ADDIS ABABA UNIVERSITY SCHOOL OF GRADUATE STUDIES

Assessment of Benthic-Macroinvertebrate structures in relation to Environmental Degradation in some Ethiopian Rivers

by

Baye Sitotaw

July 2006

ACKNOWLEDGMENT

I wish to express my deepest gratitude and thanks to my adviser Dr. Seyoum Mengistou; without his initiative to this work would not have been undertaken. I also recall and appreciate his invaluable financial and moral support to start my study earlier and to complete it on time. His encourage ment and appreciation throughout my study at the University and while I was working for my thesis have been very indispensable.

I am also very grateful to Dr. Abebe Getahun for his invaluable advice and financial support. I would like to extend my thanks to the Biology Department of Addis Ababa University, for the supply of necessary chemicals and equipment to conduct Laboratory analysis.

My thanks also goes to Prof. Zerihun Woldu for his credited support in the statistical analysis, Ato Solomon Akalu for his unreserved co-operation during field and laboratory work; and Ato Ayalew Wondie and Ato Taddesse Fetahi for their continuous advice in my study.

I am highly indebted and grateful to my brother, Tilahun Zewdu, my sister Tsigie Sitotaw, as well as, my friends Ato Fekade Asmamaw and Ato Mekashaw Yimer for their encouragement during my study. I am also indebted to Ato Asnake Mekuriaw for his invaluable advice to continue my education and to join Addis Ababa University.

Last but not least, I would like to thank all my classmates for their co-operative and enjoyable friendship during my stay in the University.

Above all, thanks to the Almighty God; without His will, nothing could have happened.

LIST OF FIGURES

Figures

LIST OF TABLES

Tables

LIST OF APPENDICES

ABSTRACT

Surface water monitoring programs rely on biological, chemical, and habitat information to make science-based judgments on aquatic life use-support designations. Urbanization and extensive agriculture within and adjacent to stream corridors can seriously impact aquatic species and their habitats. This study assessed biological impairment to macroinvertebrate communities in some rivers/ streams primarily disturbed by extensive agricultural activities, industrial and urban land use in Ethiopia. These primary land uses are considered to be the most important threatening factors to aquatic ecosystem. A total of 15 sites were sampled for macroinvertebrates and environmental parameters. These data were collected between August 2005 and June 2006. Sites were categorized *a priori* into three groups (reference, rural, and urban) based on the predominant land use upstream of the sampling reach. Macroinvertebrate sampling was conducted in accordance with Rapid Bioassessment Protocol. Physicochemical parameters (by using standard methods) were collected and habitat features were scored with the EPA Rapid Bioassessment Protocol (RBP) Habitat Assessment procedures. Streams data were compared to reference conditions. Sites were assessed with the Benthic Index of Biotic Integrity (B-IBI), an aggregate index that incorporates 14 metrics. Exploratory box plots and scatter plots were viewed along with Pearson correlation coefficients and linear regression to evaluate relationships between environmental and biological data. Multivariate techniques such as principal components analysis (PCA), correspondence analysis (CA) and cluster analysis were used. Significance tests were performed on environmental and biological Parameters with the student t- test. There were significant differences in most of the environmental variables ($p<0.05$) between most categories, but reference and residential sites were not significantly different in some parameters. The dispersion of disturbed sites in PCA ordination space clearly demonstrated that environmental factors deviated from the reference condition. Taxonomically, visual inspection of the CA ordination suggested that reference communities were highly similar to each other. However, substantial departure of urban sites from the reference site array indicated very different community makeup. This analysis also demonstrated distinct separation of assemblages from rural versus urban sites. Streams from the urban categories had significantly lower B-IBI and positive metrics scores, and significantly higher negative metrics scores than reference sites ($p<0.05$). The B-IBI and its associated metrics were significantly correlated ($p<0.05$) to most physiochemical parameters and RBP total habitat scores. The dramatic decrease of EPT taxa at urban sites indicated that these organisms are especially sensitive to excessive nutrient and organic loading. Overall, the B-IBI indicated that nearly all urban sites were impaired. The data presented here indicated that macroinvertebrate communities are sensitive and vulnerable to urban/industrial land uses. To best characterize and monitor ecological conditions of these rivers, regular sampling of all variables and development of a single mutlimetric index developed from biological and environmental variables is suggested.

1. INTRODUCTION

1.1. BACKGROUND

Rapid population growth, agricultural activities, urbanization and industrial development have been adversely degrading the environment, and moreover pollution has reached alarming proportions. The major consequences of man's activities on the environment are habitat degradation and water pollution, and the resultant deterioration of the aquatic ecosystem. Until recently, the environmental degradation and deterioration of water quality by pollution was not a serious problem because human populations were small, lived in scattered communities, the quantity and complexity of wastes were much below the assimilative capacity of the environment and hence, wastes dumped into rivers were subject to dilution and natural self purification (Mason, 1990).

As human population, agricultural activities and industrialization increased the water pollution problem becomes more critical, since these things result in habitat loss and the excessive addition of pollutants into the water bodies; and this affects the use and the natural balance of the aquatic ecosystem, by this the amount of impervious area and/or amount of disturbed land increased. Land disturbances directly influence the magnitude of storm water runoff, and ultimately increasing the amount of stream flow from surface runoff rather than from base flow or groundwater (Richards and Host, 1994; Booth and Jackson, 1997). The results are higher and more frequent high flow events and low flow or even no flow during dry weather conditions. Higher flow rates result in an increase in sediment losses from disturbed areas and in bank erosion and channel scouring. Consequently, the hydrological changes alter the habitat and geometry of the streams and increase the amount of sediment pollution (Knighton, 1984).

Excessive sediment load is thought to be major contributors to the decline of a stream's benthic community (USEPA, 1990). Sediment affects the benthic community by altering water movement, food quality, and interstitial spacing (Minshall, 1984). Fine sediment decreases diversity since the suspended solids absorb heat from sunlight, causing temperature increase and ultimately reduction in dissolved oxygen (MIDEQ, 2000; Murphy, 2000). Sediment also reduces habitat, gradually decreasing the standing crop, taxa richness, and diversity without a drastic change in overall taxonomic composition (Lenat *et al.,* 1981).

In addition to sediment pollution, increased concentrations of pollutants in the runoff affect the benthic community. Pollutants of concern include nutrients, toxics, and suspended materials. Temperature and dissolved oxygen effects may also be present due to both runoff and loss of riparian vegetation (Hem, 1992; Watzin and McIntosh, 1999). The geomorphic, hydrologic, riparian zone and water quality parameters affecting the invertebrate community make isolation of a single agent difficult (Allan, 1995). Thus, aquatic resources may be under stress posed by a multitude of practices within a watershed. So, the biological community can provide an ideal response indicator serving as a pertinent measure for water quality goals.

The sustainable management of aquatic environment, therefore, requires ecological status assessment based on monitoring of the structure and functioning of aquatic ecosystems. As shown in Figure 1, the integrity of streams requires the management of indicated factors. To restore and maintain the factors (chemical, physical, and biological integrity of the water bodies) these three parameters should be monitored (Novotny and Olem, 1994). Of the three characteristics, biological integrity may be the most important since organisms not only integrate the full range of environmental influences (chemical, physical, and biological), but also complete their life cycles in the water and, as such, are continuous “monitors” of environmental quality (Richards and Host, 1994). Therefore, evaluation of benthic conditions and development of benthic-stressor relationships are of great importance to meeting water quality goals in a given nation.

Assessment of water quality has traditionally been mainly based on chemical aspects but current legislations set ecological quality objectives and demand water quality to be assessed using biological quality elements such as phytoplankton, fish, and benthic flora and fauna.

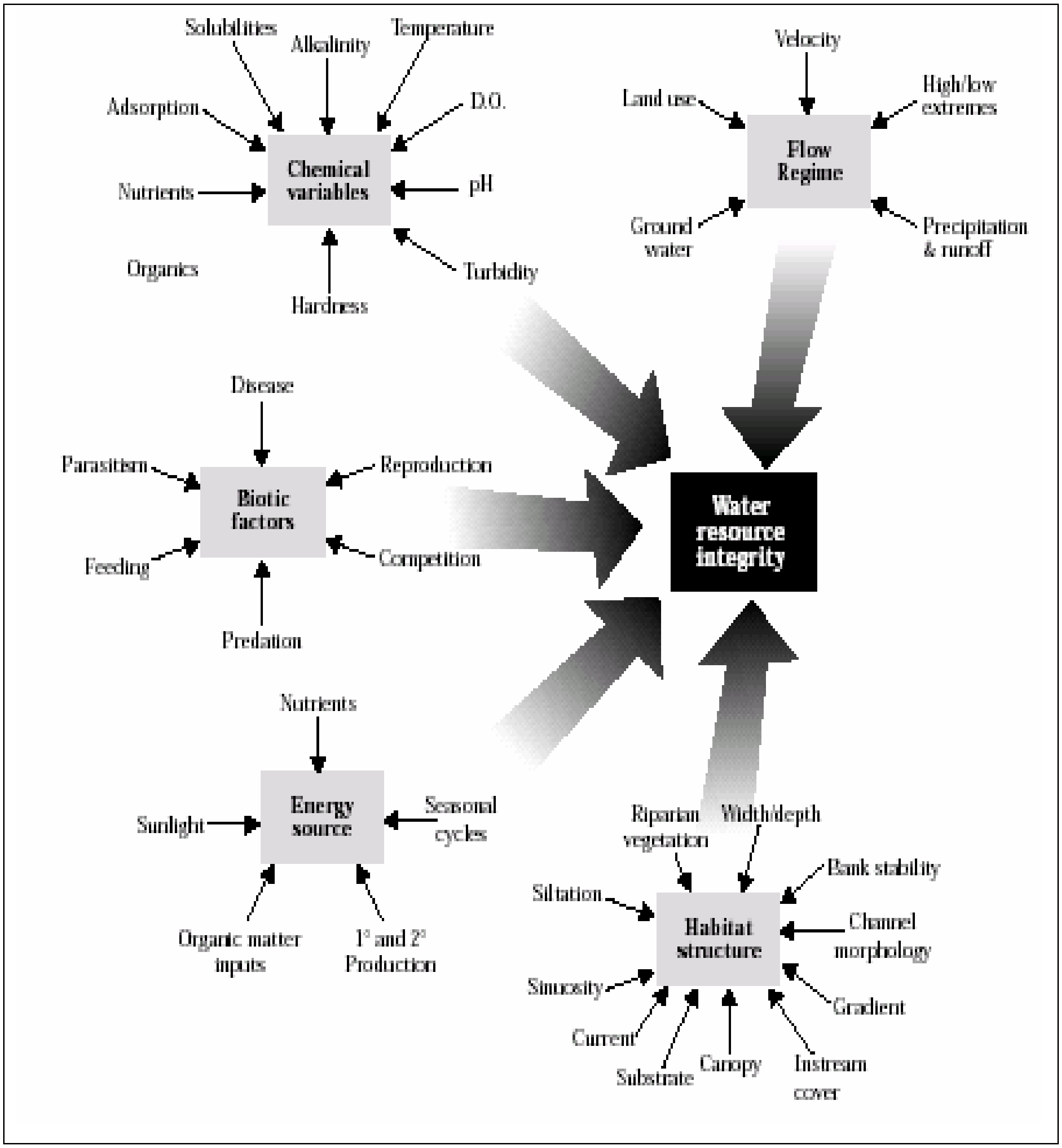


Figure 1. Factors that influence the integrity of streams (Modified from Karr, 1986)

Traditional measures or performance based standards of water quality, such as levels of dissolved oxygen or concentrations of toxic contaminants in water are indirect ways to determine the health of a water body. Conclusions about expected effects on aquatic life may be inferred from the performance-based standards; however, the biological responses in the stream cannot be directly studied. By assessing the structure of benthic invertebrate communities and comparing the results to those found in pollution-free areas, it is possible to determine whether or not pollution is causing ecological effects, such as the loss of sensitive groups of organisms (Pawlak, 1999).

1.2. BENTHIC MACROINVERTEBRATES FOR BIOASSESSMENT

Benthic macroinvertebrates are stream-inhabiting organisms, easily viewed with the naked eye, that spend at least part of their lives, living in or on the stream bottom. The name benthic macroinvertebrate is derived from the fact that they are bottom dwelling (benthic), large enough to be seen (macro), and small organisms without backbones (invertebrates). Since the invertebrates inhabit the stream bottom, any modification of the streambed by pollutants, deposited sediment and water shade degradation, will most likely have a profound effect upon the benthic community. These make Macroinvertebrates attractive water quality study subjects, with advantages over other community members.

Multimetric indices derived from biological data are increasingly used to measure the ecological health of streams. The indices consist of a collection of metrics that summarize information from population, community, and ecosystem levels into a single number through bioassessment.

Bioassessment is a monitoring technique intended to characterize the overall health of a water body. A water body's health is determined by gathering multiple measures of biological data, converting the data into a single numeric index, then comparing the index with an index developed for a reference condition. Reference conditions are established by characterizing the biology and water quality of reference sites with unimpacted water bodies (Pawlak, 1999).

To a varying degree, water quality, habitat quality, and biodiversity are intimately related (Chapman, 1990; Burton and Scott, 1992; Nelson *et al*., 1992; USEPA, 1992b; Rosenberg and Resh, 1993). Consequently, a convergence towards the integral study of hydrology and ecology takes shape in watershed management. Biometrics can be used to offer assimilative indication of water quality, to measure overall system's health, and to directly measure valued ecological components of a system placed under widespread management (Burton and Scott, 1992; Chapman *et al*., 1992; Rosenberg and Resh, 1993; Chapman, 1995). While benthic algae and fish are used in many stream assessments, the benthic macroinvertebrates are the most commonly used taxonomic group because they live in close association with the substrate.

Southerland and Stribling (1995) reported that more than 85% of state water quality agencies in the United States used some form of multimetric biocriteria to monitor their aquatic resources. 90% percent of those programs used benthic macroinvertebrates.

According to De Pauw and Hawkes (1993) and Bode *et al. (*1996), the advantages of benthic macroinvertebrates in biomonitoring and stream ecology studies are:

1. While the flying adult stages of many insects have sufficient mobility to permit them to reach anywhere in the entire watershed, they are only able to survive as aquatic larvae in those stream locations sustaining tolerable environmental conditions.
2. As a group, macroinvertebrates communities are sensitive and respond to both natural and man-induced changes in their environment. Some stream-bottom macroinvertebrates cannot survive in polluted water. Others can survive or even thrive in polluted water. In a healthy stream, the stream-bottom community will include a variety of pollution-sensitive macroinvertebrates. In an unhealthy stream, there may be only a few types of non-sensitive macroinvertebrates present.
3. Because taxa (family, genus or species) differ in their tolerance to pollutants, particular taxa make useful "indicators" of conditions. In other words, there are a large number of taxa, and different stresses produce different macroinvertebrate communities;
4. They are large enough to be seen with the unaided eye, making them relatively easy and inexpensive to collect;
5. Benthic macroinvertebrates are small enough to be easily collected and identified;
6. Because they are relatively abundant, there is little danger of depleting sparse populations through sampling.

7. With some practice and modest equipment, they are relatively easy to identify. A biologist experienced in macroinvertebrate identification will be able to determine relatively quickly whether the environment has been degraded by identifying changes in the benthic community structure of the water resource;
8. Physical/chemical conditions within a stream can be monitored directly, although this tells us only about conditions "at the moment." As long-term inhabitants of streams, the presences of macroinvertebrates reflect stream conditions over the preceding days, weeks, or months. So the presence of the biological community or of particular "indicator" species found at a given location depends on the availability of a range of required conditions during the past several weeks or months. Therefore, studies of macroinvertebrate communities provide valuable historical perspective missing in direct physical/chemical studies.
9. Small order streams often do not support fish but do support extensive macroinvertebrate communities;
10. Macroinvertebrates generally have limited mobility, thus they are indicators of localized environmental conditions;
11. Since benthic macroinvertebrates retain (bioaccumulate) toxic substances, chemical analysis of them will allow detection where levels are undetectable in the water resource;
12. Sampling of macroinvertebrates under a rapid assessment protocol is easy, requires few people and minimal equipment, and does not adversely affect other organisms;
13. Stream-bottom macroinvertebrates are the primary food source for recreationally and commercially important fish. An impact on macroinvertebrates impacts the food web and designated uses of the water resources, as they are a link in the aquatic food chain. In most streams, the energy stored by plants is available to animal life either in the form of leaves that fall in the water or in the form of algae that grows on the stream bottom. The algae and leaves are eaten by macroinvertebrates. The macroinvertebrates are a source of energy for larger animals such as fish, which in turn, are a source of energy for birds, raccoons, water snakes, and even fishermen
14. By doing so, they also re-cycle nutrients tied up in detritus.

According to Bode *et al. (*1996), there are some disadvantages of using macroinvertebrate as bioindicators. These are:

1. Benthic macroinvertebrates do not respond to all impacts;
2. Seasonal variations may prevent comparisons of samples taken in different seasons;
3. Drifting may bring benthic macroinvertebrates into waters in which they would not normally occur. Knowledge of drifting behavior of certain species can alleviate this disadvantage; and
4. Certain groups are difficult to identify to the species level.

Within these range of knowledge, a major concern of stream ecologists has been, therefore, to understand which variables best explain the observed patterns of distribution and abundance of macroinvertebrates. Several factors have been considered as decisive in structuring macroinvertebrate assemblages in streams. According to the River Continuum Concept (Vannote *et al.*, 1980), community structure and function match with certain geomorphic (e.g. gradient), stream order, physical and biotic characteristics such as stream flow, channel morphology, substrate, detritus loading, size of particulate organic matter, biotic interactions, characteristic of autotrophic production and thermal loading. However this concept seldom holds in many lotic systems due to longitudinal changes in environmental conditions caused by agricultural, human settlements or industrial activities which in turn affect the water shed and the riparian zone (Harding *et al.*, 1999)

The types and numbers of macroinvertebrates (mostly insect larvae/nymphs) that form the biological community at a particular stream location are influenced by the composite environmental conditions discussed above flowing by the site during the recent past. The drainage (the broader upstream landscape), riparian zones and in-stream conditions are a direct reflection of the degree of environmental stress in the surrounding area. A strategically placed collection of macroinvertebrate samples can provide a method for evaluating water quality of the entire watershed and for pinpointing specific problem areas within it.

1.3. OVERVIEW OF THE STATUS OF USING BIOMONITORING PROGRAMME IN ETHIOPIA

The history and trend of aquatic ecology degradation and water pollution in Ethiopia follows the same pattern as in other places (Zinabu Gebremariam and Elias Dadebo, 1989). Even though, we have few industries and few developed urban areas, water bodies, near some cities, such as Addis Ababa, have shown severe pollution problem progressively. Moreover, the unwise agricultural activities in our country can be mentioned as one of the major threats to the aquatic ecosystems. The above issues call for a rational approach to the protection and monitoring and use of aquatic environment in easier and effective way nationwide.

In Ethiopia and to larger extent the whole of Africa, the use of macroinvertebrate characteristics for assessment and monitoring of stream conditions is still uncommon. However, a South Africa Scoring System for rapid bioassessment of water quality in rivers is being used in a National Biomonitoring Programme in South Africa (Dallas, 1997). In East Africa, only few studies have attempted to describe the structure and composition of macroinvertebrates in lotic systems. For instance in Kenya, Mathoko (2002) looked at the colonization of artificial substrates by aquatic insects in Naro-Moru River, Barnard & Biggs (1988) studied macroinvetebrates in the catchments streams of Lake Naivasha while Kinyua & Pacini (1991) surveyed macroinvertebrates of Nairobi River. Tumiwesigye *et al.* (2000) investigated the structure, taxonomic composition and the temporal distribution of benthic macroinvertebrates in Nyamweru River in Uganda.

In Ethiopia, Harrison and Hynes (1988) studied the benthic fauna of highland streams of Ethiopia and they tried to establish a faunal standard of reference for Ethiopian mountain benthos in undamaged high-level streams and rivers. They also pointed out the effects of population pressure, drought and land degradation on highland benthos. Tesfaye Berhe (1988) studied the degradation of Kebena River by using macroinvertebrate structures and composition and Worku Legesse *et al*. (2004) also did the physicochemical and biological assessment of the same river. These studies clearly showed the relation between the chemical and physical change along the river and the change in species composition and density of macroinvertebrates. Also, the studies showed that natural as well as anthropogenic disturbances represent a considerable challenge to the survival of benthic organisms in highland rivers of Ethiopia. However, these studies are simply a start as compared to the demand for the development of a national biomonitoring program.

Although, Ethiopia is recognized as a classical example for its contrasting landscape and biodiversity, attempts to explore its river biota are almost non-existent. This lack of information has hindered the potential use of biological communities as indicators of water quality, making biomonitoring programs a remote possibility to the nation. Thus this study was designed to assess the structures of macroinvertebrates and the status of conditions in some rivers in Ethiopia (Chacha, Kebena, Akaki, Modjo, Megecha, Wabe, Ghibe, Dabena and Sor Rivers, Ethiopia) with the view to set basis for national biotic index development by compiling macroinvertebrate baseline data from these rivers.

2. OBJECTIVES

2.1. GENERAL OBJECTIVES

To investigate the structures of benthic macroinvertebrates, and other environmental factors in Modjo, Kebena, Akaki, Chacha, Megecha, Wabe, Ghibe, Dabena and Sor rivers in Ethiopia, with the view to understand the ecological status of these rivers and to set basis for biotic index development for monitoring water quality in the country.

2.2. Specific objectives are to:

1. Describe macroinvertebrates structure in these rivers,
2. Calculate multimetric indices from the macroinvertebrate data and determine the over all Benthic Index of Biotic integrity (B-IBI) scores for each site,
3. Determine some water physico-chemical characteristics (NO_3-N, PO_4, TDS, DO, conductivity, pH and Temperature) of the sites in these rivers,
4. Evaluate habitat integrity by calculating a Rapid Biological Assessment Protocol (RBP) habitat scores of each study site and
5. Relate these macroinvertebrate multimetric data with habitat score and organic pollution

3. THE STUDY AREAS

The study was conducted in some selected headwater rivers/streams in: the Upper Awash (Kebena, Akaki and Modjo Rivers), Blue Nile (Chacha and Dabena Rivers), Omo-Ghibe (Ghibe, Wabe and Megecha rivers) and Baro-Akobo (Sor River) basins, Ethiopia.

In choosing the study areas the criteria was primary land use type and extent of impact (based on preliminary assessment). The major categories were:

- Heavily impacted streams (Urban and or industrial sites)- Kebena (lower reach), Akaki and Modjo downstream sites.
- Less impacted (Rural sites: deforested and or agricultural) - Upper Kebena site, Modjo upstream sites and Chacha River sites.
- Unimpacted rivers (benchmark sites) – Megecha, Wabe, Ghibe, Sor and Dabena rivers in SW Ethiopia.

The reference condition establishes the basis for making comparisons and for detecting water quality impairment (Gibson, 1996). Data collected from minimally impaired reference reaches will be used in restoration projects to establish the functional capacity of the stream and to denote benchmark, or representative, conditions. Though reference reaches must be established upstream of each study areas, or regional references in similar sized catchments and with many similar attributes (e.g. Ecoregion) of streams, this study uses regional references that might not fulfill these criteria, because most impacted streams lack sites that can be taken as real reference and moreover, the primary objective of this study is to assess macroinvertebrate structure in minimally, moderately and highly impacted rivers to set a general baseline data on these rivers. Factors that need to be considered when selecting a regional reference reach include the following (after Gibson, 1996):

- No upstream impoundments
- No known discharges or contaminants in place
- No known spills or other pollutant incidents
- Low human population density
- Low agricultural activity
- Low road and highway density
- Minimal non-point source problems
- Best water shed and riparian vegetation cover

This study considered most of these criteria in choosing reference sites. The study stretches in the rivers are about 200 meters, which included all sorts of microhabitats available. The altitude, coordinates, length, average width, flow condition, average depth, study site codes and other information are given in Table 1 and Appendix 1.

3.1. STUDY SITES IN UPPER AWASH BASIN

The Awash basin extends from its source at Ginchi up to Lake Abbe. It is bounded by the Blue Nile basin in the north and west, by the Omo basin in the southwest and by the rift valley lakes basin in the south.

The basin includes the central part of the country where the most densely populated and most industrialized towns are located. Important commercial towns, like Addis Ababa and Modjo are found within this basin. Therefore, socio-economic developments are growing faster and wider in the basin than anywhere else in Ethiopia.

These facts about the Awash basin indicate that the pollution of surface water have always been a subject of prime importance. Rivers, which contribute a lot to satisfy water demand and homes for aquatic lives, are at great risk in the basin.

The rapid increase of all kinds of anthropogenic activities in the basin has affected the aquatic ecosystems. As a result, complex interrelationships between socio-economic factors and natural hydrological and ecological conditions have been identified. The following two rivers in the basin have been studied.

3.1.1. Modjo River

Modjo town is located to the south east of Addis Ababa on the main road on the way to Nazret (Adama). According to the 1994 population and housing census result, the total urban population residing in Modjo town was 26,471. It is about 73 km by road from Addis. The Modjo River (Figure 2) is found with in $8^{O}38'$N, $39^{O}06'$E to $8^{O}26^{0}$'N, $39^{O}01'$E. Mean annual rainfall in Modjo area is 73 mm (Belema Gemechu, 2003). The town is found on the floor of the rift valley. The elevation ranges from 1780 m to 1781 m a.s.l. Modjo River is a perennial river that flows throughout the year and it is a tributary of Awash River. There are a number of factories (textile, tannery and others) in and at the vicinity of the Modjo area, which appear to cause contamination of the Modjo River.

In addition, extensive agricultural activities and human settlements in the area have been degrading the watershed and riparian zone of Modjo river. Physio-chemical characteristics of Modjo River is well documented in the literature e.g. in Belema Gemechu (2003) and Seyoum Leta *et al*. (2003).

3.1.2. Kebena-Akaki Rivers

Kebena-Akaki Rivers drain the whole area of Addis Ababa, the capital city of Ethiopia, (Figure. 3) and this watershed includes the commercial, manufacturing, dense urban settlement and many industries in Addis Ababa city. Geographically, the studied stream stretch is located at 9^{O}03'52"N, 38^{O}45'53"E to $8^{O}51^{042"}$'N, 38^{O}46'42"E. The lowest and the highest annual average temperatures are between 10 and 25°C. April and May are the driest months. The main rainy season occurs between mid June and mid September, which is responsible for 70% of the annual average rainfall of 1400 mm. It is characterized by intense rainfall of short duration. The major threats on these streams are industrial and household wastes, agricultural activities and habitat degradation by human activities. Physio-chemical characteristics of Kebena-Akaki River are also well documented in the literature e.g. in Tesfaye Berhe (1988) and Worku Leggesse *et al*. (2004).

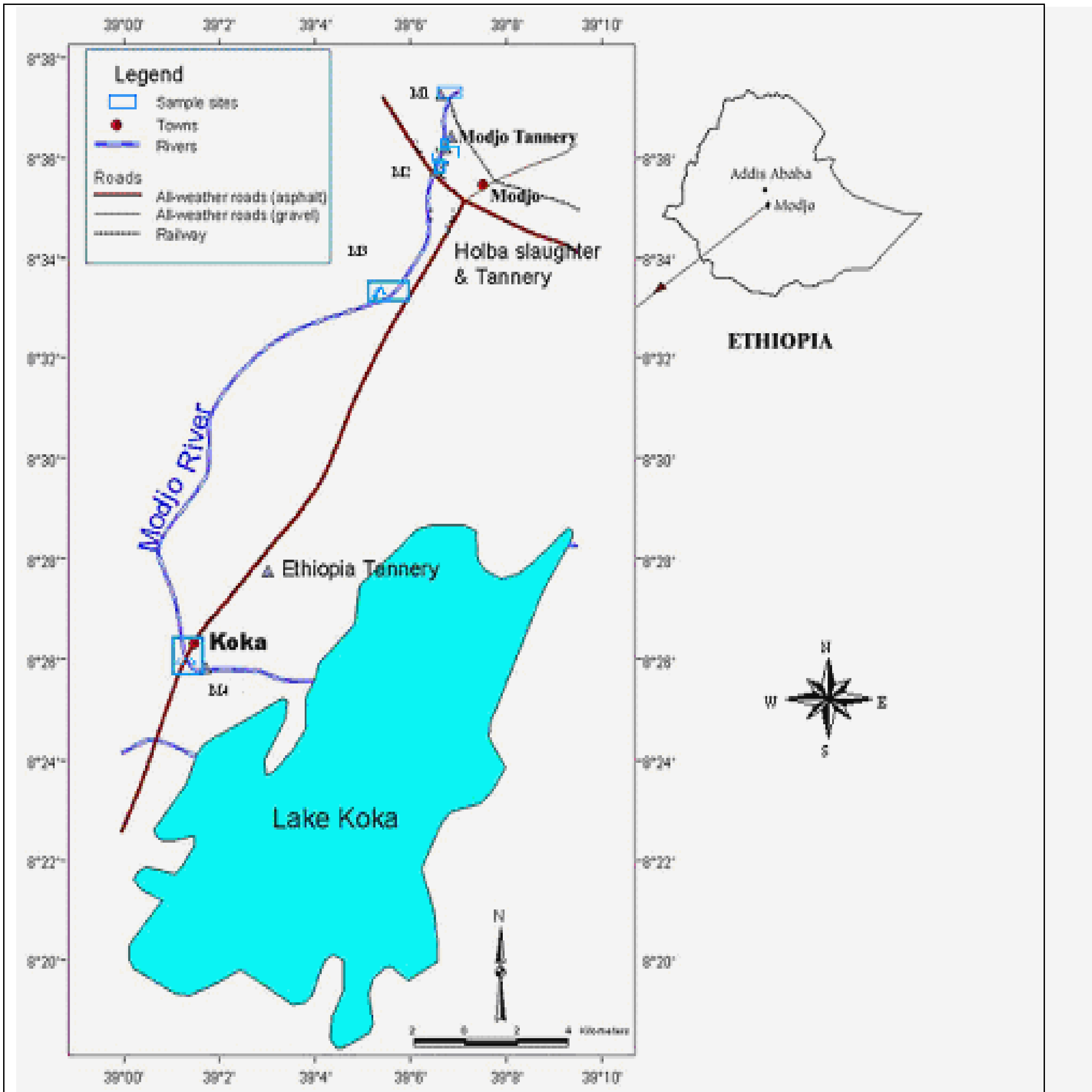


Figure 2. Map showing study locations and sampling sites along Modjo River until it joins Lake Koka (Seyoum Leta *et al*., 2003),

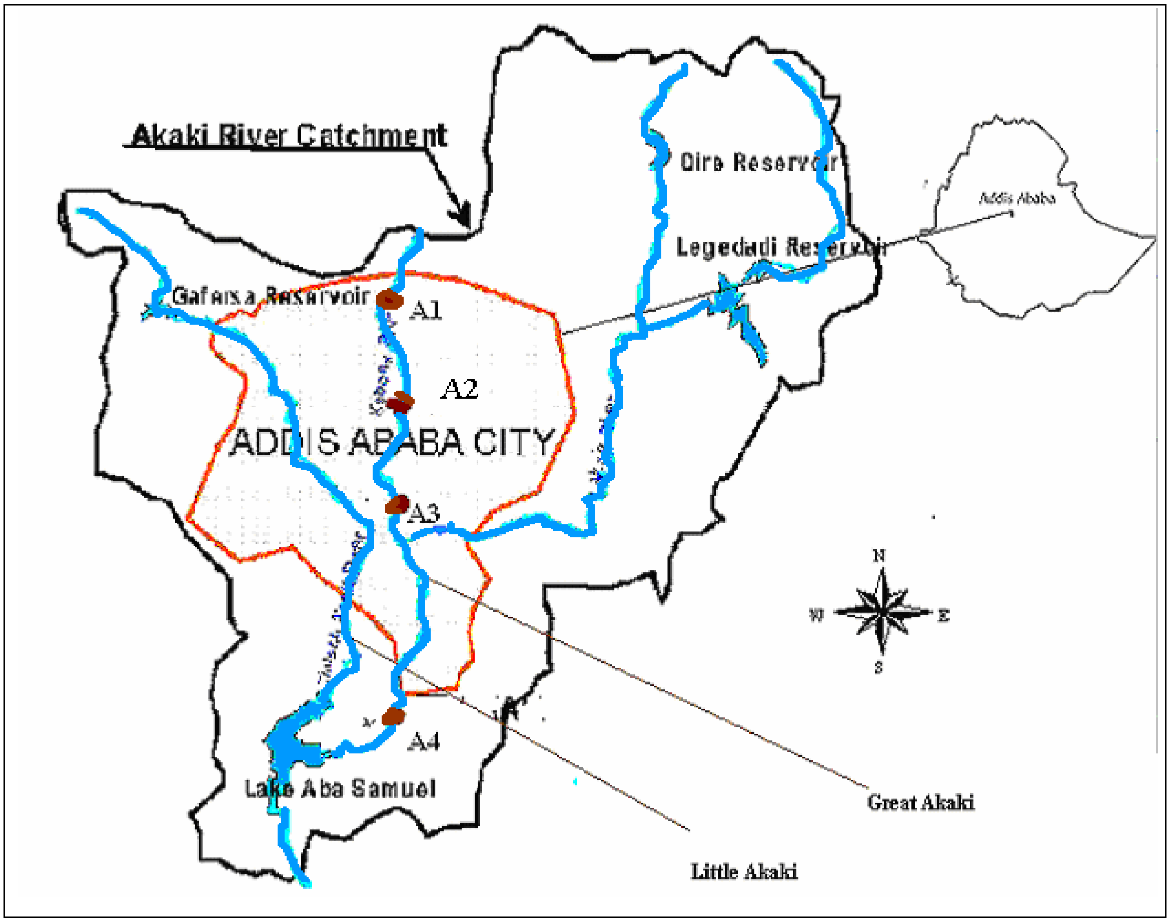


Figure 3. Map showing study locations and sampling sites on Kebena-Akaki Rivers (A1, A2, A3, A4)

3.2. STUDY SITES IN ABAY (BLUE NILE) BASIN

3.2.1. Chacha River

Chacha is located in North Shewa zone of the Amhara National Regional State to the north east of Addis Ababa on the main road on the way to Debreberehan (capital city of North Shewa zone). The Chacha River (Figure 4) passes across Chacha town after draining considerable areas in the Chacha Woreda. This river begins at the border of Abay and Awash basins and it is the tributary of Jemma River, which in turn drains to Blue Nile River.

Chacha town is about 110 km by road from Addis. The Chacha River is located at $8^{O}38'$N, $39^{O}06'$E to $8^{O}26^{0}'$N, $39^{O}01'$E. The elevation of the study sites ranges from 2764 to 2766 m a.s.l.

The Chacha area has adequate rainfall, an agreeable climate with favorable temperature, moisture and soil conditions for the cultivation of a variety of crops and the raising of domesticated animals. There are no factories and dense population settlements in the vicinity of the Chacha area that might have been affecting the river biota, however, the land has been over cultivated and overgrazed for generations. It has been deforested, degraded and eroded. Only very limited areas remain with natural forest coverage mainly on riverbanks. Domestic wastes from the Chacha town together with the intense agricultural activities, cattle grazing and their wastes, have been threatening the study stretch. But the riverbanks in the study sites are well covered and protected by dense grasses and emergent macrophytes. In addition, the river section at the study sites due to its very low gradient, acts as a wetland and these conditions help the aquatic fauna to colonize the river. This has been observed during the study, where considerable diversity and abundant macroinvertebrates were sampled.

No similar studies have so far been conducted in Chacha River. This study, therefore attempts to evaluate the ecological status of Chacha River, which will contribute important data for future studies in the area.

