-97	13	7.44	401.7	46	Non objectable	158.4
S2	15-07-97	15.5	7.33	223	195	‘’	69
S3	‘’	15	7.62	380	224	‘’	126
S4	‘’	14.5	7.88	1300	214	‘’	290
S5	17-07-97	13	8.01	242	171	‘’	41
S6	‘’	15	8.04	278	276	‘’	53
Mean		14	8	471	188		123
S7	“	16	8.01	187	48	‘’	53
S8	21-07-97	15	7.78	2138.5	261	‘’	197.1
S9	‘’	15.5	7.79	2072.8	277	‘’	461.4
S10	‘’	16.5	7.89	1618	352	‘’	425.9
S11	28-07-97	15	7.57	1100.4	297	‘’	167.9
S12	‘’	15.5	7.56	1079.7	274	‘’	260.9
S13	‘’	15.5	7.61	1414.9	279	‘’	408.1
S14	31-07-97	16	7.72	867.3	131	‘’	127.8
S15	‘’	17	7.73	1087	193	‘’	261.8
S16	‘’	17	7.85	1307.6	213	‘’	364.5
S17	04-08-97	17	7.74	4610	208	‘’	660
Mean		16	8	1589	230		308
S18	‘’	17	7.78	3790	218	‘’	570
S19	07-08-97	18	7.64	1564	243	‘’	286
S20	‘’	17.5	7.68	2446	237	‘’	473
S21	14-08-97	14	7.82	40.5	218	‘’	13
S22	01-08-97	13	7.82	25.3	184	‘’	7.1
Mean		16	8	1573	220		270

Appendix (11c) Short rainy Season Chemical Analysis Results

Sample sites	Date	COD	BOD	DO	Alkalinity	Total Hardness	Cl	SO_4	PO_4	NH_3	NO_3	NO_2	H_2S
S1	15-01-99	1	0	6	0	0	0	0	0.13	0	0	5.7	0
S2	‘’	20	12	6.6	0	0	0	0	0.62	0	0	6.3	20
S3	‘’	26	16	6.2	0	0	0	0	0.48	0	0	6.1	2
S4	17-04-99	46.08	3.7	6.6	0	0	50	0	0.682	8.4	0	1.7	0
S5	‘’	53.76	4.2	4.6	0	0	47.7	0	0.83	5.26	0	12	0
S6	‘’	199.7	56	2.8	0	0	50	0	2.9	10.6	0	4.6	0
Mean		58	15	5	0	0	25	0	1	4	0	6	4
S7	23-04-99	261.12	36	1.4	0	0	0	0	15	4.7	0	0.2	55
S8	‘’	145.92	7.9	3.1	0	0	7.3	0	12.4	7.3	0	2	29
S9	14-05-99	71.7	20.2	4.9	227	268	92	0	11.3	22.6	0	0.8	0
S10	‘’	320	114	0	222	334	50	19.9	40.3	32.8	0	1.3	115
S11	21-05-99	308.8	110	4.6	408	250	141	0	23.5	42.85	0.003	1	55
S12	‘’	1123	576	0	416	220	170	0	24.23	55.5	0.0121	1.2	123
S13	26-05-99	429	177	2	310	180	120	31.4	11.5	31.1	0	0.9	47.8
S14	‘’	349	147	4	230	190	105	49.4	4.43	18.8	0	2.1	0
S15	‘’	355	136.2	0	308	243	148	56.6	6.61	24.05	0	1.5	400
S16	02-06-99	1500	309	0	348	234	423	41.8	6.03	32	0	0	3.2
S17	‘’	175	48.1	0	317	239	136	46.1	5.2	33.9	0	0	400
Mean		458	153	2	253	196	127	22	15	28	0	1	112
S18	09-06-99	185	37	3	318	246	228	130	12	37.3	0.013	2.8	0
S19	‘’	252	43	0	486	252	325	101	27.1	18.8	0	0	0
S20	18-06-99	53	10	5.2	239	198	98.5	35.6	1.71	19.25	0	0	0
Mean		163	30	3	348	232	217	89	14	25	0	1	0

Appendix (11c.a) Short rainy Season Physical Analysis Results.

