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THE WATER QUALITY DEGRADATION OF UPPER AWASH RIVER, ETHIOPIA

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Abstract

Benthic macroinvertebrate based assessment of water quality in the upper Awash River, along the river course of about 500 kms was conducted on quarterly bases between September 2009 and August 2010. This paper reports the complete identification of macroinvertebrates together with measurements of physico-chemical parameters and heavy metal concentrations which were considered as a tool for assessing the water quality status of upper Awash river, Ethiopia. Benthic animals and water samples were collected from three different sampling sites located in the upper Awash River, and analyzed to evaluate stressor sources and the general stream water quality. The percentage abundance of families of various macroinvertebrates taxonomic groups was identified from all sites. Accordingly, Koka bridge site of the upper Awash River had low water quality status which is likely to be due to poor farming, untreated effluents from factories and poor provision of sanitation facilities to the riparian communities. Apparently, the concentrations of the selected nutrients and heavy metals did not differ significantly among the sampling sites (ANOVA, P > 0.05), presumably due to pollution of the whole stream reach by the catchment nutrient sources. Ten orders of benthic macroinvertebrates consisting of 36 families were identified. The highest family richness was observed in Ginchi, slightly impacted site (1) whilst the least faunal diversity was observed in Koka Bridge (7 families) indicating the effect of water quality class differences among the sampling sites.

Key words: *Macroinvertebrates, organic pollution, heavy metals, water quality, anthropogenic impact, upper Awash River*

Introduction

Water is critical for sustainable livelihoods and is impossible for a single life to live without it. Water never exists alone, but it is a part and parcel of ecological unit consisting of land, substrate structures, flora and fauna. Streams and rivers are major sources of water to satisfy human needs such as domestic uses, agriculture, transport, industries, power production and recreation. Combinations of various natural factors and anthropogenic activities in the rivers and their catchments are, however, affecting the river water qualities and their biodiversity. In Ethiopia, human activities such as land use and modification, urbanization, human settlement and other practices associated with rapid population growth are the major water quality degrading factors (Zinabu and Elias, 1989).

Evaluating the status of water quality and climate change by examining fauna has been well established in both theory and practice for several decades (Davis, 1995). In this regard, benthic macroinvertebrates (BMI) are useful in evaluating water quality and the overall health of flowing water systems. They are affected by changes in a stream's chemical and/or physical structure (Karr and Kerans, 1991). Species of aquatic macroinvertebrates living in the aquatic environment are sensitive in varying degrees to temperatures, dissolved oxygen, sedimentation and scouring; nutrient enrichment, chemical and organic pollution (Resh and Jackson, 1993). This sensitivity allows them to be effective indicators of specific anthropogenic disturbances and climate changes (House *et al.*, 1993). Therefore, the purpose of this study was to determine the water quality status of the upper Awash River using biological indicators and some selected key water quality parameters.

Methodology

Study Area

This study was conducted in upper Awash River (upstream to Koka reservoir), a total course of 500 km. Awash River basin is the most important river basin in the country. It covers a

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catchment area of 110,000 km^2 and serves as home to 10.5 million inhabitants. The river originates from a high plateau near Ginchi town, about 80 km to the west of Addis Ababa and flows along the rift valley into the Afar triangle and ends in saline Lake Abbe. Irrigation, electric power generation, fish production, serving as water source for domestic consumption to the inhabitants dowelling near by the river course as well as for domestic and wild animals of the area are some of the most important services provided by the Awash River water. Samples were collected from three different sites where different levels of anthropogenic impacts are observed: forest areas with less human impact, scattered silviculture with agricultural activities and deforested, irrigated and highly impacted areas.