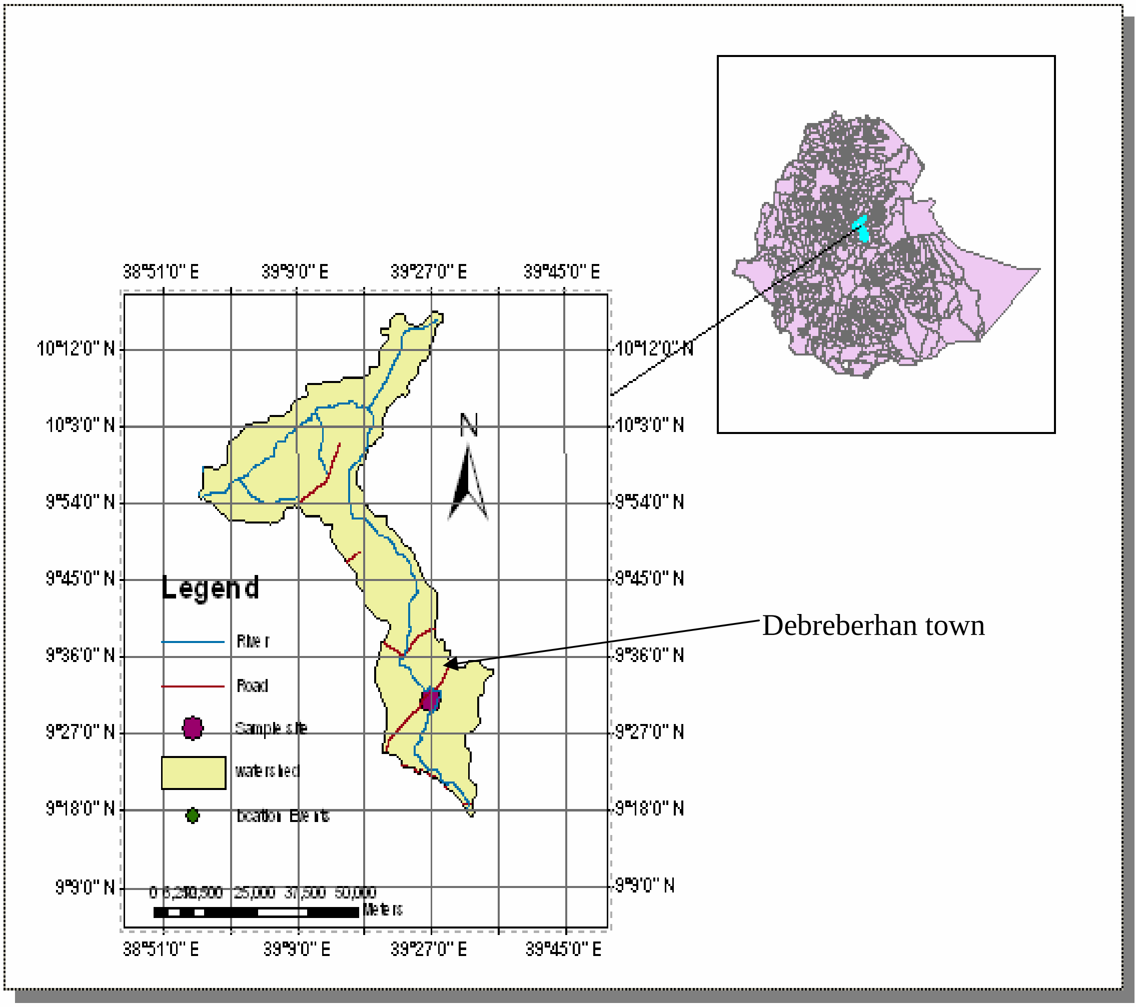


Figure 4. Map showing study locations and sampling sites in Chacha River

3.2.2. Dabena River

Dabena River (Figure 5) is located in Bedele Woreda (Illubabor Zone of Oromia Regional State) 490 km SW from Addis Ababa on the way to Metu town. This river begins at the border of Omo-Ghibe and Baro basins, drains large areas and is the tributary of Hanger River, which in turn drains in to Blue Nile River.

The Dabena River is bounded with in 8^{O}11'N, 36^{O}30'E to 9^{O}01'N, 36^{O}09'E. The elevation of the study sites ranges from 1821 to 1825 m a.s.l. The area has high rainfall and good climatic conditions for all sorts of agricultural activities. According to National Meteorological Services Agency (2004), the annual rainfall and temperature of the area are 1820 mm and 20 ^{o}C respectively. Population settlement in the vicinity of the River is very scattered;and very few farmlands are located quite far from the sites that might have been affecting the river biota. There is considerable natural forest coverage on riverbanks and watershed areas. The riverbanks in the study sites are well covered and protected by dense natural vegetation. In addition, the river section at the study sites due to its medium gradient and good morphology, help the aquatic fauna to colonize the river. However, Bedele Beer Factory may be a future concern if industrial wastes are not properly managed.

No similar studies have so far been conducted in Dabena River. This study, therefore, attempts to evaluate the ecological status of Dabena River taking it as a reference site.

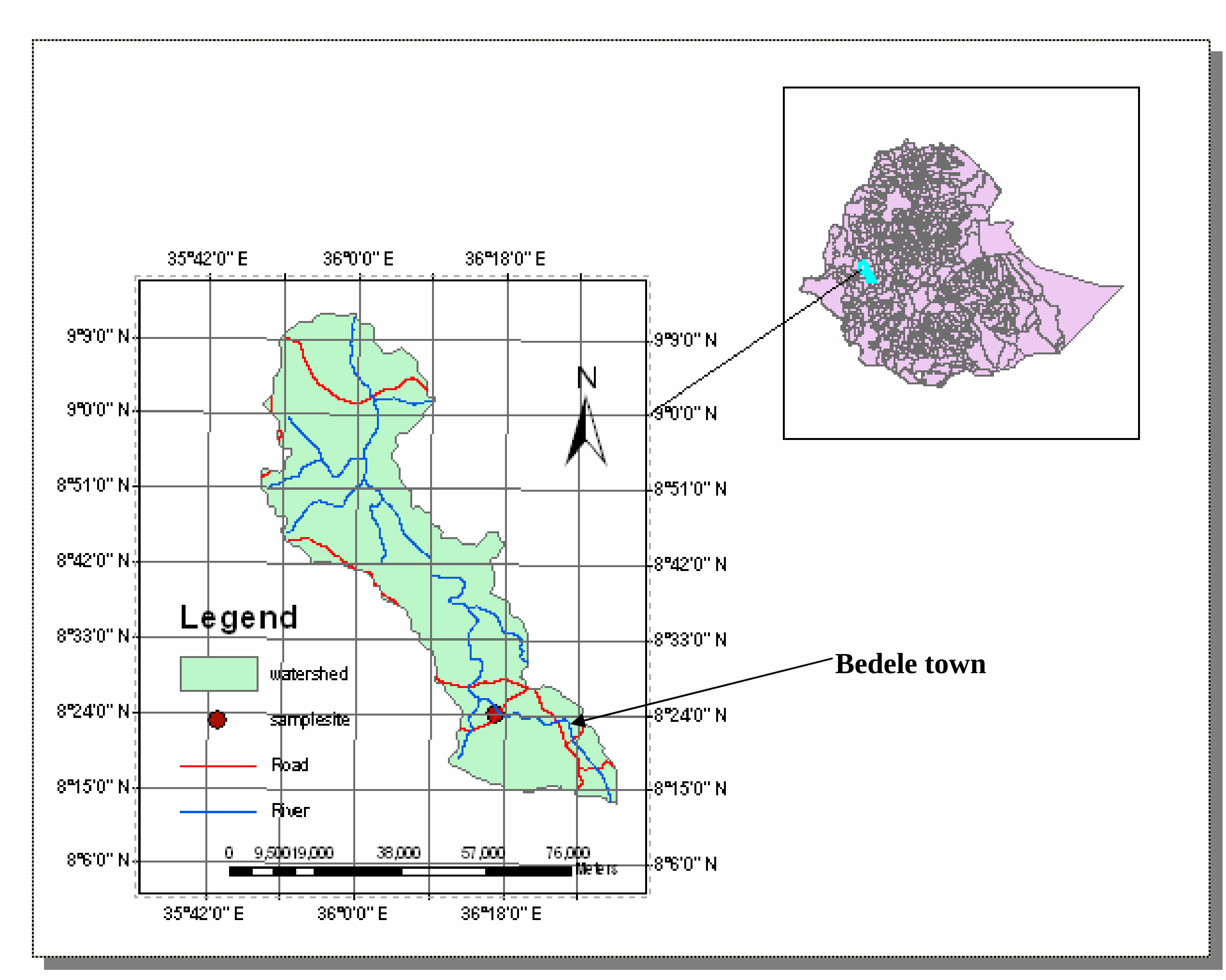


Figure 5. Map showing study locations and sampling sites in Dabena River

3.3. STUDY SITES IN UPPER OMO-GHIBE BASIN

3.3.1. Sites on Ghibe River

Ghibe River system covers the upper part of Omo-Ghibe basin, which drains very large areas from Jimma, West Shewa and Gurage zones. The study sites are located immediately above the main bridge from Addis Ababa to Jimma, downstream of the Gilgel-Ghibe Hydroelectric Dam and located at $8^{O}13$'N, $37^{O}34$'E to $8^{O}15^{0}$'N, $37^{O}32$'E. The elevations of the study sites ranges from 1082 to1086 m a.s.l. (Figure 6)

Riverine vegetations and grasses characterize the natural vegetations in the study sites. There are scattered farmlands in the vicinity of the riparian zone. From observations, during the study periods, the possible threats on the biota are the upstream Gilgel-Ghibe hydroelectric dam and large-scale deforestation of catchment areas. However, the present status of the sites is somehow suitable for faunal colonization

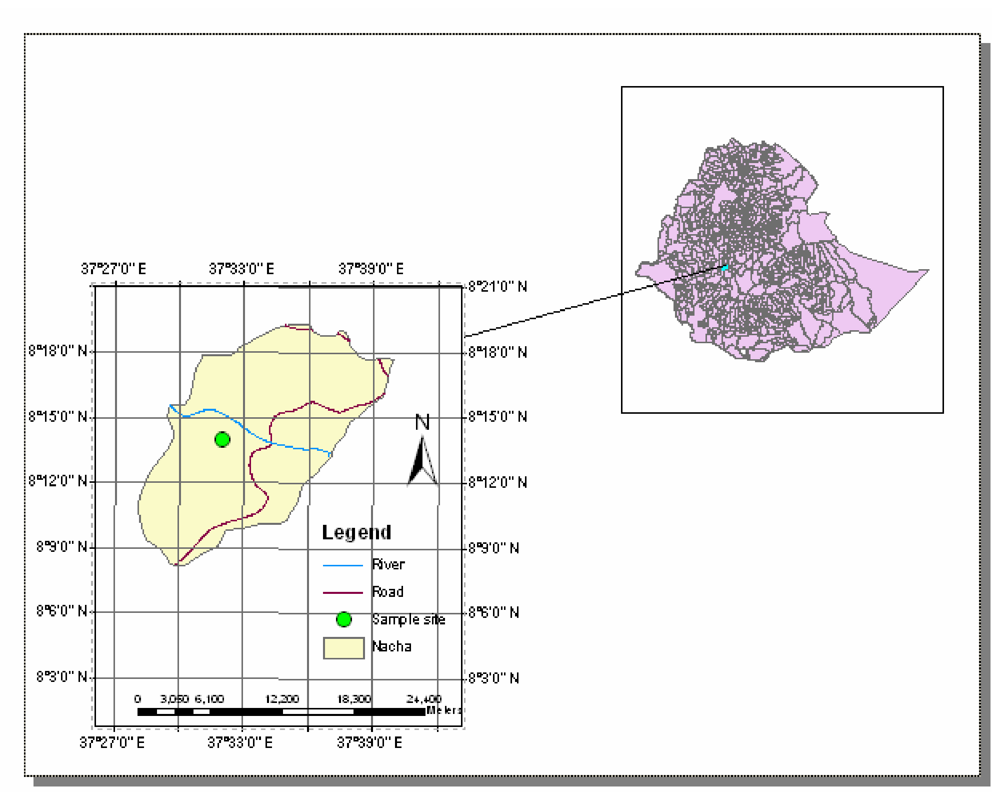


Figure 6. Map showing study locations and sampling sites in Ghibe River.

3.3.2. Wabe and Megecha Rivers

The Wabe and Megecha Rivers are tributaries of Ghibe (Upper Omo) River (Figure 7), about 185 km southwest of Addis Ababa, found in Abeshge district (woreda), which is one of the districts of Gurage zone in Southern Nation, Nationalities and Peoples Region (SNNPR). Abeshge district is found at the extreme west of the zone and located between latitudes $8^0$30'N to $9^0$25'N and longitudes $37^0$45'E to $38^0$00'E (SNNPR Statistics and Demography Office, 2004)

The altitude of the study sites ranges from 1670 to 1860 m.a.s.l. Population density of the study areas in these river systems is about 141 km^{-2} (AWANRDPO, 2004). According to AWANRDPO (2004) the land use of the areas includes seasonal (annual) field crops, permanent (perennial) crops, forest and bushland, area occupied by construction (village), grazing land, and uncultivable land.

The mean annual temperature of the area is between 15^0C and 37^0C. The mean annual rainfall is 1294.2 mm (National Meteorological Services Agency, 2004). Climatically the area is classified as lowland (10%) and middle highland (90%) (AWANRDPO, 2004). The natural vegetation in the study area is characterized by riverine vegetation, bushy-grass land and open grassland. One can find livestock in all vegetation types.

As to the observation during the study periods, Wabe and Megecha Rivers are in better condition: they have well vegetated riparian zone, relatively well protected and vegetated watersheds though not of all the catchment; good in-channel morphologies that can be suitable for faunal colonization and very few agricultural activities in the vicinity of the rivers. The possible impacts on these rivers would be site-specific human and cattle influences and materials brought from long distance catchments during flooding.

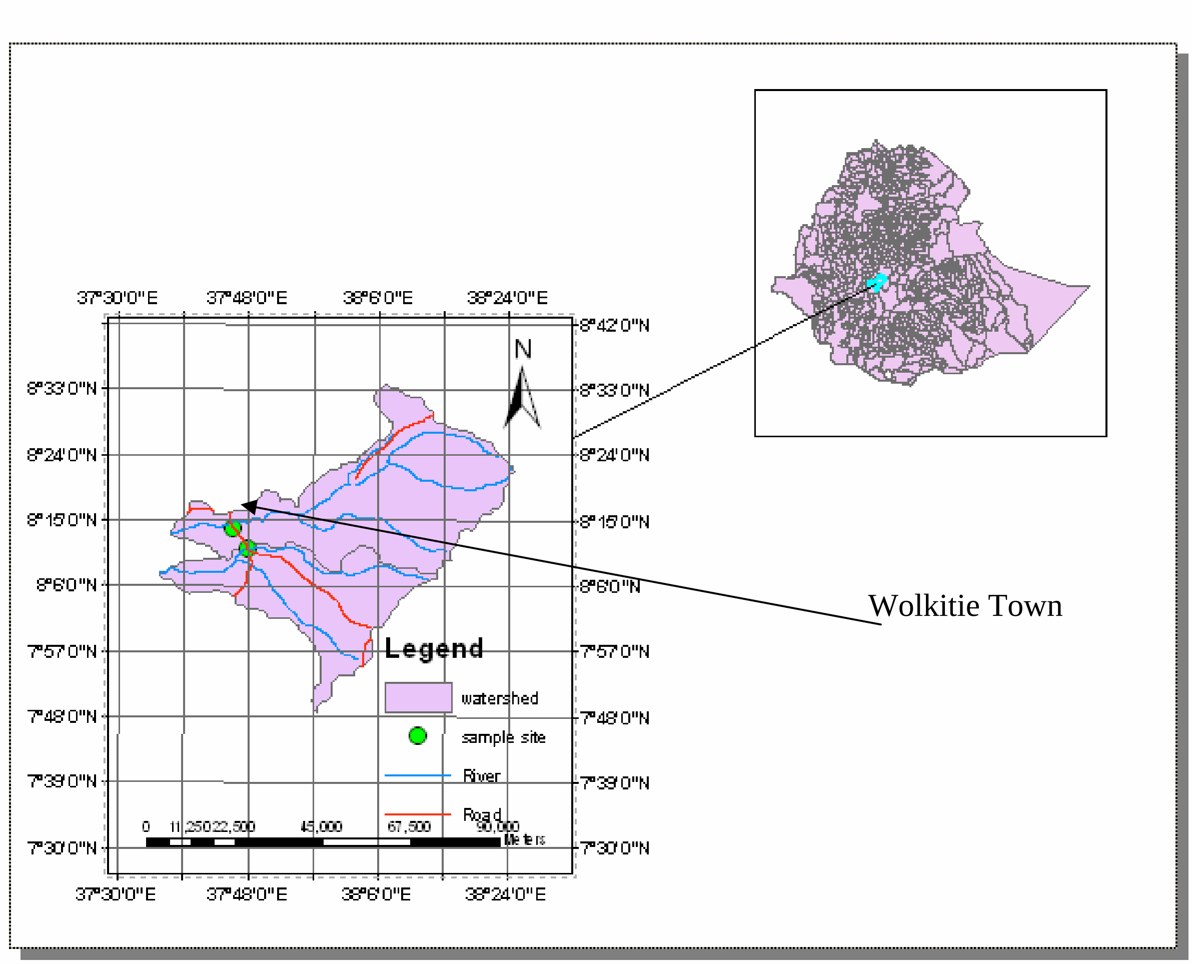


Fig 7. Map showing study locations and sampling sites in Wabe and Megecha rivers.

3.4. STUDY SITES IN BARO BASIN

3.4.1. Sor River

Baro basin is the most forested, well protected and with high rainfall. Sor River is one of the major tributaries of Baro River (Figure 8). It is located in Illubabor zone of Oromia Regional State near Metu town. The study sites on this river are located upstream of Metu town. The Sor river sites are located at $7^{O}55'$N, $35^{O}52'$E to $8^{O}28'$N, $35^{O}21'$E. The elevation of the study sites ranges from 1544 to 1548 m a.s.l. According to National

Meteorological Services Agency (2004), the annual rainfall and temperature of the area are 1800 mm and 21 °C, respectively.

The river has well forested watershed and riparian zone. The channel morphologies at the sites are also suitable for faunal colonization. However, the large volume of water in the channel has reduced the microhabitats for faunal colonization. In addition (though not significant at present), the impacts from Metu town and nearby small agricultural activities can be possible threats to the river in general and to the studied sites in particular.

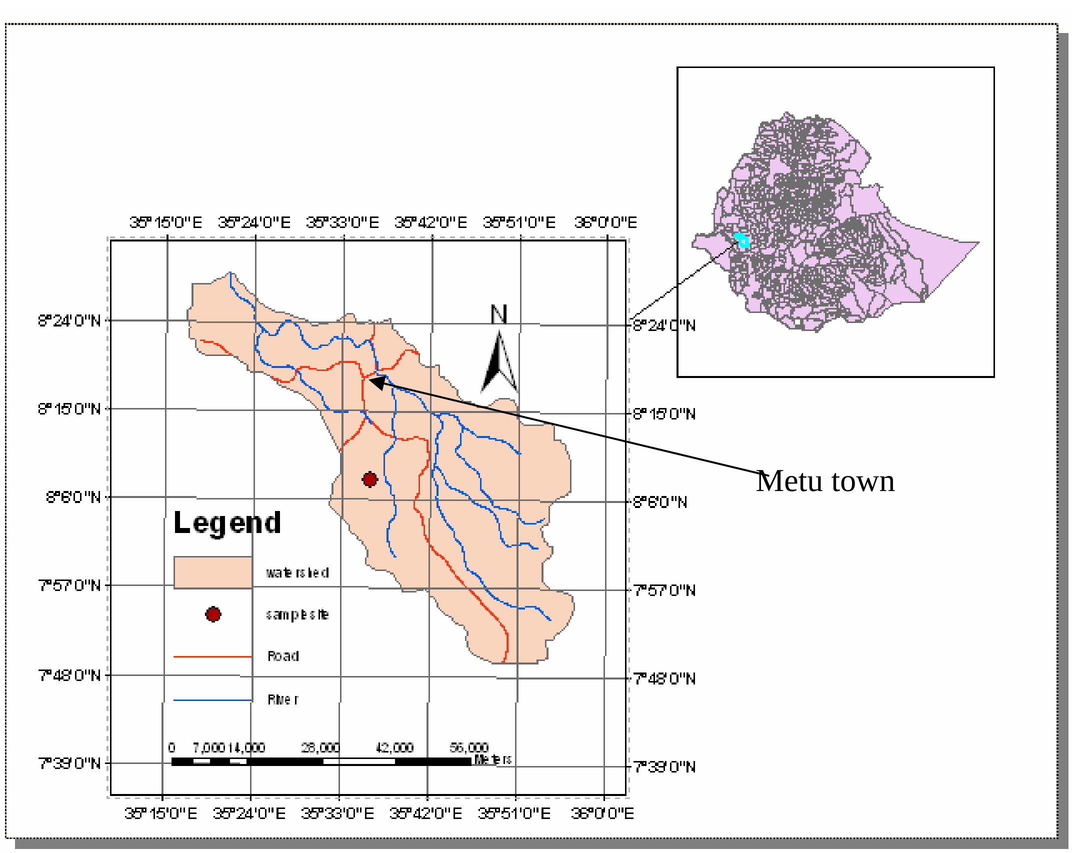


Fig. 8. Map showing study locations and sampling sites in Sor River.

Basin	Rivers /streams	Sites/Codes	Status and land use
Abay	Dabena	D (10 km south of Bedele town)	Reference -un impacted
Baro	Sor	S (Near Metu town)	Reference -un impacted-
Omo-Ghibe	Megecha	M (Upstream Gubre town)	Reference -un impacted
	Wabe	W (7km SW of Wolkitie Town	Reference -un impacted
	Ghibe	G (upstream of the main bridge to Jimma)	Reference -un impacted
Abay	Chacha	C_1 (Up stream of Chacha town) C_2 (Downstream of Chacha town)	Rural -less impacted (Deforested- agricultural)
Awash	Modjo	M1 upstream of Modjo town	Rural -less impacted (Deforested- agricultural)
		M2 after the effluent of Modjo tannery	Urban-highly impacted (Residential-industrial)
		M3 down stream of all tanneries in Modjo	Urban-highly impacted (Residential-industrial)
		M4 at the joint of Modjo River to Koka dam	Rural-Highly impacted (Deforested, agricultural irrigation)
	Kebena-Akaki	A1.(Gurara at Entoto)	Rural -less impacted
		A2.(Kebena bridge)	Urban-highly impacted (Residential-industrial)
		A3. (Bole bridge)	Urban-highly impacted (Residential-industrial-irrigation)
		A4. (Down stream Akaki Textile Factory)	Urban-highly impacted (Residential-industrial-irrigation)

Table 1. Summary of the study sites

4. METHODOLOGIES

The study Sites were visited for biological, environmental and physico-chemical sampling from August 2005 to June 2006. The study area was mapped using geographic information system (Ethio-GIS Arch view soft ware) using the data obtained by global positioning system (GPS).

4.1. MACROINVERTEBRATE SAMPLING, PROCESSING AND IDENTIFICATION

Macroinvertebrate sampling was conducted in accordance with methods for Assessing Biological Integrity of Surface Waters (Plotnikoff and Chad.2001; KDOW, 2002a; Barbour *et al*. 1999). Stream sites were typically assessed at the reach scale, generally 200 m in length. For all sites (reference and disturbed), it was impossible to assume that the available niches (e.g., stones in riffles, sticks in pools, leaf packs, fine sediments e.t.c) were present in the same proportions; however, in nearly all streams, the same kinds of niches were available for sampling within the 200 m reach (except M3, M4 and A4). Riffles were sampled semi -quantitatively using surber (as a kick net), D-frame net or haul (scoop) net. Macroinvertebrate samples representative of the range of water flow conditions collected from all possible microhabitats were pooled into single sample for each site. To avoid possible seasonal effect samples were taken nearly in all seasons from most sites and again pooled for each site. In the field, all macroinvertebrates present in this composite (pooled) sample were preserved in 70% ethanol or 10% formalin (for highly polluted sites). To eliminate effects of substrate diversity biasing the semi-quantitative sampling, an effort was made to sample riffle habitats that afforded macroinvertebrates with the best arrangement or layering of cobble, gravel, and small boulders (e.g., habitat complexity, availability). Non-riffle habitats were sampled qualitatively to try to collect as many specimens as possible within the stream reach. To maintain the consistency of sampling effort, a sample was generally obtained within one hour at each site (30 minutes for riffle and 30 minutes for other micro habitats). In the laboratory, all invertebrates were sorted from debris, identified to the family level and enumerated.

For sites with high abundance of specimens (sites C2, A2 and M1), sub-sampling technique was used to isolate at least 200 individuals, from the original composite sample. These animals were sorted, enumerated, and identified. Animals remaining in the composite sample were surveyed, and single individuals representing rare ones not already included in the 200+ individual-sub sample were added to it. This step permitted us to note the presence of potentially important indicator species in the sample that otherwise would have been omitted.

The macroinvertebrates were identified in the laboratory to the family level using dissecting microscope and keys from literatures for tropical Africa (Durand, 1981) and other temperate keys (Merritt and Cummins, 1996). Scores for tolerance levels are given in ranges 0-10 in Bode *et al. (*1996)

4. 2. MACROINVERTEBRATE DATA ANALYSIS

Metrics: Attributes of the macroinvertebrate community that change in predictable ways in response to habitat disturbance are called “metrics.” A number of biotic metrics and indices were generated that described the macroinvertebrate community at each site. Multimetric analysis uses a set of metrics, or community attributes, that are known to be responsive to stream degradation (Karr and Chu, 1999). Each of these metrics is calculated from the sample data and then converted to a standardized score using scoring criteria. Scoring criteria are developed from examining relationships between individual metric scores and an indicator of impairment across a range of impairment levels, including undisturbed reference conditions. The standardized scores are then added to produce the final multimetric score for each site. These metrics, indices, and associated interpretation are described in the following subsections.

Benthic Index of Biological Integrity (B-IBI): The B-IBI was used for this study as this metric combines several distinctive, stress-influenced community characteristics into a single aggregate value that can be used to compare the level of stress evidenced by communities from different stream localities. For comparison, this Index is also applied to communities found at minimally disturbed, "reference" sites within the region. A B-IBI metric is tailored to a particular region by selecting for inclusion in the measure of those community characteristics which correlate most closely with a sequence of sampling sites arrayed by personal observation along a known gradient from least to most disturbed (Karr and Chu, 1999). In this case, disturbance reflects regionally appropriate sources such as sedimentation, run-off from congested areas, flow interruption by impoundments, etc. A description of each metric together with its expected response to disturbance is shown in Table 2.

Hilsenhoff Family Level Biotic Index (H-FBI): was used in this study as the Hilsenhoff Biotic Index summarizes the overall pollution tolerances of the taxa collected. This index has been used to detect nutrient enrichment, high sediment loads, low dissolved oxygen, and thermal impacts. It was originally developed to detect organic pollution. Individual families are assigned an index value from 0 to 10. Taxa with H-FBI values of 0-2 are considered intolerant, clean water taxa and taxa with H-FBI values of 9-10 are considered pollution tolerant taxa. A family level biotic index was calculated for each sample. Samples with H-FBI values of 0-2 are considered clean, 2-4 slightly enriched, 4-7 enriched, and 7-10 polluted. This index was combined with the above metrics for B-IBI calculation. H-FBI can be calculated as:

$$\text{H- FBI} = \Sigma\,(x_i * t_i)/(n),$$

Where,

x_i = number of individuals within a taxon
t_i = tolerance value of a taxon
n = total number of organisms in the sample.

Table 2. Description of each macroinvertebrate metric **(Barbour, *et al.* 1999)**

*BMI Metric	Description	Response to Impairment
Positive metrics		
Taxa Richness (TR)	Total number of individual taxa	Decrease
%Ephemeroptera (Ephem)	Percent composition of mayfly	Decrease
% Plecoptera (Pleco)	Percent composition stonefly	Decrease
% Trichoptera (Trico)	Percent composition of caddisfly	Decrease
% Baetidae (Baet)	Percent composition of mayfly family nymphs	Decrease
% EPT	Percent composition of mayfly, stonefly and caddisfly larvae	Decrease
% Odonata (Odon)	Percent composition of damson flies and dragonflies	Decrease
Shannon Diversity Index (SDI)	General measure of sample diversity that incorporates richness and evenness (Shannon and Weaver 1963)	Decrease
Negative metrics		
%Bloodred Chironomid(ChiR)	Percent composition of blood red midge larvae	Increase
% Diptera (Dipt)	Percent composition of “true” fly larvae	Increase
% Oligochaeta(Oligo)	Percent composition of aquatic worms	Increase
% Non-insect (NoIT)	Percent composition of non-insect BMIs	Increase
% Dominant Taxon (DT)	Percent composition of the single most abundant taxon	Increase
Abundance (#/ sample) (ABN)	Number of BMIs in sample	Variable

***** Benthic Macroinvertebrates Index

The above 14 metrics (including H-FBI), except abundance, were used to calculate the final macroinvertebrate multimetric values (B-IBI) for each site. The range of numbers that might be observed for each of these characteristics is divided into 3 sub-ranges representing values expected from least stressed ("reference" sites), intermediate, and most stressed communities. Then, depending on the range into which a specific characteristic at a particular site falls, it is assigned a score of 5, 3, or 1, respectively. This scoring is simply a standard. The B-IBI value is the sum of these character scores, generating a maximal (least stressed) score of 70 (14 characters each with a maximal score of 5) and a minimal value (most stressed) of 14x 1 = 14. B-IBI values were calculated in this way for each site. The B-IBI values are then standardized to 100-point scale giving 100 (least stressed), 60 (moderate) and 20 (most stressed) B-IBI values. To categorize the sites in to various impairment levels, the range of B-IBI numbers is divided into 3 sub-ranges, and then impairment levels were given as shown in table 3. So, the 100-point scale B-IBI values calculated at the family level may correspond to the following water quality assessments (Table 3)

Table 3. Methods of classification of water quality status based on impairment level from B-IBI data

B-IBI Value	**Water Quality Characterization**	**Impairment**
20-46	Very poor to Poor	Sever to Slight
46-72	Fair to Good	Moderate to Less
72-100	Very good to Excellent	Very little to None

4.3. ENVIRONMENTAL OBSERVATIONS

Elevation, altitude and coordinates were measured by using GPS model Garmin'seTrex^{R} Personal navigation ^{TM} . Total stream lengths were estimated from Microsoft Encarta premium software (2006). Catchment areas were determined from Ethio-GIS Arch view soft ware.

4.3.1. Stream Gradient

The average elevational change per stream length, or gradient, was visually estimated for the stream or stream segment lying upstream from each sampling site (as high, medium or low).

4.3.2. Physico-chemical data collection

Water samples for nutrients were collected from each site. 12 replicate samples were taken from each site. In the lab NO_3-N was measured calorimetrically (Hach spectrophotometer model DR/2010) by high range cadmium reduction or Medium range cadmium reduction method; Orthophosphate was measured by molybdate or Ascorbic acid method; At each site *in situ* metered-readings of dissolved oxygen (Hanna Instruments Model HI9443); temperature with a mercury thermometer; Conductivity and TDS by direct measurement method using Hach instrument and pH by pH meter (Hanna Instruments Model H9024) were taken.

4.3.3. Habitat assessment

Habitat features, guided by photographs and descriptions, were scored with the EPA Rapid Bioassessment Protocol (RBP) Habitat Assessment procedure following Barbour *et al.* (1999). This procedure qualitatively evaluates 10 important habitat components such as epifaunal substrate quantity and quality, embeddedness, velocity/depth regimes, sediment deposition, channel flow status and channel alteration, stream bank stability, bank vegetation protection, and riparian zone width (for high to medium gradient streams and other components for low gradient as indicated in Table 5. For this study, other five components supposed to be pertinent (Nutrient enrichment, water appearance, bank grass cover (graze), manure/human waste presence and canopy cover) were included. Some of these habitat factors can be more objectively determined and more useful than others. Each component was scored on a 20-point scale with a total possible summed score of 300. Detailed description of the above components and how to score each parameter are found in Barbour *et al*. (1999**).** For individual metrics and the total score, higher scores indicate better habitat and lower scores indicate habitat degradation.

4.4. STATISTICAL ANALYSES

A combination of univariate, bivariate, and multivariate statistics were used to evaluate differences in environmental and biological parameters among the references and impacted sites. Excel spreadsheet, Statistical soft wares like SPSS version 10 and MINITAB releaser. 14 were used for the statistical analysis.

The B-IBI in this study uses 14 metrics that are supposed to be most important and these are standardized to 5-point scale as discussed in section 4.2. After standardization, metric scores are added to produce the B-IBI score on a 70-point scale (then converted to 100-point scale). Detailed description for these metrics is provided in Table 2. The B-IBI is broken down into five narrative water quality ratings. Best communities are those that score at or above the 50th percentile of the reference distribution. Good communities score between the 5th and 50th percentile. Trisection of scores below the 5th percentile yields narrative ratings of Fair, Poor, and Very Poor. Actual rating criteria are done based on Pond *et al*. (2003)**.** For the purpose of this study, streams/rivers B-IBI values below a score of 68 would be impaired (i.e., fair, poor and very poor) (Table 4).

Exploratory box plots and scatter plots were viewed along with Pearson correlation coefficients and linear regression to evaluate relationships between environmental and biological data. Multivariate techniques (i.e., non-testable, exploratory statistics) including forms of ordination: principal components analysis (PCA), correspondence analysis (CA) and cluster analysis (dendrogram) were applied here. Ordination uses various algorithms that order sets of data points with respect to one or more axes (i.e., “the displaying of a swarm of data points in a two or three dimensional coordinate frame so as to make the relationships among the points in many dimensional space visible on inspection” [Pielou, 1984]). To assure statistical normality for these multivariate techniques, physical and biological variables were transformed (log (x+1)), square root, or arcsine), where appropriate.

Taxa composition was evaluated with Correspondence Analysis (CA). Correspondence Analysis is a weighted-average method that reciprocally double-transforms community data and computes eiganalysis to construct corresponding taxa and site ordinations (Ludwig and Reynolds, 1988). CA was used for exploratory purposes in investigating how communities differed from one another among differently impacted sites and reference sites. In CA, sites are plotted as points along the first two axes in taxa space. Points close together in ordination space indicate more similar faunal composition than points distant in ordination space. Other multivariate techniques included were principal component analysis and cluster analysis. The former technique was used to elucidate patterns in abiotic factors related to individual sites and among *a priori* site categories. PCA also uses eigenanalysis and constructs orthogonal axes (components) where sites are plotted as points in ordination space, and environmental variables are plotted as vectors where their length and direction (correlations or loadings) depends on their statistical importance to the overall ordination. To examine site reaches for patterns in community composition, cluster analysis was also performed on the data using the Sorenson (Bray-Curtis) association measure and flexible UPGMA (Un weighted Pair Group Method with Arithmetic mean)

Finally, significance tests were performed on environmental and biological parameters among the reference and the other impacted sites with student t-test. This test was used to determine the significant differences between group means in an analysis of variance setting, with alpha set at 0.05.

5. RESULTS AND DISCUSSIONS

A total of 15 sites from 8 rivers were surveyed during the study period. These included five reference sites, five slightly impacted sites and five highly impacted sites (Table 1). Mean physico-chemical data, RBP habitat score and summary of the macroinvertebrates collected from each site are given in Table 4, Table 5 and Appendix 3, respectively.

