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Assessment of downstream impact of Bahir Dar tannery effluent on the head of Blue Nile River using macroinvertebrates as bioindicators

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A study was conducted to determine the downstream impact of Bahir Dar Tannery wastewater on the head of Blue Nile River using macroinvertebrates as bioindicators. Four sampling sites (one upstream and three downstream) were selected along the river and samples were collected from October to March, 2010/11. Macroinvertebrates were collected using standard dip net based on the Rapid Bioassessment Protocols for use in streams and wadeable rivers and identified to the family level. A total of 9,162 individuals belonging to 28 families were collected during the study period. Results of analysis of variance (ANOVA) showed that, there was significant difference in macroinvertebrate metrics among sampling sites. Percent Ephemeroptera Plecoptera Trichoptera (EPT) Index, Shannon Diversity Index and Benthic Macroinvertebrate Index were higher and percent Diptera, Chironomidae and Hilsenhoff Family level biotic index were lower at the reference site. The categorization of sites based on Benthic macroinvertebrate index value indicated that the site just below the effluent discharge and 200 m from it were severely to slightly, the last downstream site moderately to less and the reference or upstream site very little to none impacted. The water quality at these sites was also very poor to poor, fair to good and very good to excellent, respectively. The most impacted sites ranked last in all sensitive metrics while the reference ranked first in sensitive metrics indicating the severe impact of the effluent on downstream sites. The result gave the trends of pollution of the river by the effluent and the urgent need for measures to be taken.

Key words: Tannery effluent, macroinvertebrates, bioindicators, Blue Nile River.

INTRODUCTION

Rapid population growth, urbanization and industrial development have been adversely degrading the environment (Mason, 1990) by their effect through loss of biodiversity and pollution from wastes. Industrialization, like other human activities that impact on the environment, often results in pollution and degradation. It carries inevitable costs and problems in terms of pollution of the air, water resources and general degradation of the natural environment (Suflita et al., 1983). Industrial waste is the most common point source of water pollution in the present day (Ogedengbe and Akinbile, 2004) and it increases yearly due to the fact that industries are

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increasing because most countries are getting industrialized. In Ethiopia too, industries are increasing in number turning out wastes which are peculiar in terms of type, volume and pollution strength depending on the type of industry, raw materials used and process and technological variations applied to the process.

As compared to other industries, leather tanning is one of the most polluting activities (Khan et al., 1999) as it consumes huge amount of water in several stages, generating an enormous sum of liquid effluents (Farenzena et al., 2005) which are hazardous for the environment to which they are discharged. Tannery wastewater is highly polluted in terms of biological oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), Nitrogen, conductivity, sulphate, sulphide and chromium (Mondal et al., 2005) and in most developing countries tannery effluents are discharged directly into sewers or water bodies without treatment (Verheijen et al., 1996; Favazzi, 2002). In Ethiopia also industries turnout wastes directly into the nearby water bodies. This makes industrial and chemical pollution to become the third major problem in the country and one of the great environmental concerns (Zinabu and Zerihun, 2002). This is becoming evident through the pollution of water bodies and human habitat in the major cities, rivers and lakes. So it is very important to assess the ecological impact of the wastes.

Usually, chemical and physical monitoring was widely utilized to assess the extent of pollution of water bodies from point and non-point sources. Recently, rivers sustaining rich and diverse fauna have been recognized for their resource value (Abel, 1996). A more comprehensive approach of biological assessment of water quality recently introduced the Benthic Macro-invertebrate Index (BMI) (Karr, 1981). This has led to an increased focus towards stream ecological well being, and the use of ecological indicators' of water quality (Yandora, 1998).

In Ethiopia and to larger extent the whole of Africa, the use of macro-invertebrate for assessment and monitoring of stream conditions is still not well practiced. However, rapid bio-assessment of water quality in rivers has been 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 macro-invertebrates in lotic systems. Mathooko (2002), Barnard and Biggs (1988) and Kinyua and Pacini (1991) in Kenya and Tumiwesigye et al. (2000) in Uganda studied the macro-invertebrate composition of the rivers and lakes. In Ethiopia, Baye (2006) and Solomon (2006) studied the relation between physicochemical change and biological communities in rivers with different sources of pollution. Hayal and Seyoum (2009) studied water quality and macroinvertebrates index of biotic integrity of wetlands. On the other hand, Birnesh (2007) studied downstream pollution profile of Tikur Wuha River from point source. So in Ethiopia, the use of macroinvertebrates in assessing pollution status is in its infant stage. Hence, this study aims to assess the downstream impact of Bahir Dar Tannery effluent on the Blue Nile River using macroinvertebrate as bioindicators.

