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LAND USE EFFECTS ON BENTHIC MACROINVERTEBRATE ASSEMBLAGES AND DIVERSITY IN INFRANZ RIVER, NORTHWEST ETHIOPIA

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DEPARTMENT OF BIOLOGY

LAND USE EFFECTS ON BENTHIC MACROINVERTEBRATE ASSEMBLAGES AND DIVERSITY IN INFRANZ RIVER, NORTHWEST ETHIOPIA

THESIS SUBMITTED TO THE DEPARTMENT OF BIOLOGY BAHIR DAR UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN BIOLOGY

BY

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APPROVAL SHEET

As thesis research advisor, I hereby certify that I have read and evaluated this thesis prepared under my guidance by Kesete Aboye Dagnaw entitled “land use effects on benthic macroinvertebrate assemblages and diversity in Infranze river, northwest Ethiopia.’’ I recommend this thesis to be submitted as fulfilling the requirements for the degree of MSc in Biology.

Ayenew Gezie (PhD) ___________________ _____________

Advisor Signature Date

As member of the Board of Examiners of the MSc Thesis Open Defense Examination, we certify that we have read and evaluated the thesis prepared by Kesete Aboye and examined the candidate. We recommended that the thesis to be accepted as fulfilling the thesis requirement for the Degree of Master of Science in Biology.

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External examiner	Signature	Date
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Department Head	Signature	Date

DECLARATION

I the undersigned biology student declared that this thesis is my own original work under the supervision of Dr. Ayenew Gezie and it has not been presented for a degree in this or other Universities. All the sources of the materials used for this thesis and all people who gave support for this are fully acknowledged.

Name: Kesete Aboye Dagnaw

Place: Bahir Dar University

Signature_________________

Date of Submission_________________

This thesis work has been submitted for examination with my approval as a University advisor.

Advisor's name ____________________

Signature _________________________

Date _________________________

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ACRONYMS

ANOVA---Analysis of variance

APHA -- -------- American Public Health Agency

ASPT ---Average score per taxon

WT---Water temperature

BMWP--- --------Biological monitoring working party

CSA ---Central Statistical Agency

CTE --- Coleopteran, Trichoptera, and Ephemeroptera

DO---Dissolved oxygen

DOS (%) --Dissolved oxygen saturation

EPT--Ephemeroptera, Plecoptera, and Trichoptera

EC--- Electrical conductivity

FBI---family biotic index

GPS--Global position system

Indi---Individuals

M.a.s.l.---Meter above sea level

NTU--Nephelometric turbidity unit

SPSS --Statistical package for social science

SASS---South Africa scoring system

TDS--Total dissolved solid

TSS--- ---------Total suspended solid

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ABSTRACT

Freshwater ecosystems provide various services to many people worldwide. However, degradation of freshwater ecosystems and loss of their services have become pervasive environmental issue across Ethiopia due to ever intensifying human activities, lack of awareness and logistic constraints. As a result, there is an urgent call to develop conservation, management, restoration guidelines, and detail scientific information. To this end, understanding how freshwater biodiversity responding to different human activities is indispensable. Therefore, the purpose of this study was to investigate benthic macroinvertebrate structure in relation to land use types. Benthic macroinvertebrates and physicochemical parameters of water were recorded from 39 sampling sites along Infranz River that represents different human land use activities such as low (n=12), moderate (n=14) and high (n=13) during dry season. The total of 1052 macroinvertebrates belong to 55 families was collected. Macroinvertebrate metrics such as, biological monitoring working party, Shannon diversity index, Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness, total family richness, and average scoring per taxa were decreased with increasing human land use activity: whereas, family biotic index increased with increasing human disturbances. Stepwise regression analysis showed that farming, cattle grazing, and vegetation removal were important predicators of macroinvertebrate metrics ($p<0.05$). Generally, high values of electrical conductivity, turbidity, total suspended solids, total dissolved solid, and ammonia were record in sites which are characterized by high human disturbance.