5.1. PHYSICAL COMPARISON

Environmental variables that are modified by watershed, riparian and in-channel habitat disturbances are well documented elsewhere in the literature (Branson and Batch, 1972; Curtis, 1973; Talak, 1977; Dyer, 1982; Green et al*. 2000; Howard* et al*., 2001; USGS, 2001a). Pond and McMurray (2002) reported that conductivity, dissolved oxygen, pH, sedimentation, and general habitat degradation were the most significant factors found between reference and impaired sites in streams. In this study high organic load, losses of riparian, in-channel and watershed vegetation (a resultant increase in TDS and conductivity) were the most significant factors that differentiate impacted from unimpacted sites.*

5.1.1. pH

pH was significantly higher ($p<0.05$) at Urban/industrial sites than at reference sites (Figure 9a). Reference and less impaired sites were also significantly different. However, less impaired versus Urban/industrial sites were not significantly different. Reference sites averaged 7.28 while less impaired, and Urban/industrial sites averaged 8.066 and 8.06 respectively. The highest values were found at impacted sites where pH ranged between 7.7 (A2) and 10 (M2).

When streams become excessively acidic or alkaline, the change can adversely impact the biota. As those fish and macroinvertebrates unable to tolerate the altered conditions decline, tolerant organisms increase in numbers due to a lack of competition for food and habitat. This results in an unhealthy biological community dominated by a few tolerant taxa. pH can have a direct effect on the physiology of an organism (Kimmel, 1983).

Mayflies are one of the most sensitive groups of aquatic insects to low pH. Stoneflies and caddisflies are generally less sensitive. Mayflies and other insects that normally live in neutral water experience a greater loss of sodium in their blood when exposed to low pH than do acid tolerant species (Sutcliffe and Hildrew, 1989). In this study, pH was higher than the neutral value, so the problem of low pH on the macroinvertebrates structure was improbable.

Elevated pH can also cause the toxicity of other pollutants. For example, at lower pH levels ammonia is ionized and not toxic to aquatic life. Above a pH of 9 (depending on temperature), ammonia becomes un-ionized and therefore toxic.

An increase of one pH unit will generally increase ammonia toxicity by a factor of ten. One of the most significant environmental impacts of pH involves synergistic effects. Synergy involves the combination of two or more substances that produce effects greater than their sum, a process important in surface waters. For example at lower pH levels, the toxicity of copper increases in the presence of zinc. The result of this study showed that there was a significant increase in pH at impacted sites than reference sites. The maximum pH (10) recorded was at Modjo down stream site (M2), which might have been the reason for the disappearance of most taxa, which were found at the immediate upstream site (M1).

5.1.2. Conductivity

In the present study, there were significant differences in conductivity (p<0.05) between most categories (Figure 9b). Reference and less impaired sites were also significantly different. Reference sites averaged 79.08 µS/cm, while less impaired (rural) and highly impaired (urban) sites averaged 306.1,and 871.25µS/cm, respectively. The highest values were found at five Urban/ industrial sites (A2, A3, A4, M2 and M3) where conductivity ranged between 674 and 1201µS/cm. It is generally known that watershed disturbance (and associated erosion) and urban organic loading increase stream water ionic concentrations and subsequently conductivity (Curtis, 1973; Dyer, 1982; Dow and Zampella, 2000). In general, runoff from urban areas, which might bring multitude of wastes such as point discharge of industrial and residential wastes, contributes to this elevated conductivity, and can add high amounts of sediment to receiving streams. The results of this study agree with this idea.

5.1.3. Total Dissolved Solids (TDS)

In this study, there were significant differences in TDS (p<0.05) between most categories (Figure 9c). Reference and less impaired sites were also significantly different. Reference sites averaged 51.1 mg/l, while less impaired (rural) and highly impaired (urban) sites averaged 203.1, and 642.07mg/l, respectively. In the same way as conductivity, the highest values were found at five Urban/ industrial sites (A2, A3, A4 M2 and M3) where TDS ranged between 424 and 1040 mg/l. The most probable reason for this elevation of TDS is watershed disturbance (and associated erosion) and urban organic detritus loading.

5.1.4. Dissolved oxygen (DO)

There were significant differences in dissolved oxygen (p<0.05) between most sites (Figure 9d). Reference and less impaired sites were also significantly different. Reference sites averaged 11.3 mg/l, while less impaired (rural) and highly impaired (urban) sites averaged 9.1, and 5.03 mg/l, respectively. The *highest values were found at all reference sites and three rural sites (A1, M1, and C1) where it ranged between 9.24 and 14.1 mg/l.*

5.1.5. Nitrate-Nitrogen (NO_3-N)

There were significant differences in nitrate-nitrogen ($p<0.05$) between urban sites and other sites (Figure 9e). Reference and less impaired sites were also significantly different. Reference sites averaged 0.816 mg/l, while less impaired (rural) and highly impaired (urban) sites averaged 1.63 and 20.68 mg/l, respectively. The highest values were found at three Urban/ industrial sites (A2, A3 and A4) where it ranged between 31 and 36 mg/l. The slightly elevated nitrate-nitrogen in the reference sites was found during flooding where the flood brings nutrients from wide array of the catchment area.

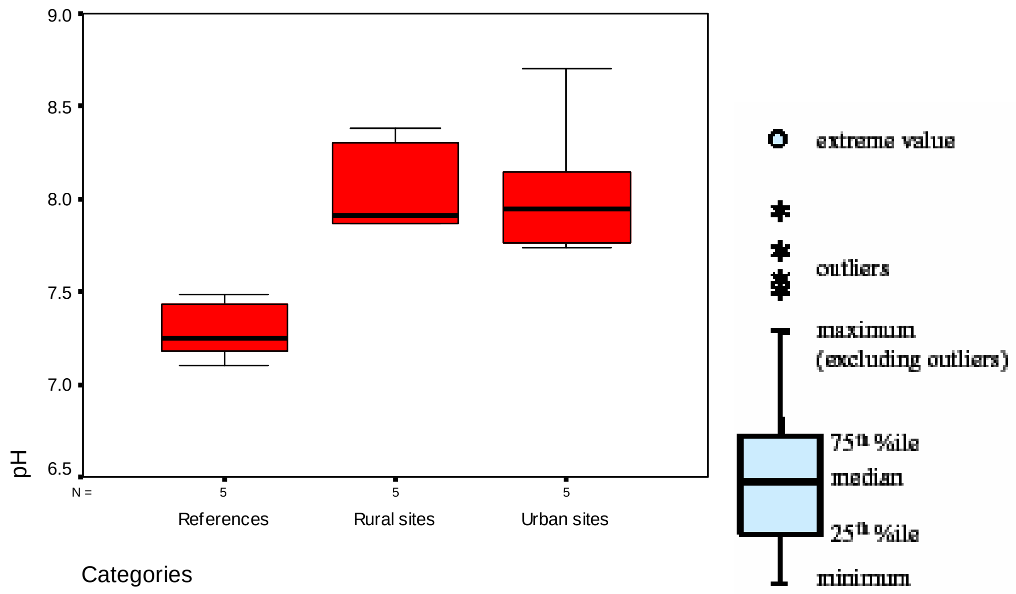
5.1.6. Phosphate (PO_4)

Phosphate result is in line with that of NO_3-N. There were significant differences in phosphate ($p<0.05$) between urban sites and other sites (Figure 9f). Reference and less impaired sites were not significantly different. Reference sites averaged 0.133 mg/l, while less impaired (rural) and highly impaired (urban) sites averaged 0.38 and 2.9 mg/l, respectively. The highest values were found at three Urban/ industrial sites (A2, A3 and A4) where the mean values ranged between 2.86 and 5.99 mg/l.

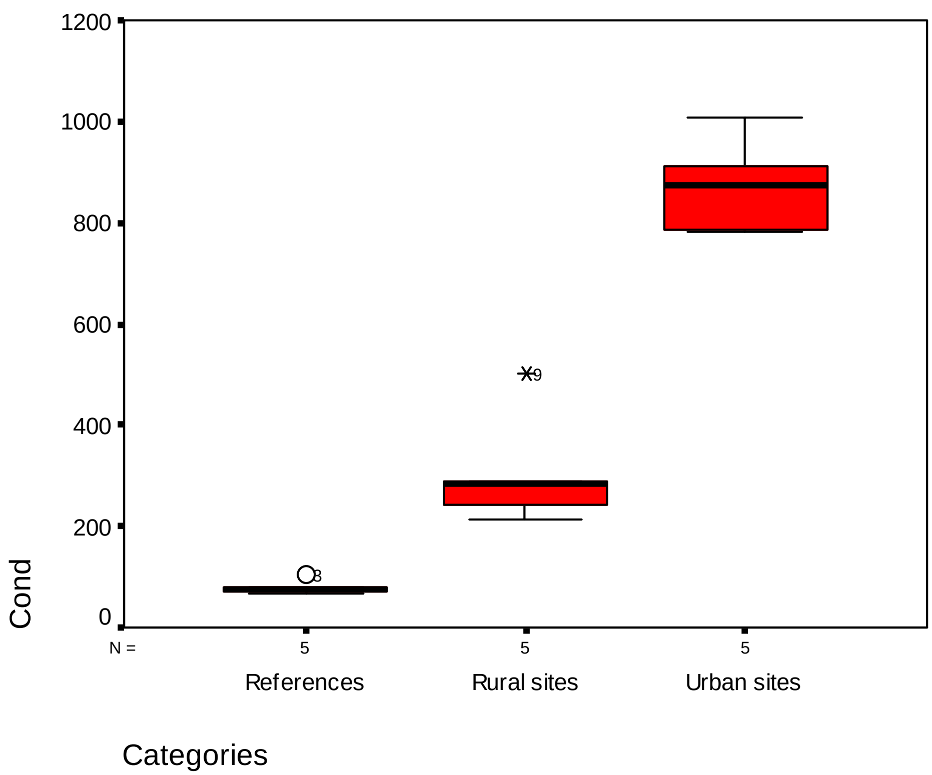
Table 4. Mean values (±SD, N=12) of some physico-chemical characteristics of the study sites (conductivity in µS/cm, pH in pH scale, Nutrients, dissolved oxygen (DO) and Total dissolved solids (TDS) in mg/l, and Temperature in ^{o}C)

Sites	**Parameters**						
	pH	**Conductivity**	**TDS**	**Temp.**	**DO**	**NO_3-N**	**PO_4**
D	7.1±0.11	69.54±8.2	33.814±3.5	22.4±2.1	13.17±0.86	0.86±0.33	0.025±0.01
S	7.25±0.13	74.83±18	33.389±10.2	21±1.2	12.23±0.25	0.76±0.14	0.19±0.051
G	7.18±0.21	103.25±30.2	93.17±40.1	27.15±0.31	10.3±3.6	0.79±0.58	0.2±0.09
W	7.43±0.2	79.29±11	57.886±29.4	20.65±0.69	10.1±0.99	0.85±0.27	0.14±0.004
M	7.48±0.13	68.49±15.63	37.357±25.2	19.85±1.2	9.725±1.01	0.82±0.26	0.11±0.007
C1	7.91±0.16	285.6±25.01	182.4±15.3	17.8±3.96	9.243±1.66	1.9±0.63	0.41±0.1
C2	8.3±0.5	287.4±15	191.37±38.5	15.33±0.52	8.009±2.1	1.97±0.19	0.39±0.11

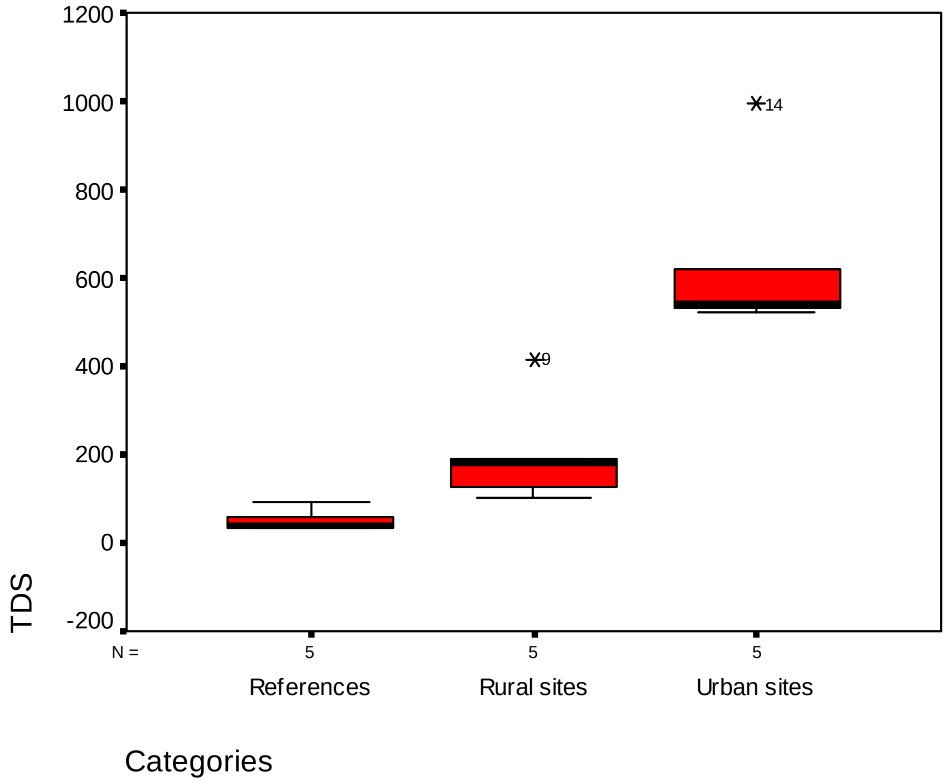
M1	7.87±0.54	213±95.31	125.79±85.3	23.69±5.2	9.58±2.15	0.7±0.5	0.21±0.11
M2	8.7±0.82	910.2±186.8	543.37±134.6	24.18±4.3	6.1±4.01	1.15±0.28	1.987±1.01
M3	8.15±0.15	781.3±120.1	619.82±78.12	23.9±5.37	6.14±1.75	1.5±. 52	0.6±1.04
M4	7.87±0.1	500.5±204.7	415.87±105.2	19.68±3.4	7.45±0.89	2.7±. 124	0.52±0.004
A1	8.38±0.24	244±29.1	103±2.71	21±1.2	11.54±1.25	0.91±0.29	0.36±0.002
A2	7.74±0.08	873±48.32	524±32.12	20±2.1	5.2±1.98	31.5±5.14	3.1±1.9
A3	7.95±0.12	1006±100.1	993.5±70.7	19.3±1.2	3.1±2.4	36.66±11.2	5.99±2.5
A4	7.760±0.15	785.75±28.6	529.6±57.3	19.6±1.3	4.9±2.01	32.6±6.72	2.86±1.04


9.0
8.5
8.0
7.5
7.0
6.5
pH
N =
5
5
5
References
Rural sites
Urban sites
Categories
extreme value
outliers
maximum
(excluding outliers)
75th %ile
median
25th %ile
minimum

a

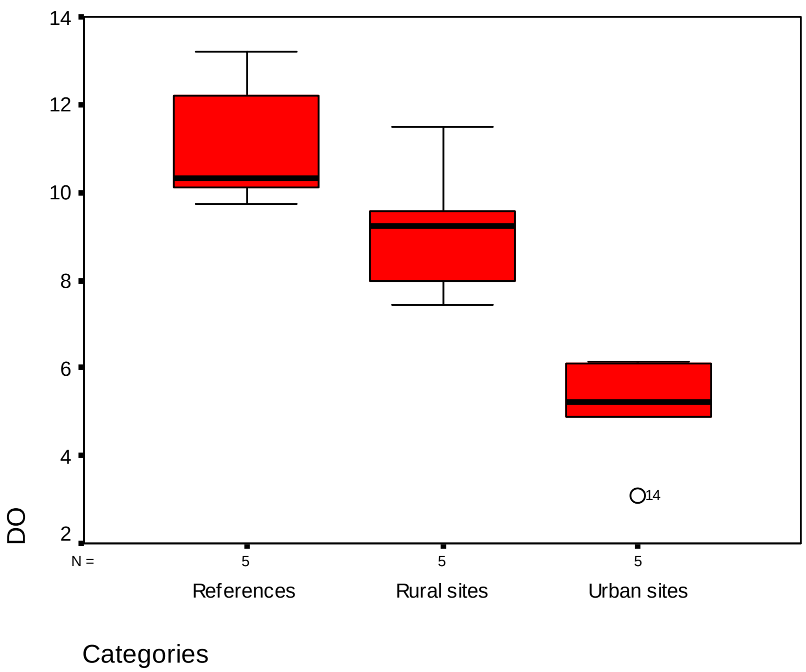

1200
1000
800
600
400
200
0
Cond
9
3
N =
5
5
5
References
Rural sites
Urban sites
Categories

b



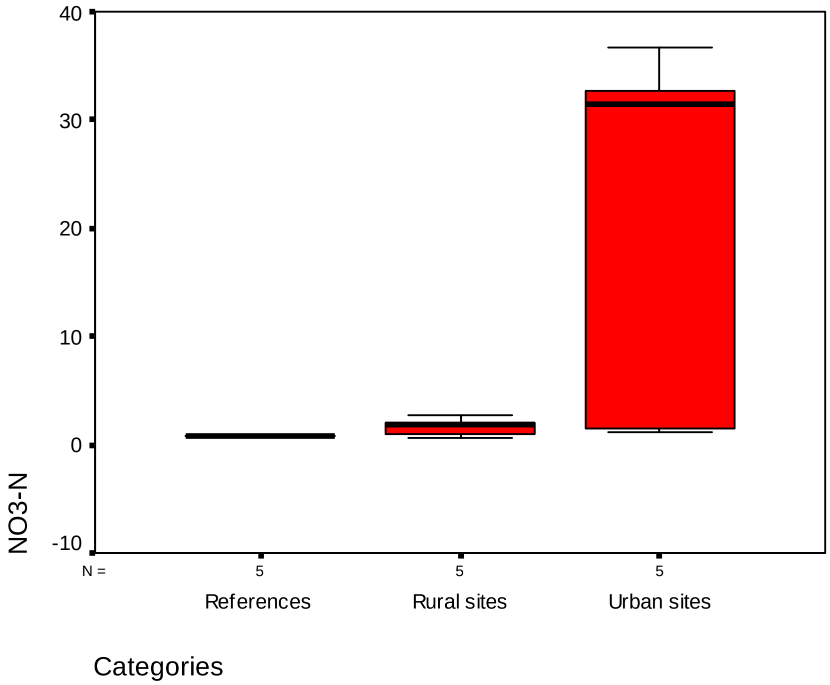
1200
1000
800
600
400
200
0
-200
TDS
14
9
N =
5
5
5
References
Rural sites
Urban sites
Categories

c

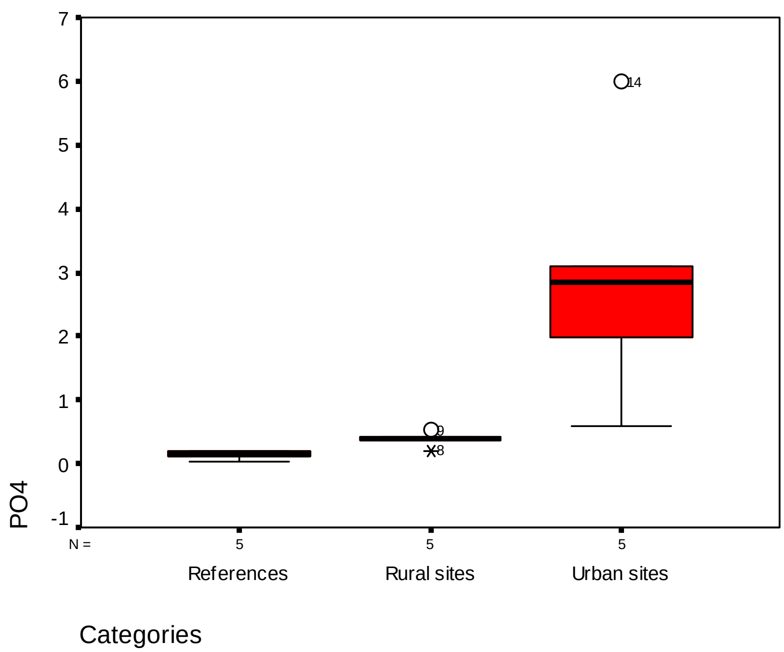


14
12
10
8
6
4
2
DO
14
N =
5
5
5
References
Rural sites
Urban sites
Categories

d



e



f

Figure 9. Box plots of (a) p^H, (b) conductivity, (c) TDS, (d) Dissolved oxygen. (e) NO3-N and (f) PO4 among primary land-use types. Legend for box plots is shown at the far right of page 35.

5.1.7. Habitat quality parameters

In terms of general habitat degradation, reference streams had significantly higher total habitat scores ($p<0.05$) (Figure10h), also substantial differences were found between rural (deforested/agricultural) and Urban/industrial sites. The average reference habitat score was 97.32, while deforested /agricultural and Urban/industrial sites averaged 68.32 and 50.18, respectively. Excessive organic loading (Plate I-N) and extensive riparian zone degradation (Plate I) in Akaki-Kebena and Modjo down stream sites have adversely affected these rivers' faunal structure. In addition, intensified bank erosion (bank instability) caused by hydrologic modification (e.g., impoundment, roads, bridges, and culverts) has substantially increased sedimentation in Akaki-Kebena down stream site (A4) and Modjo site (M4) (plate J).

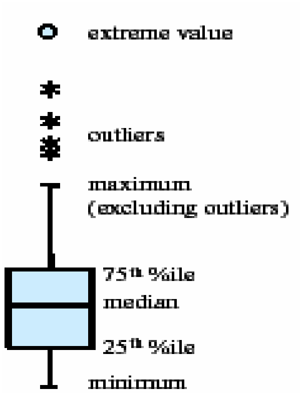
Other factors such as reduced canopy cover and riparian width can have direct influences on macroinvertebrate communities that respond to stream temperature, bank habitat and stability, and changes in the food-energy base (e.g., Sweeney, 1993). Most reference sites had the natural complement of mature forest with dense canopies (Plate A-D), but this condition was met at none of impacted site except little vegetation cover at site A1.

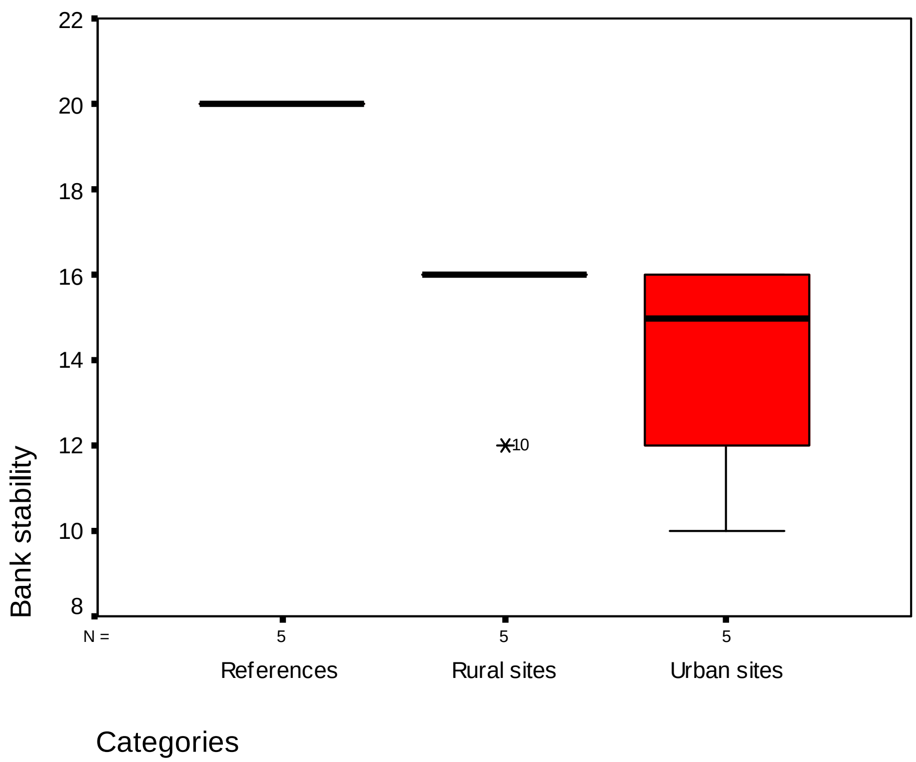
In intermittent streams, many aquatic insect taxa are adapted to resist desiccation through resting or diapausing eggs, larvae or pupae (Williams, 1996). Dense summer canopies may maintain high relative humidity and reduce desiccation stress in the dry streambed sediments (Fritz and Dodds, 2004), thus assuring recruitment of the next year's insect community. With regard to riparian zone width reference sites had significantly higher width than the two disturbed categories, but rural (deforested /agricultural) sites had less scores than even Urban/industrial sites (Figure 10c), this indicated that extensive agricultural activities with subsequent riparian deforestation in the rural areas has been the main threats to aquatic ecology.

Table 5. Habitat parameters score of each site (ND=Not determined, HG=high gradient, LG=low gradient, site codes are as in Table 1)

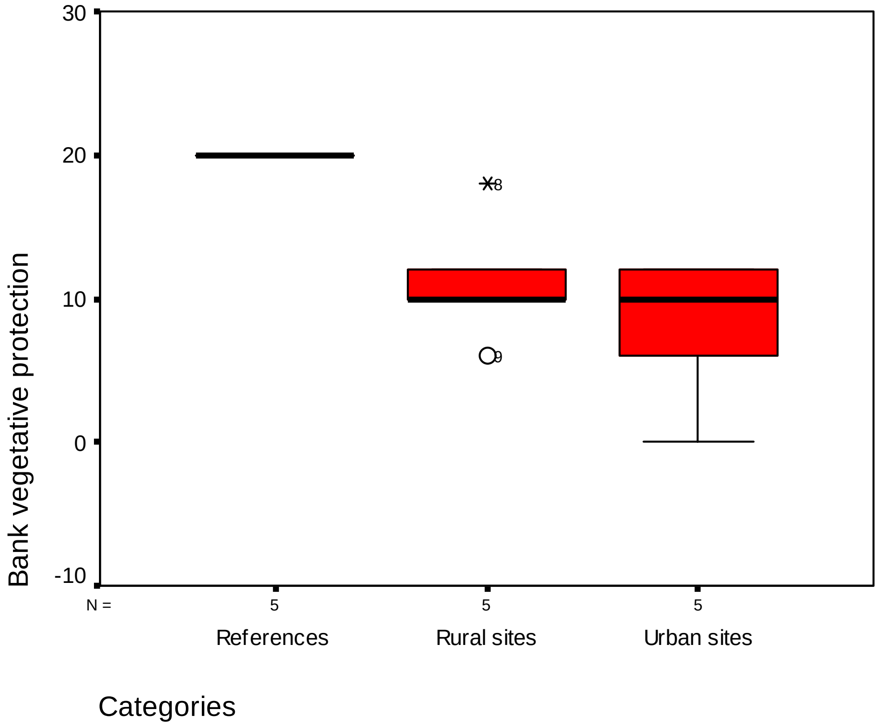
Parameters	Sites														
	D	S	G	W	M	C1	C2	M1	M2	M3	M4	A1	A2	A3	A4
Epifaunal substrate / available cover	20	20	20	20	20	16	16	18	18	5	10	18	20	20	15
Embeddedness **(**HG**)**	20	20	20	20	20	ND	ND	18	18	10	0	20	20	20	ND
Pool substrate characterizations (LG)	ND	ND	ND	ND	ND	20	20	ND	ND	ND	10	ND	ND	ND	10
Pool variability (LG)	ND	ND	ND	ND	ND	20	20	ND	ND	ND	15	ND	ND	ND	10
Sediment deposition	20	20	20	20	20	20	20	18	18	20	0	20	20	20	5
Channel flow status	20	20	20	20	20	20	20	18	18	18	20	6	10	10	20
Channel alteration	20	20	20	20	20	20	20	18	10	18	15	20	15	15	15
Channel sinuosity (LG)	ND	ND	ND	ND	ND	20	20	ND	ND	ND	18	ND	ND	ND	20
Bank stability	20	20	20	20	20	16	16	16	16	16	16	12	12	10	15
Bank vegetative protection	20	20	20	20	20	10	10	18	10	0	6	12	12	12	6
Riparian vegetative zone width	20	20	20	20	20	0	0	10	10	0	6	12	10	10	10
Frequency of riffles (or bends) **(**HG**)**	20	20	20	20	20	ND	ND	18	18	18	0	20	20	20	ND
Velocity / depth regime **(**HG**)**	20	20	20	20	20	ND	ND	16	16	16	0	10	16	16	ND
Manure presence / human waste	20	20	20	20	20	4	4	6	4	10	8	16	0	0	0
Canopy cover	20	20	4	15	15	0	0	0	0	0	0	0	0	0	0
Nutrient enrichment	20	20	18	18	18	10	10	10	0	0	5	18	0	0	0
Water appearances	20	20	18	20	20	16	15	15	0	4	10	20	0	0	4
Graze (bank grass covers)	20	20	18	18	18	20	20	10	6	0	15	5	6	6	8
Total habitat score	300	300	278	291	291	212	211	209	162	133	154	209	161	159	138
Scores (from100%)	100	100	92.6	97	97	76	75.6	69.6	54	44.3	51.3	69.6	53.6	53	46

Legend

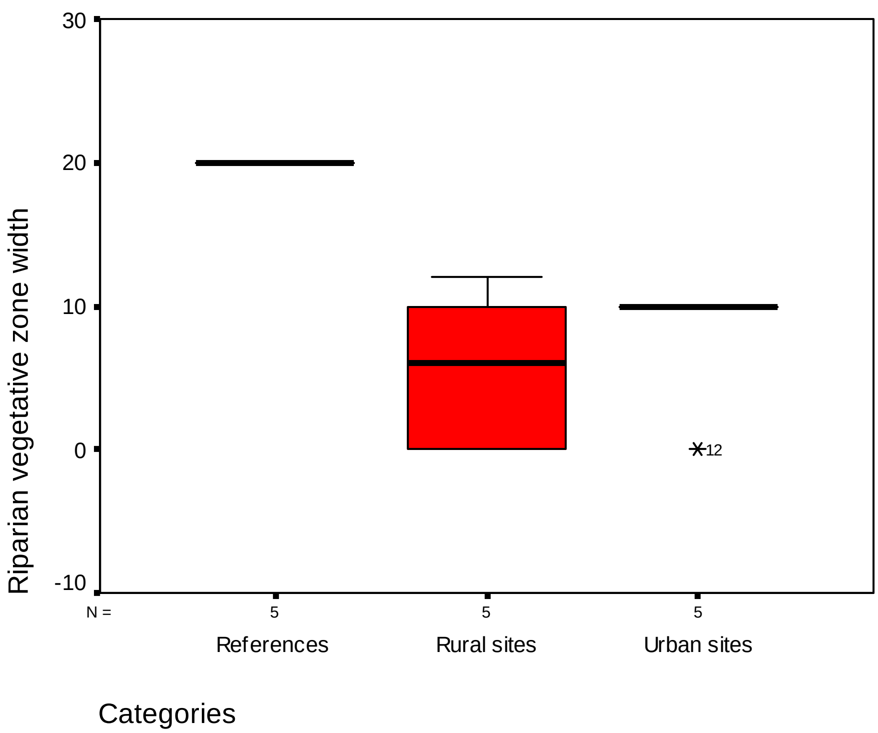

extreme value
outliers
maximum
(excluding outliers)
75th %ile
median
25th %ile
minimum


22
20
18
16
14
12
10
8
Bank stability
10
N =
5
5
5
References
Rural sites
Urban sites
Categories

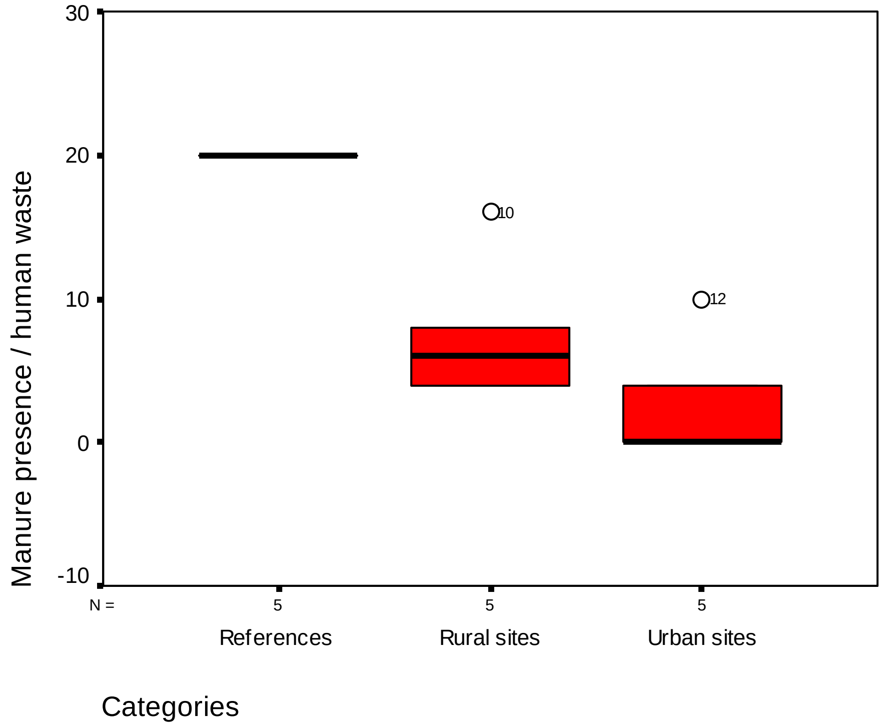
a


30
20
10
0
-10
Bank vegetative protection
8
9
N =
5
5
5
References
Rural sites
Urban sites
Categories

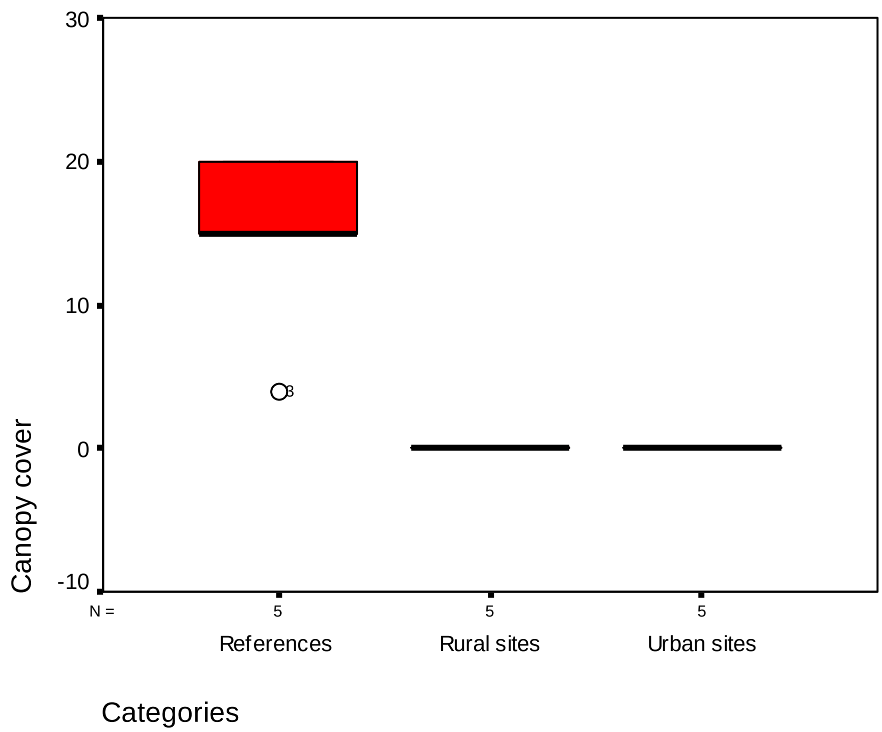
b


30
20
10
0
-10
Riparian vegetative zone width
12
N =
5
5
5
References
Rural sites
Urban sites
Categories