MATERIALS AND METHODS

Description of the study area

The study was conducted in Bahir Dar, the capital city of Amhara Region which is situated on the southern shore of Lake Tana, the source of Blue Nile (Abay) River. Bahir Dar Textile factory and Tannery are the most important industries in the city. Both the textile factory and the tannery discharged their effluent directly into the Blue Nile River. The downstream part of the river is used for domestic activities including drinking, irrigation and recreation (swimming and bathing). The use of the river in this way may lead to bioaccumulation of toxic pollutants like chromium which is hazardous for human beings as well as livestocks.

Sampling

The study was conducted from October, 2010 to March, 2011. This time was selected to sample from both dry and wet periods so as to avoid possible seasonal effect. Based on the method stated in Klemm et al. (1990) which is mostly used to specify sites for studying pollution from point sources, four sampling sites (one upstream and three downstream) were established on the study area. All the sites had almost similar microhabitats (pools and vegetated areas) and designated as S_1 to S_4 as shown in Figure 1. Qualitative macroinvertebrate data collection was carried out at the same sampling sites based on the Rapid Bioassessment Protocols that are used in streams and wadeable rivers (Barbour et al., 1999). Macroinvertebrates were sampled using standardized dip net (500 μm mesh size). To maintain the consistency of sampling effort, a sample was generally obtained within 30 min at each site and a sampling reach length of 100 m was used. Then macroinvertebrates collected from all microhabitats of each site were pooled so as to obtain a single sample from each site. In the field, macroinvertebrate samples were preserved in 70% ethanol or 10% formalin (for highly polluted sites) for later sorting and identification. All the organisms in the sample were enumerated and identified to the lowest practical taxonomic level (family level) using a dissecting microscope and standard keys (Edmondson, 1959; Jessup et al., 1999; Gooderham and Tysrlin, 2002; Bouchard, 2004).

Data analysis

Macroinvertebrate metrics were calculated from the sample data and final Benthic Macroinvertebrate Index (BMI) was calculated from aggregation of these metrics

Metrics selection and index development

Metrics to be included in the Benthic Macroinvertebrate Index (BMI) for this study were selected from a list of macroinvertebrate community attributes by testing their responsiveness to disturbance and redundancy with other metrics. Based on this, eight non-redundant metrics (Percent Taxa Richness, Percent Ephemeroptera Plecoptera Trichoptera (EPT) Index, Percent Diptera, Percent Chironomidae, Percent Dominant Taxa, Percent Non-Insect Taxa, Hilsenhoff Family-level Biotic Index (HFBI), and Shannon Diversity Index (SDI) that responded well to disturbance