Description of Sample Sites

The sampling sites were characterized as reference or impaired based on physical, chemical, biological and land-use information. The first sampling station (S1) was located about 80 km west of Addis Ababa, near Ginchi town. In this sampling station, there are natural vegetation's in the bank of the river. Anthropogenic activities such as farming and grazing, washing clothes and bathing were common during our sampling periods. Little turbidity (187 FTU) was observed during the dry season while it increased considerably following the onset of the rainy season. Neither odor nor foam was detected from this sampling site. The benthic-macroinvertebrate community is relatively diverse and dominated by pollution sensitive taxa like EPT. Hence, it was considered as slightly impacted site for this study. The second sampling station (S2) was located about 50 km south-west of Addis Ababa, near Awash Bello town. There is no natural vegetation except the scattered eucalyptus trees which are planted at the river bank. In this sampling station, agricultural activities are intense including river water abstraction for irrigation using motor pumps. The river water is quite turbid (319 - 472 FTU) in both dry and wet seasons. The benthic-macroinvertebrate community is dominated by pollution tolerant organisms such as chironomids and oligochaetes. This sampling station was considered to be moderately impaired. The third sampling station (S3) was located at 100 km south-east of Addis Ababa, above the bridge of Awash River near Koka town. Water is turbid (365 - 502 FTU) in both dry and wet seasons. There are many factories like Shoa and Ethio-tanneries, Mojo oil mill factory which discharge their raw effluent directly into the river. Furthermore abattoir houses and poultry farms were observed in the sub-catchment of the river in this sampling station. The benthic-macroinvertebrate community diversity is very poor and usually dominated by chironomids.

Sampling

Sampling of water, benthic animals and physico-chemical parameters were conducted on quarterly bases between September 2009 and August 2010 from all the sampling stations to cover both dry and wet periods. In this study, we are restricted to indices focused on the determination of water quality.

Physico-chemical parameters

Dissolved oxygen (DO), specific conductivity, pH, water and air temperature were measured *in-situ* using a multi-probe (Model HQ40d, HACH Instruments). Water samples were collected in 500 ml polyethylene bottles and were transported to laboratory for inorganic nutrient analysis at Addis Ababa Environmental Protection Authority (AEPA). Analyses were done by following the standard methods (APHA, 1995). Selected heavy metals: Fe, Cb, Pb, Cd and Zn, which are present in industrial effluents released to the rivers catchments, were analyzed following the standard methods (APHA, 1995) using Shimadzu AA 6200 atomic absorption spectrophotometer.

Macroinvertebrates

Benthic macro invertebrates were sampled from the river using AQEM net sampler (frame shape rectangular, area 625cm^2, net mesh size 500µm from multi-habitat units) following standard methods developed for Rapid Bioassessment Protocol (Barbour *et al*., 1996). The coverage of biotic habitat (macro-algae, macrophytes, CPOM, woody materials and sandy substrate) is allocated by distributing them to the mineral habitat of the sampling reach. For each sampling unit, stationary sampling was accomplished by positioning the net upright on the stream bed and disturbing the upstream with hand. At S2 and S3, where the water is deep Ekman grab (area=250 cm^2) was used for sampling.

Samples collected from each microhabitat were mixed together in the container and fixed with 4% formalin (final concentration) to prevent carnivore macroinvertebrates from eating other specimen and to harden the specimens and keep them intact during transportation and storage required until analysis.

Benthic Samples

Before sorting, the complete samples were passed through sets of sieves mounted under tap water in order to wash away the formalin, rinse the fine materials from the sample and separate size classes of macroinvertebrate groups. Macroinvertebrate trapped in the coarse fraction of the sieve were sorted completely in the laboratory by naked eyes. Organisms trapped in the smaller fraction of the sieve were sorted with help of light microscope and naked eyes. After sorting, animals were identified to the family level and preserved in 70% alcohol for further taxonomic purpose. The identification was made using different identification keys includes those of McDonald *et al.* (1991) and Pescador *et.al* (1995).

Data Analyses

For sampling site comparisons, all the data collected were subjected to statistical analysis suitable for the multimetric approach. Subsequently, the ecological quality of the water body was expressed as a number using richness (number of EPT taxa, overall taxa) and composition measures and tested with analysis of covariance for significant differences of the water quality status among the sampling sites. For all statistical tests, a probability of $P<0.05$ was considered significant.