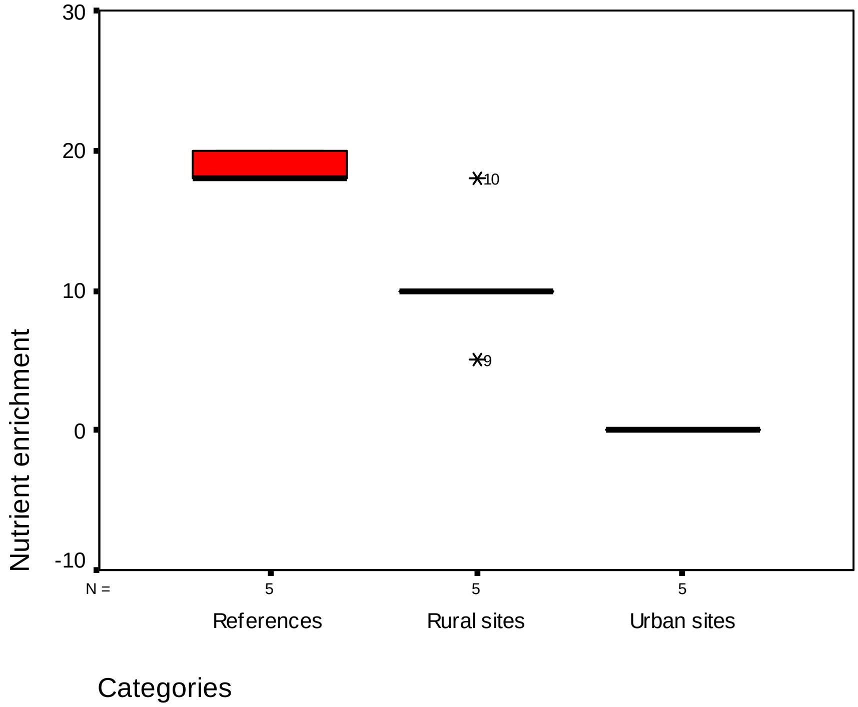
c


30
20
10
0
-10
Manure presence / human waste
10
12
N =
5
5
5
References
Rural sites
Urban sites
Categories

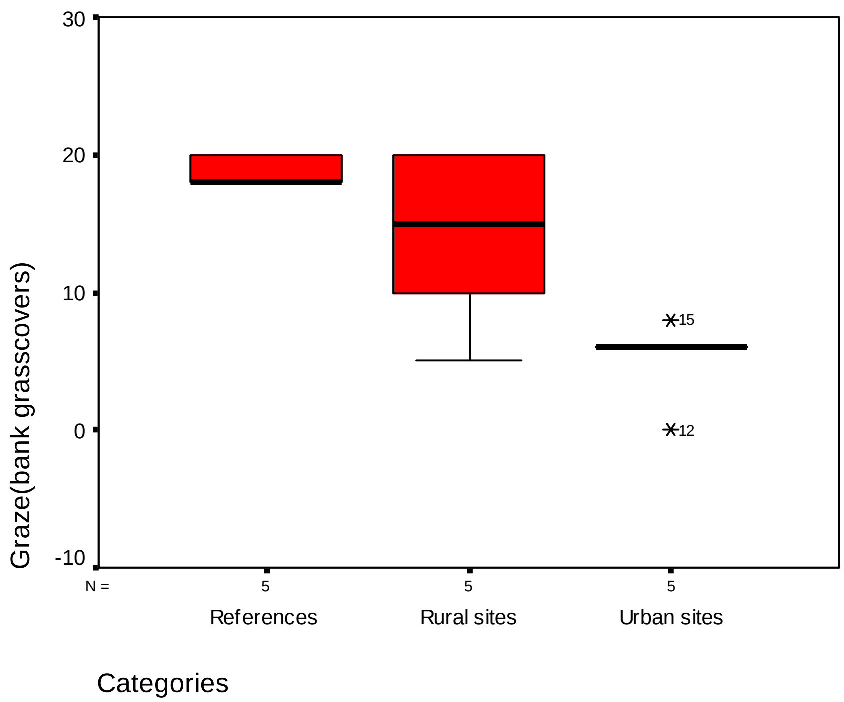
d


30
20
10
0
-10
Canopy cover
3
N =
5
5
5
References
Rural sites
Urban sites
Categories

e


30
20
10
0
-10
Nutrient enrichment
10
9
N =
5
5
5
References
Rural sites
Urban sites
Categories

f


30
20
10
0
-10
Graze(bank grasscovers)
15
12
N =
5
5
5
References
Rural sites
Urban sites
Categories

g

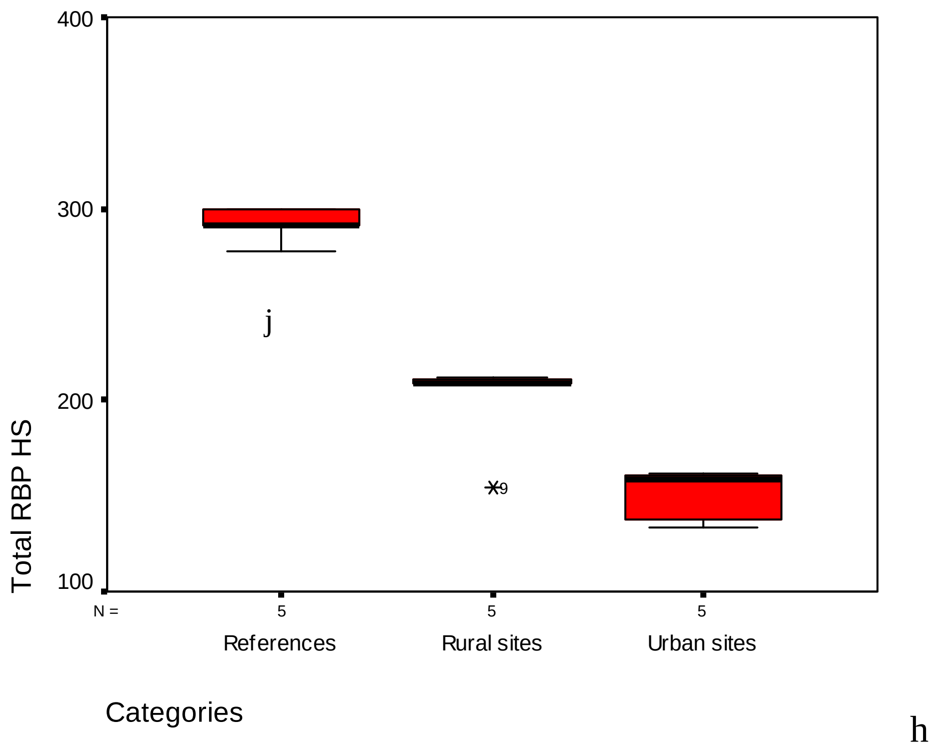


Figure 10. Box plots of most Habitat parameters (a - h) among primary land-use types. Legend for box plots is shown at the top of page 40.

The PCA ordination (Figure 11) verified that reference sites were highly similar with respect to physical variables such as RBP habitat parameters and physicochemical measurements. The dispersion of disturbed sites in ordination space also clearly demonstrated that physical habitat was different from the reference condition. It was not surprising that habitat metric scores (shown as lines) were weighted toward reference sites in ordination space since by definition all reference sites have good habitat. The conductivity, TDS, NO_3-N, $P0_4$ and pH vectors pointed toward impacted sites. Axis 1 explained 58.5 percent of the variance whereas axis 2 explained only 13.8 percent of the variance. Eigenvalues for the first four axes and PCA loadings (correlations) of all variables are shown in Appendix 2. The RBP total habitat score (-0.282), conductivity (0.28), nutrient enrichment (-0.28), dissolved oxygen (-0.271), TDS ((0.261) and water appearance (-0.271) had the highest factor loadings on axis 1. These parameters represent the most important factors related to the dispersion of sites along the horizontal axis.

Epifaunal substrate available, PO_4, NO_3-N, riparian vegetation, channel flow status and bank vegetation cover scores had highest loadings on axis 2 (0.476, 0.368, 0.35, 0.344, -0.337 and 0.313, respectively). Most of the variance (72.3%) is explained by axis 1 and 2. Although axis 3 and 4 variables contributed much less than the first axes and also less than axis 2, they added a combined 16.2% of the total explained variance. Compared to environmental conditions found at reference sites, the PCA ordination showed most of the urban sites had higher axis 1 and axis 2 coordinates, while the majority of rural sites plotted with lower axis 1 and axis 2 coordinates. This suggests measurable differences in these two land-use categories.

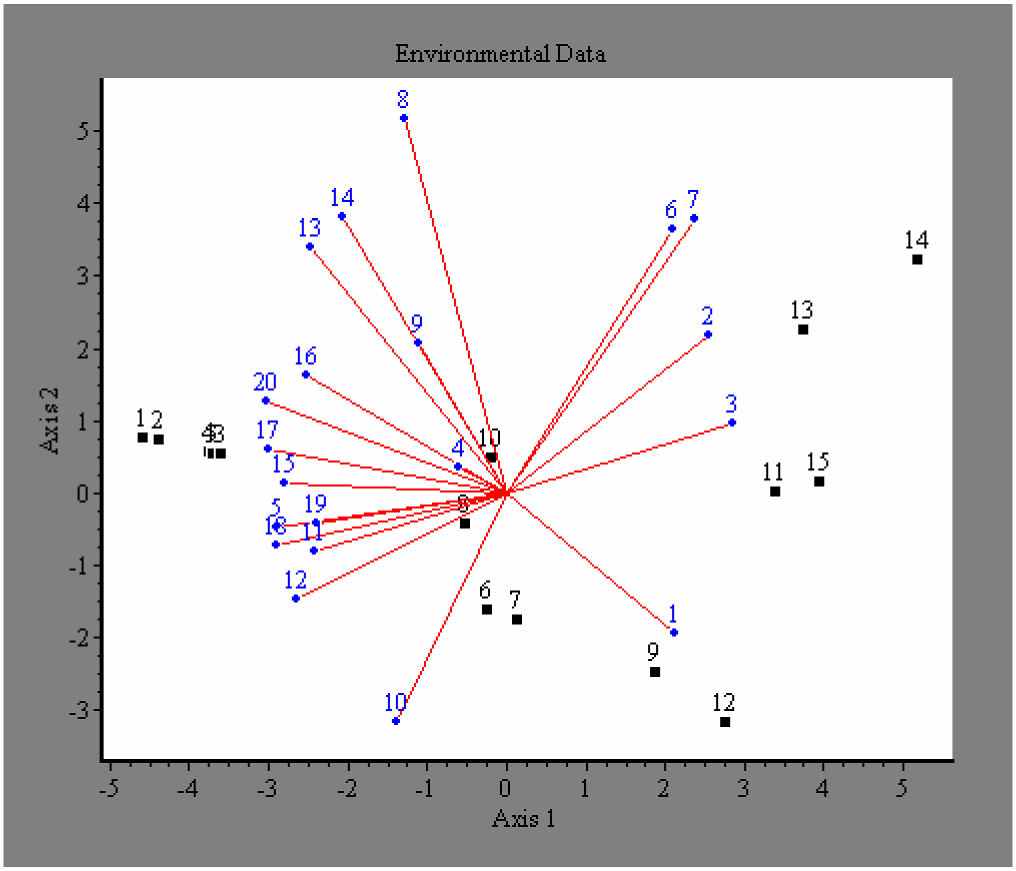


Figure11. Principal components analysis (PCA) ordination based on RBP habitat metrics and physicochemical measurements (vectors) among land-use categories. Numbers 1-20 in blue color stands for all parameters and numbers1-15 in black color refer to the sites as indicated in the table below.

Keys for figure 11 below

Code	Sites	Variables			
1	RF-Dabena	1	P^H	11	Channel alteration
2	RF-Sor	2	Conductivity	12	Bank stability
3	RF-Ghibe	3	Total dissolved solids	13	Bank vegetative protection
4	RF-Wabe	4	Temperature.	14	Riparian vegetative zone width
5	RF-Megecha	5	Dissolved oxygen	15	Manure presence / human waste
6	RU-Chacha1	6	NO_3-N	16	Canopy cover
7	RU-Chacha2	7	PO_4	17	Nutrient enrichment
8	RU-Modjo1	8	Epifaunal substrate / availablecover	18	Water appearances
9	RU-Modjo4	9	Sediment deposition	19	Graze (bank grasscovers)
10	RU-Akaki-kebena1	10	Channel flow status	20	RBP totttal habitat score
11	UR-Modjo2				
12	UR- Modjo3				
13	UR-Akaki-Kebena2				
14	UR- Akaki-Kebena3	15	UR-Akaki-kebena4		

5.2 BIOLOGICAL PARAMETERS

5.2.1. Benthic Macroinvertebrates

A total of 17,847 macroinvvertebrate individuals belonging to 63 families were collected from 15 sites during the survey work. Taxonomic groups and their relative abundances at each collection site and among major categories (Land uses) are shown in Appendices 3 and 4, respectively. Macroinvertebrate sample sizes ranged from 161(Ghibe site) to 2910 (Akaki- Kebena site 2) animals per sample at the sites, and taxa richness at the sites ranged from 11 (Akaki-Kebena site 3 and Modjo site 3) to 34 families (Dabena River site). Chironomidae (Diptera) was the most abundant family collected (5992 individuals), followed by Simulidae (Diptera, 2269 individuals), Oligochaeta (1628 individuals), Baetidae (mayflies, 1620 individuals), Corixidae (waterboatsmen) (Hemiptera, 1365 individuals), then Caenidae (mayflies, 1294 individuals*).* Among the 63 families collected, 33 were common or very common and the rest 30 were rare. The relative distribution of the common ones are shown in Table 6. Most of the rare families were collected from reference sites.

Table 6 (a-d). Common macroinvertebrate families at major categories (land uses)

(a) Taxa very common in Reference sites

Taxa	Abundance	%
Heptageniidae (Flathead Mayflies)	72	66.7
Aeshnidae (darner Dragonflies)	16	64
Gomphidae (Club-Tail Dragonflies)	13	81.3
Macromiidae(Common-Skimmer Dragonflies)	25	100
Libellulidae (Common-Skimmer Dragonflies)	32	65.3
Perlidae (Common Stoneflies)	45	100
Philopotamidae (Finger-Net Caddisflies)	42	87.5
Phryganeidae(Giant Case-Maker Caddisflies)	17	68
Tipulidae (Crane Flies)	24	85.7
Turbellaria(Flat worms)	30	90.9

(b) Taxa very common in rural sites

Taxa	Abundance	%
Caenidae (Small Square-Gill Mayflies)	1206	86.5
Coenagrionidae(Narrow Winged Damselflies)	240	93.8
Corixidae (waterboatmen)	1235	90.5
Notonectidae (back Swimmers)	630	89.1
Veliidae(Broad Shouldered Water Striders)	41	61.2
Dytiscidae (Predaceous Diving Beetles)	109	84.5
Gyrinidae (Whirligig Beetles)	193	90.2
Hydrophilidae (Water Scavenger Beetles)	75	75
Chironomidae, Other (including pink)	1198	62.6
Sciomyzidae(snail-killing,marsh flies)	19	86.4
Simulidae (Black Flies)	1411	62.3

(c) Taxa very common in urban sites

Taxa	Abundance	%
Chironomidae (Blood-red)	4042	99.09
Culicidae (Mosquitoes)	205	90.31
Ephydridae (Shore Flies, Brine Flies)	39	97.5
Psychodidae (Moth Flies)	265	97.43
Syrphidae (Rat-Tailed Maggots)	47	100
Physidae(Snails)	140	99.29
Oligochaeta (Aquatic Earth worms)	1616	99.26
Bolded taxa =The most abundant		

(d) Taxa more common to reference and rural sites

Taxa	RF	%	RU	%
Baetidae (Small Minnow Mayflies)	587	36.2	906	55.9
Naucoridae(Creeping Water Bugs)	81	47.9	86	50.9
Elmidae (Riffle Beetles)	98	47.3	94	45.4
Ceratopogonidae (Biting Midges)	23	40.4	27	47.4

Midge larvae were encountered at all sites, and in significantly different abundances. The universal nature of chironomids suggests that relative abundances of the larvae may be a useful measure of water quality in these areas. Chironomidae larvae may be more effective indicators of increased stress, as they have been shown to become dominantly abundant under these circumstances (Buss et al.*, 2002).*

Blood-red chironomids, found in abundance at impacted sites, are able to withstand low levels of dissolved oxygen because they use high affinity hemoglobin and thus are indicative of high levels of organic pollution (Thorp and Covich, 1991). Accordingly, these Bloodred chironomids were extremely dominant at all highly impacted sites (A2, A3, A4 and M3) (Table 6c).

The complete absence of perlidae (stoneflies) from impacted sites nominates them as indicators of good water and habitat quality. Perlidae absence is probably due to high organic input, and thus low dissolved oxygen concentrations due to bacterial respiration (Wetzel, 2001).

Lower abundances of individual macroinvertebrates observed at all reference streams are in accordance with the concept that as stream canopy cover increases primary production decreases, and can thus support fewer invertebrates than a stream that is not light limited (Hauer and Lamberti, 1996). In addition, mild pollution has a tendency to increase total abundance.

Taxa richness was almost as in a typical of pristine streams at non-impacted sites in this study. However, more additional taxa should have been collected, as most reference sites are very pristine. The under expected number of taxa from these reference sites was most likely due to small sample size and not sampling all available habitats as the sampling reach are short stretches. As sample areas increase, it would be expected that the homogeneity of habitat type in the impacted streams, due to pollution, would lead to lower taxa accumulation, while taxa accumulation would increase in non-impacted sites with a far more diverse range of habitats. Future studies should sample more areas and different habitat types to compile relatively complete taxa lists at a given area.

Macroinvertebrate metrics were generated from these biological data as shown in Table 7. Using the 15-sampling sites from these rivers, community characteristics most closely follow such a human-related stress gradient (Figure 12). The B-IBI and related metrics result in Table 8 showed the impairment levels of the study sites as six of the sites were highly disturbed, two were moderately disturbed, and the rest were relatively undisturbed.

Table 7(a). Metric scores of macroinvertebrate communities at each of 15 sites sampled. Rives are listed in order of their overall condition rank from highest to lowest ranks (status)(RF=references, RU=rural sites, UR=urban sites; site codes are as in Table 1)

								Raw Scores									
SITES	**Land use**	**Relative Abn**	**Abundance**	**RelativeTR**	**% Baet**	**%Trico**	**%Pleco**	**%Ephem**	**% Odonat**	**%EPT**	**SDI**	**%DT**	**%Diptera**	**H-FBI**	**%oligo**	**% red chiro.**	**%Non-ins**
D	RF	3.41	608	53.1	15	14.5	3.5	32.6	2.3	50.5	2.7	16	20	4.54	0.3	0.3	4.1
S	RF	1.87	333	45.3	41	3.3	3.6	68.5	2.4	74.2	4	41	4.5	4.9	0	0	1.2
G	RF	0.9	161	34.4	21	1.24	8.9	25	19	33	2.5	21	11	4.3	1.2	0	3.1
W	RF	3.33	594	50	18	8.9	0.2	20	4.8	31	2.2	34	53	4.8	0.1	0.1	1.2
M	RF	4.45	794	46.9	27	5.3	0.5	31	3.4	36	2.2	34	43	5.1	0.5	0.5	1.6
C1	RU	6.1	1088	37.5	24	0.9	0.1	28	7.5	29	2.3	24	9.8	5.1	0	0.1	1.8
C2	RU	6.33	1130	37.5	21	0.5	0	39	11	36	2.3	21	15	5.8	0.1	8.8	1
M1	RU	9.35	1669	32.8	6.6	1.2	0	7.4	2.2	8	1.7	49	10	5.3	0.1	0.1	0
M2	UR	4.14	739	28.1	1.1	16	0	12	0	28	1.6	41	27	7.4	41	23	41
M3	UR	8.34	1489	17.1	0.4	0	0	0.4	0	0.4	0.6	84	96	7.3	8	84	0
M4	RU	9.37	1673	28.1	1.1	2.5	0	1.7	0.8	4	0.8	84	87	5.5	0	0.1	0.1
A1	RU	12.4	2214	35.9	12	0.2	0	57	0.4	88	1.5	44	37	5.2	0	0.6	0
A2	UR	16.3	2910	28.1	1	0	0	1.3	0.2	1.3	1.5	88	88	8	7.3	56	10
A3	UR	4.16	742	17.1	0.1	0	0	0.1	0	0.1	1.4	42	62	8.7	30	42	37
A4	UR	9.54	1703	26.5	0.4	0	0	0.4	0.1	0.4	1.1	51	47	8.3	51	37	52

Table 7(b) Standardized score of selected 14 metrics from Table 8a

Parameters															
SITES	**%TR**	**% Baet**	**%Trico**	**%Pleco**	**%Ephem**	**% Odonata**	**%EPT**	**SDI**	**%DT**	**%Diptera**	**H-FBI**	**%oligo**	**% Redchiro.**	**%Non-ins**	**B-IBI**
D	5	3	5	5	3	3	5	5	5	5	5	5	5	5	64
S	5	5	1	5	5	3	5	5	5	5	5	5	5	5	64
G	3	3	1	5	3	5	3	3	5	5	5	5	5	5	56
W	5	3	3	3	1	3	3	3	5	3	5	5	5	5	52
M	5	3	3	3	3	3	3	3	5	3	5	5	5	5	54
C1	5	3	1	1	3	5	3	3	5	5	5	5	5	5	54
C2	5	3	1	1	3	5	3	3	5	5	3	5	5	5	52
M1	3	1	1	1	1	1	1	3	3	5	5	5	5	5	40
M2	1	1	5	1	1	1	1	1	3	5	1	1	5	1	28
M3	1	1	1	1	1	1	1	1	1	3	5	5	1	5	28
M4	3	1	1	1	1	1	1	1	1	1	5	5	5	5	32
A1	3	1	1	1	5	1	5	1	3	3	5	5	5	5	44
A2	3	1	1	1	1	1	1	1	1	1	1	5	1	5	24
A3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
A4	1	1	1	1	1	1	1	1	3	3	1	1	3	1	20

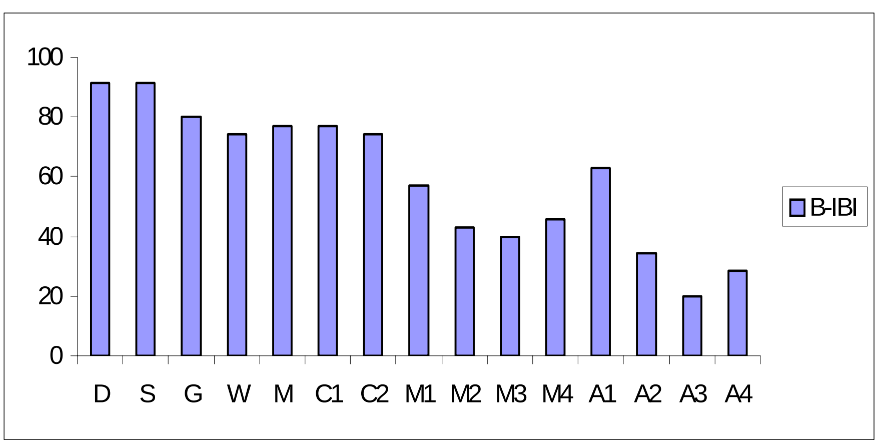


Figure 12.B-IBI score of all sites showing a decreasing pattern from reference to highly impacted (Urban) sites.

Table 8. Categorization of sites into different impairment levels based on B-IBI result (Site codes are as in Table 1)

B-IBI Values	Water Quality Characterization	Impairment	Sites at each impairment level
20-36	Very poor	Severe	A2, A3, A4
36-52	Poor	Slight	M2, M3.M4
52-68	Fair	Moderate	M1 and A1
68-84	Good	Less	G, W, M, C1, C2
84-100	Very good	Very little	D, S

Distinctive community level characteristics were found among the three categories (References, Deforested-agricultural and Urban-Industrial). Visual inspection of the CA ordination and dendrograms (Figure 13, 14 and 15) suggests that reference communities were highly similar to each other. There was considerable overlap among reference sites, indicating a relatively repeatable and predictable community in least-disturbed environments. Both Figure 13 and 14 categorized the sites into two major disturbance categories, which indicate that urban sites were distinctively separated from the other sites. Chacha 1 and 2, Akaki-Kebena1 and Modojo1 sites that fell within the reference site cluster (Figure 13) could possibly be considered unimpaired based on taxonomic composition and structure, but these sites showed differences from reference sites based on all biological physiochemical and habitat parameters (Figure 15). These sites generally had lower conductivity and higher RBP habitat scores than urban sites. However, substantial departure of most other Modjo and Akaki-Kebena down stream sites from the reference site array indicated very different community makeup. These urban sites were different from the reference site cluster and plotted fairly evenly throughout higher axis 1 and 2-ordination space (Figure 14).

It is also important to note that upstream sites in Akaki and Modjo rivers (rural sites) clustered more closely with other rural sites (deforested-agricultural sites) (negative portion of axis 2 of Figure 14 and Figure 15), while sites with more organic loading from upstream industries (M3) and one site with less urban density (M4) plotted alongside other urban-industrial sites (positive portion of axis 2 of Figure 14). This further suggests disturbance-specific affinities by these invertebrate assemblages.

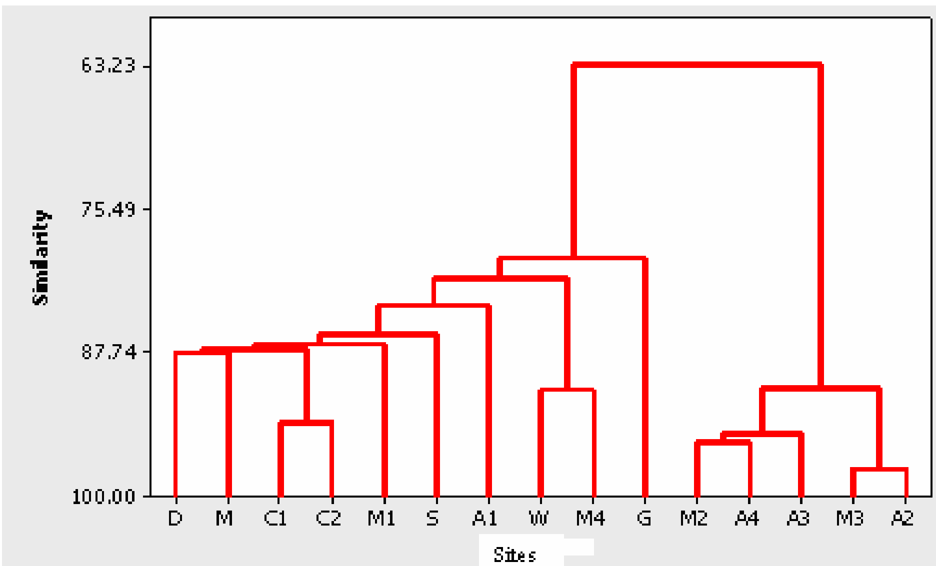


Figure 13. Dendrogram of cluster analysis of Curtis-Bray association measures of macroinvertebrate communities sampled from 15 sample reaches (using all taxa)

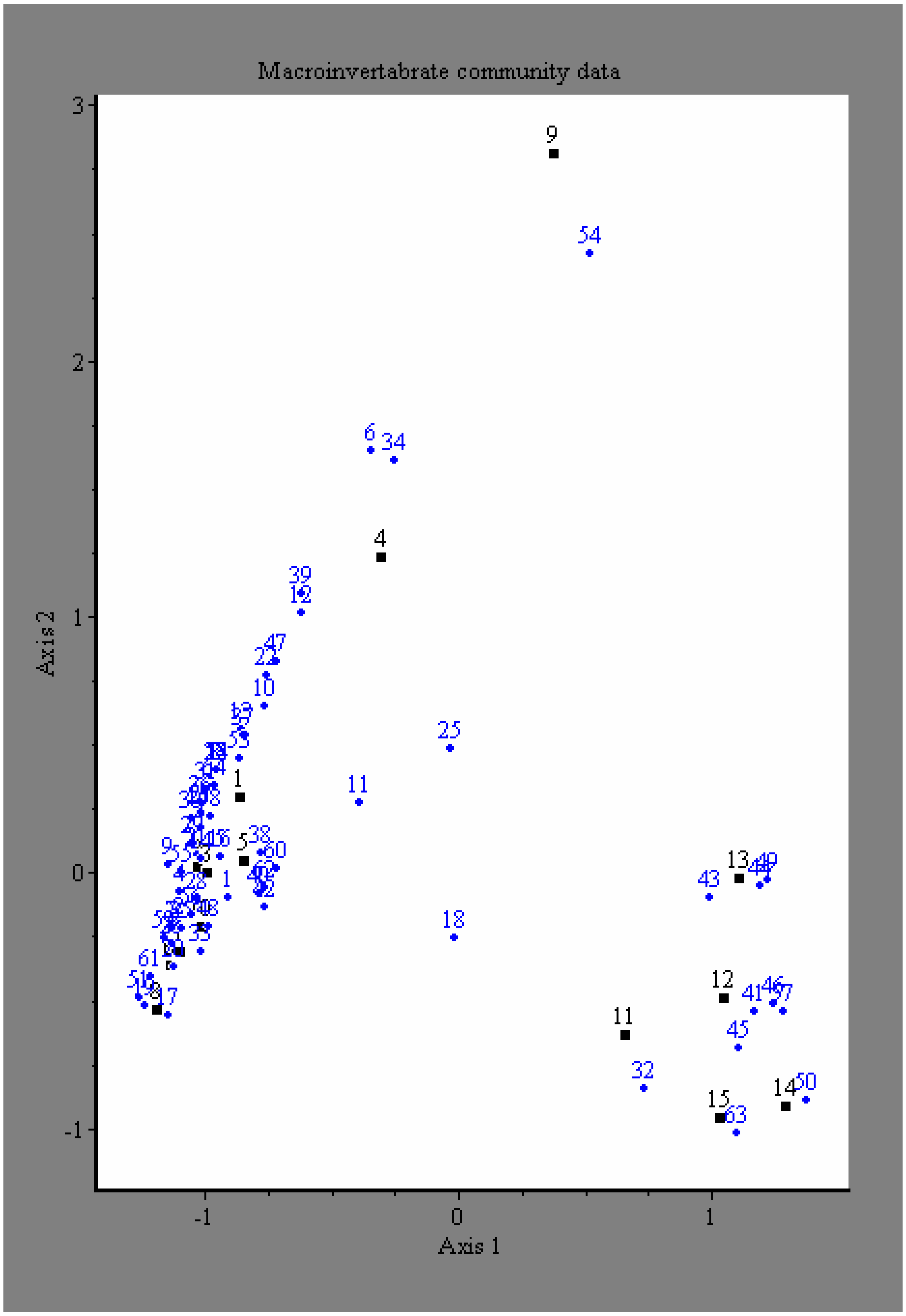


Figure 14. Correspondence Analysis of macroinvertebrate communities grouped by land-use category (Numbers in black color are 1-5 reference sites, 6-10 rural sites and 11-15 urban sites; and numbers in blue color are macroinvertebrate groups as in Appendix 4)

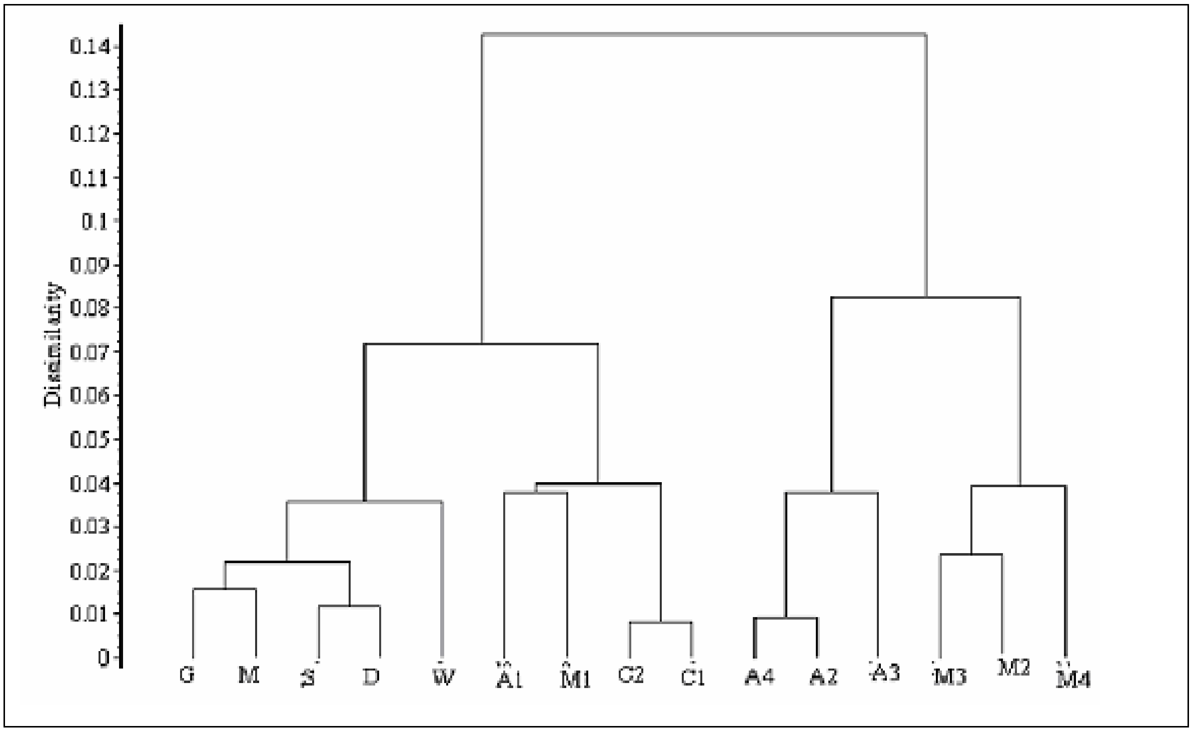


Figure 15. Dendrogram of cluster analysis of Curtis-Bray association measures of Macroinvertebrate community metrics and their habitat parameters sampled from 15 sample reaches (Using all data).

With regard to taxonomic composition among different categories, Appendix 3 gives the details of the relative abundance at each major category (raw total) and with respect to overall total organisms collected. Figure 16 also shows the occurrence frequency of the top EPT taxa between reference sites and disturbed sites. While most families were considered to be sensitive to disturbance, some taxa can be considered somewhat facultative to disturbance. For example, at urban-industrial sites the chironomidae (non-bloodred), baetidae (mayflies), simulidae and caddisfly (hydropsychidae-from Modjo downstream-M2 site) were frequently collected which were also abundant in reference sites. At rural (agricultural/defrosted) sites, caenidae (the mayfly), Coenagrionidae (the damsonflies), corixidae, notonectidae and veliidae, (hemiptera), gyrinidae and dytiscidae (coloeptera) were fairly ubiquitous. This suggests that with regard to the above taxa, there was no precise clear-cut distinction between these macroinvertebrates and disturbance and due to this further, analysis macroinvertebrates to genus or species level is required.