Sample Sites	Date	Temperature (oC)	P^H	SS(mg/l)	DS (mg/l)
S1	15-01-99	13.5	7.4	12	126
S2	‘’	15	7.2	39	614
S3	‘’	16	7.3	30	430
S4	17-04-99	16	6.64	10.8	261
S5	‘’	15	6.75	15.28	233
S6	‘’	16.5	6.84	177	321
Mean		15	7	47	331
S7	23-04-99	18	7.45	89	355
S8	‘’	16	7.41	217	362
S9	‘’	20	7.33	50	391
S10	14-05-99	21	6.88	152.6	585
S11	14-05-99	20	3.5	75.6	609
S12	21-05-99	21	6.6	488	673
S13	‘’	19	6.97	433	482
S14	26-05-99	20	6.86	334	406
S15	26-05-99	20	6.9	522	521
S16	26-05-99	21	9.11	593	677
S17	02-06-99	22	8.22	178.2	545
Mean	‘’	20	7	285	510
S18	09-06-99	21	7.54	118	825
S19	‘’	20	7.48	121	871
S20	18-06-99	ND	7.44	37	380
Mean		21	7	92	692

Appendix (11d) Sample sites location for EPB 2002 data

Sample No.	Sample Sites Locality	Distance (Km)	Remark
S1	Behind Anbessa Garage before the river enters a residential area nearby	0	One of the source streams TAR Tributary
S2	Shegole River where a stream from rufael area meets a tributary of TAR	1.1	
S3	Near medhanealem School at a bridge	1.5	
S4	Below Ethiopian Marble Factory (rocky Basin)	2.1	
S5	To the Right of Taiwan Tera	2.7	
S6	Main Kolfe Bridge	3.2	
S7	Behind Ehil berenda	3.8	
S8	To the Right of Amanuel Total	4.3	
S9	Gimira Sefera	5	
S10	Infront of Coca Cola Factory	6.2	
S11	Past lideta Health Center	7.1	
S12	Below the National Tobacco and Matches Factory	8.4	
S13	Below Addis Ababa Abattoirs (Kera Sefer)	10.4	
S14	Down the National Alcohol and Liqour Factory	12.4	At a point a little below where TAR and Mekanisa Rivers Meet
S15	Gofa Sefer Between Gofa EELPA and Gofa Military Camp	14.88	
S16	Inside the behere Tsege park after the Ethiopickling effluent enters	16.42	
S17	Infront of Walia Tannery	19.0	
S18	Behind Kality WWTP at the Gorge	21.9	
S19	Down Kality EELPA	25.7	During the rainy seasons TAR over floods the nearby Farms
S20	Chefe Mettele Farmers association (oromia region)	30.5	>>
S21	Hechu Farmers Association at the inlet point of the Aba Samuel Dam	34.3602	>>

S22	Dewera Tino Farmers association at the outlet of Aba Samuel Dam	42.9561	The surface of the entire catchment of the dam is covered with the hyacinth plant

Generally the above Sample sites are grouped in to:
*** Upstream S_1-S_5 Mid Stream S_6-S_{15} & Down Stream S_{16}-S_{22}**

Appendix (12) May 1999

No.	Sampled From	Date	UTM E	UTM N	Alti. (m)	Temp. (oC)	P^H @25^{o}C	EC @25^{o}C
1.	TAR(DwnStream)	23-05-99	472633	983922	2080	23	7.6	1124
3.	Geffersa River(UPStm)	29-05-99	457710	1002800	2570	15.6	7.15	166
4.	TAR(mid)astecko	29-05-99	465829	1000681	2470	22.4	7.05	338
6.	Lideta River(Midstm)	29-05-99	471038	995131	2320	18.6	7.59	1291
7.	TAR(DwnStream)	30-05-99	473218	987047	2150	21.3	7.64	1177
9.	Mekanisa River(midstm)	30-05-99	471215	992561	2220	21.8	7.3	860