Results

The different stream sections were preclassified using expected values for dissolved oxygen and conductivity (Table 1). Accordingly sampling site 1 falls under quality class II (with $7.84 mgl^{-1}$ DO and 327.67 µS cm^{-1} conductivity) whereas stream sections 2 and 3 falls under quality class III with DO and conductivity given in Table 2.

Physical and Chemical Parameters

The values of temperature, pH, dissolved oxygen (DO), Conductivity, total nitrogen (TN), total phosphorus (TP), ortho phosphate (SRP), nitrate-nitrogen ($N\text{-}NO_3^-$), total-ammonia (TA) and some heavy metals are given in Tables 2 and 3. Temperature in the head water was relatively lower (23.53 ^oC) than middle and lower reaches (25.65 ^oC). DO variation was significant (ANOVA, $P < 0.05$), ranged between 4.67 and 7.84 mgl^{-1} for all sampling stations. An increasing trend in conductivity was observed along the river course during the sampling periods. Low value for conductivity (327.67 µS cm^{-1}) was observed in S1 (Ginchi) and the highest value (492.87 µS cm^{-1}) was in S3 (Koka bridge). pH values for all the sites were more stable with range between 8.15 and 8.63. During the sampling periods, the concentrations of inorganic nutrient increased from head water (slightly impacted site) to escalating perturbation, S3 (Table 2).

Heavy Metals

The concentration of heavy metals in the sampling stations of upper Awash River is presented in Table 3. From the results, it was found that Fe, Cb, Pb, Cd and Zn are present in Awash River water. There were significant variations (ANOVA, $P < 0.05$) in heavy metal concentration over the sampling stations. Generally, an increasing temporal trend was observed for most of the heavy metals across the sampling stations excluding Cb and Pb, which were lower across the increasing perturbation (Table 3).

Macroinvertebrate Composition and Abundance

A total of 36 individuals composed of 10 orders of macroinvertebrate community were collected during the sampling periods (Table 4). The highest family richness was observed in Ginchi (50% of the total community), slightly impacted site (S1) whilst the least faunal diversity was observed in severely impacted site (S3), Koka Bridge (19% of the total taxa) indicating quality class differences among the sites.

Discussion

Temperature and pH

Water temperature is one of the controlling factors for the dynamics of aquatic environments; because it interferes in the organism's metabolism, influencing the reproduction, accelerating the reactions' speed and increasing the degradation rate of organic matter (Bottrell *et al.,* 1976). The water temperature during the sampling period across the sampling sites was not significantly different (ANOVA, $p > 0.05$). As depicted in Table I, water temperature at S1 was lower (average = 23.53 ^oC) than at S3 (average = 25.65 ^oC). This might be attributed to the fact that S1 is located relatively in the head water (Ginchi) which have more shade and located at a high altitude. Likewise, pH variation was not significant (ANOVA, $p > 0.05$) between head water (S1) and the impacted site (S3). Therefore, water temperature and pH may not be a key parameter in defining the water quality class among the sampling sites during our sampling periods. However, temperature and pH are important parameters that can influence chemical and biological processes in the stream water (Rosenberg and Resh, 1993).