Keywords: Land use, Benthic macroinvertebrate, Assemblages, Family richness

1. INTRODUCTION

1.1. Background

Freshwater ecosystems provide various services to many people worldwide. However, these water bodies are the most disturbed environments across the world. They have become the most vulnerable and fragile resources in the world. They have affected to the direct or indirect impacts of population explosions (McAllister *et al*., 2001). According to Hardin (1968), rapid population growth is important hindrance to live in harmony with nature. Hardin (1968) showed that it is impossible to maintain healthy environment and stability without restricting human right to breed and human mind enhancement. Population growth, urbanization, industrialization, and agriculture activities are major factors for environmental quality degradation (Bizuayehu Tefera *et al.*, 2002, Franze *et al*., 2004; Dudgeon *et al.,* 2006). These human related activities lead to habitat modifications and degradations, resource overexploitation, pollution, exotic species invasion, and climate change. Water body ecosystems are exhausted by such human activities (Dudgeon *et al.*, 2006; Braatne *et al.,* 2008; Strayer and Dudgeon, 2010; McCartney et al., 2010).

In Ethiopia, land, soil, and water degradations have become pervasive environmental issues. Therefore, resource degradation is a pressing concern across the country. This is due to unwise resource utilization, rapid population growth and climate change effects. Human needs and its impact on natural ecosystem increase as per the population size (Bizuayehu Tefera *et al.,* 2002, Hardin, 1968). People migration from rural into urban areas has become high in need of jobs and better life (Hardin, 1968). The number of rivers and streams passing through urban areas are increasing (Beyene *et al.*, 2009a; Beyene *et al.,* 2009b).

Waste management strategies are poor in urban areas (Beyene *et al.,* 2009a; Beyene et al., 2009b). Rivers are dammed to address the needs of humans through irrigation and hydropower (Seid Tiku Mereta *et al.,* 2013). Thus, rivers and streams have been highly polluted (Ayemer Awoke *et al.,* 2016). Urbanization, industrialization, deforestation and agricultural activities are intensifying factors in rivers and streams (Alemneh Temesegen *et al.,* 2016; Ayenew Gize *et al.,* 2017).

Like other parts of Ethiopia, Lake Tana watershed had been exposed to various human induced threats. The watershed is under rapid environmental alternations because of the effects of rapid population growth and socioeconomic developments. Recently, wetlands have been draining and changing into agricultural land or settlement sites. Many tributary rivers of Lake Tana have been dammed for irrigation and hydropower developments. Lake Tana watershed is known by its huge natural freshwater reservoir in Ethiopia and the source of the Abay/Blue Nile River. It is well known for its biodiversity, cultural and socioeconomic values. It provides enormous ecosystem services such as fishing, water for drinking, tourism, transportation, electricity generation and irrigation (Ayalew Wondie, 2010). There is high need to utilize the potentials of water resource in the region to its optimal level.

Detailed understanding the ecological condition of river ecosystem is important to develop ecological and environmentally sound management and restoration strategies. Among the numerous rivers that are potential at risk due to human activities in Lake Tana watershed, Infranz River was a case in point. This river feed Lake Tana and it had been exposed to various human activities. Infranz River had become a part of Bahir Dar city administration. However, the expansion of Bahir Dar city has not reached to Infranz river watershed yet. Infranz river is a source of drinking water for Bahir Dar city population. Infranz river watershed is characterized by extensive grazing and subsistence agricultural activities (Abrehat Kahsaye *et al*., 2014; Ayenew Gezie *et al.*, 2017). However, detailed studies about the ecological conditions of Infranz have not been well documented.

However, the impacts of the natural nature of the river ecosystems on aquatic biodiversity have not been well documented. It would have a great implication on success of river ecosystem restoration guide lines. However, before intensification of human activities, the ecology of streams and rivers has not well documented. Lack of awareness and logistic constrains were major factors for further environmental degradation. To assess, monitor the conditions of water bodies and develop conservation, management, and restoration strategies in the country, there is lack of detail scientific knowledge that provide valuable inputs for decision and policy makers (Welp, 2001; Ayenew, 2007).