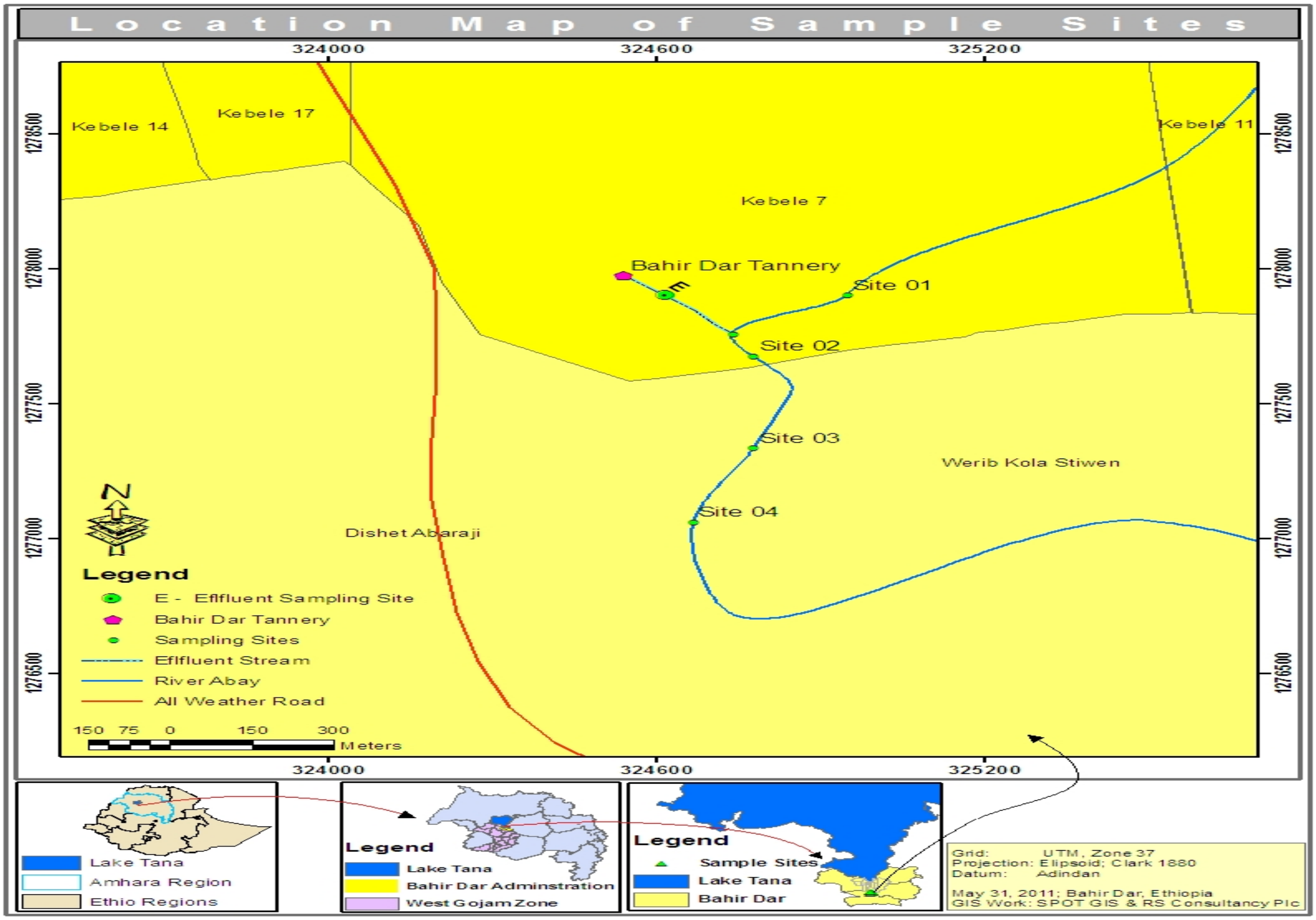

Figure 1. Map showing the study location and sampling sites along the Blue Nile River.

were selected. The metrics values were then converted to a standardized score using scoring criteria by examining relationships between individual metric scores and an indicator of impairment across a range of impairment levels, including undisturbed reference conditions. The standardized scores were then added to produce the final multimetric score of Benthic Macroinvertebrate Index (BMI) for each site. BMI values were calculated in this way for each site and then standardized to 100-point scale. Based on this BMI, value the sites were categorized in to various impairment levels which in turn determine the water quality at each site (Table 3).

Statistical data analysis

Macroinvertebrate percentage data were Arcsine transformed before analysis. One-way ANOVA was used to compare the magnitude of macroinvertebrate metrics among the sampling sites. Means were separated using Tukey HSD.

RESULTS AND DISCUSSION

A total of 28 taxa comprising 9,162 individuals were collected from the four sites during the study period. As shown in Table 1, the total number of taxa present at each site ranged from 18 (S_2) to 25 (S_1), while the total number of individuals present at each site ranged from 988 (S_1) to 5129 (S_2). The major components of the community were Chironomidae (3520), Ephydridae (1584), Clucidae (860), Baetidae (458). The families least encountered were Heptagenidae (1), Caenidae (5) Hydropsychidae (6) and Gerridae (9). The EPT families, Aeshnidae and Naucoridae were absent from the most impacted sites (S_2 & S_3) while Clucidae, Ephydridae, and Chironomidae were more abundant at these sites (Table 1). The result also showed that the number of individuals increased with increase in perturbation while the number of taxa showed a decreasing trend.

Macroinvertebrate metrics characterization along Blue Nile River

Benthic macroinvertebrate assemblage data which were

Table 1. Number of macroinvertebrates collected from the study sites in 2010/11.

