Physico-chemical and biological evaluation of Blue Nile River at Lake Tana, Ethiopia, in relation to discharge of tannery effluent

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ABSTRACT

Pollution of aquatic ecosystems with waste-water coming from tanneries is a serious challenge worldwide. The purpose of this study was to assess the water quality of Blue Nile River at a tannery in Bahir Dar, Ethiopia, using physicochemical and biological attributes. Four sampling sites were selected along the river based on the degree of degradation and major land-use types. Phyisco-chemical data, water samples, and chironomid larvae were collected monthly from March-May, 2016. Two liters of water were collected from each site and stored in the icebox and transported to Bahir Dar University. Water samples were analyzed for nutrients following standard procedures. Chironomid larvae were collected using a D- Frame net of 500 µm mesh size. One-way ANOVA was used to compare variations in all measured parameters among the sampling sites. Low dissolved oxygen (2.8 mg/l) was recorded at the site where the tannery meets the river. Moreover, the concentration of soluble reactive phosphorus, SRP (25.5±14.3 µg/l) and conductivity (1907.3±39.5 µS/cm) were low in the most upstream site of the river. A total of six Chironomid genera belonging to the subfamilies Chironominae and Tanypodinae were identified. The genus *Chironomus* dominated the impacted sites that had low dissolved oxygen levels. The other five genera were not found in those impacted sites. The result of this study indicated that the tannery effluent had impact on chironomid distribution as well as on river water quality.

Keywords: Bioindicator, Biomonitoring, Chironomid, Pollution, Tannery
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INTRODUCTION

Unsafe domestic and industrial waste disposal contaminates surface water anywhere in the world especially in developing countries such as Ethiopia.

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Communities dwelling near river basins suffer most from these wastes (Arega Shumetie and Molla Alemayehu, 2014). Water quality is monitored using physicochemical parameters and biological organisms. The latter is the preferred one in terms of cost and timing, but also because of its safety to the environment (Vermeulen, 1995). When a given aquatic ecosystem is polluted, the benthic macroinvertebrates face the challenges first. This is because their larval stages tend to be stationary as their mobility is naturally limited (Porinchu and Mcdonald, 2003; Chaib *et al.,* 2013). It is this behavior that makes benthic macroinvertebrates an ideal candidate to assess water quality worldwide. Their response to impacts might vary depending on many factors. Some taxa might not tolerate increased contaminant concentration and changes in river structure. However, some taxa are highly adapted to these changes and can be considered as an indicator of poor or bad water quality (Shimba and Jonah, 2016).

In the tropics, various reports are available on the use of benthic macroinvertebrates as a potential indicator of water quality (Baye Sitotaw, 2006; Solomon Akalu, 2006; Admasu Tassew, 2007; Abebe Beyene *et al*., 2009; Amanuel Aklilu, 2011; Assefa Wosnie and Ayalew Wondie, 2014; Aschalew Lakew, 2015). Most of these studies focused on the entire macroinvertebrate assemblages and used higher-level taxonomic resolution. However, nowadays attention is given to lower-level taxonomic resolutions with special emphasis to chironomid larvae. If properly identified, chironomid larval data could be used to properly interpret water quality issues. Chironomid larvae comprise much of the taxonomic and functional diversity within an aquatic ecosystem. Their diverse and wide distribution, abundance, relatively short life cycle, and colonizing ability make them survive in most climates and a wide range of water quality classes. As a result, they are excellent candidates for monitoring water quality in both lotic and lentic ecosystems (Getachew Beneberu and Seyoum Mengistou, 2014). Ethiopia, a Horn of African nation often referred to as the Water Tower of eastern Africa suffers water pollution due to fast-growing towns adjacent to water bodies, untreated and semi-treated effluents from tannery industries, hospitals, urban, textile, domestic waste, and agricultural run-off directly discharged into nearby water bodies (Amanuel Aklilu, 2011). Critical analysis of the organisms living there especially benthic macro-invertebrates can provide useful information about the ecological integrity of a system. Therefore, this study was conducted to assess the water quality of the Blue Nile River using physicochemical and biological attributes.