1.2. Statement of the problem

Lake Tana watershed has national and international importance. The region has been selected as one of economic growth corridor in Ethiopian because of its water resource potentials. The water resources in the watershed provide services to millions of people. The resources have provided wild foods such fish and raw materials for both subsistence and commercial uses in addition to supporting the usual agricultural activities such as grazing and cropping. However, various human activities such urbanization, agricultural activities, industrialization, population growth, pollution and environmental degradation as well as invasive species had been active threats for the sustainability of the water resources in the region. Numerous dams have been constructed in the watershed (ZurHeide, 2012). The watershed encompasses many wetlands, seven perennial rivers and around sixty seasonal rivers (Nagelkerke, 1997).

Water is highly polluted with different harmful contaminants due to increased population, use of fertilizer and man-made activities. Evaluations of water quality parameters are necessary to enhance the performance of an assessment operation and develop better water resource management plan (Ruchi *et al.*, 2016). The problem of water pollution affects communities of macroinvertebrate which are vital in identification and knowing the pollution status of river, moreover it enables to rank the macroinvertebrate communities based on their range of water pollution (Tesfaye Selemon, 2016). Urbanization affects ecological integrity of river ecosystem through altering the physical, chemical and biological nature of freshwater ecosystems (Ayemer Awoke *et al.,* 2016). Little information is documented about the biodiversity of river ecosystems before urbanization intensified and encroach river ecosystem condition. Therefore, documenting biodiversity of Infranz River before the river ecosystem influenced by urbanization is an urgent call.

1.3. Research Questions

- What is the structure of benthic macroinvertebrates in relation to various land use types in Infranz River?
- Which physicochemical parameters have strong association with macroinvertebrate communities of Infranz River?
- What is the relationship between macroinvertebrate metrics and physicochemical parameters?
- Which macroinvertebrate taxa are dominant in low, moderate and high land use sites in the study area?

1.4. Objective

1.4.1. General objective

The purpose of this study was to investigate the impacts of human induced environmental changes on the diversity and distribution of macroinvertebrate assemblages in Infranz River, northwest of Ethiopia.

1.4.2. Specific objectives

The Specific objectives of this thesis were:

- To investigate the influence of various land use types on macroinvertebrate diversity and distribution.
- To determine the relationship of different land use types with physicochemical parameters macroinvertebrate distribution
- To assess the impacts of habitat quality on macroinvertebrate assemblage

1.5. Significance of the study

This study was designed to assess how various human activities affect macroinvertebrate assemblages. Therefore, the study would come up with an important input that could support in developing river ecosystem management and conservation, and restoration strategies and guideline. It was also expected to provide background information about the effects of land use on macroinvertebrate assemblage for other researchers interested to conduct research on the same issue at the study area.

1.6. Limitation of the study

The limitations were encounter during the research process come forth from lack of resource, time, transportation, and budget which limit the detailed investigation and analysis of data from the study area.

2. LITERATURE REVIEW

2.1. Freshwater ecosystems

Freshwater ecosystems throughout the world are threatened by human activities that directly change hydrology system, such as construction of physical barriers to flow, water extraction, and filling or draining of shallow habitats. Freshwater degradation can further exacerbate the shortage and unfair water resource distributions across the country (Ayemer Awoke *et al.,* 2016). Pollution of water bodies with toxic substances and excessive nutrients, as well as destructive land use practices in areas surrounding freshwater ecosystems, lead to reductions in water quality. Freshwater ecosystems depend strongly on physical features such as water quantity, quality and flow; many of the threats to these ecosystems involve activities that alter fundamental physical characteristics (Dudgeon *et al.,* 2006). One of the major problems that Ethiopia is facing with achieving sustainable development is maintaining environmental quality (Argaw Ambelu, 2010). Lack of awareness, logistic constraints, communication gaps, ineffectiveness of environmental policies and laws are important obstacles for conservation of resources in the country (Ayemer Awoke *et al.*, 2016).