Continued

No.	DO (mg/l)	DO Satu. (%)	Eh(V)	NO_2 (mg/l)	NO_3 (mg/l)	SO_4 (mg/l)	PO_4 (mg/l)	Cl^- (mg/l)	Mn (mg/l)	∑(Fe) (mg/l)
1.	3	47		< 0.01	81.11	63.63	-	137.42	0.89	0.24
3.	3.8	50		<0.01	0.89	1.11	<0.1	3.56	0.06	0.23
4.	3.7	53		<0.01	3.13	1.85	<0.1	5.86	0.07	<0.1
6.	0.1	1		<0.01	-	-	17.88	106.52	<0.05	0.29
7.	1.5	23		0.02	124.66	46.67	5.61	135.78	<0.05	0.24
9.	3.3	51		< 0.01	116.07	12.62	<0.1	102.7	0.81	<0.1

Appendix (13) NOV&DEC, 2000 (Gizaw B. A.)

No.	Sampled From	Date	UTM E	UTM N	Alti. (m)	Temp. (oC)	P^H @25°C	EC @25°C
2.	TAR(downstream)	23-11-00	472633	983922	2080	17.9	7.92	990
5.	TAR (Midstream)	07-12-00	465945	1000842	2510	9.6	7.83	336
8.	TAR(dwn stream)	07-12-00	473237	987096	2190	25	7.96	1210

No.	DO (mg/l)	DO Satu. (%)	Eh(V)	NO_2 (mg/l)	NO_3 (mg/l)	SO_4 (mg/l)	PO_4 (mg/l)	Cl^- (mg/l)	Mn (mg/l)	∑(Fe) (mg/l)
2.	4.26	59	379	-	73.96	42.08	2.26	88.19	1.41	0.45
5.	5.19	61	392	<0.01	9.88	1.84	-	12.32	0.48	0.24
8.	0.03	0.5	-18	-	1.42	74.36	1.77	139.28	1.33	0.29

Appendix (14) Physico-Chemical Parameters of Tinishu Akaki River (Bulletin of the Chemical Society of Ethiopia, Vol. 21, No. 2, 2007)

Site	T°C		P^H		EC(µS/cm)		TDS(mg/l)		DO(mg/l)		COD(mg/l)			BOD_5(mg/l)	
S1	-	21.2	-	8.1	-	56	-	28	-	6.7	-	18		-	7.6
S2	15	18.9	7.1	8.6	209	202	106	104	3.4	5.2	12	17		-	7.6
S3	15	18.5	8.1	8.6	156	142	79	71	3.2	4.8	12	28		-	11
S4	15.8	18.5	8.1	7.9	163	147	81	73	2.3	4.8	13	4		2.7	-
S5	15.7	14	8.4	7.9	161	170	80	85	2.2	5.1	23	8		5.8	-
S6	18.7	15.2	8.2	7.8	273	390	146	200	2.5	1.2	76	27		15	11
S7	19.7	16.6	8.9	7.8	714	785	358	396	1.1	1.3	360	426		138	137