Dissolved Oxygen and Conductivity

Dissolved oxygen is essential to all forms of aquatic life. Its solubility and concentration varies with temperature and turbulence; the photosynthetic activity of algae and aquatic plants; bacterial decomposition and respiration processes (Wetzel, 2001). The solubility of oxygen decreases as temperature increases. In this study, however, variation in dissolved oxygen concentrations were probably attributed to biological activities as temperature was relatively about the same. The low oxygen concentration ($4.67 mgl^{-1}$) at S3 (Koka bridge) was recorded mainly due to high organic load (Table II) which subsequently consume oxygen for decomposition by bacteria (Hall *et al.*, 1992). Therefore, dissolved oxygen could probably be the key parameter for the water quality class differences among the sampling sites. Conductivity can be influenced largely by geology of the catchments as the later highly influences mineral salts (Talling and Lemoalle, 1998). In this study, fluctuation of conductivity between the head water (slightly impacted site) and severely impacted site (Koka Bridge) was significant (ANOVA, $P < 0.05$). Conductivity increased along the river course (downstream) coupled with increasing perturbation. S3 is located downstream of different factories which are known to discharge wastes containing ions using the river as main waste dumping site. Hence, conductivity could probably be excellent discerning parameter for water quality class in the upper Awash River.

Heavy Metals in Water

The occurrence of heavy metals in excess of natural loads has attracted a great deal of interest (FAO, 1992; Mansour and Sidky, 2002). The rapid growth of population and subsequent urbanization, industrial units located in and at the outskirts of the city, exploration and exploitation of natural resources, intensive agricultural practices within the river basin and indiscriminate disposal of domestic and municipal wastes are the main sources of water pollution in Ethiopia. Heavy metals, from natural and anthropogenic sources, released into the environment find their way into the aquatic phase, and once in the water they will be taken up by aquatic organisms (Tarrio *et al.*, 1991). Heavy metals are a serious threat to both aquatic organisms and also to humans who are consuming these organisms; because of their toxicity, long persistence, bioaccumulation, and biomagnifications in the food chain (Eisler, 1988). In the present study, it was found that Fe, Cb, Pb, Cd and Zn are present in Awash River water. The average total concentration of Fe and Zn at S3 was ten-fold (Table 3) higher than that of S1, while Cd concentration was twofold higher than in S1.However, it is lower than the recommended safety thresholds for drinking water (WHO, 2008).Therefore, the heavy metal content in downstream of Awash water was not significantly higher than the natural elemental level in freshwater (Lokeshwari *et al.,* 2006). Nonetheless, this study demonstrated potential risks to aquatic ecosystems attributed to industries effluent downstream of upper Awash River, including reduced DO concentrations, elevated inorganic nutrient and heavy metal contents.

Major sources of wastewater effluents downstream of awash river include: Shoa and Ethio- tanneries which discharge their raw effluent (very close to the third sampling station) directly into the Mojo river a tributary of upper Awash; Mojo oil mill factory which drain its effluent to Mojo River; abattoir houses and poultry farms, which operate in the catchments of the river and release their effluents through Mojo River. Principally, Akaki River (great and little Akaki) is one of the main tributary of Awash River which drains from its source to Koka reservoir. The Akaki Rivers named as great and little flow within the Addis Ababa city both commencing from the north mountainous escarpments and flowing towards the south and ending at Awash River which final converge to Koka reservoir. Pollution of the rivers becomes most apparent as it flows through the city and slum areas and finally alarmingly high levels in the industrial areas. The catchment and area around little Akaki River has been the concentration site for industrial establishments in the country, possibly selected for its suitability of releasing wastewater directly to the river.

Moreover, there are recent developments towards intensive farming in the catchments of upper Awash River, mainly focusing on floriculture which uses fertilizers and pesticides that are sources of heavy metal residues. Heavy metals occurring in phosphate fertilizers are: Pb, Cd, As, Cr, Pb, Hg, Ni, and V (Mortvedt, 1996). Metals and/or metalloids released in such manner are easily transferred to all of the food chain, thereby affecting human and animal health. Apparently, the concentrations of the selected nutrients did not differ significantly among the sampling sites (ANOVA, $P > 0.05$), presumably due to pollution of the whole stream reach by the catchment nutrient sources.