Freshwater habitats are under risk due to human impacts. Hence studies of biodiversity and the effects of human activities are important. Aquatic ecosystems perform numerous valuable environmental functions. Aquatic invertebrates comprise a taxonomically diverse and ecologically important and interesting group of animals in fresh water systems. They play a very important role in the processing and cycling of nutrients as they belong to several specialized feeding groups (Zhang *et al*., 2018). Headwater streams make up a large proportion of the total length and watershed area of fluvial networks, and are partially characterized by the large volume of organic matter (large wood, detritus, and dissolved organic matter) and invertebrate inputs from the riparian forest, relative to stream size. Much of those inputs are exported to downstream reaches through time where they potentially subsidize invertebrates (Aschalew Lakew and Moog, 2015). The streambed of low order tropical streams is composed mainly by dead leaves and tree branches originated from riparian forest. This substratum is decomposed by physical, chemical and biological factors, and can be colonized by a characteristic macroinvertebrate. The colonization dynamics of these substrates by invertebrates can reflect how they use the multidimensional space of the environment (Zhang *et al.,* 2018). Furthermore, wetlands are being transformed into agricultural fields or settlements. Erratic rainfall due to climate change have made the rain-fed agricultural systems unable to satisfy human needs. Decision support tools and comprehensive scientific information provide valuable inputs for decision and policy makers. The sustainability of natural resources across the nation has been in risk. Therefore, learning from the ecology of streams and rivers is very important to decide the extent of impacts of human induced environment changes on freshwater biodiversity and degenerating policy relevant comprehensive scientific information is an urgent call and a pressing issue in Ethiopia. To develop conservation, management and restoration guidelines and ecological sound strategies, detailed scientific information is mandatory (Argaw Amblu, 2010). However, numerous studies are conducted after urbanization has affected rivers ecosystems (Beyene *et al.,* 2009a; Beyene *et al*., 2009b; Ayemer Awoke *et al.,* 2016). Generally, environmental policies and laws formulated based on information and knowledge gain from developed countries with minor modifications without considering the actual local scenario and resource conditions in Ethiopia (Ayemer Awoke *et al.,* 2016). These forms of policies and laws have mostly ended up with insufficient results in the implementation on the real grounds. As a result, there are possible potential challenges that lead environmental collapse and escalating poverty in Ethiopia, if effective and locally applicable water guide lines policies with appropriate institutional framework and assessment tools may not be designed and implemented.

2.2. Aquatic invertebrates

Aquatic macroinvertebrates are commonly used as indicators of stream health. They are a very abundant and diverse group that inhabits a variety of aquatic environments. Invertebrates are vital component of aquatic food webs because they break down and process organic matter and supply food for invertebrates and vertebrates. Despite their importance in aquatic ecosystems, very few aquatic invertebrates spend their entire lives submerged in water. Most aquatic invertebrates such as insects undergo an aquatic immature stage followed by a terrestrial adult. Even in cases where both the larva and adult are aquatic, often the adult can exit the water (Zhang *et al.,* 2018).

Aquatic invertebrates are very different from the larger vertebrate animals that most people are familiar with them. They are a diverse group with a vast range of different body shapes, behaviors, and life cycles. Aquatic invertebrates have adapted to a wide variety of conditions, such as developing ways of surviving during periods of drought, adapting to increased salinity, and surviving in highly contaminated waters (Williams, 2004). Invertebrates have a major importance in the study of running water ecosystems, particularly concerning the linkage between their community structure and environmental variables, where they are initially applied as indicators in streams. Additionally, invertebrate communities are widely used for water quality assessment due to their enormous variety of taxonomic and functional feeding groups, which provides them advantages as indicators of the ecological status of aquatic ecosystem (Rosado *et al.,*2008). Aquatic invertebrates are one of the most sensitive indicators for measuring the quality of streams, rivers, lakes, and wetland. However, the relative importance of various environmental variables varies significantly among different ecological settings (Yigezu *et al.*, 2018).