S8	18.8	16.5	8.9	7.9	729	970	366	492	0.9	0.8	280	280		86	85
S9	19.7	18.8	8.1	7.6	951	1225	478	626	1.1	1.5	266	130		80	42
S10	17.9	12.4	7.6	8.1	940	318	473	161	1.2	5.2	46	13		-	5
S11	18.7	14.1	7.7	7.9	1053	1143	525	569	1.8	2.4	29	60		8.8	18
S12	19	13.7	7.9	8	883	882	440	443	0.6	1.1	70	69		17	22
S13	15.3	14.2	7.8	8.2	1116	1055	557	533	1.3	1.6	44	66		16	22
S14	-	14.1	7.9	7.9	971	994	487	497	2.1	3.1	49	37		7.2	13
S15	17	14.5	-	7.4	885	883	442	443	1.9	2.3	30	52		9	16
S16	18.8	13.8	7.8	8.3	-	938	-	479	-	2.7	-	314		-	97
S17	19	14.4	7.9	7.9	908	876	456	454	0.7	1.4	275	352		61	113
S18	18.8	16.9	7.4	7.6	912	873	460	439	0.1	1.1	263	85		91	33
S19	19	17.4	7.6	7.8	874	849	439	426	0.2	1.2	216	90		62	33
S20	18.8	16.7	7.7	7.9	914	915	459	459	1.4	2.9	94	237		40	77
S21	19.4	16.9	7.6	8	979	931	491	467	1.6	4.2	533	239		204	77
S22	21.8	21.7	7.6	7.8	1150	1269	577	639	0.6	0.01	239	158		89	44
S23	20.9	22.1	7.8	8	972	1116	488	559	0.4	0.01	121	128		31	43

Appendix (14a) Nutrients and major ions composition of water samples taken along the course of TAR (Nov-Jan, 2003/2004)

Site	Ca^{2+}(mg/l)	Mg^{2+}(mg/l)	Cl^{-}(mg/l)	SO_4^{2-}(mg/l)	HCO_3^{-} (mg/l)	NO_3^{-}(mg/l)	NO_2^{-}(mg/l)	NH_3^{-}(mg/l)	PO_4^{3-}(mg/l)
S4	22	3.4	4.5	10.2	87	2.64	-	-	0.06
S5	19	7.3	19.5	4.9	87.8	1.85	-	0.6	0.05
S6	45	16	22	-	198	4.29	0.12	0.4	0.04
S7	38	8.3	88	65.4	199	-	-	20.8	0.85
S8	32	11.7	108	65.7	185	-	-	20.6	0.67
S9	40	14.6	129	37.2	212	-	-	17.9	0.18
S10	37	11.2	21.5	-	154	5.83	0.42	0.8	0.1
S11	48	15.6	189	70.8	198	9.24	1.06	7.1	0.14
S12	63	20.9	85	-	381	-	0.15	17.4	4.95
S13	54	16	193	56.7	234	5.86	1.03	9.3	1.52
S14	50	17	154	63.1	251	1.72	0.3	9.3	1.8
S15	58	16.5	156	60.6	234	5.72	1.22	7.3	1.72
S16	58	28.2	159	15.1	429	-	-	30	14.8
S17	64	23.8	138	39.1	332	-	-	25.1	5.21
S18	64	31.6	125	33.4	386	-	-	30.4	6.05
S19	64	36	112	28.8	395	-	-	24	8.64
S20	65	26.3	115	27.8	412	-	-	28.2	7.32
S21	64	23.3	121	25.2	417	-	-	19.5	6.45

S22	67	19	91	22.9	437	-	-	34.9	9.63
S23	61	17.5	87.5	23.3	407	-	-	25.5	8.77
World Rivers Average	8.0	2.4	3.9	4.8	30.5	0.1	-	-	0.01

Appendix (15) Extracted and Arranged after EPA Monitoring Data for the Years 2005 and 2006 arranged for spatial extents.

YEAR	WATER COARSE	MONTH	DO(mg/l)
2005	Upstream	Aug	7.21
2005	Upstream	Mar	5.8
2006	Upstream	Aug	5.4
2005	Midstream	Aug	5.36
2005	Midstream	Mar	0.32
2006	Midstream	Aug	0.33
2005	Down Stream	Aug	3.23
2005	Down Stream	Mar	5.8
2006	down Stream	Aug	2.82
2006	Down Stream	Aug	4.84

Appendix (16a) **Extracted and Arranged after EPA**

Data Produced by: Environmental Pollution Control Department and Environmental Laboratory Service Year Aug 2005