Macroinvertebrate Composition and Abundance

In the present study, a total of 36 individuals of macroinvertebrate community were identified. The highest family richness was observed in S1, slightly impacted site whilst the least faunal diversity was observed in S3, Koka Bridge; indicating quality class differences among the sites (Figure1). As presented in Table 4, the number of sensitive taxa in the insect orders Ephemeroptera, Plecoptera and Trichoptera were decreased with increasing perturbation. The results of the present sampling were in agreement with other studies in Asian and African countries which demonstrated the impacts of human activity on the water quality of streams and rivers using biological indicators (Kumar, 1994). The absence of the sensitive taxa such as Mayflies, stoneflies, and caddisflies at S3 was attributed to relatively low concentrations of dissolved oxygen, high level of organic and inorganic in stream pollution from the catchment (Tables 2 and 3).The diversity of species at each sampling stations were affected by changes in physico-chemical parameters. Besides, the pollution sensitive taxa dominating the first sampling station (S1) were switched to pollution tolerant organisms such as chironomids and oligochaetes at the second (S2) and third sampling stations (S3).Therefore, downstream of the upper Awash River was determined to be polluted based on biotic indices assessment of water quality. This is in agreement with the water quality classification based on physico-chemical parameters (Moog and Sharma, 2005).

In summary, the present study concluded that S1 has been found to have relatively better water quality status(quality class II) compared to S2 and S3 (moderately impacted)assessed on the basis of some physico-chemical features and benthic-macroinvertebrates distribution. The result reflected also the land use type in the surrounding watershed of the River. Moreover, we understood that benthic-macroinvertebrates may be suitably used as a quick and economical tools for assessing the ecological status of the streams and rivers compared to the measurement of physico-chemical parameters which are not only costly but much time consuming (Plafkin *et al.,* 1989). We did not discuss localized pollution in this paper. However there is evidence of pollution and water-borne diseases at fishing villages around Koka reservoir, downstream of the upper Awash River (Fasil Degefu *et al*., 2011).

These types of pollution may not have affected the water quality in the reservoir as a whole, if it was monitored at the catchment level upstream of the reservoir. Owing to the results of the present study, we strongly recommend for integrated catchment management program around the upper Awash River; which instrumentally improves the stream water quality. Besides, the industries which are operating in the upper catchment of the River need to treat their wastes before discharging into the adjacent river. In most cases, solid and liquid wastes from these sources are discharged directly into the river system having undergone no treatment whatsoever, thereby severely damaging the river ecology as well as posing serious risks to human health. The River itself is now considered as an environmental health hazard, due to the high concentrations of chemical and bacteriological pollution. Despite this, nearly half of the town and all the rural population of the catchment areas are at one time or other, dependent on it as a source of water for domestic use and in the worst cases, for drinking. Most heavily affected are the town and the rural poor, who are also dependent on this River for irrigation of vegetables and other crops that they grow with in the town as a source of income. These crops inevitably find their way to the middle class homes as the public buy the cheap, healthy looking produce from town farmers, not knowing the potential danger posed through the uptake of heavy metals and bacteriological contamination. Therefore, it is important to create awareness among all stakeholders to encourage more integrated catchment management and sustainable practices among the riparian communities.

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Table 1 Expected and observed values of dissolved oxygen concentrations among pre-classified classes

Quality class	Expected Values		Observed values		Sampling sites
	DO (mg L^{-1})	DO saturation (%)	DO (mg L^{-1})	DO saturation (%)	
I	8 or more	95-110	7.84	105.80	1
II	> 6	70-125	6.98	99.20	2
III	4 or less	50-150	4.67	60.30	3
IV	2 to 4	25-200			
V	< 1	< 10			

Note: expected values are from Moog and Sharma (2005) for different quality classes

Table 2 Some physical and chemical features of upper Awash River during the sampling periods