Taxon order/family	Pollution. tolerance	Number collected at sampling site				Total
		1	2	3	4	
Ephemeroptera (mayflies)						
Baetidae	5	260	0	0	198	458
Caenidae	6	5	0	0	0	5
Heptagenidae	3	1	0	0	0	1
Trichoptera (caddis flies)						
Hydropsychidae	4	6	0	0	0	6
Odonata (damselflies and dragonflies)						
Aeshnidae	3	83	0	0	40	123
Coenagrionidae	9	9	48	26	17	100
Libelulidae	9	13	29	10	22	74
Hemiptera (water or true bugs)						
Belostomatidae	9	26	59	156	64	305
Corixidae	8	34	87	14	82	217
Geridae	6	1	0	3	5	9
Naucoridae	8	0	0	0	24	24
Nepiedae	7	10	0	16	0	26
Notonectidae	9	25	16	18	14	73
Pleidae	8	6	17	10	16	49
Veliidae	7	9	13	2	26	50
Coleoptera (beetles)						
Dytiscidae	5	92	127	87	13	319
Elmidae	4	45	9	17	25	96
Haliplidae	5	55	137	154	13	359
Hydrophilidae	5	46	302	52	9	409
Diptera (two winged / true flies)						
Ceratopogonidae	6	3	0	18	3	24
Chironomidae	8	82	2338	714	386	3520
Culicidae	8	12	725	96	27	860
Ephydridae	6	0	1028	406	150	1584
Syrphidae	10	0	140	0	0	140
Mollusks (snails)						
Planorbidae	7	4	9	12	36	61
Physidae	8	15	0	27	17	59
Arachnida						
Hydracarina (water mites)	6	62	19	1	7	89
Hirudinae (Leeches)	10	84	26	0	12	122
Total Individual		988	5129	1839	1206	9162
Total taxon		25	18	20	23	28

Table 2. Effect of the tannery effluent on macroinvertebrate metrics at different Sites along Blue Nile River in 2010/11.

Parameter	%Taxa richness	% EPT	% Diptera	% Dominant taxa	% Non-insect taxa
Sampling sites					
S_1	78.0^a	32.9^a	9.7^c	37.0^a	14.9^a
S_2	87.5^a	0.0^b	81.8^a	42.5^a	1.0^b
S_3	75.0^a	0.0^b	68.4^a	40.5^a	2.2^b
S_4	78.0^a	18.2^{ab}	46^b	34.6^a	6.0^{ab}

Sampling sites	Macro-invertebrate metrics			
	% Chironomidae	HFBI	SDI	BMI
S_1	8.0^b	6.0^b	2.2^a	33^a
S_2	42.5^a	7.3^a	1.7^c	18^b
S_3	40.5^a	7.1^a	1.8^{bc}	19^b
S_4	31.9^a	6.9^a	2.0^{ab}	23^b

Means within a column followed by the same letter are not significantly different from each other according toTukey HSD (p<0.05).

Table 3. Categorization of sites in to different impairment levels based on BMI results

BMI Value	Water quality characterization	Impairment	Sites at each impairment level
20-46	Very poor to poor	Severe to slight	S_2 and S_3
46-72	Fair to good	Moderate to less	S_4
72-100	Very good to excellent	Very little to none	S_1

condensed into eight metrics represented different ecological characteristics along the river gradient. The results indicated that the reference site (S_1) was different from the downstream sites, with slightly better biological activity at the reference site. Metric scores for each study site (Table 2) showed that the metrics closely follow pollution stress gradient. Percent Dipterans, % DT, and HFBI increased with increase in perturbation while % EPT and SDI showed a decreasing trend.

Percent taxa richness

The mean value of this metric ranged from 75% (S_3) to 87.5% (S_2). Taxa richness normally decreases with decreasing water quality (Vinson, 2006). Unlike the findings of Yandora (1998) and Birnesh (2007) and what is stated above, in this study, there was no significant difference in percent taxa richness among sampling sites (F=2.03, P=0.18, R2=0.74) (Table 2) and the upstream site showed lower diversity than the first downstream site. This might be due to the elimination of the sensitive taxa at the impacted sites.

Plafkin et al. (1989) stated that sites with greater than 26 taxa as non-impacted, 19-26 as slightly impacted, 11-18 as moderately impacted and 0-10 as severely impacted. Based on this criterion, the upstream site falls in slightly impacted range while the site just below the effluent falls in the moderately impacted range. So the low taxa richness at downstream sites is attributed to the low water quality and the strong negative response of percent taxa richness.