S. No	Sampling Site	GPS Reading		Parameters																							
		Loca-tion	Eleva-tion M	*Physical*				Chemical																			Micro biolo-gical
				pH	EC	Do_2	Tem	Turb	NH_3	Po_4^{3-}	SO_4^{2-}	Cl^-	F^-	NO_2^- NO_3^-	Fe	Mn	Al	Pb	Cr	BOD_5	COD	Ca^{2+}	K^{+1}	Mg^{2+}	Na^{+1}	Hard-ness	Faecal Coli-form
2	Little Akaki River on Arbegnoch street above Gulele Shirt Factory	N09^{o} 03.932 E38^{o} 41.769	2630	6.34	169	7.21	14.4	-	-	-	2	12.78	0.92	3.8	Nil	Nil	Nil	Nil	12.78	-	6	-	-	-	-	-	-
4	Little Akaki, near Bihere Tsigie Park	N08^{8} 57.041 E38^{o} 45.182	2224	6.66	371	5.36	19.4	-	-	-	15	25.92	18.7	4	0.94	1.09	0.20	Nil	NIL	-	17	-	-	-	-	-	-
6	Little Akaki at the inlet point to Aba Samuel Lake near by the EEPC Station	N08^{8} 51.94 E38^{o} 44.745	2060	7.66	487	3.23	19.8	-	-	-	38	39.05	9.18	3	1.07	0.88	3.29	Nil	0.02	-	25	-	-	-	-	-	
7	Outlet point of Aba Samuel Lake	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix (16b) Year Nov 2005

S. No	Samling Site	GPS Reading		Parameters																							
		Loca-tion M	Eleva-tion	***Physical***				Chemical																			Micro-biolo-gical
				pH	EC	Do_2	Tem	Turb	NH_3	Po_4^{3-}	SO_4^{2-}	Cl^-	F^-	NO_2^- NO_3^-	Fe	Mn	Al	Pb	Cr	BOD_5	COD	Ca^{2+}	K^{+1}	Mg^{2+}	Na^{+1}	Hard-ness	Faecal Coli-form
2	Little Akaki River on Arbegnoch street above Gulele Shirt Factory	-	-	8.11	3.92*	-	-	-	-	-	141.2	119.0	-	5.95	Nil	-	-	-	-	-	2	58.1	2.84	7.42	15.7	-	-
4	Little Akaki, near Bihere Tsigie Park	-	-	7.16	1153.7	-	-	-	-	-	392.4	433.5	-	1.89	0.41	-	-	-	-	-	-	59.8	23.0	4.81	48.5	-	-
6	Little Akaki at the inlet point to Aba Samuel Lake near by the EEPC Station	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	Outlet point of Aba Samuel Lake	-	-	8.17	1447.8	-	-	-	-	-	390	310.0	-	15.6	1.08	-	-	-	-	-	34	74.2	16.2	4.78	47.0	-	-

Appendix (16c) Season Mar.2005

S. No	Sampling Site	GPS Reading		Parameters																							
		Loca-tion	Eleva-tion M	***Physical***				Chemical																			Micro-biolo-gical
				pH	EC µm/s	Do_2	Tem	Turb	NH_3	Po_4^{3-}	SO_4^{2-}	Cl^-	F^-	NO_2^- NO_3^-	Fe	Mn	Al	Pb	Cr	BOD_5	COD	Ca^{2+}	K^{+1}	Mg^{2+}	Na^{+1}	Hard-ness	Faecal Coli-form
2	Little Akaki River on Arbegnoch street above Gulele Shirt Factory	N09° 03.890 E038° 41.733	2572	7.9	390	5.8	20	-	Nil	Nil	5	16	0.03	3.9	0.26	0.4	Nil	Nil	Nil	-	35	-	-	-	-	-	-
4	Little Akaki, near Bihere Tsigie Park	N08° 57.040 E038° 45.187	2203	7.52	1196	0.32	20.1	-	21	14.3	17	98	0.39	1.1	0.63	1.60	0.40	Nil	Nil	-	270	-	-	-	-	-	-
6	Little Akaki at the inlet point to Aba Samuel Lake near by the EEPC Station	N08° 51.966 E038° 44.706	2054	7.8	1416	2.3	23.5	-	25.9	13.4	14	124	0.85	3.6	0.27	1.2	0.6	Nil	Nil	-	116	-	-	-	-	-	-
7	Outlet point of Aba Samuel Lake	N8° 47.245 E38° 42.390	2029	7.78	795	5.8	20.5	-	1.36	1.23	35	64	0.4	1.4	0.92	0.4	0.6	Nil	Nil	-	33	-	-	-	-	-	-