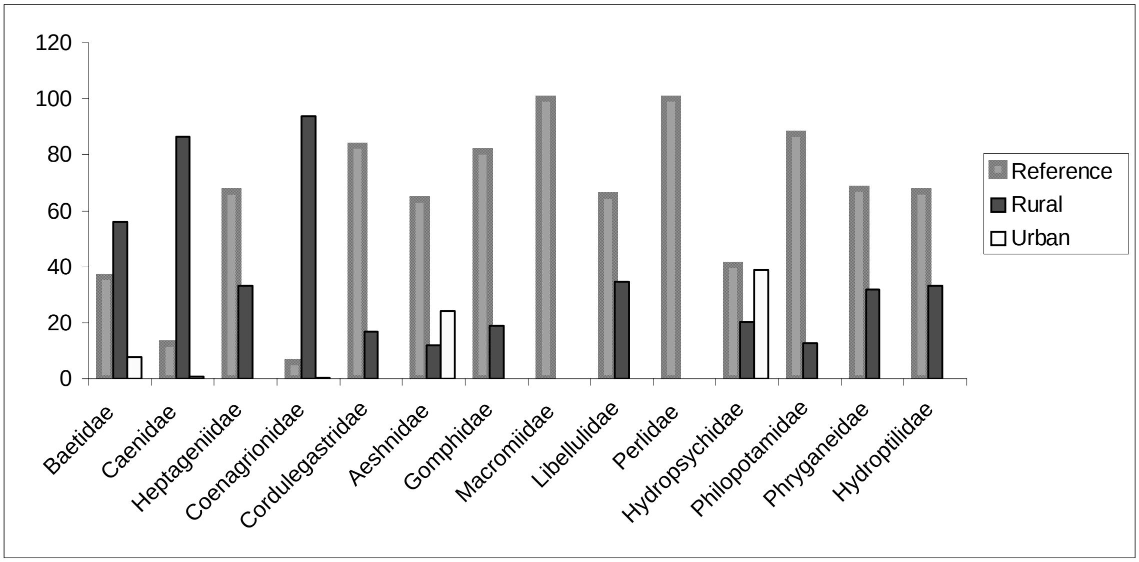
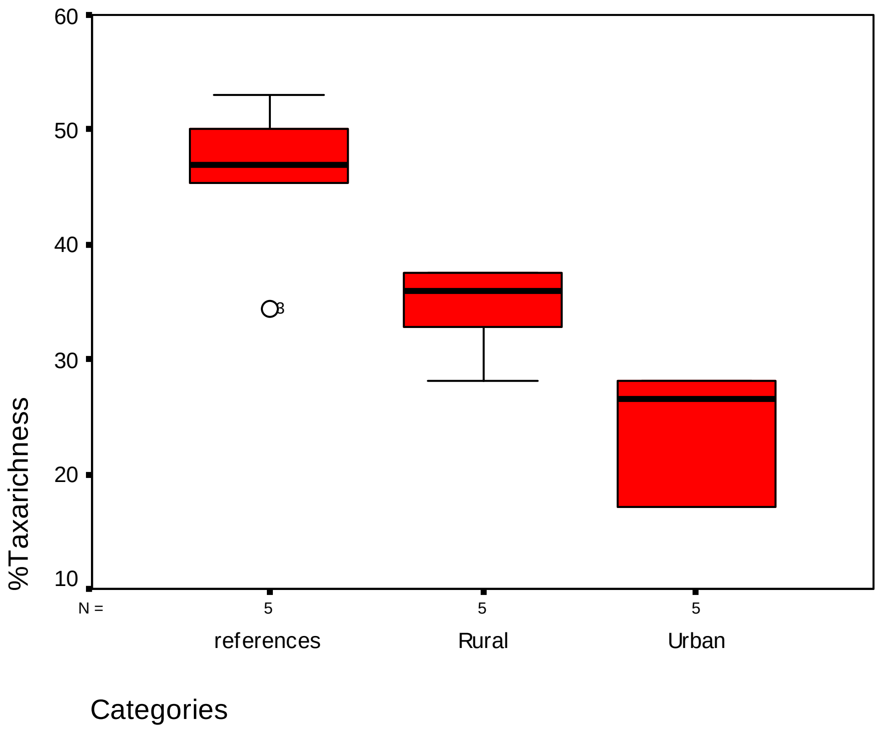


Figure 16. Presence/Absence frequency histogram comparing top most important EPT families among a) reference (b.) rural and (c.) urban sites

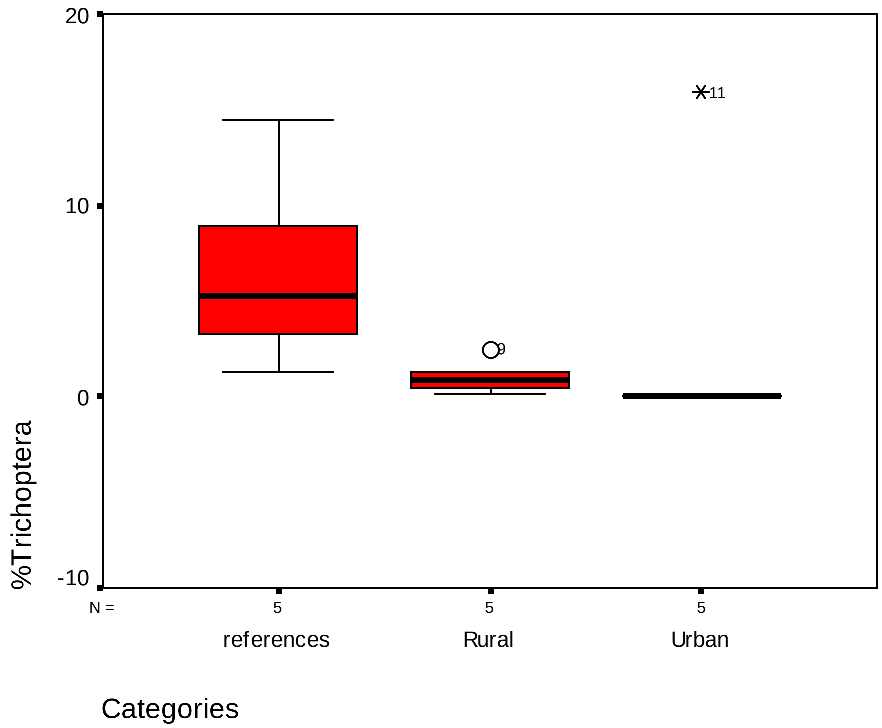
At the reference sites perlidae (the stoneflies) Philopotamidae (Caddisflies) Tipulidae (crane flies) and planarian (flatworms) were found fairly frequently which were totally absent in disturbed sites. This suggests the potential use of these taxa for biomonitoring.

5.2.2. B-IBI and Metric Comparisons among major land use types

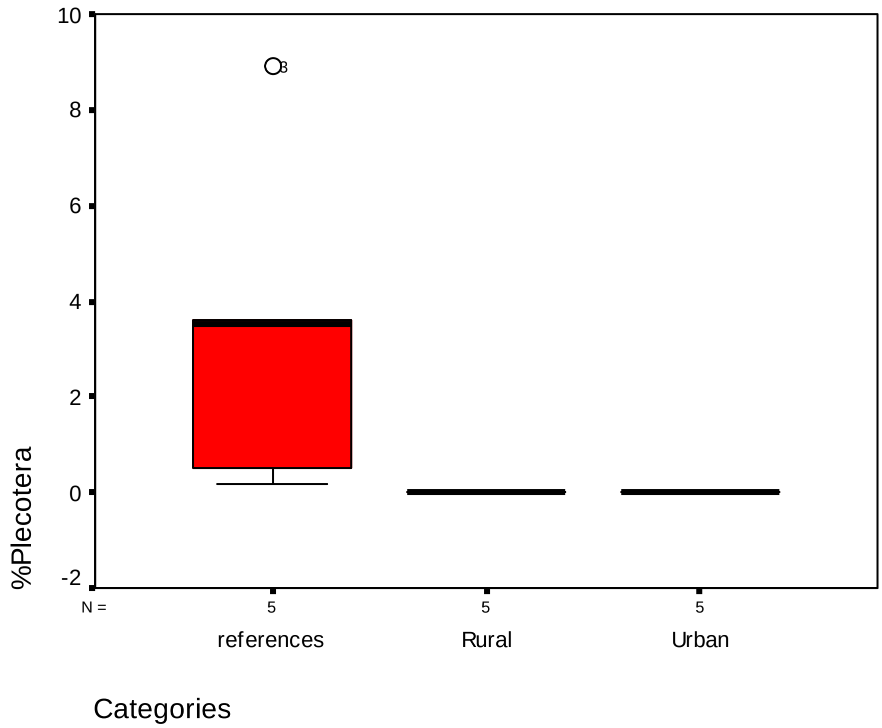
Figure 17 shows B-IBI and metrics values among the three categories of sites. Streams from disturbed category (urban) had significantly lower B-IBI scores, %Taxa richness, %Plecoptera, %EPT, %Ephemeroptera, Shannon Diversity Index, and significantly higher H-FBI, %Dominant taxa, %Diptera %Bloodred Chironomid %none-insect taxa and %Oligochaeta values than reference sites ($p<0.05$). There was a general similarity between the two disturbed categories (Figure 17); however, the %Ephemeroptera was significantly reduced and FBI, %Bloodred chironomid and %Oligochaeta significantly increased at urban-industrial sites compared to all other sites. Macroinvertebrate abundance was not affected by disturbance as the disturbed sites have higher total number of individuals, which was significantly lower at reference sites. However, this increase in the total abundance doesn't show better environment, as mild disturbance may favor some tolerant taxa with subsequent reduction in sensitive taxa (the community will be dominated by few taxa).



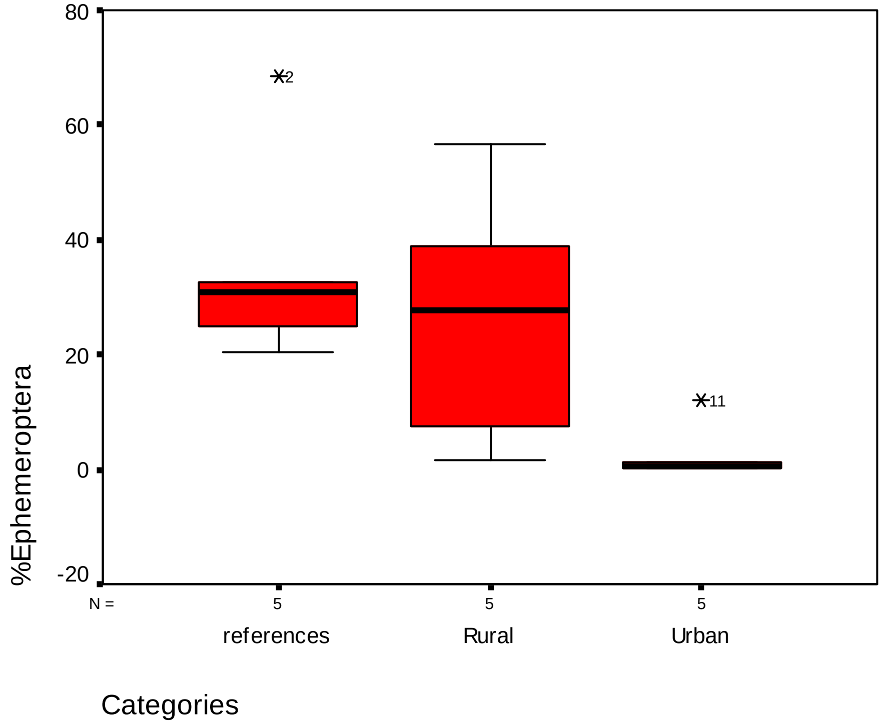
a


20
10
0
-10
%Trichoptera
11
9
N =
5
5
5
references
Rural
Urban
Categories

b

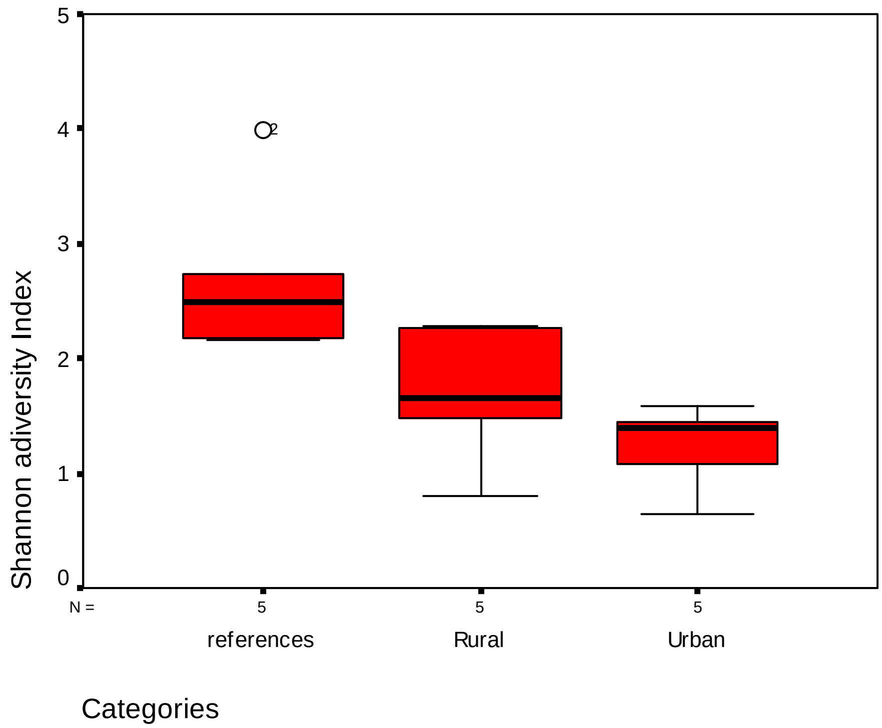

10
8
6
4
2
0
-2
%Plecotera
8
N =
5
5
5
references
Rural
Urban
Categories

c



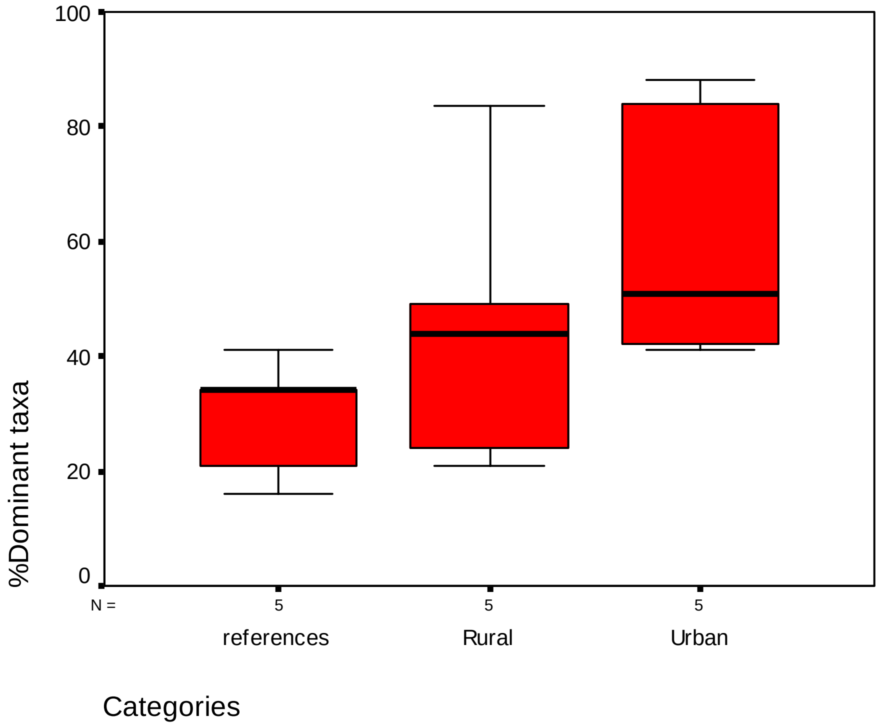
80
60
40
20
0
-20
%Ephemeroptera
2
11
N =
5
5
5
references
Rural
Urban
Categories

d

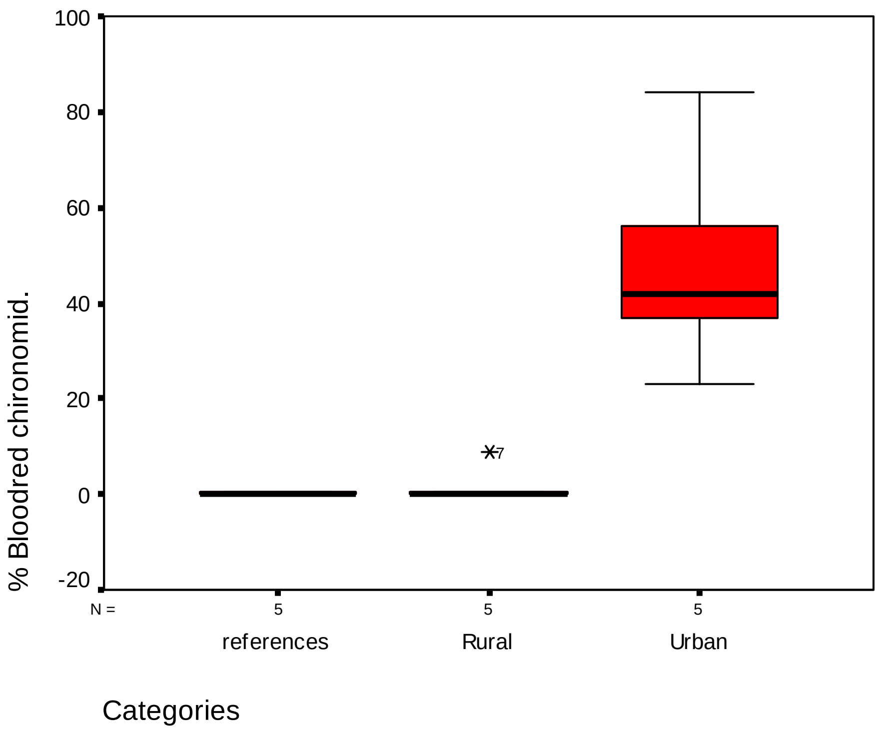


5
4
3
2
1
0
Shannon adiversity Index
2
N =
5
5
5
references
Rural
Urban
Categories

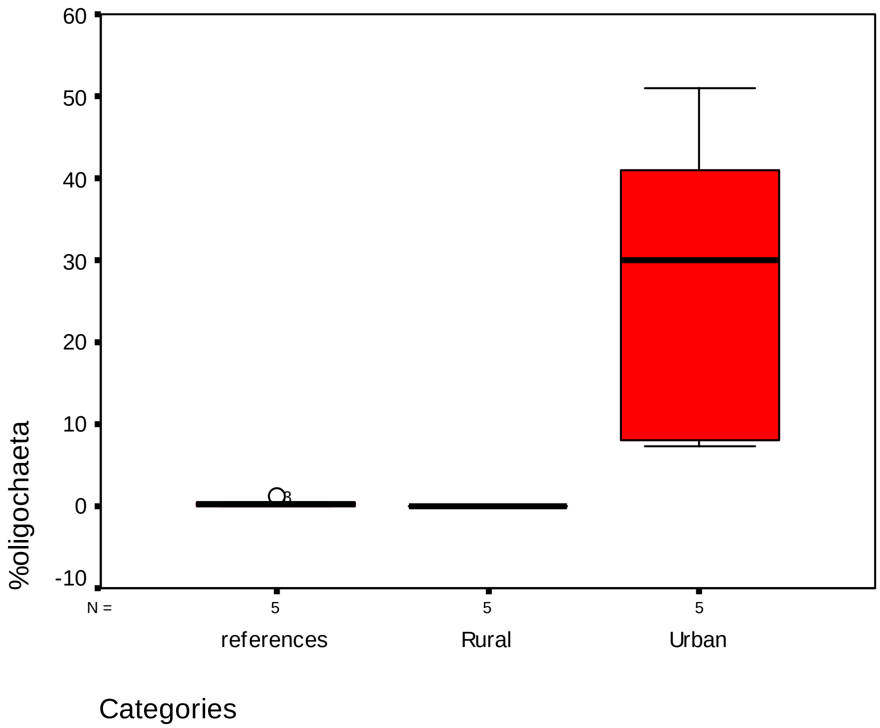
e


%Dominant taxa
100
80
60
40
20
0
N =
5
5
5
references
Rural
Urban
Categories

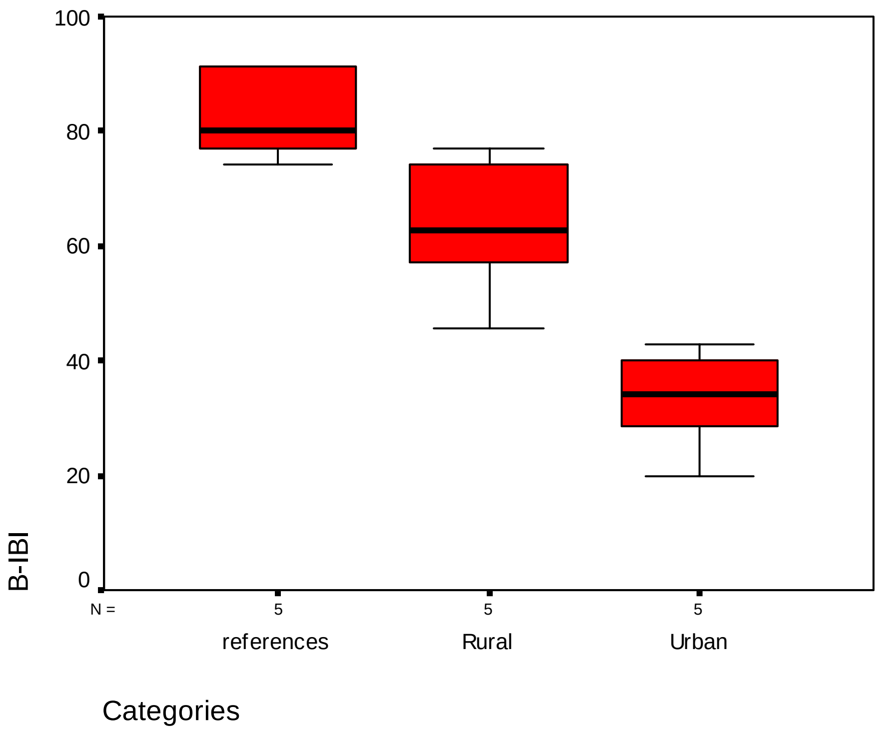
f


% Bloodred chironomid.
100
80
60
40
20
0
-20
7
N =
5
5
5
references
Rural
Urban
Categories

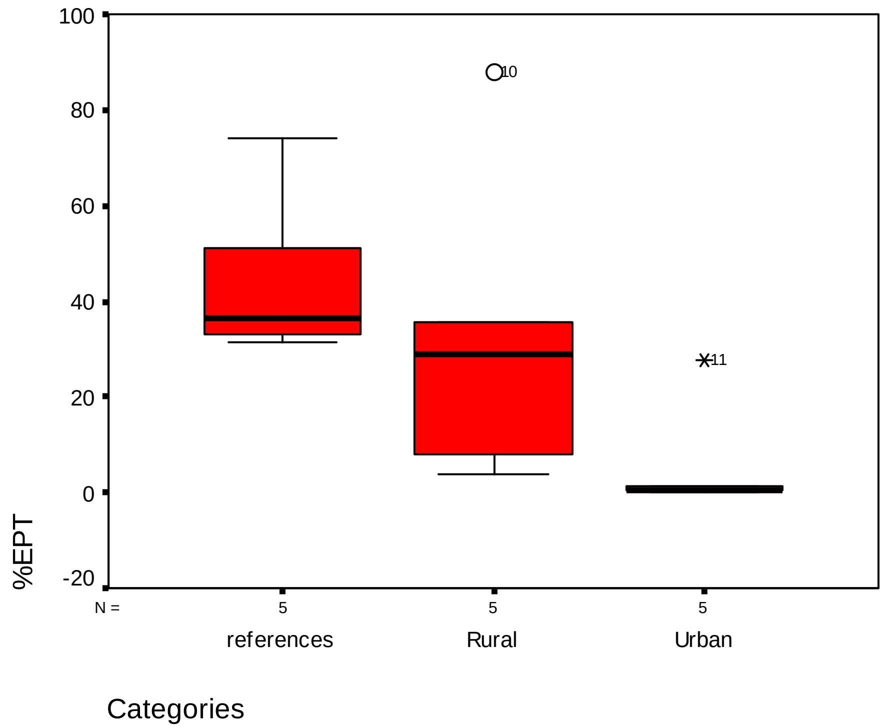
g


60
50
40
30
20
10
0
-10
%oligochaeta
N =
5
5
5
references
Rural
Urban
Categories

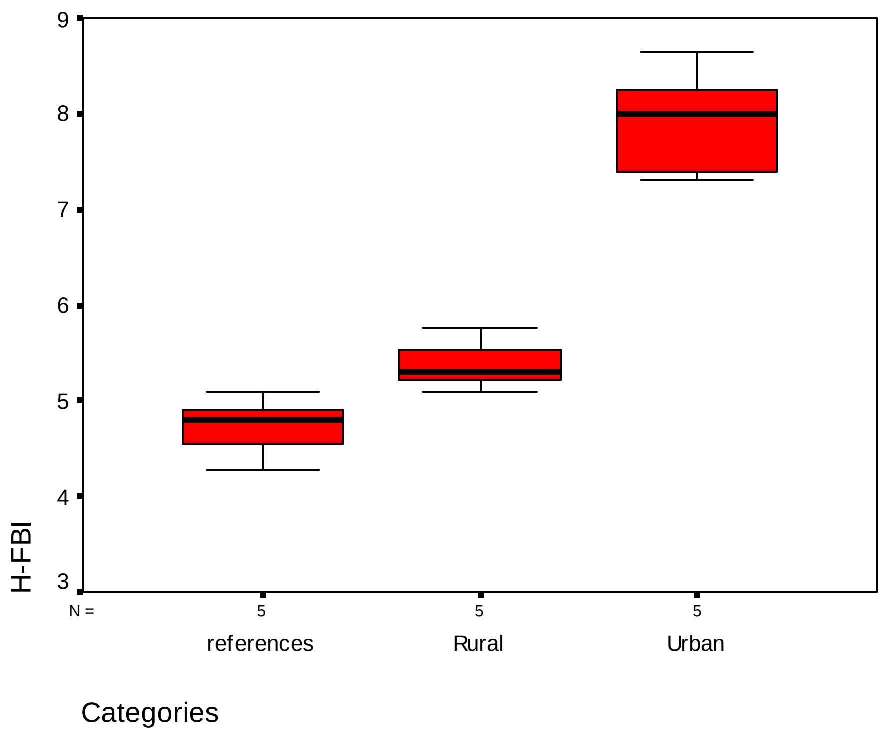
h


100
80
60
40
20
0
B-IBI
N =
5
5
5
references
Rural
Urban
Categories

i



j



k

Figure17 (a-k). Box plots of most of the B-BI metrics among land-use categories (Legend as in figure 10).

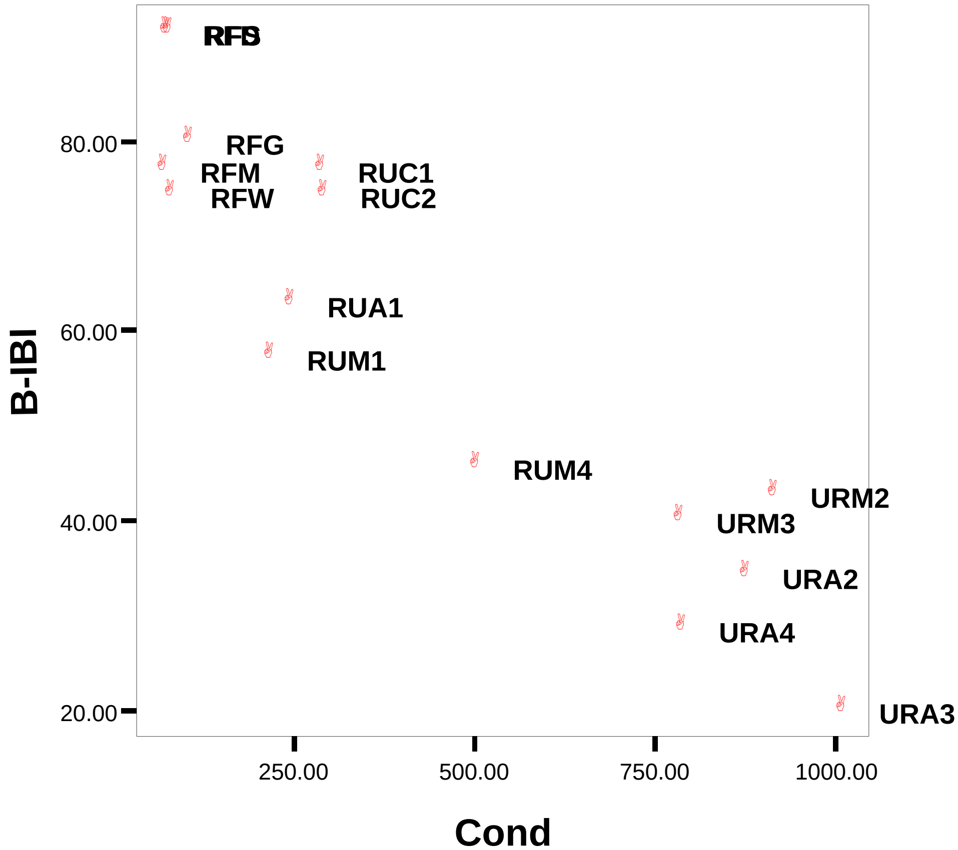
5.2.3. B-IBI and Metric correlations to Environmental Variables

The B-IBI and its associated metrics were significantly correlated ($p<0.05$) to many physicochemical parameters and habitat quality (Appendix 6). Namely, DO, conductivity, TDS, NO_3-N, PO_4, total RBP habitat score, and most of the individual habitat parameter scores (bank stability, channel alteration, bank vegetation cover, bank grass cover (graze), manure and or human excreta, canopy cover) had the highest correlations to the B-IBI ($r > \pm 0.7$). Out of all of the RBP habitat metrics, nutrient enrichment (organic loading) and water appearance scores had the highest correlation to B-IBI scores ($r >0.9$) and to all other B-IBI metrics (except to %Trichoptera) (range of $r =0.44-0.94$). Some RBP metrics (i.e., sediment deposition, channel flow status and epifaunal substrate available) were not significantly related to B-IBI scores or to most associated B-IBI metrics, suggesting that within the range of these sites used in this study, these parameters were not a factor for B-IBI variation.

5.2.4. B-IBI and Metrics Relationships to Environmental variables

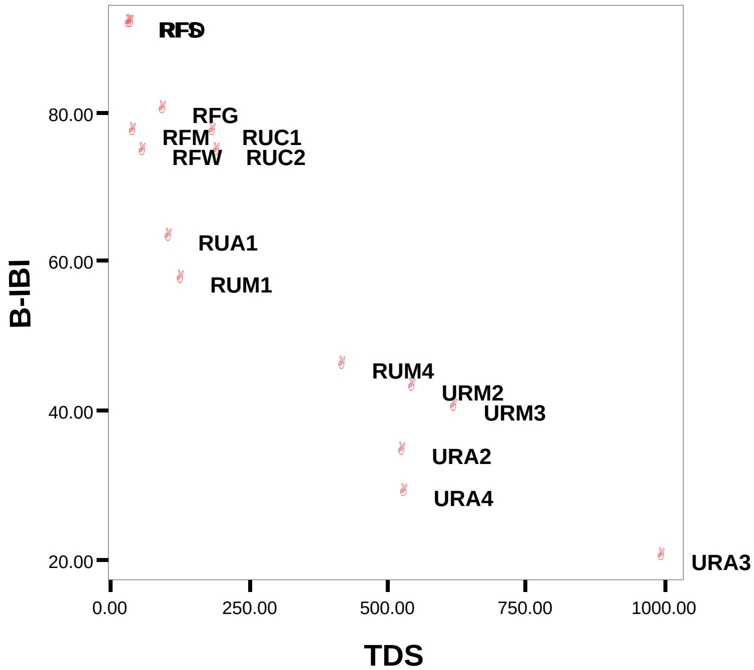
A) B-IBI

Figure 18a-f and Appendix 7 show the relationships between biological metrics and environmental variables. Among all sites, the B-BI showed a strong negative relationship to conductivity ($R^2=0.86$, $p<0.001$), TDS ($R^2=0.83$, $p<0.001$), NO_3_N ($R^2=0.53$, $p<0.005$) and PO_4 ($R^2=0.62$,$p<0.001$). However, between the two disturbed categories, a slight pattern was detected that might distinguish effects of land use on conductivity, TDS, NO_3-N, and PO_4 influences (Regression analysis by land use). This suggests that factors other than these parameters are involved in B-IBI variability between these land-use categories. The B-IBI responded positively to increasing habitat quality ($R^2=0.80$, $p<0.001$) and dissolved oxygen (.$R^2=0.85$,$p<0.001$). Between the three disturbed land-use categories, no pattern was detected that might distinguish land-use-specific habitat influences (Appendix 7).