MATERIALS AND METHODS

Description of the study area

The study area is located in Bahir Dar, the capital city of Amhara Region (ANRS), located in Northwest Ethiopia some 565 km northwest of Addis Ababa, Ethiopia. It is situated at 11°36'N latitude and 37°23'E longitude, at the southern shore of Lake Tana, the source of the Blue Nile River that crosses the city. Along its way, the river receives contaminants from domestic, agricultural, and industrial sources. For example, Bahir Dar tannery discharges its effluent directly into this river without any prior treatment (Figure 1). The shore of the riverbank is dominated by various macrophytes.

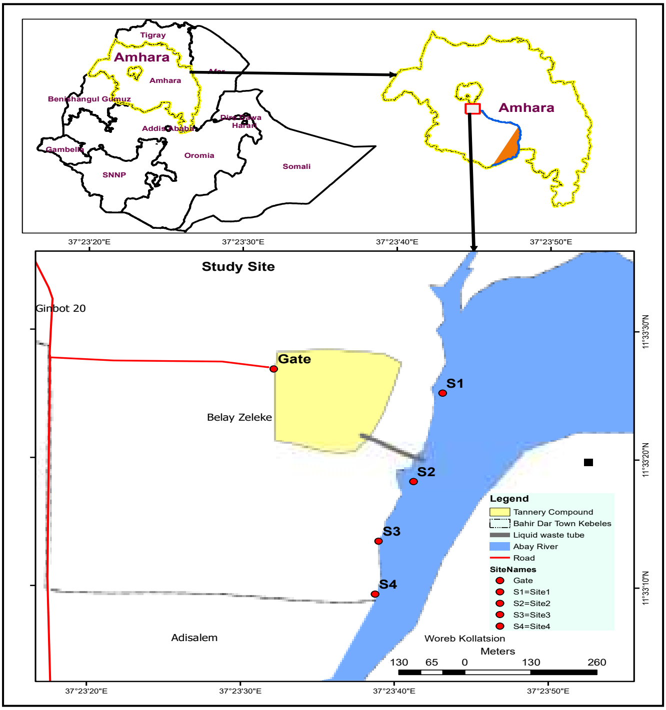

Figure 1. Map of study area showing the four sampling sites along the Blue Nile River.

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Sampling and sample collection

A section of the river close to the tannery was considered for this particular study. Based on major land-use systems and point and non-point sources of pollution, four sampling sites were selected. Each sampling site was marked using a Geographic Positioning System (MAGELLAN GPS, 315). Sites were coded as S1, S2, S3, and S4. The first site (S1) was located upstream of the tannery effluent and the remaining three sites were below the effluent discharge (Figure 2).

Figure 2. Sampling sites (S1, S2, S3, and S4 arranged clock-wise from left top corner) and a tube showing the discharge of the tannery effluent into the river.

In-situ measurements

Electrical conductivity, water temperature, and total dissolved solids (TDS) were measured in situ with a field conductivity meter (Model 4200, JANWAY). Similarly, dissolved oxygen (DO) was measured using the DO meter (model HI 9143, HANNA).

Environmental variable analysis

The water sample was taken from each site using a one-liter plastic bottle and labeled or coded. Samples were then immediately transported to the laboratory. Immediately in the laboratory, the pH was measured using a pH meter (model pH-016). The water samples were then filtered using the Whatman filter paper (GF/C). The filtrate was used for the analysis of (NO_3-N), (PO_4-P) and (NH_4-N) following standard procedures (USEPA, 1983). For all measurements, a stock solution, intermediate and finally serially diluted known concentration of working solutions were prepared before analysis.

Chironomid sampling and processing

Chironomid larvae were collected using a D-frame net and preserved in 70% ethanol and taken to the laboratory for further taxonomic identification. For numerical analyses, all samples from the 100 m river section were pooled and treated as one composite sample. Chironomid larvae were, then, placed in 10% KOH solution and left overnight to make the soft tissue transparent. Head capsules were mounted in glycerin on microscope slides and then, covered with a coverslip. Finally, they were identified morphologically using keys for comparison (Wiederholm, 1983; Harrison, 1991, 1992, 1996; Epler, 2001; Eggermont and Verschuren, 2003, 2004a, b; Getachew Beneberu and Seyoum Mengistou, 2014). Images of representative specimens were taken using a Sony cyber shot (model S40) digital camera.

Data analysis

One-way ANOVA was used to compare variations in the mean values of all the measured parameters among the sampling sites. Microsoft Excel spreadsheet and SPSS statistical software version 21 were used for data analysis and graphs.