Appendix (16d) Year Aug2006

S. No	Sampling Site	GPS Reading		Parameters																							
		Loca-tion	Eleva-tion M	***Physical***				Chemical																			Micro-biolo-gical
				pH	EC	Do_2	Tem	Turb	NH_3	Po_4^{3-}	SO_4^{2-}	Cl^-	F^-	NO_2^- NO_3^-	Fe	Mn	Al	Pb	Cr	BOD_5	COD	Ca^{2+}	K^{+1}	Mg^{2+}	Na^{+1}	Hard-ness	Faecal Coli-form
2	Little Akaki River on Arbegnoch street above Gulele Shirt Factory	-	-	7.15	340	5.4	14.2	-	Nil	0.32	7	153	-	Nil	0.24	0.08	Nil	Nil	Nil	-	122	-	-	-	-	-	-
4	Little Akaki, near Bihere Tsigie Park	N8° 56.996 E38° 45.179	2194	6.98	1043	0.33	20.6	-	Nil	8.8	35	153	0.64	Nil	1.98	1.52	Nil	Nil	0.43	-	175	-	-	-	-	-	-
6	Little Akaki at the inlet point to Aba Samuel Lake near by the EEPC Station	N8° 51.092 E38° 46.917	2048	6.73	624	2.82	20.3	-	Nil	2.43	8	77	0.61	Nil	1.09	1.36	Nil	Nil	Nil	-	3	-	-	-	-	-	-
7	Outlet point of Aba Samuel Lake	N8° 47.210 E38° 42.506	2032	5.79	428	4.84	18.8	-	0.02	0.15	15	70	0.66	0.02	0.02	0.10	Nil	Nil	Nil	-	Nil	-	-	-		-	-

Appendix (16e) Year Nov 2006

S. No	Sampling Site	GPS Reading Loa-tion	GPS Reading Eleva-tion M	Parameters: Physical pH	EC µm/s	Do_2	Tem	Chemical Turb	NH_3	Po_4^{3-}	SO_4^{2-}	Cl^-	F^-	NO_2^- NO_3^-	Fe	Mn	Al	Pb	Cr	BOD_5	COD	Ca^{2+}	K^{+1}	Mg^{2+}	Na^{+1}	Hard-ness	Micro-biolo-gical Faecal Coli-form
2	Little Akaki River on Arbegnoch street above Gulele Shirt Factory	N9° 03.932 E38° 41.769	2630	6.98	402	-	-	-	0.01	0	4	76	Nil	5.7	0.27	0.04	Nil	Nil	-	-	9	-	-	-	-	-	-
4	Little Akaki, near Bihere Tsigie Park	N08° 47.052 E38° 45.175	2224	7	1256	-	-	-	0.1	15.4	13	282	0.65	4.1	2.9	1.4	0.3	Nil	-	-	210	-	-	-	-	-	-
6	Little Akaki at the inlet point to Aba Samuel Lake near by the EEPC Station	N08° 52.48 E38° 45.191	2058	7.57	1550	-	-	-	0.01	10.5	65	373	0.48	2.3	2.3	1.5	0.2	Nil	-	-	128	-	-	-	-	-	-
7	Outlet point of Aba Samuel Lake	N08° 47.260 E039° 42.425	2033	7.48	916	-	-	-	0.15	0.5	20	170	0.54	12.2	7.54	2.7	4.2	Nil	-	-	190	-	-	-	-	-	-