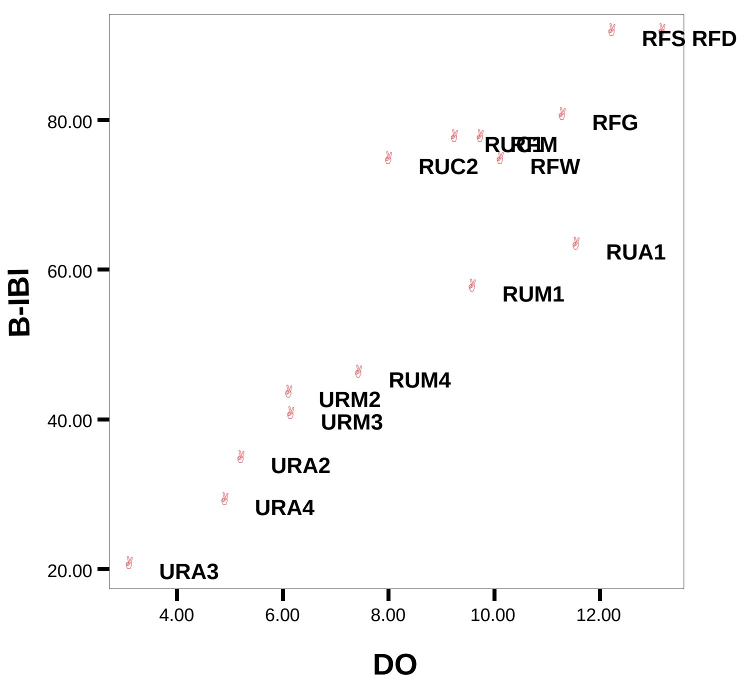
a

(*RF=reference, RU =Rural, UR = urban. Site codes are as in Table 1)



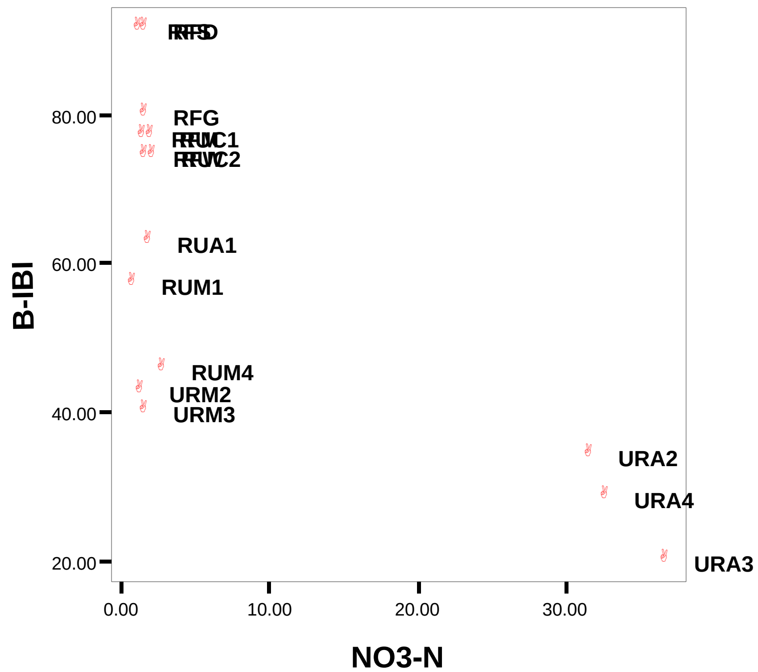
RFS
RFD
RFG
RFM
RUC1
RFW
RUC2
RUA1
RUM1
RUM4
URM2
URM3
URA2
URA4
URA3
80.00
60.00
40.00
20.00
B-IBI
0.00
250.00
500.00
750.00
1000.00
TDS

b

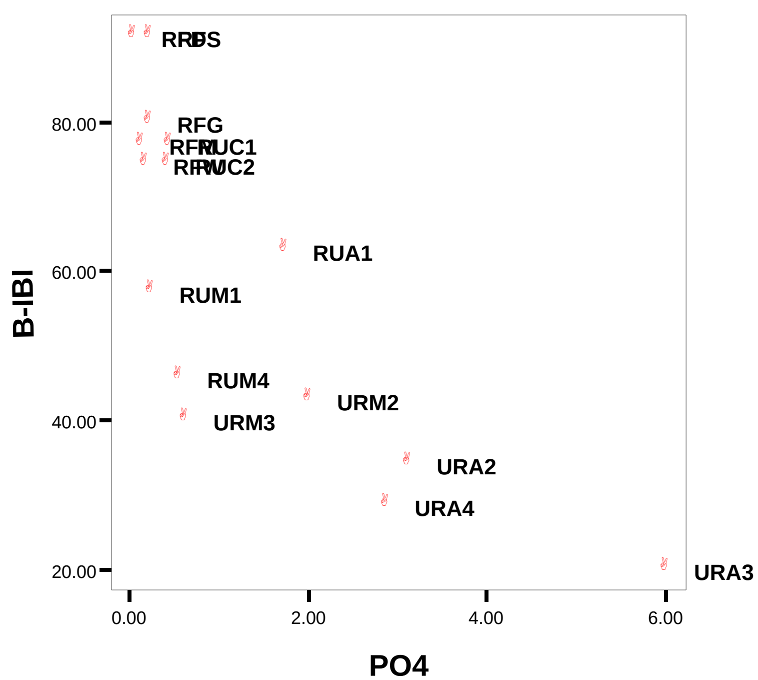


RFS RFD
RFG
RUC1
RFM
RUC2
RFW
RUA1
RUM1
RUM4
URM2
URM3
URA2
URA4
URA3
80.00
60.00
40.00
20.00
B-IBI
4.00
6.00
8.00
10.00
12.00
DO

c


B-IBI
NO3-N
80.00
60.00
40.00
20.00
0.00
10.00
20.00
30.00
RFG
RUA1
RUM1
RUM4
URM2
URM3
URA2
URA4
URA3

d


B-IBI
PO4
80.00
60.00
40.00
20.00
0.00
2.00
4.00
6.00
RFG
RUA1
RUM1
RUM4
URM2
URM3
URA2
URA4
URA3

e

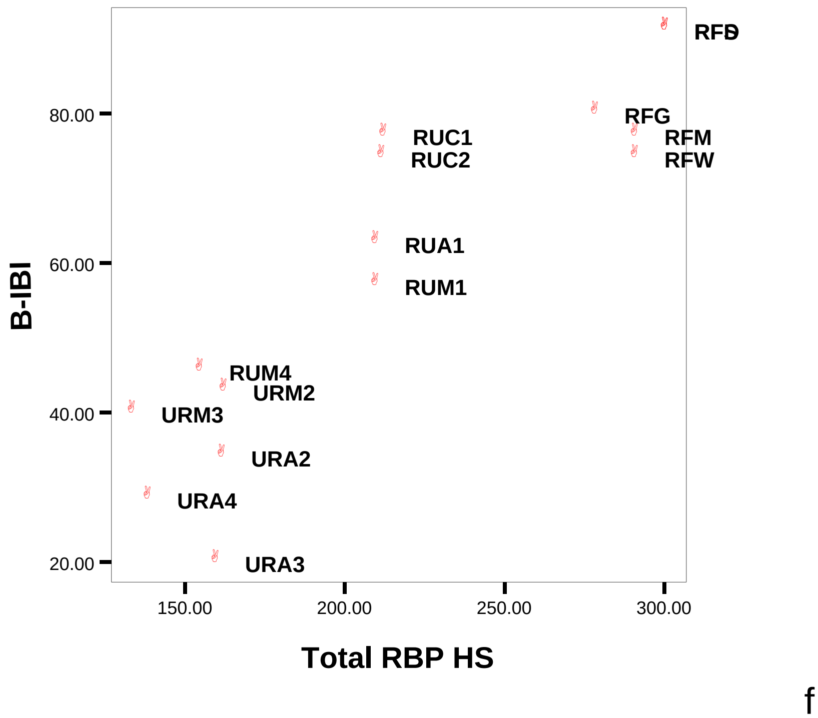


Figure 18.Scatter plot of B-IBI scores versus (a) conductivity b) TDS, c) Dissolved oxygen, d) NO_3-N, e) PO_4 and f) Total RBPHS by land-use category.

Most of the fourteen metrics that make up the B-IBI responded predictably to conditions associated with both urban and agricultural/deforestation disturbances (Appendix 6 and 7). Metrics showed the highest significant relationships to conductivity, DO, TDS, NO_3-N, PO_4 and habitat quality.

B) %EPT (The order Ephemeroptera, Plecoptera and Trichoptera)

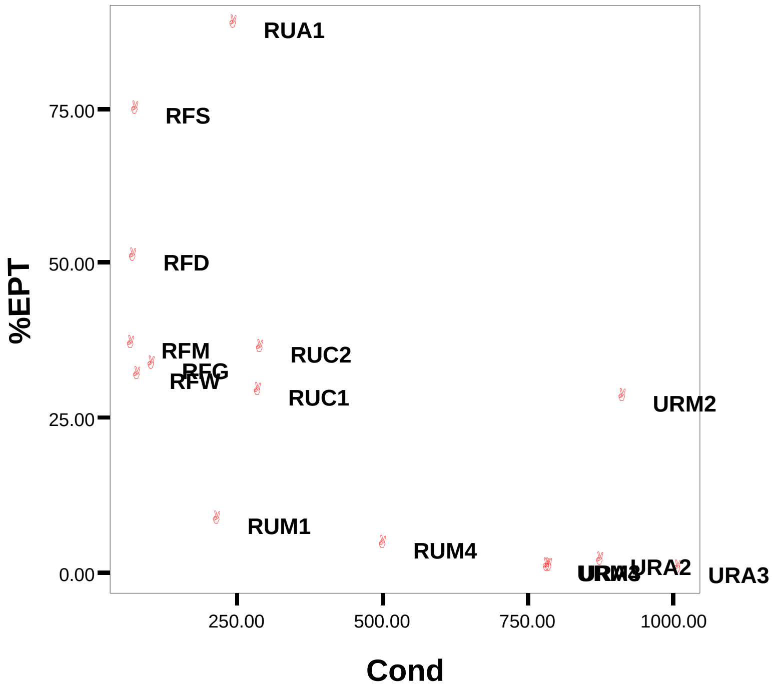
Low EPT percentages may prove good indicators of increased anthropogenic waste run-off as many families of Ephemeroptera, such as Heptageniidae, and Plecoptera such as Perlidae, are known to be sensitive to low dissolved oxygen concentrations (Thorp and Covich, 1991). However, it may not be an effective indicator of sediment pollution because some net spinning Trichopterans, such as Hydropsychidae, and Ephemeropterans, such as Caenidae, thrive in heavily sedimented streams (Thorp and Covich, 1991). Also, as these stressors often occur simultaneously, EPT percentage may not be the best measure of water quality

In this study, %EPT declined considerably along an increasing conductivity, NO_3-N and TDS gradients at disturbed sites (R^2= 0.42, 0.27 and 0.47, respectively, $p<0.05$) (Figure 19). This was likely attributed to nutrient loading or organic enrichment and habitat degradation with the resultant decrease in dissolved oxygen. No significant pattern was detected along PO_4 gradient. %EPT increased considerably along an increasing dissolved oxygen gradient (R^2=0.61, $p<0.01$); a clear pattern was also detected between the two disturbed categories (Figure 17j). % EPT is probably the most sensitive indicator of stream condition (Tesfaye Berhe, 1988; Barbour *et al.*, 1999 and Worku Leggesse *et al.*, 2004), and has been found to respond to organic pollution (Garcia-Criado *et al*., 1999; Green *et al.,* 2000; Howard *et al*., 2001). In the present study, reference sites had significantly higher %EPT, and these results indicate that many EPT taxa will disappear in the presence of severe organic pollution from both urban and industrial sources. However, some disturbed sites (rural) displayed high % EPT (e.g. A1). This suggests that %EPT may not be an effective tool to discriminate between mild disturbance and undisturbed conditions. Thorp and Covich (1991) also support this idea as stated above.

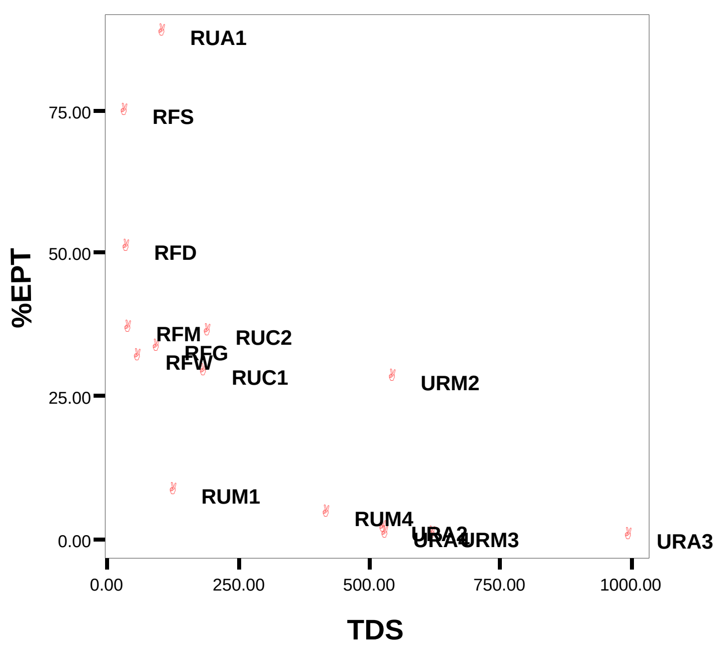
The EPT fauna can also be affected by other impacts such as extensive agricultural activities, which bring about deforestation of riparian zones. However, the duration of impairment can vary with the magnitude of the operation of deforestation. For example, Stone and Wallace (1998) detected limited differences in macroinvertebrate community indices between two reference and clear-cut headwater streams in North Carolina. In fact, some increases in %EPT were observed. While the authors noted significant increases in the H-FBI, those reported values might not indicate impairment in streams. Increased richness and production of macroinvertebrates in the logged (deforested) stream was in response to elevated light, temperature, and nutrients. They also noted changes in the food web or trophic structure of the communities. However, compared to organic loading, these disturbances are generally more benign and temporary (~5-10 years) and do not cause wholesale loss of sensitive taxa as it was found in the present study in Chacha river sites and Akaki-Kebena upstream site (A1) which have clear riparian zones. Moreover, only minor increases in conductivity may occur from deforestation. For example, Stone and Wallace (1998) reported that, one reference site in the Daniel Boone National Forest (Carolina) was heavily deforested six years prior to sampling, but the conductivity was only 50 µS/cm, 32 EPT taxa were collected, and the B-IBI score was excellent. However, the %EPT metric showed a stronger relationship to general habitat quality (R^2=0.46, $p<0.001$,) (Figure 19f) than to most individual habitat parameters. This further demonstrates that this metric is good for diagnostic purposes when multiple stressors are responsible for impairment.

Although most parameters chose %EPT as an indicator to distinguish land-use types, it had a lower correspondence to most individual habitat parameters NO_3-N and PO_4 than other metrics (Appendix 6, Figure 19d and e). As it is stated above, some EPT taxa could tolerate elevated organic loading. In this study, fairly abundant hydropsychid caddisflies were collected from Modjo downstream site immediately below Shewa tannery effluent. However, no stoneflies taxa were collected from all impacted sites, which prove they are good indicators of impairment than hydropsychids. This commonly used metric (%EPT) may be improved by excluding the hydropsychid caddisfly *Cheumatopsyche*, and it is possible that exclusion of other tolerant EPT taxa would strengthen this metric.

What was interesting in this study was the total disappearance of stoneflies (Plecoptera) from all disturbed sites (Rural and Urban)(Appendix 4). This result therefore, suggests the potential use of stoneflies for even mild disturbance detection than other EPT families.

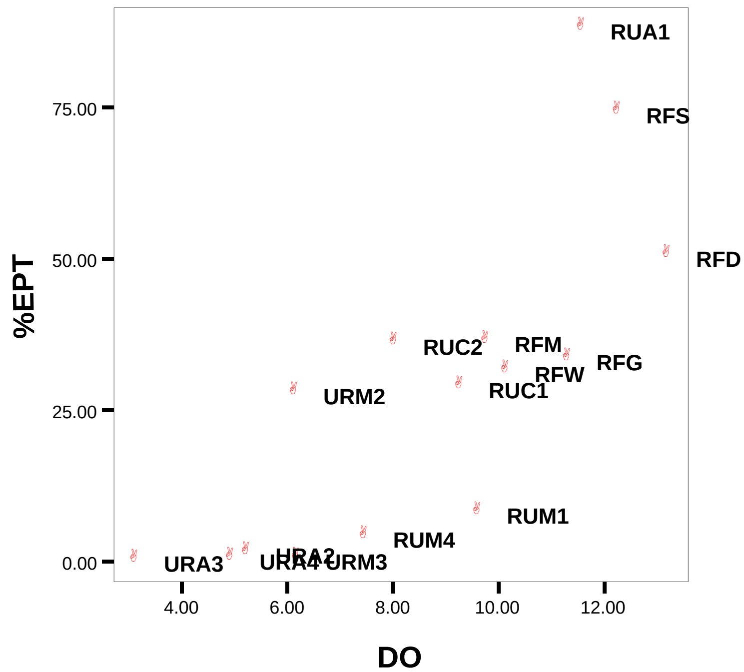


a

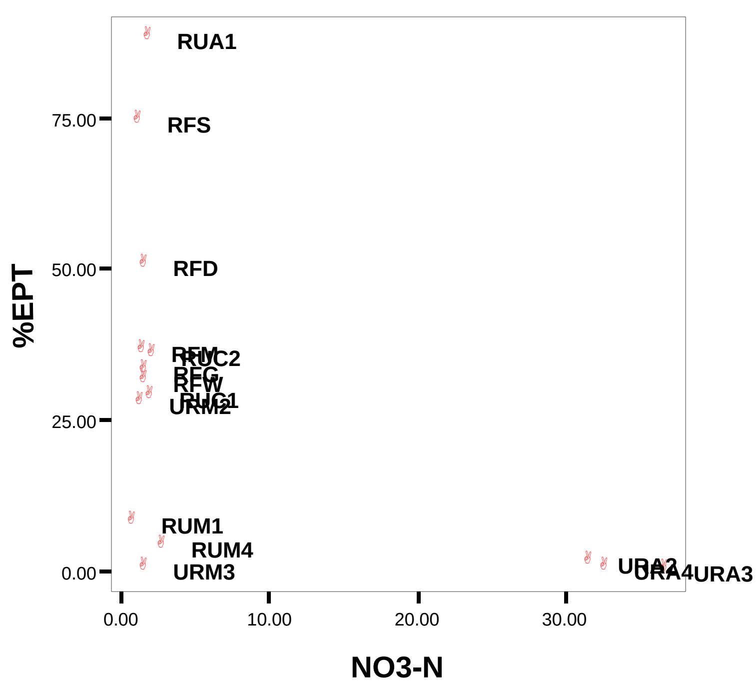


b

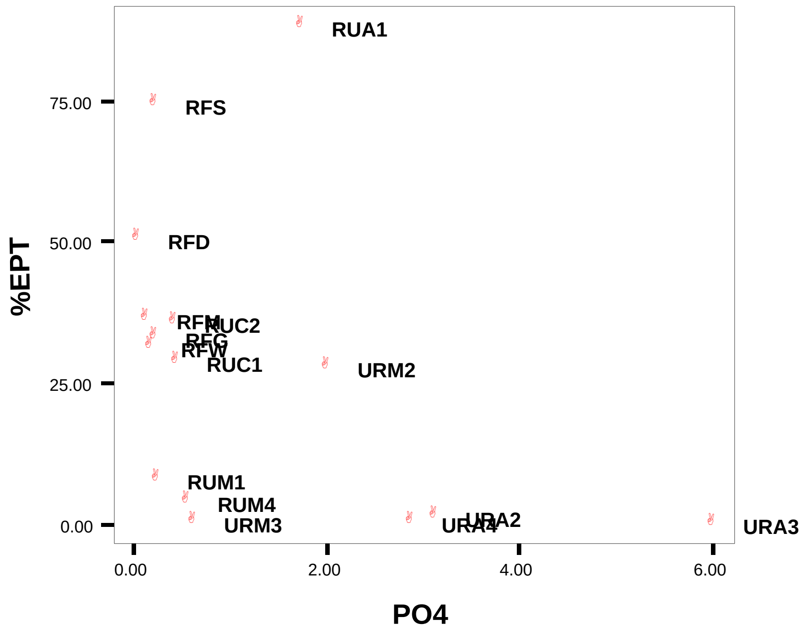
(*RF=reference, RU =Rural, UR urban. Site codes are as in Table 1)


%EPT
DO
0.00
25.00
50.00
75.00
4.00
6.00
8.00
10.00
12.00
RUA1
RFS
RFD
RUC2
RFM
RFG
RFW
RUC1
URM2
RUM1
RUM4
URA3
URA2
URA4
URM3

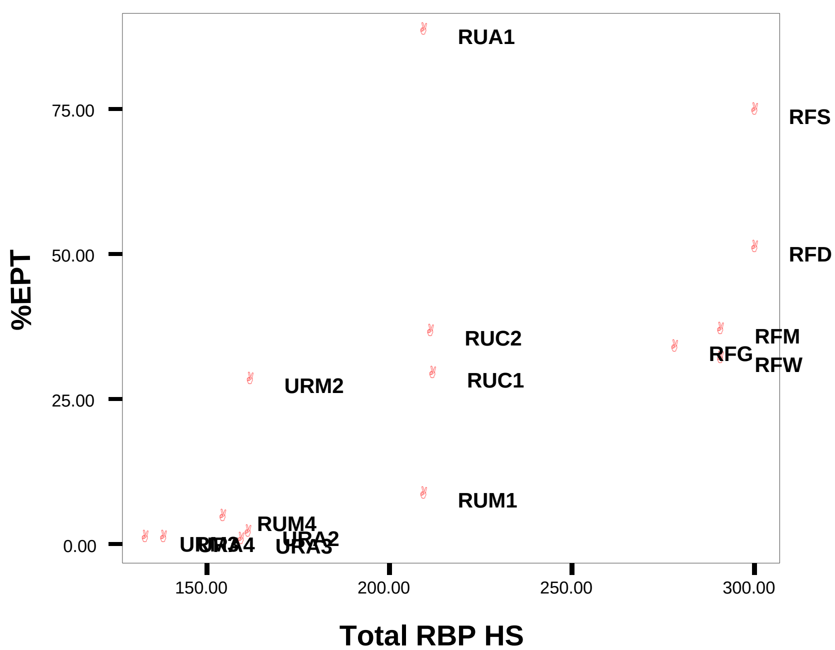
c


%EPT
NO3-N
0.00
25.00
50.00
75.00
0.00
10.00
20.00
30.00
RUA1
RFS
RFD
RFM
RUC2
RFG
RFW
RUC1
URM2
RUM1
RUM4
URM3
URA2
URA4
URA3

d



e



f

Figure 19. Scatter plot of %EPT scores versus (a) conductivity b) TDS, c) Dissolved oxygen, d) NO3-N, e) PO4 and f) Total RBPHS by land-use category

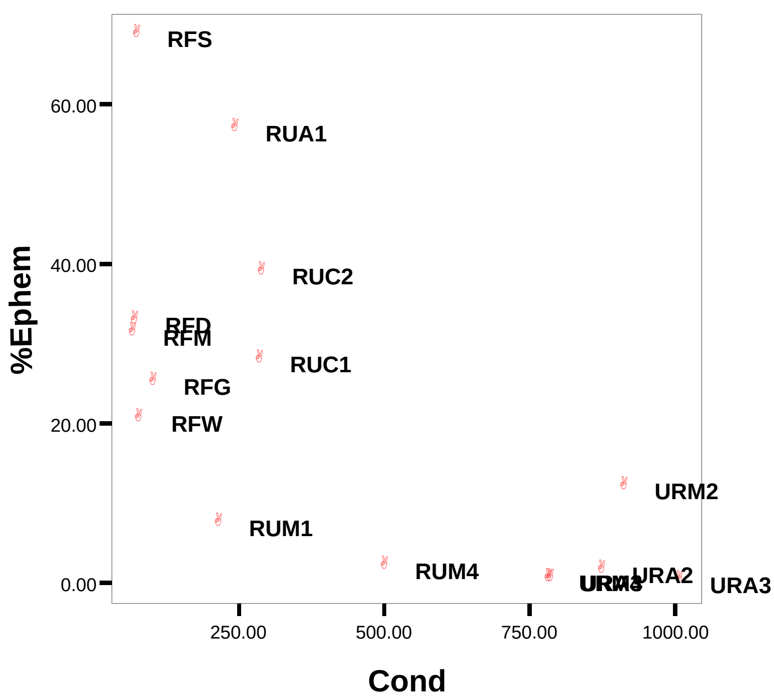
C) % Ephemeroptera

%Ephemeroptera (Mayflies) declined considerably along an increasing conductivity and TDS gradients (Figure 20a and b) and especially at urban/industrial sites (R^2=0.48 and 0.49, respectively, p<0.005,). However, %Ephermeroptera didn't show clear pattern between reference and slightly impacted sites with respect to NO_3-N and PO_4 (Figure 20d and e), which might indicate that they are not negatively affected by mild organic input. The sharp decline in the %Ephemeroptera metric in highly impacted urban sites indicated that this metric is very sensitive to high organic loading rather than mild pollution. %Ephemeroptera was also related strongly with total habitat quality score (R2=0.43, p<0.005) (Appendix 7).

The total loss of most sensitive Ephemeroptera taxa and other EPT taxa (Plecoptera, trichoptera (except family hydropsychidae), Odonata (Appendix 3)) at urban /industrial sites indicates that excessive organic loading, increased total dissolved solids and conductivity from households and industrial wastes are harmful to these organisms. These relationships have also been reported by Tesfaye Berhe (1988) and Worku Legesse et al*. (2004) at Kebena stream.*

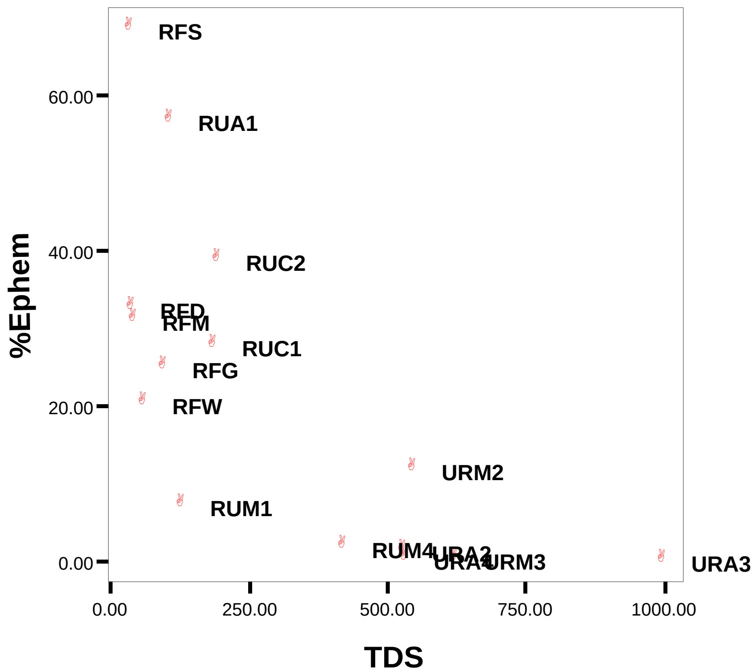
Figure 20a and b emphasize how increasing conductivity and TDS from urban wastes impact the relative abundance of Ephemeropterans. Mayfly assemblages of usually averaging nearly 50% of all organisms collected, dominate healthy headwater streams. Figure 17d depicts decreases in mayfly richness between reference and highly impacted land-use categories. Clearly, urban sites had significantly lower %mayflies compared to reference sites. It is important to note that not all mayfly taxa are sensitive to high impacts. Several facultative mayflies (e.g., *Baetis, Isonychia, Caenis, Tricorythodes*) that are typically present in reference sites can also invade headwater habitats that have elevated conductivity or nutrients (Pond *et al*., 2003). In this study the family Baetidae was collected from highly impacted sites (A2, A3, A4 and M2,) though they were very few in numbers. Further studies on the level of tolerance among mayflies are therefore, warranted.

Although not all sites had corresponding water chemistry data, elevated nutrients (phosphorus and nitrate-nitrogen and other organic wastes) were frequently found below urban/industrial areas with improper on-site wastewater treatment systems. General habitat degradation may also be partially responsible for mayfly decline at urban/industrial sites, which is shown at Modjo downstream site (M3) where it has the poorest in-channel and riparian habitat and with no mayfly collected (plate I).

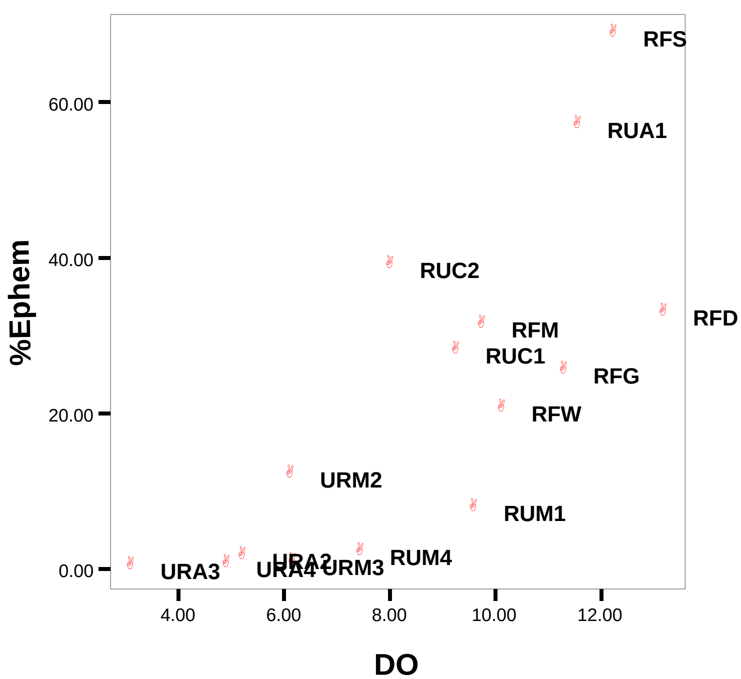


a

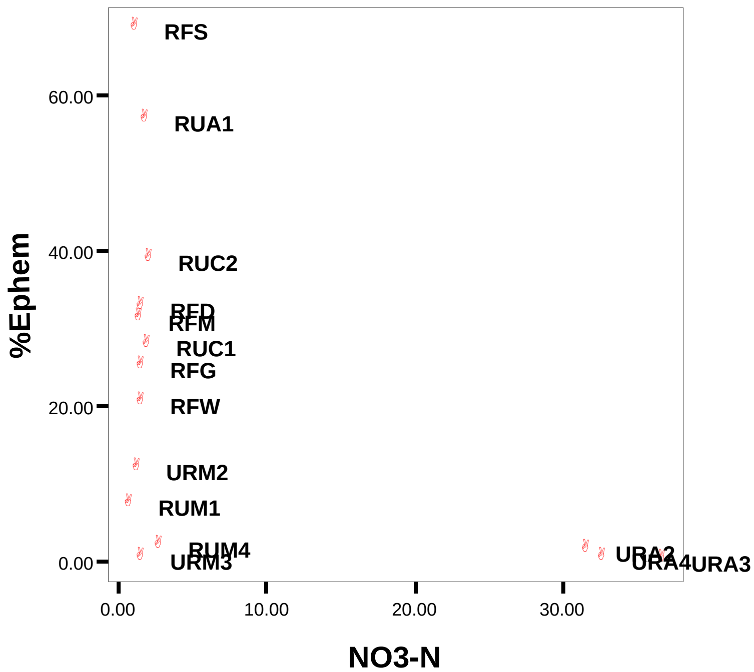
(*RF=reference, RU =Rural, UR urban. Site codes are as in Table 1)


RFS
RUA1
RUC2
RFD
RFM
RUC1
RFG
RFW
URM2
RUM1
RUM4
URA2
URA4
URM3
URA3
%Ephem
60.00
40.00
20.00
0.00
0.00
250.00
500.00
750.00
1000.00
TDS

b

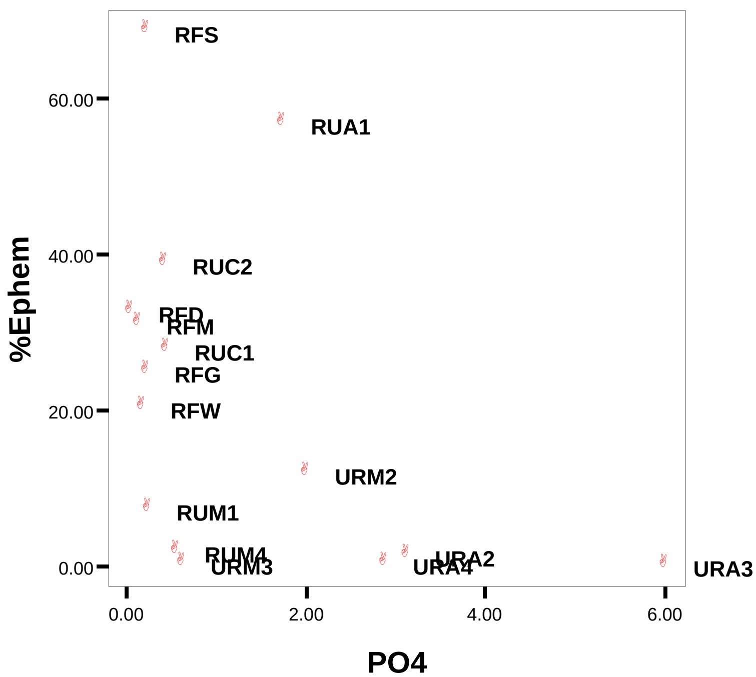

RFS
RUA1
RUC2
RFD
RFM
RUC1
RFG
RFW
URM2
RUM1
RUM4
URA2
URA4
URM3
URA3
%Ephem
60.00
40.00
20.00
0.00
4.00
6.00
8.00
10.00
12.00
DO

c



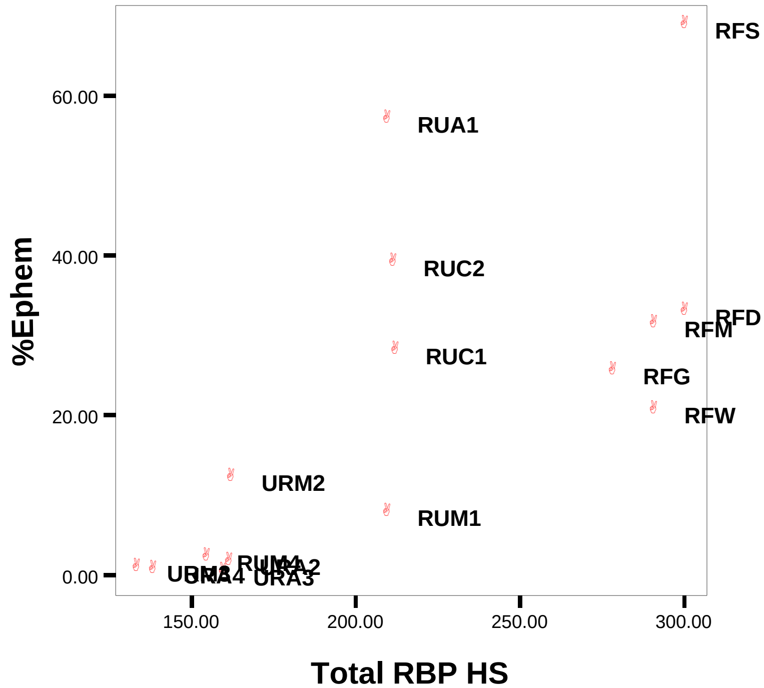
RFS
RUA1
RUC2
RFD
RFM
RUC1
RFG
RFW
URM2
RUM1
RUM4
URM3
URA2
URA4
URA3
60.00
40.00
20.00
0.00
0.00
10.00
20.00
30.00
%Ephem
NO3-N

d



RFS
RUA1
RUC2
RFD
RFM
RUC1
RFG
RFW
URM2
RUM1
RUM4
URM3
URA2
URA4
URA3
60.00
40.00
20.00
0.00
0.00
2.00
4.00
6.00
%Ephem
PO4

e



f

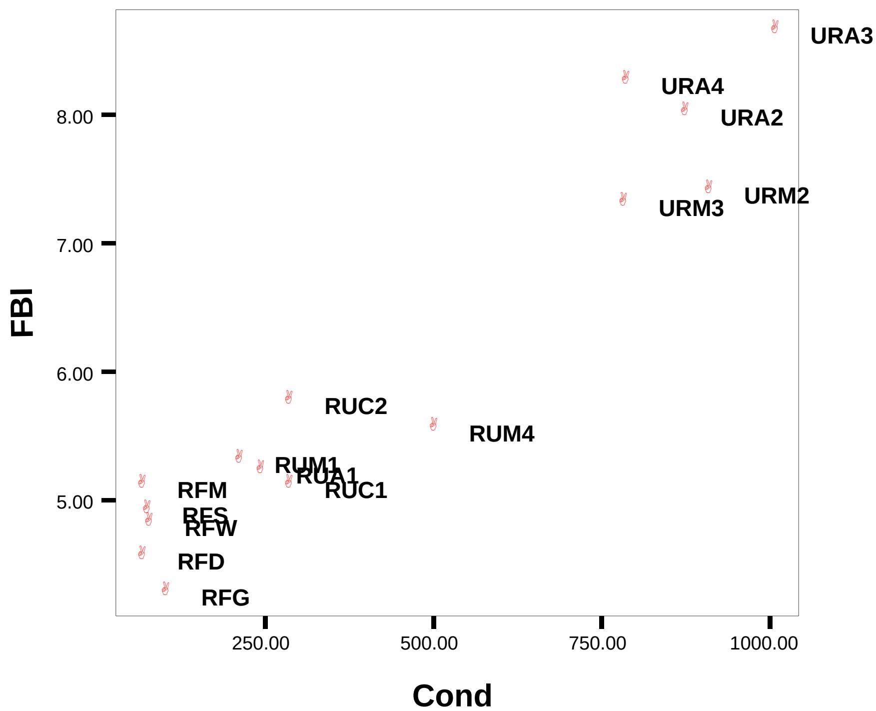
Figure 20. Scatter plot of %Ephemeroptera scores versus (a) conductivity b) TDS, c) Dissolved oxygen, d) NO3-N, e) PO4 and f) Total RBPHS by land-use category.