Percent EPT

The metrics has a zero value at severely impacted sites (S_2 and S_3) and its value ranged from 0 (S_2 and S_3) to 32.9 (S_1). There was significant difference among sampling sites (F=5.82, P=0.017, R^2=0.73); downstream sites having significantly lower value than the reference (upstream) site. Here, the last downstream site also had significantly higher value than the two downstream sites (Table 2), but there was no difference between S_1 and S_4 and also between S_2 and S_3.

Organisms in the EPT orders are qualified as indicators of good water quality. The higher the EPT index, the cleaner the stream (Perry, 2005). So their complete absence S_2 and S_3 and presence at the upstream site showed how seriously pollution affected these organisms. Yandora (1998), Baye (2006) and Birnesh (2007) reported the same result in absence of EPT at impacted sites.

Percent Diptera, Dominant Taxa and Chironomidae

The value of percent Dipterans ranged from 9.7 (S_1) to 81.77 (S_2). Its values showed significant variation among sampling sites (F=94.36, P<0.0001, R^2=0.97); the upstream site having significantly lower value than the downstream sites. But the last downstream site (S_4) also had significantly lower percent diptera than the rest downstream sites while S_2 and S_3 did not vary significantly (Table 2). This indicated the organic pollution load at downstream sites.

Percent chironomidae values ranged from 8.02 (S_1) to 42.48 (S_2). This index significantly vary among sampling sites (F=23.93, P=0.0001, R^2=0.89); upstream site having significantly lower value than downstream sites. But the three downstream sites did not vary significantly (Table 2). The large abundance of chironomidae at downstream sites is an indication of organic pollution and nutrient enrichment. Yandora (1998) reported that a sample in which greater than 50% is chironomidae suggested eutrophic condition and chironomidae increase with a decrease in water quality. Weigel et al. (2002) also reported that chironomids were the only taxa at sites with severe point-source pollution.

Percent Chironomidae and percent Dominant Taxa showed similar trend. The two metrics had almost similar value at the downstream sites showing chironomids were the dominant taxa at downstream sites. But percent dominant taxa did not show significant variation among sampling sites (Table 2). Percent dominant taxon at S_2 and S_3 was higher than S_1 and it is the contribution of chironomidae. Its average values at these sites were 42.5 and 40.5%, respectively. Percent dominant taxa greater than 45 indicate impaired, 40-45 possible impaired and less than 40 unimpaired (Barbour et al., 1999) condition. In this study, S_2 and S_3 indicated possible impaired condition while S_1 (8.02) and S_4 (31.9) indicated unimpaired condition.

Hilsenhoff family-level biotic index

The value of this metrics ranged from 6 (S_1) to 7.3 (S_2). There was significant difference in its value among sampling sites (F=15.48, P=0.0007, R^2=0.85). The reference site scored a significantly lower value than the three downstream sites while the downstream sites did not show significant variation among them (Table 2). High values are indicative of organic pollution while low values are indicative of clean water (Hilsenhoff, 1988). In this study, the higher values at S_2 and S_3 are indicators of the organic pollution load from the tannery effluent.

Shannon diversity index

The value of this metrics followed a decreasing trend from reference site to the severely impacted sites indicating that it has been affected by pollutants and it was able to discriminate mild and severe impacts from reference condition. Its value ranged from 1.7 (S_2) to 2.2 (S_1) and it significantly vary among sampling sites (F=11.37, P=0.002, R^2=0.81). The reference site had significantly higher diversity than the two consecutive adjacent downstream sites (S_2 and S_3). Site four also had significantly higher value than S_2. But SDI value of the upstream site did not show significant difference with the last downstream site and also S_2 with S_3 and S_3 with S_4 did not show significant variation (Table 2). The results of Baye (2006), and Birnesh (2007) also showed the decreasing trend of this index along pollution gradient.

Benthic Macroinvertebrate Index (BMI)

The BMI developed from the selected metrics ranged from 45 (S_2) to 81 (S_1) (Table 2). Its value showed significant difference among sites; the reference site (S_1) having higher value than the three downstream sites. But the downstream sites did not show significant variation among them (Table 2).