Appendix (16f) Year Mar 2006

S. No	Sampling Site	GPS Reading		Parameters																							
		Loca-tion	Eleva-tion M	***Physical***				Chemical																			Micro-biolo-gical
				pH	EC µm/s	Do_2	Tem	Turb	NH_3	Po_4^{3-}	SO_4^{2-}	Cl^-	F^-	NO_2^- NO_3^-	Fe	Mn	Al	Pb	Cr	BOD_5	COD	Ca^{2+}	K^{+1}	Mg^{2+}	Na^{+1}	Hard-ness	Faecal Coli-form
2	Little Akaki River on Arbegnoch street above Gulele Shirt Factory	-	-	7.97	200	-	-	-	-	-	-	22	-	-	0.20	-	0.5	Nil	Nil	-	110	-	-	-	-	-	-
4	Little Akaki, near Bihere Tsigie Park	-	-	7.09	770	-	-	-	-	-	-	-	-	-	0.30	-	0.45	Nil	Nil	-	36.2	-	-	-	-	-	-
6	Little Akaki at the inlet point to Aba Samuel Lake near by the EEPC Station	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
7	Outlet point of Aba Samuel Lake	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix (17) Ethiopian Drinking Water Quality Standards

Parameter	Maximum permissible limit (mg/l unless otherwise stated)
Turbidity (NTU)	25
Color Units	50
Odour and Taste	Unobjectionable
Calcium	200
Chloride	600
Copper	1.5
Flouride	1.5
Ammonia	0.10
Iron	1.0
Manganese	0.5
Magnesium	150
P^H	6.5-9.2
Nitrate	10
Arsenic	0.05
Cadmium	0.01
Hexavalent Chromium	0.05
Lead	0.1
Selenium	0.01
Total mercury	0.001
Total Coliform MPN/100ml	10
E. Coli, MPN/100ml	Nil

Appendix (18) Provisional Effluents permit limit for all categories of existing industries in Ethiopia (EPA 2001, Vol. 3)

Basic Parameters	Limit for discharges into surface water within 15 meters of out fall
Temprature ^{o}C	35
P^{H}	6-9
DO	5.0
Color (Lovibond Units)	7.0
Alkalinity	400
BOD_5 @ $20^{o}C$	100
Coliform Bacteria Count MPN/100ml	400
TSS	50
TDS	2000
Ammonia	4.5
Chlorides (as Cl)	200
Hydrogen Sulphide (H_2S)	0.5
Sulphate	600
Sulfide	0.2
Nitrate	45
Phosphate (as PO_4)	0.7
Other Parameters	
Phenolic Compounds (as Phenol)	0.02
Arsenic (As)	0.02
Barium (as Ba)	5.0
Tin (as Sn)	10.0
Iron (as Fe)	20.0
Manganese (as Mn)	5.0
Chlorine (free)	1.0
Cadmium (Cd)	<1
Chromium (as +III, or +VI)	<1
Copper	<1
Lead	<1
Mercury	0.05
Nickel	<1
Selenium	<1
Silver	0.1
Zinc	<1
Calcium	200
Magnesium	200
Boron	5.0
Cyanide	0.2
Detergent	1.5
Alkyl mercury compounds	10
Polychlorinated biphenyls	0.003
Alpha emmiters µc/ml	$<0.01 \times 10^{-7}$
Beta emmiters µc/ml	$<0.01 \times 10^{-6}$

Declaration

I the undersigned, declare that this thesis is my original work and has not been presented for the award of a degree in any university and all the sources of materials used for this thesis work have been duly acknowledged.

Name: Abdulshikur Mohammed Signature_________________.

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