D) Hilsenhoff Family level biotic index (H-FBI)

The H-FBI metric also showed a strong response to conductivity, TDS, DO, NO_3-N and PO_4 (R^2 ranged 0.65-0.87, p<0.001) (Figure 21a-e). This metric also responded strongly to total habitat quality score and to most individual habitat parameters (R^2=0.66, p<0.001) (Figure 21f, Appendix 7). The tightly clustered distribution of H-FBI values further demonstrated the predictability of reference site expectations (Figure 21). Although this biotic index \was originally formulated to detect organic pollution (Hilsenhoff, 1988), these results showed that the metric responded well to habitat degradation associated with urbanization industrialization and intense agricultural activities. This metric has shown sensitivity to increased nutrient enrichment and habitat degradation (Pond *et al.*

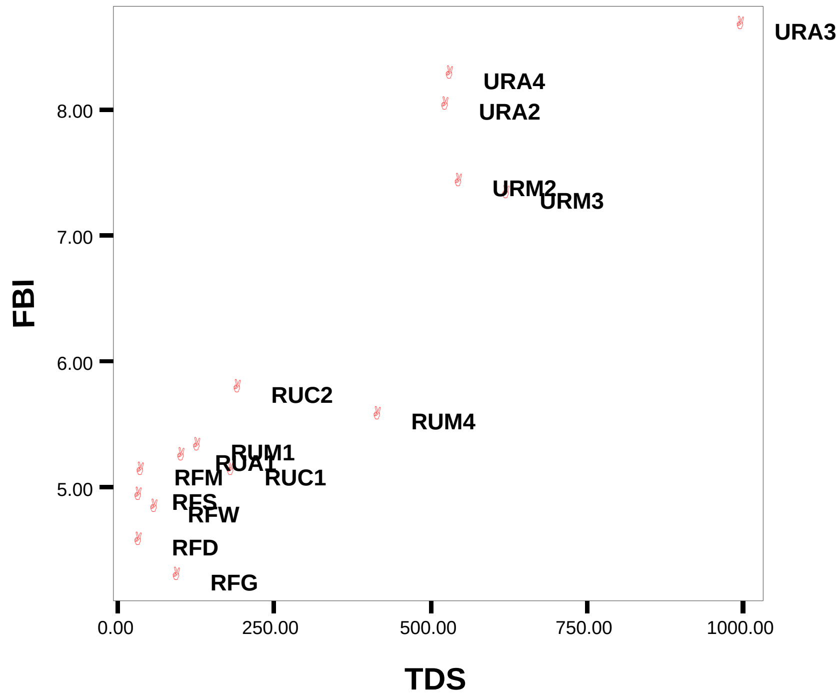
2003) and insecticides (Wallace *et al.,* 1996). Thus, assigned tolerance values indirectly integrate a wide variety of taxa responses to stress.

The inverse relationship between H-FBI and physical habitat quality shown in Figure 21 supports the stated hypothesis. Temperate region tolerance values reported in Hauer and Lamberti (1996) appear to be adequately applicable to this region of the tropics for determining family biotic indices as the scores are inversely related to physical habitat quality. While the H-FBI scores determined above showed different macroinvertebrate assemblages exist within impacted and non-impacted watersheds, further studies are needed to assess the tolerances of tropical taxa to specific stressors.

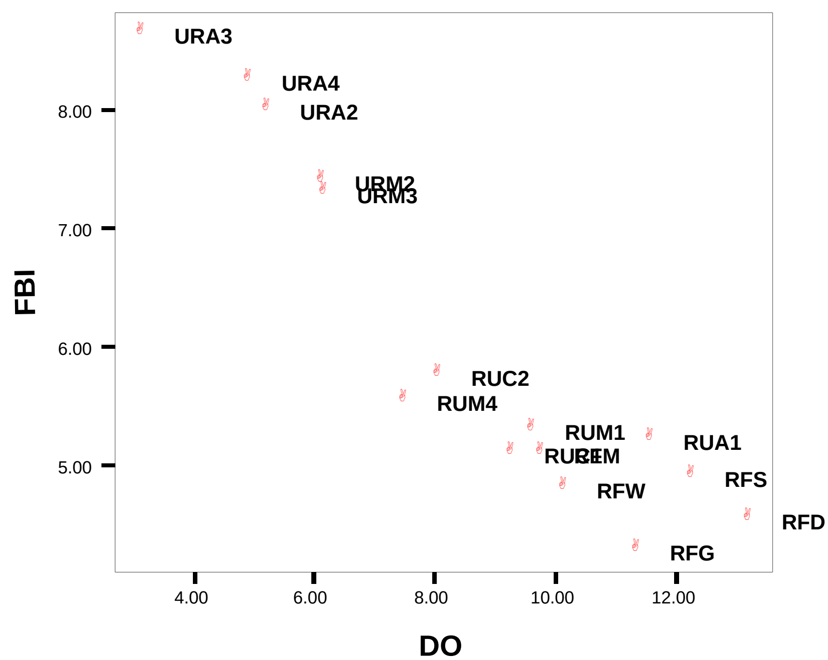


a

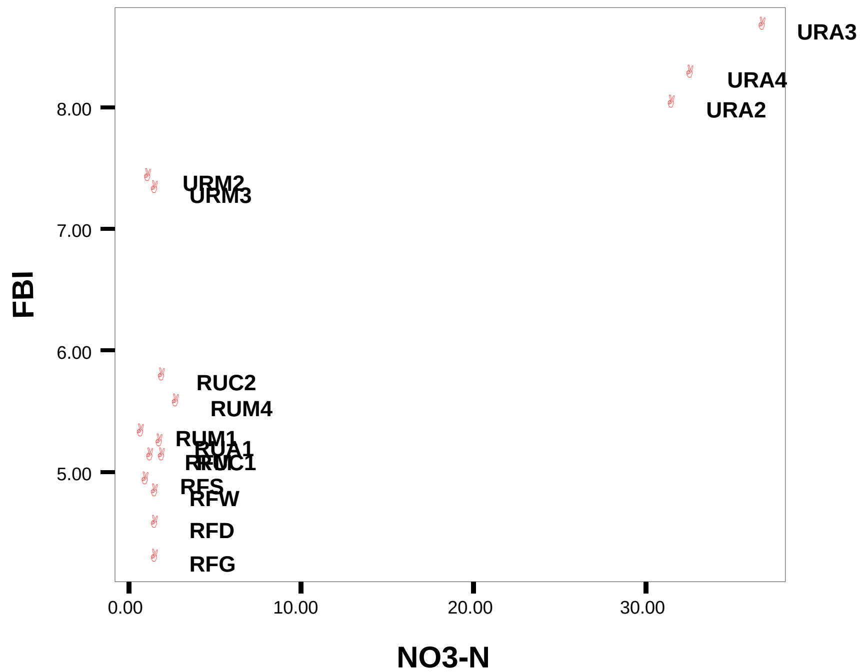
(*RF=reference, RU =Rural, UR urban. Site codes are as in Table 1)


URA3
URA4
URA2
URM2
URM3
RUC2
RUM4
RUM1
RUA1
RFM
RUC1
RFS
RFW
RFD
RFG
FBI
8.00
7.00
6.00
5.00
0.00
250.00
500.00
750.00
1000.00
TDS

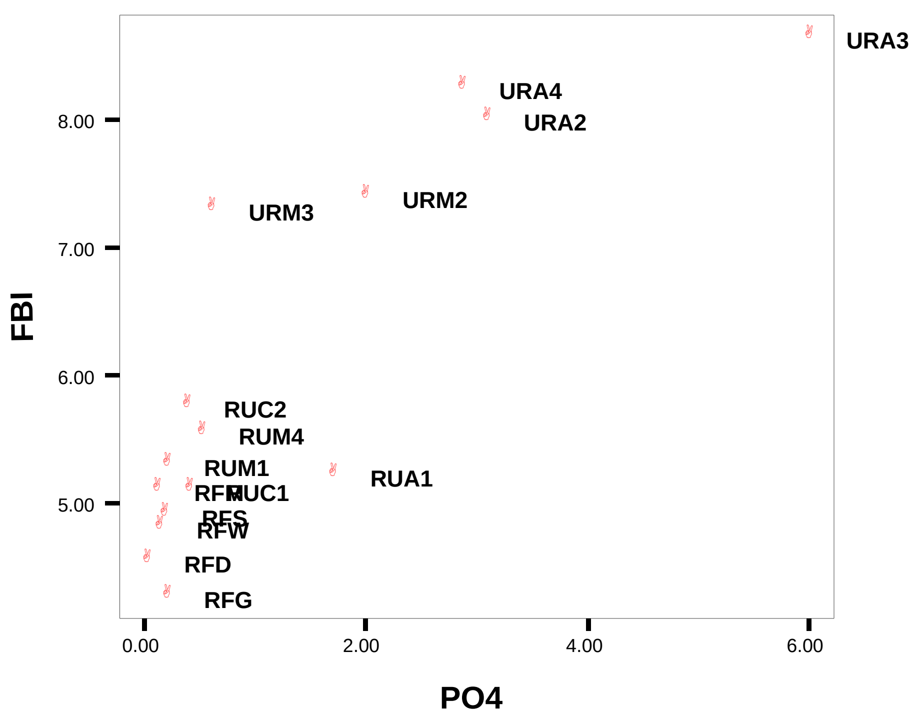
b


URA3
URA4
URA2
URM2
URM3
RUC2
RUM4
RUM1
RUA1
RUC1
RFM
RFS
RFW
RFD
RFG
FBI
8.00
7.00
6.00
5.00
4.00
6.00
8.00
10.00
12.00
DO

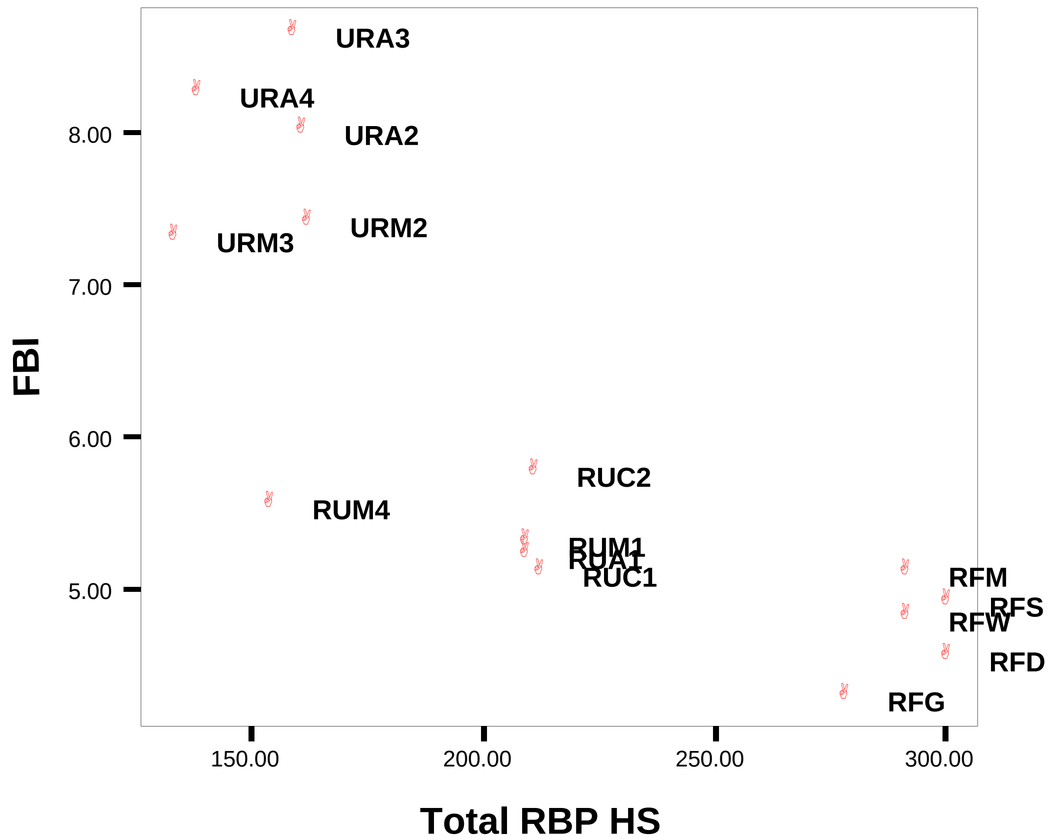
c


URA3
URA4
URA2
URM2
URM3
RUC2
RUM4
RUM1
RUA1
RFM
RUC1
RFS
RFW
RFD
RFG
8.00
7.00
6.00
5.00
FBI
0.00
10.00
20.00
30.00
NO3-N

d


URA3
URA4
URA2
URM3
URM2
RUC2
RUM4
RUM1
RUA1
RFM
RUC1
RFS
RFW
RFD
RFG
8.00
7.00
6.00
5.00
FBI
0.00
2.00
4.00
6.00
PO4

e



f

Figure 21. Scatter plot of H-FBI scores versus (a) conductivity b) TDS, c) Dissolved oxygen, d) NO3-N, e) PO4 and f) Total RBPHS by land-use category

6. CONCLUSIONS AND RECOMMENDATIONS

Several studies have recognized relationships between land use and water quality with macroinvertebrate communities' characteristics (metrics) (Fore et al., 1996; Barbour et al., 1999). These studies show that total number of taxa and %EPT (%Ephemeroptera, %Plecoptera, %Tricoptera) are all expected to decrease with increased perturbation. Percent Diptera and Chironomidae increase with increasing disturbance. Additionally, H-FBI is expected to increase with increasing disturbance (organic pollution) (Kerans and Karr, 1994).

The results of this study more or less concur with previous studies. Trends in this study data show that as habitat and water quality are degraded, number and percentage of EPT decreased, while percentages of diptera and bloodredchironomids increased. Moreover, there were significant correlations between macroinvertebrates and most environmental variables. However, there are some trends in these data that indicate some of these and other variables may need to be studied in finer detail on a microhabitat, and genus or species level.

The condition of macroinvertebrate communities varies considerably among stream reaches of these rivers. The data indicate that a number of streams, including Akaki-Kebena (A2, A3, and A4) and Modjo downstream sites (M3 and M4), contain reaches that have macroinvertebrate communities that are heavily degraded by human influence. These streams are characterized by the absence of any sensitive or sediment-sensitive taxa; few if any, mayflies, or caddisflies; greater dominance by only a few taxa; and larger numbers of macroinvertebrates that are tolerant to pollution and physical habitat degradation. These conditions typify macroinvertebrate communities that have been moderately to severely affected by human influence. In general, stream reaches classified as urban had the worst metric scores. These reaches in the more developed areas of the study reaches have lost much of their capacity to support diverse benthic communities. Physical habitat information for this study, determined that aquatic habitat features, including channel morphology, riparian condition, stream bank stability, instream cover, and substrate, have been degraded by human development (Plates L-N). Clearly, these perturbations have affected macroinvertebrate communities.

Macroinvertebrate communities in other stream reaches (classified as rural sites), namely those scoring B-IBI below the reference site values, have also been degraded by human actions, but not to the extent as those scoring the lowest B-IBI.

A number of stream reaches, including the reaches in Baro basin (Sor river sites) Abay basin (Dabena river sites) and Omo-Ghibe basin (Wabe, Megecha, and Ghibe river sites), currently support diverse macroinvertebrate communities that are well represented by more sensitive taxa, including mayflies, stoneflies, and caddisflies. These reaches which are designated as reference sites are all located in relatively well-forested areas with intact riparian zones and little land use other than forestry (Plates A-D). One of the major challenges of biological monitoring lies in properly defining and selecting reference sites. Of the sites selected for this study, these five sites were least affected by human actions, and are among the least disturbed in the studied reaches. However, to better characterize least disturbed macroinvertebrate communities in the country, such sites should be identified and sampled over a larger area. For example, Baro basin harbors the greatest diversity of macroinvertebrates and may well best represent the least disturbed condition among the studied rivers.

Based on field observation, the reference reaches were among those with the medium gradients in the study. Stream gradient affects stream morphology and habitat characteristics, which in turn, influence the structure of biological communities (Rosgen, 1996). To minimize these differences in physical habitat among streams with different gradients, all categories were made to include medium and low gradients. It is important to note, however, that land use type clearly appears to be exerting the greatest influence on macroinvertebrate community conditions in this study. These relationships between lands use type/intensity and macroinvertebrates community conditions should be further examined to more precisely determine the causes of the significant variation in macroinvertebrate community conditions among these sites.

When macroinvertebrate multimetric scores are calculated, streams are grouped into four categories based on scores: no impairment, slight impairment, moderate impairment, and severe impairment (Karr and Chu, 1999). To measure the ability of the ranking system used for this study and to determine site condition relative to other sites in the study, multimetric scores were calculated for each site using all sorts of microhabitats available in the sites. These scores do demonstrate the ability of the ranking system to determine the least impaired sites within the data set. For the data set, which includes wide range of disturbance levels, the range of scores can be divided into more categories so that wide ranges of impairment levels can be identified.

This study provides the first comprehensive set of data describing macroinvertebrate communities in the studied reaches. Stream reaches were identified that support healthy, diverse macroinvertebrate communities, and other streams were characterized relative to these reaches. As a result, stream reaches were identified with impaired macroinvertebrate communities. Though the selection of best macroinvertebrate groups for biomonitoring purposes in these river basins is not precisely answered by this study, the data provide a means to help prioritize restoration efforts based on severity of current impairment of biological condition and serve as baseline information to assess further degradation or future improvement of stream reach conditions. Moreover the data provides macroinvertebrate metrics that can clearly identify severe degradation. For example, the disappearance of most EPT taxa and dramatic increase (to a monoculture level) of bloodredchironomids at highly polluted rivers strongly showed the potential use of these macroinvertebrate groups as a tool to assess severe degradation.

Though this study considered some physical, chemical and biological parameters of the study reaches, it was beyond the scope of this study to include more parameters and to develop a single multimetric index (score) from the above parameters which best characterize the river status in comparison with the reference sites. Therefore, this study suggests that:

Efforts to monitor biological conditions in these and other rivers should include regular sampling of macroinvertebrate communities at least once per year. Regular sampling provides more certainty in community characterizations by capturing the temporal and spatial variability that occurs at each site and provides for a more precise and accurate evaluation of the response of macroinvertebrate communities to restoration efforts.

Regular sampling should also include trace elements (e.g Fe, Chromium and others from tannery effluents), nutrients and other important physiochemical parameters, which clearly define macroinvertebrate responses to degradation; and from this, best macroinvertebrate multimetric indices will be established.

For more precision, other biological parameters such as fish, aldae, periphytes and macrophytes should also be included in such studies so that overall integrative type of multimetrics index from biological, chemical and physical parameters can be developed. Once those biological parameters, which respond in a predictable way to all sorts of degradation, have been identified for each river basin, a few biological parameters may be used to assess environmental conditions regularly as this is cost effective.

7. REFERENCES

1. Allan, J.D. (1995). *Stream Ecology: Structure and Function of Running Waters*. Chapman & Hall, London.
2. AWANRDPO (2004). Statistical Information. Abeshge woreda agricultural and Natural Resource Development and Protection Office, Ethiopia (unpublished).
3. Barbour, M.T.; Gerritsen, J.; Snyder, B.D. and Stribling, J.B. (1999). *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish*, 2nd ed. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water. Washington D.C.
4. Barnard, P.C. & Biggs, J. (1988). Macroinvertebrates in the catchment streams of Lake Naivasha, Kenya. *Rev. Hydrobiol. Trop.* **21:**127–13
5. Belema Gemechu (2003). *Natural hydrochemical variations and anthropogenic influences on surface water and ground water systems in the selected urban centers in the upper awash basin*. M.Sc Thesis, School of Graduate Studies, Addis Ababa University.
6. Bode, R.W.; Novak, M.A., and Abele, L.E.(1996).Quality *Assurance Work plan for Biological Stream Monitoring in New York State*. NYS Department of Environmental Conservation, Albany, Ny.
7. Booth, D. B., and Jackson, C. R. (1997). Urbanization of aquatic systems-degradation, thresholds, stormwater detention, and the limits of mitigation. *Journal of the American Water Resources Association* **22**(5): 1–17.
8. Branson, B. A. and D. L. Batch. (1972). Effects of strip-mining on small-stream fishes in eastcentral Kentucky. *Proc. Biol. Soc.Wash*. **84**(59): 507-518.

9. Burton, G.A. and Scott, K.J. (1992). Sediment toxicity evaluations: their niche in ecological assessments. *Environ. Sci. Technol*. **26**: 2068-2075.
10. Buss, D.F., D.F. Baptista, M.P. Silveira, J.L. Nessimian and L.F.M. Dorville (2002). Influence of water chemistry and environmental degradation on macroinvertebrate assemblages in a river basin in southeast Brazil. *Hydrobiologia*, **481:**125-136.
11. Chapman, P.M. (1990). The sediment quality triad approach to determining pollution-induced degradation. *Sci. Tox. Environ*. **97**(8): 815-825.
12. Chapman, P.M. (1995). Do sediment toxicity tests require field validation? *Environ. Toxicol.Chem*. **14**(9): 1451-1453.
13. Chapman, P.M.; Power, E.A. and Burton, Jr. (1992). Integrative assessments. **In:** *aquatic ecosystems*, pp. 313-340 (Burton, Jr. ed.) , Lewis Publishers, Chelsea, MI.
14. Curtis, W. R. 1973. Effects of strip-mining on the hydrology of small mountain watersheds in Appalachia. **In**: *Ecology and reclamation of devastated lands,* vol. 1, (Hutnik, R.J. and Davis. G., eds.). Gordon and Breach Publ. New York, NY.
15. Dallas, H.F. (1997) A preliminary evaluation of aspects of SASS (South Africa Scoring System) for rapid bioassessment of water quality in rivers. *S. Afr. J. Aquat. Sci.* **23:** 79–94.
16. De Pauw, N. & Hawkes, H.A. (1993). Biological monitoring of river water quality**. In**: *River Water Quality Monitoring and Control,* Pp265-300, (Walley, W. J. and Judd, S., eds). Aston University, Birmingham, UK.
17. Dow, C. L. and Zampella, R.A. (2000). Specific conductance and pH as indicators of watershed disturbance in streams of the New Jersey Pinelands, USA. *Env. Mgmt.* **26** (4): 437-446.

18. Durand, J.R. and Leveque,C.(1981).Flore et Faune Aquatiques de l'Afrique.Vol.2,PP.873,O.R.S.T.O.M,Paris.
19. Dyer, K.L. (1982). *Stream water quality in the coal region of eastern Kentucky. USDA Forest* Serv.Techn. Rep. NE-74. Northeastern Forest Experiment Station, Berea, Ky.
20. Fore, L.S.; Karr, J.R. and Wisseman, R.W. (1996). Assessing invertebrate responses to Human activities: evaluating alternative approaches. *Journal of the North American Benthological Society* **15**(2): 212-231.
21. Fritz, K.M., and W.K. Dodds. (2004). Resistance and resilience of macroinvertebrate assemblages to drying and flood in a tallgrass prairie stream system. *Hydrobiologia* **1:** 1-14.
22. Garcia-Criado, F.; Tome, A.; Vega, F.J and Antolin, C. (1999). Performance of some diversity and biotic indices in rivers affected by coal mining in northwestern Spain. *Hydrobiol*. **394**:209-217.
23. Gibson, G. R.; Barbour, M. T; Stribling, J. B; Gerritsen, J. and Karr, J. R. (1996). *Biological criteria: technical guidance for streams and small rivers*. EPA 822-B-96-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC.
24. Green, J.; Passmore, M. and Childers, H.(2000). *A survey of the condition of streams in the primary region of mountaintop mining/valley fills coal mining.* U.S. Environmental Protection Agency, Region III. Wheeling, W. Va.
25. Harding, J.S.;Young, R.G.; Hayes, J.W.; Shearer, K.A. and Stark, J.D. (1999) Changes in agricultural intensity and river health along a river continuum. *Freshw. Biol.* **42**; 345–357.
26. Harrison, A. D. and Hynes, H.B.N. (1988). Benthic fauna of Ethiopian mountain streams and rivers. *Hydrobiologia* **1**:1-36
27. Hauer, F.R. and Lamberti, G.A. (1996). *Benthicmacroinvertebrates. Methods in stream ecology*. Academic Press.

28. Hem, J.D. (1992). *Study and interpretation of the chemical characteristics of natural water*. Water-Supply Paper 2254, U.S. Geological Survey, Washington, D.C.
29. Hilsenhoff, W.L. (1988). Rapid field assessment of organic pollution with a family level biotic index. *J. North Am. Benthol. Soc*. **7**(1): 65-68.
30. Howard, H. S.; Berrang, B.; Flexner, M. Pond, G. and Call, S. (2000). *Kentucky mountaintop mining benthic macroinvertebrate survey.* U. S. Environmental Protection Agency, Science and Ecosystem Support Division, Ecological Assessment Branch, Athens, Ga.
31. Karr, J.R. and Chu, E.W. (1999). *Restoring life in running waters: Better biological monitoring. Island* Press, Washington, D.C.
32. Karr, J.R.; Fausch, K.D.; Angermeier, P.L. ; Yant, P.R. and Schlosser I.J. (1986). *Assessing biological integrity in running waters: A method and its rationale*. Special publication 5.Illinois Natural History Survey.
33. Kentucky Division of Water (KDOW) (2002a). *Methods for assessing biological integrity of surface waters.* Kentucky Department for Environmental Protection, Division of Water, Frankfort, Ky.
34. Kerans, B.L. and Karr, J.R. (1994). Development and testing of a benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley. *Ecological Applications* **4**(4).
35. Kimmel, W.G. (1983). The Impact of Acid Mine Drainage on the Stream Ecosystem. **In**: *Pennsylvania Coal: Resources, Technology and Utilization*, pp. 424-437, (Majumdar, S.K. and Miller, W.W., eds.). The Pennsylvania Academy of Science Publication.
36. Kinyua, A.M. and Pacini, N. (1991). The impact of pollution on the Ecology of the Nairobi-Athi River system in Kenya. *J. Biochem. Phys.* **1**: 5−7.

37. Knighton, D. (1984). *Fluvial Forms and Processes*. Edward Arnold, London.
38. Lenat, D.R., and Penrose, D.L. (1981). Variable effects of sediment addition on stream benthos. *Hydrobiologia* **79:**187-194.
39. Ludwig, J.A. and Reynolds, J.F. (1988). *Statistical ecology: a primer on methods and computing.* John Wiley and Sons. New York, NY.
40. Mason, C.F. (1990). Biological aspects of freshwater pollution**. In**: *Pollution*, p 99-125, (Harrison, R.M. ed.), The Royal society of chemistry, Cambridge CB4 4WF.
41. Mathoko, J.M. (2002). The sizes, maturity stages and biomass of mayfly assemblages colonizing disturbed streambed patches in Central Kenya. *Afri. J. Ecol.* **40**:84–93.
42. Merritt, R. W. and Cummins, K. W. (1996). An introduction to the aquatic insects of North America. Third Edition. Kendall/Hunt Publishing Co., Dubuque, IA.
43. MIDEQ (Michigan Department of Environmental Quality) (20000). Surface Water Quality Division Permits Section; Total Suspended Solids. Available on line at: http://www.deq.state.mi.us/swq/permits/parameters/tss.htm
44. Minshall, G.W. (1984). Aquatic insect-substratum relationships. **In**: *The Ecology of Aquatic Insects*, pp. 358-400, (Resh, and V.H. and Rosenberg, D.M. ,eds.), Praeger, New York.
45. Murphy, S. (2000). General information on solids. BASINS, Boulder Area Sustainability Information Network. Available online at: http://bcn.boulder.co.us/basin/data/FECAL/info/TSS.html
46. National Meteorological Services Agency (2004). Climate of Ethiopia series, Vol.1, NO.1: Rain*fall*. Addis Ababa, Ethiopia, pp134.
47. Nelson, R.L.; Platts, W.S.; Larsen, D.P. and Jensen, S.E. (1992). Trout distribution and habitat relation to geology and geomorphology in the North Fork Humboldt River drainage, northeastern

Nevada. *Transactions of the American Fisheries Society* **121**(4): 405-426.

48. Novotny, V. and Olem, H. (1994). *Water Quality: Prevention, Identification, and Management of Diffuse Pollution.* Van Nostrand Reinhold, New York.

49. Rosenberg, D.M. and Resh, V.R. (1993). *Freshwater Biomonitoring and BenthicMacroinvertebrates.* Chapman and Hall, New York.

50. Pawlak, B. (1999). The basics of bioassessment: reference conditions. *Virginia Lakes &Watersheds Association Newsletter* **48**: 8-9.

51. Pielou, E. C. (1984). *The interpretation of ecological data: a primer on classification and ordination*. Wiley, N.Y.

52. Plotnikoff,W.R. and Chad, W.(2001). *Benthic Macroinvertebrate Biological Monitoring Protocols for Rivers and Streams 2001 Revision. Environmental Assessment Program,* Olympia, Washington 98504-7710 Publication No. 01-03-028,pp50.

53. Pond, G.J. and McMurray, S.E. (2002). *A macroinvertebrate bioassessment index for headwater streams in the eastern coalfield region*, Kentucky. Kentucky Department for Environmental Protection, Division of Water, Frankfort, Ky.

54. Pond, G.J.; Call, S.C.; Brumley, J.F. and Compton, M.C. (2003). The Kentucky macroinvertebrate bioassessment index: derivation of regional narrative criteria for headwater and wadeable streams. Kentucky Department for Environmental Protection, Division of Water, Frankfort,Ky.

55. Richards, C. and Bacon, K.L. (1994). Influence of fine sediment on macroinvertebrate colonization of surface and hyporheic stream substrates. *Great Basin Naturalists* **54**(2): 106-113.

56. Rosgen, D. (1996). *Applied river morphology*. Wildland Hydrology, Pagosa Springs, CO.

57. Seyoum Leta, Fassil Assefa and Gunnel, D. (2003). Characterization of Tannery wastewater and assessment of downstream pollution profiles along Modjo River in Ethiopia. *Ethiop. J. Biol. Sci*. **2**(2): 157-168.
58. SNNPR Statistics and Demography Office (2004). Statistical Information. Southern Nation and Nationalities People' Region Statistics and Demography Office, Awassa (unpublished).
59. Southerland, M.T. and Stribling, J.B. (1995). Status of biological criteria development and implementation. **In**: *Biological Assessment and Criteria*: *Tools for Water Resource Planning and Decision Making,* pp. 81-96. (Davis, W.S. and Simon, T.P., eds.) , Lewis Publishers, Boca Raton, FL.
60. Stone, M.K.; and Wallace, J.B. (1998). Long-term recovery of a mountain stream from clear-cut logging: the effects of forest succession on benthic community structure. *Freshwater Biology* **39**:151-169.
61. Sutcliffe, D.W. and Hildrew, A.G. (1989). Invertebrate Communities in Acid Streams*. **In***: *Acid Toxicity and Aquatic Animals*. Society for Experimental Biology Seminar Series, vol.34, pp. 13-30, (Morris, R. et al., eds.), Cambridge University Press.
62. Sweeney, B.W. (1993). Effects of streamside vegetation on macroinvertebrate communities of White Clay Creek in Eastern North America. Proc. *Acad. Nat. Sci. of Phil.* **144**: 291-340.
63. Talak, A. (1977). *The recovery of stream insect communities following coal strip mining in the Cumberland Mountains of Tennessee*. M.S. Thesis. Univ. of Tenn, Knoxville.
64. Tesfaye Berhe (1988). *The Degradation of the Abo- Kebena River in Addis Ababa. Ethiopia.* M.Sc Thesis, school of Graduates Studies, Addis Ababa University.

65. Thorn, J.H. and Covich, A.P. (1991). Ecology and classification of North American fresh water invertebrates. Academic press Inc., San Diego.

http://clean-water. uwex.edu/wav/onitroing/biotic/group 2.Htm.

66. Tumiwesigye, C.; Yusuf, S.K. and Makanga, B. (2000). Structure and composition of benthic macroinvertebrate of a tropical forest stream, River Nyamweru, western Uganda. *Afri. J. Ecol.* **38**:72–77.

67. U.S. Environmental Protection Agency (USEPA) (1990). The Quality of our Nation's Water: A Summary of the 1988 National Water Quality Inventory. EPA Report 440/4-90-005.Washington, DC.

68. U.S. Environmental Protection Agency (USEPA) (1992b). *Framework for Ecological RiskAssessment*. EPA Report 630/R-92/001. Risk Assessment Forum. Washington, D.C.

69. U.S. Geological Survey (USGS) (2001a). *Benthic invertebrate communities and their responses to selected environmental factors in the Kanawha River Basin*, West Virginia, Virginia, and North Carolina. Water-Resources Investigations Report 01-4021.

70. Vannote, R.L.; Minshall, G.W.; Cummis, K.W.; Sedell, J.R. and Cushing, C. (1980). The river continuum concept 1. *Can. J. Fish. Aqua. Sci.* **37**: 130–137.

71. Wallace, J.B.; Grubaugh, J. W. and Whiles, M.R.(1996). Biotic indices and stream ecosystem processes: results from an experimental study. *Ecol. Applic*. **6**:140-151.

72. Watzin, M.C. and McIntosh A.W. (1999). Aquatic ecosystems in agricultural landscapes: a review of ecological indicators and achievable ecological outcomes. *Journal of Soil and Water Conservation* **54**(4): 636-644.

73. Wetzel, R.G. (2001). *Limnology: Lakes and Rivers ecosystems*, 3rd ed. Academic Press, San Diego San Francisco New York.

74. Williams, D.D. (1996). Environmental constraints in temporary fresh waters and their consequences for the insect fauna. *J. North Am. Benthol. Soc.* **15**:634-650.

75. Worku Legesse; Giller, P.S. and O'halloran,J. (2000). *Physicochemical and Biological assessment of the Kebena River*, Addis Ababa, Ethiopia. Department of zoology and animal ecology, National University of Ireland, cork.

76. Zinabu Gebremariam and Elias Dadebo (1989). Water resources and fisheries management in the Ethiopian rift valley lakes. *SINET: Ethiop. J. Sc*. **12** (2): 95-109.

8. PLATES

9. APPENDICES

Appendix 1. Summary of basic data of the study areas

Site	Total length (Kms)	Catch.Area(sq.km)	Altitude (m)	Coordinates	Ecoregion	Av width (m)		Channel	Av.Velocity (m/s)	Gradient
						Av depth (m)	Stream			
Dabena	146	3009	1821	8°24’23”N, 36°18’52”E	95%Low land 5%High land	0.5	13	10	0.62	Medium
Sor	127	2273	1544	8°17’23”N, 35°37’52”E	Low land	0.95	36	25	0.72	Medium
Ghibe	74.9	1091	1086	8°14’37”N, 37°32’37”’E	Low land	0.9	40	30	0.84	Medium
Wabe	81.8	1840	1671	8°14’54”N, 37°45’50”E	10%Low land 90%High land	0.8	16	14	0.8	Medium
Megecha	178	248	1859	8°11’00”N, 37°45’50’’E	10%Low land 90%High land	0.4	15	11	0.67	Medium
Chacha 1	108	2203	2766	9°31’28”N, 39°28’03”E	High land	0.71	14	10	0.26	Low
Chacha2			2764	9°32’11”N, 39°26’06”;E		0.8	14	11	0.26	Low
Modjo1	98.1	-	1769	8O37’16”N, 39°06’46”E	Low land (most part in rift)	0.6	12	10	0.58	Medium
Modjo2			1733	8°35’57”N, 39°06’46”E		0.3	8	4	0.56	Medium
Modjo3		-	1883	8°32’32”N, 39°05’26”E		0.4	4	4	0.64	Medium
Modjo4		-	-	8°25’23”N, 39°01’52”E		0.3	3	5	0.27	Low
Akaki -Kebena1	28.8	-	2560	9°03’52”N, 38°45’53”E	High land	0.2	10	2	0.68	High
Akaki -Kebena2			-	9°02’16”N, 38°46’17”E		0.3	6	3	0.61	Medium
Akaki -Kebena3			-	9°00’57”N, 38°46’23”E		0.4	15	10	0.62	Medium
Akaki -Kebena4			-	8°51042”’N, 38°46’42”E		0.5	14	10	0.28	Low

Appendix 2. Principal component analysis results for the first four axes for physicochemical data and RBP Habitat scores using all sites.