Categorization of Sites Based on BMI Values

Even though, the above macro-invertebrate metrics categorize the sites into different impairment levels, the BMI calculated from the condensation of the metrics categorize the four sites into three actual impairment levels with their water quality status. Based on this, S_2 and S_3 were categorized into water quality status of very poor to Poor and impairment level of sever to slight. The other downstream site (S_4) was categorized in the fair to good water quality and moderate to less impairment level. But the upstream (reference) site was under very good to excellent water quality and very little to non-impairment level (Table 3). The values of this metric followed pollution gradient, decreased with increase in pollution. The categorization of sites based on BMI values showed that the tannery effluent is seriously affecting the downstream sites (Figure 2).

Conclusion

The discharge of the highly concentrated pollutants into the river caused severe damage on the ecosystem. The impairment level at the two immediate downstream sites was severe while it was little to none at the reference site. Similarly, the water quality at the two immediate downstream sites was poor and the reference had excellent water quality. This high impairment of the downstream sites made the water unfavorable for domestic, agricultural and aesthetic use as pollutants like

Cattles crossing the effluent stream

Cattles grazing around the effluent stream

Effluent joining the river

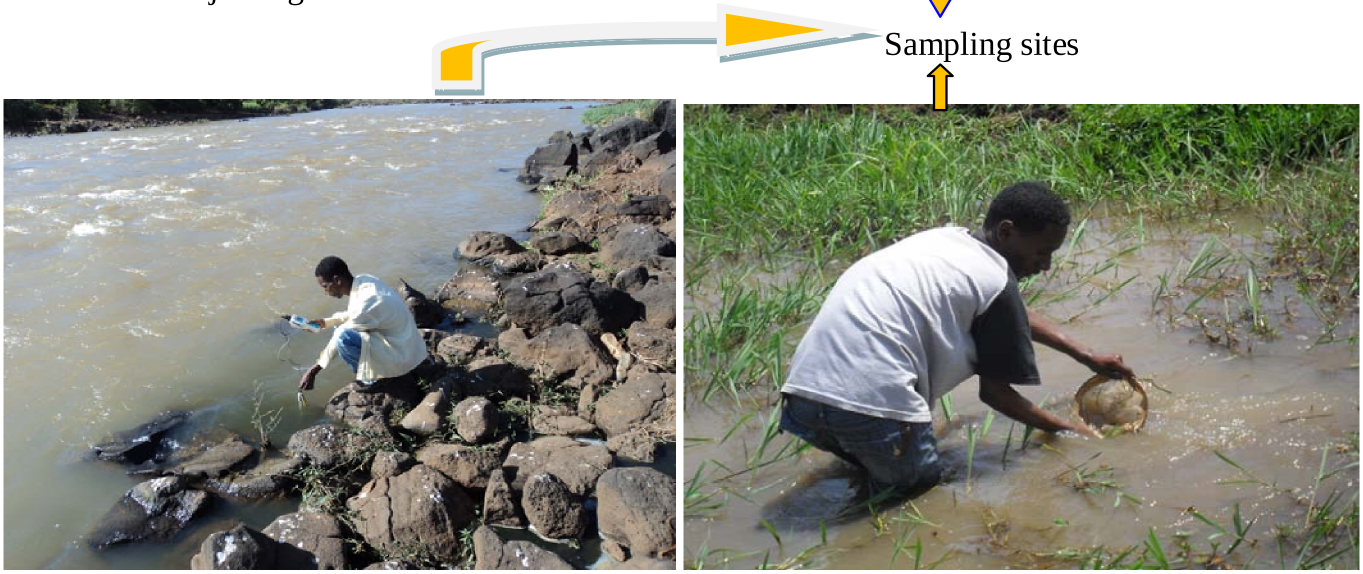

Figure 2. Plates showing some of the study sites and disturbances by the tannery effluent.

chromium from the tannery had a bio-accumulating effect. The state of the downstream sites must regularly be brought to public awareness by arranging continuous meeting with the community and telling the information for them. The development of tanning industries in Ethiopia is an encouraging phenomenon due to the country's large livestock population and government's development policy since it improves the economy and standards of living of citizens. However, the associated pollution which results from the discharge of wastewater into the environment without considering its due ecological consequences could overweigh the benefits. This can be threatening and lead towards a devastating environmental condition, unless industrial wastes are managed properly. So, environmental protection laws which consider technical and financial capability of the industries must be established so as to control industrial pollution. Not only establishment, the laws should also be enforced and environmental standards with their protocols should be followed with strict and continuous monitoring.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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