RESULTS

Environmental variables

The results of the environmental variables are summarized in Table 1. Mean water temperature varied from 23.4 to 27 °C, the highest recorded at site S2. Dissolved oxygen varied from 2.8 mg/l to 6.5 mg/l; it was low at site S2 followed by S3. The pH varied from neutral to slightly alkaline. In all sampling sites, the

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mean pH value was in the range of 7.16 to 8.04. Electrical conductivity varied from 1907 to 2246.7 µS/cm, with the highest recorded at S2 followed by S3. Total dissolved solute ranged from 1159.3 mg/l to 1355 mg/l. High conductivity and TDS were observed at S2 followed by S3. Soluble reactive phosphorus (PO4- P) ranged from 25.5 mg/l to 29.03 mg/l with the highest value recorded at site S2. The concentration of ammonia (NH4-N) ranged from 35 mg/l to 115 mg/l with the highest value recorded at site S3. A high concentration of nitrate was unusually recorded at S1.

Table 1. Mean and standard deviation of environmental variables during the study periods.

Environmental variables	**Study sites**			
	S1	**S2**	**S3**	**S4**
Temperature (°C)	23.4±0.4a	27±1.4b	26.3±0.4b	25.2±1.7ab
DO (mg/l)	6.5±0.3a	2.8±0.2b	4.0±0.5c	5.5±0.3d
Cond (µS/cm)	1907.3±39.5a	2246.7±157b	2066±185ab	1936.7±70.2ab
TDS (mg/l)	1159.3±35a	1355±110.2b	1340.3±50b	1194±32.6ab
pH	7.2±0.1a	7.82±0.2ab	8.04±0.3b	7.57±0.4ab
PO4 - P (µg/l)	25.5±14.3b	29.03±1.4b	26.3±13.2b	28.8±13.2b
NH4 - N (µg/l)	44.5±29c	84±62.4c	115±103.8c	35±22c
NO3-N (µg/l)	57.0±20.7d	53.9±13.6d	56±7.2d	37±1.2d

NB: Similar superscripts (a, b, c or d) across sites for each parameter indicate lack of significant differences (ANOVA followed by post hoc Tukey's test); DO stands for dissolved oxygen, Cond for conductivity, TDS for total dissolved solids.

Chironomid community composition

A total of six chironomid genera were identified throughout the study sites (Table 2 and Figure 3). Five taxa at site S1, one taxon at sites S2 and S3 and six taxa at site S4. The majority of the taxa were from subfamily Chironominae (*Chironomus* 69.5% (267), *Polypedilum* 8.6% (33), *Microchironomus* 7.8% (30) and *Cryptochironomus* 5.2% (20) and only two taxa from the subfamily Tanypodinae (*Nilotanypus* 3.1% (12) and *Ablabesmyia* 5.7% (22).

The genera *Polypedilum*, *Microchironomus*, *Nilotanypus*, and *Ablabesmyia* were found at sites S1 and S4 whereas *Cryptochironomus* was found only at site S4. The genus *Chironomus* was found in all sites, but more abundantly at site S2, the site close to the tannery effluent.

Table 2. Mean and standard deviation of Chironomid taxa abundance during the study period.

	Sites			
Genera	**S1**	**S2**	**S3**	**S4**
		Chironominae		
Chironomus	2.35±1.2[a]	48±5.6[b]	29.67±3.1[c]	9 ±2[a]
Cryptochironomus	0.0[a]	0.0[a]	0.0[a]	6.7±0.6[b]
Polypedilum	1.7±1.5[a]	0.0[a]	0.0[a]	9.3 ±4.5[b]
Microchironomus	6.3±4.9[a]	0.0[a]	0.0[a]	3.7±3.2[a]
		Tanypodinae		
Nilotanypus	2.7±0.6[a]	0.0[b]	0.0[b]	1.3±1.5[ab]
Ablabesmyia	6.3±5.1[a]	0.0[a]	0.0[a]	1±0.0[a]