Eigenvalue	Axis1	Axis2	Axis3	Axis4
Eigenvalue	11.708	2.752	1.700	1.550
Proportion	0.585	0.138	0.085	0.077
Cumulative	0.585	0.723	0.808	0.886

PCA Variable Loading	Axis1	Axis2	Axis3	Axis4
pH	0.199	-0.170	0.330	0.174
Conductivity	0.280	0.084	-0.135	0.051
TDS	0.267	0.107	-0.139	-0.000
Temperature	-0.051	0.054	-0.313	0.677
Disolved Oxy.	-0.271	-0.049	0.127	0.137
NO3-N	0.191	0.344	-0.123	-0.286
PO4	0.219	0.368	0.012	-0.097
EPFS	-0.128	0.476	0.055	-0.126
SEDI	-0.097	0.235	0.376	0.243
CHANF	-0.130	-0.337	-0.419	-0.209
CHANA	-0.223	-0.064	0.322	-0.104
BS	-0.244	-0.161	-0.321	0.024
BV	-0.235	0.313	-0.043	-0.014
REPV	-0.195	0.350	-0.283	0.121
MANU	-0.258	0.020	-0.053	0.241
CC	-0.235	0.144	-0.209	-0.077
NUTR	-0.280	0.054	0.150	0.022
WAT	-0.271	-0.075	0.206	-0.049
GRA	-0.228	-0.076	-0.047	-0.425
Total RBPHS	-0.282	0.109	0.036	-0.08

EPFS= Epifaunal substrate / available cover, SEDI= Sediment deposition, CHANF= Channel flow status, CHAA= Channel alteration, BS= Bank stability, BV = Bank vegetative protection, CC = Canopy cover, RIPV= Riparian vegetative zone width, MANU=Manure presence, WAT= water appearance, NUTRE= nutrient enrichment, GRA = Graze RBPHS = Rapid Bioassessment Protocol habitat score

Appendix 3. Macroinvertebrate collected at each site

Taxa list	Sites														
	D	S	G	W	M	C1	C2	M1	M2	M3	M4	A1	A2	A3	A4	Total
Ephemeroptera (Mayflies)																
Baetidae (Small Minnow Mayflies)	93	137	33	108	216	261	241	107	85	6	19	278	29	1	6	1620
Caenidae (small square –gill Mayflies)	50	85	0	14	27	39	165	16	3	0	10	976	9	0	0	1394
Heptageniidae (Flathead Mayflies)	55	6	4	7	0	3	32	0	0	0	0	1	0	0	0	108
Leptophlebiidae (Prong-gilled Mayflies)	0	0	3	0	0	0	0	0	0	0	0	1	0	0	0	4
Tricorythidae(Little Stout Crawler Maayflies)	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2
Potomanthidae(haklegill Mayflies)	0	0	0	2	0	0	0	0	0	0	0	0	0	0		2
Odonata (Damselflies &Dragonflies)																
Coenagrionidae(Narrow- Winged Damselflies)	0	0	2	7	6	80	122	27	0	0	11	0	0	0	1	256
Cordulidae(Common Skimmer Dragonflies)	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Calopterygidae(Broad-Winged Damselflies)	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Cordulegastridae(Spke-Tail Dragonflies)	0	0	2	0	3	0	0	0	0	0	1	0	0	0	0	6
Aeshnidae (Darner Dragonflies)	3	3	1	4	5	2	0	0	0	0	0	1	6	0	0	25
Gomphidae (Club-Tail Dragonflies)	1	1	1	5	5	0	0	0	0	0	2	1	0	0	0	16
Macromiidae(Common Skimmer Dragonflies)	6	1	11	7	0	0	0	0	0	0	0	0	0	0	0	25
Libellulidae (Common Skimmer Dragonflies)	3	2	13	6	8	0	1	9	0	0	0	7	0	0	0	49
Plecoptera (Stoneflies)																
Perlidae (Common Stoneflies)	21	12	10	1	1	0	0	0	0	0	0	0	0	0	0	45
Perlodidae(Patterned Stoneflies)	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	3
Hemiptera (Water or true bugs)																
Corixidae (waterboatmen)	1	1	2	8	52	234	155	804	11	47	6	36	7	0	1	1365
Nepoidae(Waterscorpion)	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	2
Notonectidae (back swimmers)	0	0	33	7	34	118	98	402	1	2	3	9	0	0	0	707
Geridae (water Striders)	0	0	0	1	3	32	14	16	0	0	2	0	0	0	2	70

Naucoridae(Creeping Water Bugs)	46	25	2	0	8	29	15	32	2	0	10	0	0	0	0	169
Veliidae(Broab-Shouldered Water Striders)	8	9	0	0	9	0	3	21	0	0	17	0	0	0	0	67
Rhagoveliinae	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
Salididae(Shore Bugs)	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Trichoptera (Caddisflies)																
Hydropsychidae (Common Net -Spinner Caddisflies)	43	3	2	53	22	2	1	17	118	0	41	1	0	0	0	303
Glossosomatidae(Saddle Case Maker Caddisflies)	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Philopotamidae (Finge-Net Caddisflies)	37	5	0	0	0	3	0	3	0	0	0	0	0	0	0	48
Phryganeidae(Giant Case-Maker Caddisflies)	0	0	0	0	17	5	3	0	0	0	0	0	0	0	0	25
Hydroptilidae(Micro Caddisflies)	3	1	0	0	0	0	0	0	0	0	0	2	0	0	0	6
Rhyacophilidae(Free-Living Caddisflies)	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Brachycentridae(Humpless Case-Maker Caddisflies)	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	5
Coleoptera (Beetles)																
Dryopidae(Long-Toed Water Beetle)	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Dytiscidae (Predaceous Diving Beetles)	1	2	7	0	1	28	52	8	1	2	2	19	6	0	0	129
Elmidae (Riffle Beetles)	49	9	3	28	9	1	1	7	6	0	77	8	2	0	7	207
Gyrinidae (Whirligig Beetles)	10	3	0	0	3	102	30	16	4	0	10	35	0	0	1	214
Helodidae	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	6
Haliplidae(Crawling Water Beetles)	1	0	10	5	0	0	0	0	0	0	0	0	0	0	0	16
Hydrophilidae (Water Scavenger Beetles)	8	2	0	2	3	21	10	11	1	1	9	24	6	1	1	100
Psephenidae (Water pennies)	1	2	0	5	0	0	0	0	0	0	0	0	0	0	0	8
Diptera (Two winged or"True flies")																
Ceratopogonidae (Biting Midges)	4	1	0	4	14	0	3	0	7	0	0	24	0	0	0	57
Chironomidae (Non-Biting)																
Chironomidae (Blood-red)	2	0	0	1	4	1	10	2	176	1265	2	15	1652	314	635	4079
Chironomidae, Other (including pink)	98	11	8	95	273	95	158	160	2	75	53	732	0	0	153	1913
Culicidae (mosquitoes)	0	0	4	1	0	3	0	4	2	4	0	10	194	2	3	227

Ephydridae (Shore Flies, Brine Flies)	0	0	0	1	0	0	0	0	0	0	0	0	37	1	1	40
Muscidae(House Flies)	0	0	0	0	0	0	0	0	2	3	0	0	2	1	1	9
Psychodidae (Moth Flies)	2	0	0	1	1	0	0	0	1	5	0	3	150	106	3	272
Rhagionidae	0	0	4	4	0	0	0	0	0	0	0	0	0	0	0	8
Sciomyzidae (snail-killing Flies, Marsh flies)	0	0	0	1	1	0	0	1	0	1	0	18	0	0	0	22
Stratiomyidae(Soldier Flies)	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Syrphidae (Rat-Tailed Maggots,Flower Flies)	0	0	0	0	0	0	0	0	0	0	0	0	13	34	0	47
Tabanidae (Horse Flies, Deer Flies)	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	8
Empididae (Dance Flies)	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Tipulidae (Crane Flies)	8	2	1	6	7	0	0	0	0	0	0	4	0	0	0	28
Simulidae (Black Flies)	7	1	0	202	44	0	4	2	6	78	1397	8	504	3	10	2266
Mollusks(Snails)																
Lymnaeidae	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	3
Ancylidae	0	0	0	0	7	0	2	2	0	0	0	0	0	0	0	11
Physidae	0	0	0	0	0	1	0	0	0	0	0	0	80	53	7	141
Planorbidae	0	0	0	0	0	5	0	0	0	0	1	0	0	0	0	6
Sphaeriidae (Fingernail or Pea Clamps)	0	0	0	1	0	7	2	0	0	0	0	0	0	0	0	10
Arachnoidea (water mites)																
Limnesidae	0	1	0	2	0	4	0	0	0	0	0	0	0	0	1	8
Lepidoptera(Butteflies & Moths)																
Pyralidae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Hirudinea(Leeches)	0	0	0	2	0	1	5	0	0	0	0	0	0	0	1	9
Oligochaeta (Aquatic Earth worms)	2	0	2	1	4	0	1	2	310	0	0	0	211	226	869	1628
Turbellaria(planerians)(Flat Worms)	23	3	0	2	2	2	1	0	0	0	0	0	0	0	0	33
Total	608	333	161	594	794	1088	1130	1669	739	1489	1673	2214	2910	742	1703	17847

Appendix 4. Macroinvertebrate collected by major land uses

NO	Taxa lists	Sites							
		Reference		Rural		Urban		Total	
		Abundance	%	Abundance	%	Abundance	%	Abundance	%
1	Baetidae	587	36.2	906	55.9	127	7.84	1620***	9.08
2	Caenidae	176	12.6	1206	86.5	12	0.861	1394***	7.81
3	Heptageniidae	72	66.7	36	33.3	0	0	108*	0.61
4	**Leptophlebiidae**	**3**	**75**	**1**	**25**	**0**	**0**	**4**	**0.02**
5	**Tricorythidae**	**2**	**100**	**0**	**0**	**0**	**0**	**2**	**0.01**
6	**Potomanthidae**	**2**	**100**	**0**	**0**	**0**	**0**	**2**	**0.01**
7	Coenagrionidae	15	5.86	240	93.8	1	0.391	256**	1.43
8	**Cordulidae**	**1**	**100**	**0**	**0**	**0**	**0**	**1**	**0.01**
9	**Calopterygidae**	**1**	**100**	**0**	**0**	**0**	**0**	**1**	**0.01**
10	**Cordulegastridae**	**5**	**83.3**	**1**	**16.7**	**0**	**0**	**6**	**0.03**
11	Aeshnidae	16	64	3	12	6	24	25	0.14
12	Gomphidae	13	81.3	3	18.8	0	0	16	0.09
13	Macromiidae	25	100	0	0	0	0	25	0.14
14	Libellulidae	32	65.3	17	34.7	0	0	49	0.27
15	Perlidae	45	100	0	0	0	0	45	0.25
16	**Perlodidae**	**3**	**100**	**0**	**0**	**0**	**0**	**3**	**0.02**
17	Corixidae	64	4.69	1235	90.5	66	4.835	1365**	7.65
18	**Nepoidae**	**0**	**0**	**1**	**50**	**1**	**50**	**2**	**0.01**
19	Notonectidae	74	10.5	630	89.1	3	0.424	707**	3.96
20	Geridae	4	5.71	64	91.4	2	2.857	70	0.39
21	Naucoridae	81	47.9	86	50.9	2	1.183	169*	0.95
22	Veliidae	26	38.8	41	61.2	0	0	67	0.38
23	**Rhagoveliinae**	**6**	**100**	**0**	**0**	**0**	**0**	**6**	**0.03**
24	**Salididae**	**4**	**100**	**0**	**0**	**0**	**0**	**4**	**0.02**
25	Hydropsychidae	123	40.6	62	20.5	118	38.94	303**	1.7
26	**Glossosomatidae**	**0**	**0**	**1**	**100**	**0**	**0**	**1**	**0.01**
27	Philopotamidae	42	87.5	6	12.5	0	0	48	0.27
28	Phryganeidae	17	68	8	32	0	0	25	0.14
29	**Hydroptilidae**	**4**	**66.7**	**2**	**33.3**	**0**	**0**	**6**	**0.03**
30	**Rhyacophilidae**	**2**	**100**	**0**	**0**	**0**	**0**	**2**	**0.01**
31	**Brachycentridae**	**5**	**100**	**0**	**0**	**0**	**0**	**5**	**0.03**
32	**dryopidae**	**0**	**0**	**0**	**0**	**1**	**100**	**1**	**0.01**

33	Dytiscidae	11	8.53	109	84.5	9	6.977	129*	0.72
34	Elmidae	98	47.3	94	45.4	15	7.246	207**	1.16
35	Gyrinidae	16	7.48	193	90.2	5	2.336	214**	1.2
36	**Helodidae**	**6**	**100**	**0**	**0**	**0**	**0**	**6**	**0.03**
37	**Haliplidae**	**16**	**100**	**0**	**0**	**0**	**0**	**16**	**0.09**
38	Hydrophilidae	15	15	75	75	10	10	100*	0.56
39	**Psephenidae**	**8**	**100**	**0**	**0**	**0**	**0**	**8**	**0.04**
40	Ceratopogonidae	23	40.4	27	47.4	7	12.28	57	0.32
41	Chironomidae (Blood-red)	7	0.17	30	0.74	4042	99.09	4079**	22.9
42	Chironomidae, Other	485	25.4	1198	62.6	230	12.02	1913**	10.7
43	Culicidae	5	2.2	17	7.49	205	90.31	227**	1.27
44	Ephydridae	1	2.5	0	0	39	97.5	40	0.22
45	**Muscidae**	**0**	**0**	**0**	**0**	**9**	**100**	**9**	**0.05**
46	Psychodidae	4	1.47	3	1.1	265	97.43	272**	1.52
47	**Rhagionidae**	**8**	**100**	**0**	**0**	**0**	**0**	**8**	**0.04**
48	Sciomyzidae	2	9.09	19	86.4	1	4.546	22	0.12
49	**Stratiomyidae**	**0**	**0**	**0**	**0**	**1**	**100**	**1**	**0.01**
50	Syrphidae	0	0	0	0	47	100	47	0.26
51	**Tabanidae**	**0**	**0**	**8**	**100**	**0**	**0**	**8**	**0.04**
52	**Empididae**	**2**	**100**	**0**	**0**	**0**	**0**	**2**	0.01
53	Tipulidae	24	85.7	4	14.3	0	0	28	0.16
54	Simulidae	254	11.2	1411	62.3	601	26.52	2266**	12.7
55	**Lymnaeidae**	**3**	**100**	**0**	**0**	**0**	**0**	**3**	0.02
56	**Ancylidae**	**7**	**63.6**	**4**	**36.4**	**0**	**0**	**11**	0.06
57	Physidae(	0	0	1	0.71	140	99.29	141*	0.79
58	**Planorbidae**	**0**	**0**	**6**	**100**	**0**	**0**	**6**	**0.03**
59	**Sphaeriidae**	**1**	**10**	**9**	**90**	**0**	**0**	**10**	**0.06**
60	**Limnesidae**	**3**	**37.5**	**4**	**50**	**1**	**12.5**	**8**	**0.04**
61	**Pyralidae**	**0**	**0**	**1**	**100**	**0**	**0**	**1**	**0.01**
62	**Hirudinea**	**2**	**22.2**	**6**	**66.7**	**1**	**11.11**	**9**	**0.05**
63	oligochaeta	9	0.55	3	0.18	1616	99.26	1628**	9.12
64	Turbellaria	30	90.9	3	9.09	0	0	33	0.18
	Total	2490	14	7774	43.6	7583	42.49	17847	

***The most abundant familes
**Abundant families
* Common
Bolded =rare families

Appendix 5. Significant test result for B-IBI, H-FBI and Total RBP Habitat score among major categories

A) B-IBI

Group Statistics

	Categories	N	Mean	Std. Deviation	Std. Error Mean
B-IBI	References	5	82.8400	8.0699	3.6090
	Rural sites	5	63.4000	12.8437	5.7439

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
B-IBI	Equal variances assumed	.888	.374	2.866	8	.021	19.4400	6.7836	3.7971	35.0829
	Equal variances not assumed			2.866	6.732	.025	19.4400	6.7836	3.2693	35.6107

Group Statistics

	Categories	N	Mean	Std. Deviation	Std. Error Mean
B-IBI	References	5	82.8400	8.0699	3.6090
	Urban sites	5	33.1000	9.1608	4.0968

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
B-IBI	Equal variances assumed	.010	.924	9.110	8	.000	49.7400	5.4597	37.1499	62.3301
	Equal variances not assumed			9.110	7.875	.000	49.7400	5.4597	37.1149	62.3651

Group Statistics

	Categories	N	Mean	Std. Deviation	Std. Error Mean
B-IBI	Rural sites	5	63.4000	12.8437	5.7439
	Urban sites	5	33.1000	9.1608	4.0968

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
B-IBI	Equal variances assumed	.584	.467	4.295	8	.003	30.3000	7.0552	14.0307	46.5693
	Equal variances not assumed			4.295	7.233	.003	30.3000	7.0552	13.7254	46.8746

B) H-FBI

Group Statistics

	Categories	N	Mean	Std. Deviation	Std. Error Mean
H-FBI	References	5	4.7220	.3233	.1446
	Rural sites	5	5.3840	.2647	.1184

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
H-FBI	Equal variances assumed	.221	.651	-3.543	8	.008	-.6620	.1869	-1.0929	-.2311
	Equal variances not assumed			-3.543	7.700	.008	-.6620	.1869	-1.0959	-.2281

Group Statistics

	Categories	N	Mean	Std. Deviation	Std. Error Mean
H-FBI	References	5	4.7220	.3233	.1446
	Urban sites	5	7.9200	.5707	.2552

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
H-FBI	Equal variances assumed	2.277	.170	-10.902	8	.000	-3.1980	.2933	-3.8745	-2.5215
	Equal variances not assumed			-10.902	6.327	.000	-3.1980	.2933	-3.9069	-2.4891

Group Statistics

	Categories	N	Mean	Std. Deviation	Std. Error Mean
H-FBI	Rural sites	5	5.3840	.2647	.1184
	Urban sites	5	7.9200	.5707	.2552

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
H-FBI	Equal variances assumed	3.729	.090	-9.013	8	.000	-2.5360	.2814	-3.1848	-1.8872
	Equal variances not assumed			-9.013	5.645	.000	-2.5360	.2814	-3.2351	-1.8369

C) Total RBP habitat score

Group Statistics

	Categories	N	Mean	Std. Deviation	Std. Error Mean
Total RBP HS	References	5	292.0000	9.0277	4.0373
	Rural sites	5	199.0000	25.1893	11.2650

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Total RBP HS	Equal variances assumed	2.590	.146	7.772	8	.000	93.0000	11.9666	65.4049	120.5951
	Equal variances not assumed			7.772	5.011	.001	93.0000	11.9666	62.2589	123.7411

Group Statistics

	Categories	N	Mean	Std. Deviation	Std. Error Mean
Total RBP HS	References	5	292.0000	9.0277	4.0373
	Urban sites	5	150.6000	13.9392	6.2338

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Total RBP HS	Equal variances assumed	3.823	.086	19.039	8	.000	141.4000	7.4270	124.2734	158.5266
	Equal variances not assumed			19.039	6.854	.000	141.4000	7.4270	123.7616	159.0384

Group Statistics

	Categories	N	Mean	Std. Deviation	Std. Error Mean
Total RBP HS	Rural sites	5	199.0000	25.1893	11.2650
	Urban sites	5	150.6000	13.9392	6.2338

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Total RBP HS	Equal variances assumed	.726	.419	3.759	8	.006	48.4000	12.8748	18.7107	78.0893
	Equal variances not assumed			3.759	6.240	.009	48.4000	12.8748	17.1877	79.6123

Appendix 6. Correlations (Pearson) among B-IBI and associated metrics, and Environmental parameters

	pH	Cond	TDS	Temp.	DO	NO3-N	PO4	EPFS
%TR	-0.570	-0.860	-0.876	-0.092	0.827	-0.524	-0.643	0.536
	0.026	0.000	0.000	0.745	0.000	0.045	0.010	0.039
% Baet	-0.500	-0.797	-0.754	-0.139	0.728	-0.506	-0.571	0.416
	0.058	0.000	0.001	0.622	0.002	0.054	0.026	0.123
%Trico	-0.087	-0.149	-0.221	0.289	0.293	-0.360	-0.240	0.294
	0.758	0.595	0.428	0.297	0.290	0.187	0.388	0.288
%Pleco	-0.639	-0.450	-0.390	0.579	0.535	-0.239	-0.310	0.323
	0.010	0.093	0.151	0.024	0.040	0.392	0.260	0.240
%Ephem	-0.203	-0.695	-0.704	-0.125	0.767	-0.509	-0.434	0.387
	0.468	0.004	0.003	0.656	0.001	0.052	0.106	0.154
% Odonat	-0.323	-0.507	-0.449	0.137	0.389	-0.342	-0.417	0.220
	0.241	0.054	0.093	0.627	0.152	0.213	0.122	0.430
%EPT	-0.135	-0.649	-0.680	0.014	0.786	-0.523	-0.384	0.408
	0.631	0.009	0.005	0.961	0.001	0.045	0.157	0.131
SDI	-0.570	-0.680	-0.653	-0.010	0.697	-0.358	-0.413	0.619
	0.026	0.005	0.008	0.972	0.004	0.190	0.126	0.014
%DT	0.264	0.582	0.517	0.048	-0.536	0.324	0.260	-0.579
	0.341	0.023	0.048	0.864	0.040	0.239	0.349	0.024
%Diptera	0.185	0.598	0.612	-0.080	-0.610	0.424	0.380	-0.531
	0.509	0.019	0.015	0.777	0.016	0.115	0.162	0.042
FBI	0.480	0.958	0.919	-0.162	-0.933	0.807	0.837	-0.234
	0.070	0.000	0.000	0.563	0.000	0.000	0.000	0.401
%oligo	0.366	0.740	0.678	0.038	-0.686	0.617	0.666	-0.047
	0.180	0.002	0.005	0.893	0.005	0.014	0.007	0.868
% red ch	0.322	0.798	0.768	0.074	-0.733	0.546	0.523	-0.492
%Non-ins	0.296	0.708	0.663	-0.013	-0.663	0.675	0.724	0.093
	0.285	0.003	0.007	0.964	0.007	0.006	0.002	0.741
B-IBI	-0.524	-0.928	-0.911	0.046	0.922	-0.729	-0.789	0.354
	0.045	0.000	0.000	0.872*	0.000	0.002	0.000	0.196*

	SEDI	CHANF	CHANA	BS	BV	REPV	MANU	CC
%TR	0.283	0.383	0.631	0.727	0.763	0.617	0.725	0.816
	0.307	0.159	0.012	0.002	0.001	0.014	0.002	0.000
% Baet	0.416	0.381	0.729	0.652	0.633	0.421	0.650	0.670
	0.123	0.161	0.002	0.008	0.011	0.118	0.009	0.006
%Trico	0.127	0.314	-0.222	0.473	0.351	0.435	0.345	0.513
	0.652	0.254	0.426	0.075	0.199	0.105	0.208	0.051
%Pleco	0.204	0.278	0.359	0.543	0.522	0.555	0.569	0.376
	0.466	0.316	0.189	0.037	0.046	0.032	0.027	0.167
%Ephem	0.412	0.012	0.633	0.378	0.493	0.362	0.621	0.537
	0.127	0.967	0.011	0.165	0.062	0.185	0.013	0.039
% Odonat	0.262	0.386	0.500	0.446	0.357	0.117	0.309	0.047
	0.345	0.156	0.058	0.095	0.191	0.678	0.262	0.868
%EPT	0.398	-0.112	0.538	0.326	0.489	0.437	0.668	0.512
	0.142	0.690	0.038	0.236	0.064	0.103	0.007	0.051
SDI	0.471	0.332	0.545	0.614	0.754	0.552	0.572	0.738
	0.076	0.227	0.036	0.015	0.001	0.033	0.026	0.002
%DT	-0.429	-0.309	-0.472	-0.445	-0.598	-0.358	-0.389	-0.412
	0.110	0.263	0.075	0.097	0.019	0.190	0.152	0.127
%Diptera	-0.348	-0.323	-0.388	-0.423	-0.579	-0.276	-0.289	-0.296
	0.203	0.240	0.153	0.116	0.024	0.320	0.295	0.284
FBI	-0.201	-0.409	-0.745	-0.726	-0.626	-0.419	-0.790	-0.545
	0.472	0.130	0.001	0.002	0.013	0.120	0.000	0.036
%oligo	-0.332	-0.090	-0.761	-0.388	-0.409	-0.127	-0.574	-0.352
	0.227	0.750	0.001	0.153	0.130	0.652	0.025	0.198
% red ch	0.024	-0.310	-0.445	-0.499	-0.664	-0.440	-0.512	-0.417
	0.934	0.261	0.096	0.058	0.007	0.101	0.051	0.122
%Non-ins	-0.303	-0.126	-0.742	-0.403	-0.303	-0.054	-0.570	-0.305
	0.272	0.655	0.002	0.136	0.272	0.847	0.026	0.270
B-IBI	0.395	0.458	0.773	0.779	0.670	0.446	0.774	0.700
	0.145*	0.086*	0.001	0.001	0.006	0.095*	0.001	0.004

	NUTR	WET	GRA	HS	%TR	% Baet	%Trico	%Pleco
%TR	0.872	0.842	0.789	0.911				
	0.000	0.000	0.000	0.000				
% Baet	0.807	0.792	0.783	0.861	0.745			
	0.000	0.000	0.001	0.000	0.001			
%Trico	0.229	0.115	0.227	0.350	0.481	0.062		
	0.411	0.683	0.417	0.201	0.070	0.827		
%Pleco	0.520	0.397	0.428	0.549	0.293	0.445	0.092	
	0.047	0.143	0.112	0.034	0.289	0.097	0.743	
%Ephem	0.791	0.750	0.518	0.705	0.665	0.836	0.098	0.326
	0.000	0.001	0.048	0.003	0.007	0.000	0.728	0.235
% Odonat	0.440	0.457	0.593	0.497	0.283	0.495	-0.135	0.695
	0.101	0.087	0.020	0.059	0.308	0.061	0.632	0.004
%EPT	0.789	0.720	0.388	0.658	0.654	0.691	0.240	0.312
	0.000	0.002	0.153	0.008	0.008	0.004	0.388	0.257
SDI	0.742	0.651	0.752	0.859	0.746	0.896	0.273	0.554
	0.002	0.009	0.001	0.000	0.001	0.000	0.326	0.032
%DT	-0.625	-0.595	-0.652	-0.706	-0.617	-0.603	-0.351	-0.417
	0.013	0.019	0.008	0.003	0.014	0.017	0.199	0.122
%Diptera	-0.582	-0.580	-0.587	-0.617	-0.541	-0.649	-0.227	-0.438
	0.023	0.023	0.022	0.014	0.037	0.009	0.417	0.102
FBI	-0.903	-0.941	-0.747	-0.824	-0.786	-0.720	-0.216	-0.495
	0.000	0.000	0.001	0.000	0.001	0.002	0.440	0.060
%oligo	-0.670	-0.724	-0.512	-0.590	-0.531	-0.552	0.124	-0.246
	0.006	0.002	0.051	0.021	0.042	0.033	0.660	0.377
% red ch	-0.765	-0.795	-0.767	-0.706	-0.738	-0.616	-0.275	-0.308
	0.001	0.000	0.001	0.003	0.002	0.014	0.321	0.263
%Non-ins	-0.618	-0.692	-0.430	-0.519	-0.470	-0.508	0.142	-0.205
	0.014	0.004	0.110	0.048	0.077	0.053	0.614	0.463
B-IBI	0.911	0.908	0.822	0.922	0.879	0.877	0.304	0.519
	0.000	0.000	0.000	0.000	0.000	0.000	0.271	0.048

	%Ephem	% Odonat	%EPT	SDI	%DT	%Diptera	FBI	%oligo
% Odonat	0.270							
	0.331							
%EPT	0.955	0.175						
	0.000	0.534						
SDI	0.775	0.429	0.661					
	0.001	0.111	0.007					
%DT	-0.542	-0.574	-0.523	-0.661				
	0.037	0.025	0.045	0.007				
%Diptera	-0.628	-0.509	-0.570	-0.737	0.832			
	0.012	0.052	0.026	0.002	0.000			
FBI	-0.642	-0.543	-0.628	-0.609	0.525	0.562		
	0.010	0.037	0.012	0.016	0.045	0.029		
%oligo	-0.478	-0.378	-0.411	-0.394	0.117	0.156	0.779	
	0.071	0.164	0.128	0.146	0.679	0.580	0.001	
% red ch	-0.588	-0.410	-0.588	-0.581	0.639	0.691	0.814	0.453
	0.021	0.129	0.021	0.023	0.010	0.004	0.000	0.090
%Non-ins	-0.445	-0.343	-0.381	-0.316	0.033	0.099	0.756	0.984
	0.096	0.211	0.161	0.251	0.906	0.727	0.001	0.000
B-IBI	0.781	0.542	0.720	0.824	-0.662	-0.673	-0.914	-0.689
	0.001	0.037	0.002	0.000	0.007	0.006	0.000	0.005

	% red ch	%Non-ins
%Non-ins	0.372	
	0.173	
B-IBI	-0.722	-0.655
	0.002	0.008

(First number Correlation and the next number P-value; codes are as in Table 2 and Appendix 2)

Appendix 7. Linear regression Analysis of B-IBI and associated metrics with some physiochemical parameters and Total RBP habitat score

B-IBI with Conductivity

The regression equation is
B-IBI = 85.3 - 0.0609 Cond

R-Sq = 86.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	6490.5	6490.5	80.44	0.000
Residual Error	13	1048.9	80.7		
Total	14	7539.5			

B-IBI with TDS

The regression equation is
B-IBI = 81.7 - 0.0733 TDS

R-Sq = 83.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	6259.5	6259.5	63.57	0.000
Residual Error	13	1280.0	98.5		
Total	14	7539.5			

B-IBI with Dissolved Oxygen

The regression equation is
B-IBI = - 1.42 + 7.18 DO
R-Sq = 85.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	6413.7	6413.7	74.06	0.000
Residual Error	13	1125.7	86.6		
Total	14	7539.5			

B-IBI with NO3-N

The regression equation is
B-IBI = 69.9 - 1.27 NO3-N

R-Sq = 53.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	4003.4	4003.4	14.72	0.002
Residual Error	13	3536.1	272.0		
Total	14	7539.5			

B-IBI with PO4

The regression equation is
B-IBI = 73.3 - 11.0 PO4

R-Sq = 62.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	4696.6	4696.6	21.48	0.000
Residual Error	13	2842.8	218.7		
Total	14	7539.5			

B-IBI with total RBP Habitat score

The regression equation is
B-IBI = - 11.2 + 0.332 Total RBP HS

R-Sq = 80.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	6094.4	6094.4	54.82	0.000
Residual Error	13	1445.1	111.2		
Total	14	7539.5			

H-FBI versus conductivity

The regression equation is
FBI = 4.33 + 0.00400 Cond

R-Sq = 91.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	27.986	27.986	144.97	0.000
Residual Error	13	2.510	0.193		
Total	14	30.496			

H-FBI versus TDS

The regression equation is
FBI = 4.60 + 0.00470 TDS

R-Sq = 84.5%

Source	DF	SS	MS	F	P
Regression	1	25.758	25.758	70.67	0.000
Residual Error	13	4.738	0.364		
Total	14	30.496			

H-FBI versus NO3_N

The regression equation is
FBI = 5.30 + 0.0894 NO3-N

R-Sq = 65.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	19.838	19.838	24.20	0.000
Residual Error	13	10.658	0.820		
Total	14	30.496			

H-FBI versus PO4

The regression equation is
H-FBI = 5.10 + 0.741 PO4

R-Sq = 70.1%
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	21.386	21.386	30.52	0.000

Residual Error	13	9.110	0.701
Total	14	30.496	

H-FBI versus Dissolved Oxygen

The regression equation is
FBI = 9.95 - 0.462 DO

Predictor	Coef	StDev	T	P
Constant	9.9455	0.4453	22.34	0.000
DO	-0.46212	0.04952	-9.33	0.000

R-Sq = 87.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	26.535	26.535	87.10	0.000
Residual Error	13	3.961	0.305		
Total	14	30.496			

H-FBI versus Total RBP habitat score

The regression equation is
FBI = 10.1 - 0.0191 Total RBPHS

R-Sq = 66.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	20.167	20.167	25.38	0.000
Residual Error	13	10.329	0.795		
Total	14	30.496			

% EPT versus Conductivity

The regression equation is
%EPT = 48.9 - 0.0500 Cond

R-Sq = 42.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	4379.9	4379.9	9.46	0.009
Residual Error	13	6019.7	463.1		
Total	14	10399.6			

%EPT versus TDS

The regression equation is
%EPT = 47.2 - 0.0643 TDS
R-Sq = 46.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	4814.6	4814.6	11.21	0.005
Residual Error	13	5585.0	429.6		
Total	14	10399.6			

%EPT versus Dissolved Oxygen

The regression equation is
%EPT = - 33.3 + 7.19 DO
R-Sq = 61.8%
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	6426.2	6426.2	21.03	0.001
Residual Error	13	3973.3	305.6		
Total	14	10399.6			

%EPT versus NO_3-N

The regression equation is
%EPT = 36.5 - 1.07 NO3-N

R-Sq = 27.4%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	2846.7	2846.7	4.90	0.045
Residual Error	13	7552.8	581.0		
Total	14	10399.6			

%EPT versus PO_4

The regression equation is
%EPT = 35.7 - 6.28 PO4
R-Sq = 14.8%
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1535.8	1535.8	2.25	0.157
Residual Error	13	8863.8	681.8		
Total	14	10399.6			

%EPT versus Total RBPHS

The regression equation is
%EPT = - 33.4 + 0.854 HS
R-Sq = 43.3%
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	4502.2	4502.2	9.92	0.008
Residual Error	13	5897.4	453.6		
Total	14	10399.6			

%Ephem versus Conductivity

The regression equation is
%Ephem = 39.3 - 0.0422 Cond

R-Sq = 48.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	3118.9	3118.9	12.16	0.004
Residual Error	13	3335.2	256.6		
Total	14	6454.2			

%Ephem versus TDS

The regression equation is
%Ephem = 37.3 - 0.0524 TDS
R-Sq = 49.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	3201.8	3201.8	12.80	0.003
Residual Error	13	3252.3	250.2		
Total	14	6454.2			

%Ephem versus Dissolved Oxygen

The regression equation is
%Ephem = - 25.5 + 5.53 DO
R-Sq = 58.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	3793.3	3793.3	18.53	0.001
Residual Error	13	2660.9	204.7		
Total	14	6454.2			

%Ephem versus NO_3-N

The regression equation is
%Ephem = 28.1 - 0.821 NO3-N
R-Sq = 26.0%
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1674.9	1674.9	4.56	0.052
Residual Error	13	4779.3	367.6		
Total	14	6454.2			

%Ephem versus PO_4

The regression equation is
%Ephem = 28.5 - 5.58 PO4

R-Sq = 18.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1214.9	1214.9	3.01	0.106
Residual Error	13	5239.3	403.0		
Total	14	6454.2			

%Ephem versus total RBPHS

The rgression equation is
%Ephem = - 30.2 + 0.720 RBPHS
R-Sq = 49.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	3203.7	3203.7	12.81	0.003
Residual Error	13	3250.4	250.0		
Total	14	6454.2			

DECLARATION

I declare that the thesis is based on my original work and has not been presented for a degree in any other university. All sources of materials used for this thesis have been fully acknowledged.

Name: Baye Sitotaw Mersha

Signature________________

Date__________________

This work has been presented with our approval as supervisors:

Dr. Seyoum Mengistou

Signature___________________

Date________________________

Dr.Abebe Getahun

Signature___________________

Date________________________

I