Parameters (Average)	Sampling stations		
	S1	S2	S3
Water temperature (^{o}c)	23.53	24.37	25.65
Dissolved oxygen (mg L^{-1})	7.84	6.98	4.67
pH	8.15	8.20	8.63
Conductivity (µs cm^{-1})	327.67	364.33	492.87
Total-ammonia (mg L^{-1})	00.03	0.13	0.05
Nitrate-nitrogen (mg L^{-1})	2.90	17.50	44.70
Total-nitrogen (mg L^{-1})	Nil	Nil	2000
Total-phosphorus (mg L^{-1})	49.00	50.00	56.00
Ortho Phosphate (mg L^{-1})	49..00	50.00	56.00

Table 3 Concentration of heavy metals in upper Awash River water during the sampling periods

Parameters (Average)	Sampling station		
	S1	S2	S3
Cadmium (mg L^{-1})	< 0.0001	0.03059	0.06603
Cobalt (mg L^{-1})	< 0.0001	3.449	1.957
Iron (mg L^{-1})	0.0887	0.2646	0.668
Lead (mg L^{-1})	< 0.0001	13.21	5.062
Zinc (mg L^{-1})	0.0869	0.0891	0.1469

Table 4 Macroinvertebrate identified during the sampling periods from upper Awash River

Order	Family/Genus	S1	S2	S3
Gastropoda	Physidae	P	A	A
	Planorbidae	A	P	A
	Thairidae	A	A	P
Oligochaeta	Octochaetidae	P	A	A
	Lumbriculidae	P	P	A
	Tubficidae	A	A	P**
Hirudinea	Salifidae	P	A	A
Ephemeroptera	Heptagniidae	P	A	A
	Baetidae	P	P	P
	Caenidae	P	P	A
Odonata	Libellulidae	P	P	P
	Aeshnidae	P	A	A
	Coenagrionidae	P	P	P
Hemiptera	Nepidae	A	P	A
Heteroptera	Micronectidae	P	P	A
	Corixidae	P	P	A
Trichoptera	Hydrophschidae	P**	P	A
Coleoptera	Elmidae	P	A	P
	Gyrinidae	P	A	A
Diptera	Chironomidae	P	P	P**
	Mucidae	P	A	A
	Tipulidae	P	A	A
	Simulidae	P	A	A

[P]presence of BMI; [A]absence of BMI; [**]Dominant taxa

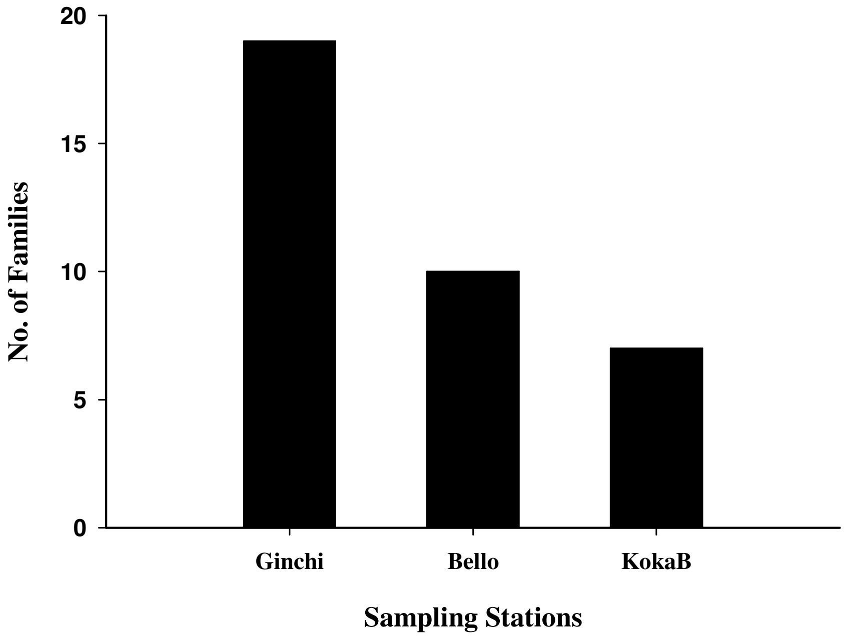

Figure 1 Abundance of benthic macroinvertebrates in upper Awash River