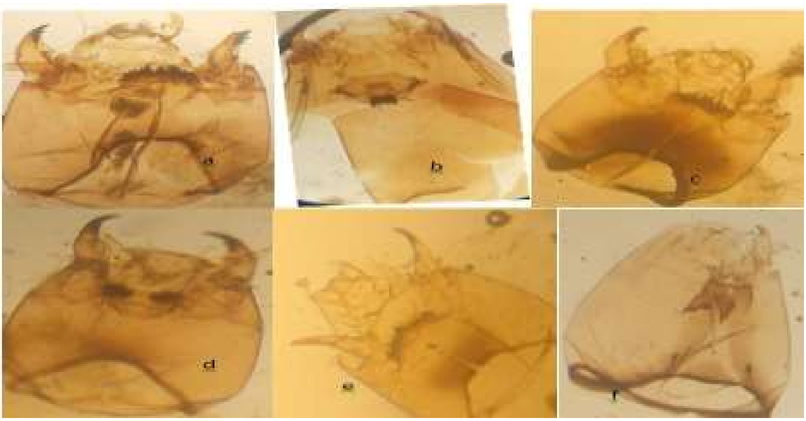

Figure 3. Head capsules of chironomid larvae identified in present study (a) *Chironomus* (b) *Ablabesmyia* (c) *Polypedilum* (d) *Cyrptochironomus* (e) *Microchironomus* (f) *Nilotanypus*.

DISCUSSION

Blue Nile River and Lake Tana are considered as one of the growth corridors of Ethiopia as it is used mainly for hydroelectric power generation and other related purposes. However, this multi-purpose river is facing multiple challenges. One of the major problems is effluent discharge from the Bahir Dar tannery industry. The tannery effluent is discharged directly into the river via a tube without any prior treatment.

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The concentration of dissolved oxygen significantly varied among all sites with the lowest recorded at the confluence between the tannery effluent discharge and the river at site S2. This might be because of the pollution load from the catchment, the tannery, and other interacting variables. The levels of DO at site S2 and S3 were below 5.0 mg/l. The optimum DO for fish to survive is about 5 mg/l and if below this value, fish production could decline and subsequently mass fish mortality can happen (Sinha and Biswas, 2011).

The same is true for electrical conductivity as it was relatively lower at sites S1 and S4. This is perhaps because the tannery effluent could not reach the site or maybe because of the well-developed riparian vegetation along the river bank. Ermias Seyoum (2007) reported a positive correlation between electrical conductivity (EC) and total dissolved solids (TDS). The same result was observed in the present study.

Only two subfamilies namely Chironominae and Tanypodinae were encountered in the present study. These subfamilies are normally expected in tropical countries together with the subfamily Orthocladinae (Getachew Beneberu et al., 2014). However, the subfamily Orthocladinae was not found in the present study. They are an indicator of good water quality and perhaps their absence might indicate deteriorated water quality in the present study sites. Number of *Chironomus* individuals was significantly different between sites except sites S1 and S4. A large number of *Chironomus* was found at site S2 that received untreated effluent from the tannery industry. Oliveira *et al.* (2010) suggested that a decrease in *Chironomid* diversity in a given site and the dominance of the genus *Chironomus*, a species tolerant to organic and industrial pollutants, indicates poor water quality. The above observation is in agreement with the present finding as S2 and S3 sites were dominated solely by genus *Chironomus*. This taxon is known to be resistant to low oxygen levels because of its high concentrations of hemoglobin (Nagell and Landahl, 1978). However, the diversity of *Chironomids* was relatively higher at site S4 as this site was relatively far from the waste discharge tube of the tannery. The subfamily Tanypodinae is intolerant to organic pollution (Oliveira *et al.*, 2010). In the present study, the subfamily Tanypodinae was found only at S1 and S4, both relatively less polluted compared to the other sites. A study by Getachew Beneberu and Seyoum Mengistu (2014) in Sebeta River indicated that the absence of pollution sensitive taxa like *Cryptochironomus* and *Polypedilum* is indicative of poor ecological status. The result of the present study is in agreement with this idea as the genera *Polypedilum* and *Cryptochironomus* were found in sites that were relatively unpolluted by tannery effluents.

CONCLUSION

The physicochemical data indicated low dissolved oxygen, high temperature, high total dissolved solids, and high conductivity at site S2. This site received a high load of pollution from the tannery. Besides, the load of PO4-P, NH4-N, and NO3-N did not vary between sites. Hence, organic pollution was less severe while industrial pollution was a major concern in the study area. Six *Chironomid* genera were found during the study period. *Chironomus* was the only genera found in the most impacted site. In general, the present study indicated spatial variation in the assemblage of the chironomid community. Consistent and continuous water quality monitoring of all sites is suggested.

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