2.3. Macroinvertebrates as water quality monitoring tool

Biomonitoring is the process of using biological signals to gauge and track human impacts in aquatic environment (Karr and Chu, 1999; Karr, 2006). Recently, bioassessment has gained popularity worldwide as it is fast, integrative and cost effective approach for assessing the impacts of environmental stressors (Zhang *et al.,* 2018; Mangadze *et al.,* 2019). According to Karr and Chu (1999), biomonitoring can be used to monitor changes in water quality conditions, changes in the aquatic habitat or changes to surrounding watersheds. Biomonitoring consists on using the resident biota of an aquatic system for dual purposes: as integrative indicators of anthropogenic stress at watershed scale and as signals to diagnose the possible causes of degradation of aquatic conditions. Macroinvertebrates are the primary food source of many fish, and play a critical role in the breaking down of organic matter and nutrient cycling (Zhang *et al*., 2018). Generally, their feeding habits, sedentary life relatively to fish, short life cycles, wide range of sensitivities to several stressors and their position in the aquatic trophic structure make macroinvertebrate most known in biomonitoring programs of aquatic health (Karr and Chu, 1999; Dickens and Graham, 2002; Zhang *et al.,* 2018). Macroinvertebrates are the primary food source of many fish, and play a critical role in the breaking down of organic matter and nutrient cycling (Zhang *et al*., 2018). Macroinvertebrate assemblages could be used to evaluate the impacts of human driven stressors at all levels of biological organization in the aquatic ecosystems (Rosenberg and Resh, 1993). Therefore, macroinvertebrates were selected as model organisms for the assessment of Infranz ecosystem condition in the Lake Tana watershed. Generally, their feeding habits, sedentary life relatively to fish, short life cycles, wide range of sensitivities to several stressors and their position in the aquatic trophic structure make macroinvertebrate most known in biomonitoring programs of aquatic health (Karr and Chu, 1999; Dickens and Graham, 2002; Zhang *et al.*, 2018). Aquatic biota considered as natural integrators of decades of human impact on conditions of an aquatic environment (Karr, 2006).

Uses of aquatic communities to assess water quality conditions have commonly applied in developed countries (Zhang *et al.*, 2018). However, biomonitoring is gradually growing in developing countries, including Ethiopia (Yimer and Mengistou, 2009; Atnafu *et al*., 2011; Ayemer Awoke *et al.*, 2016). Benthic macroinvertebrates are important bio indicators of aquatic ecosystem health (Beyen *et al.*, 2009a; Beyene *et al.*, 2009b). It has been reported that various environmental conditions such as vegetation cover, ammonium nitrogen, water pH, hardness, turbidity, nutrients, dissolved oxygen concentration, conductivity and water temperature or various human activities affect the occurrence and abundance of aquatic fauna (Seid Tiku *et al.*,2012; Yigezu *et al.*, 2018; Yi *et al.*, 2018).

Water has considered only as a resource to be consumed by human or used as raw materials for agriculture and industry (Karr and Chu, 1999; Karr, 2006). Before 1970s, physical and chemical measurements were frequently used to evaluate water quality conditions; however, these measurements provide data that primarily reflect conditions that exist as the sample is taken (Rosenberg and Resh, 1993; Karr and Chu, 1999). By contrast, biomonitoring reflects spatially and temporally integrated measure of ecosystem health. Biological monitoring focus on biological metrics; use of a minimally distributed reference condition as a benchmark; organization of sites into classes with similar environmental characteristics; assessment of change; caused by human actions; standardized sampling; laboratory; analytical procedures; numerical and verbal scoring of sites to reflect site condition, and define classes to representing degree of degradation (Karr, 2006). Recently, direct biological monitoring and assessment have got a substantial recognition as living systems provides a mechanism to directly assess the condition of water bodies, diagnose the causes of degradation, help to define actions to attain conservation and restoration goals, and evaluate the effectiveness of management decisions (Karr, 2006; Birk *et al.*, 2012; Zhang *et al.*, 2018). Groups of aquatic fauna and flora could be used for development of bio assessment tools for biomonitoring purpose (Karr and Chu, 1999). However, benthic macroinvertebrates are most often recommended organisms for assessment freshwater ecosystem conditions because of their ecological roles in aquatic ecosystems and their easily traceable characteristics (Rosenberg and Resh, 1993; Zhang *et al.*, 2018). Macroinvertebrate assemblages have been commonly used to evaluate water quality and ecological conditions of aquatic ecosystems. They tend to move very little, and their life cycles are relatively short compared to fish, they reflect changes in the environment through changes in population and community structure more quickly, they live in and feed on around sediments where toxins tend to be accumulated and hence the toxin can be accumulated in them and pass through the food chain, they vary in sensitivity to stressors and they may respond to pollutants in the water column as well as for those in the sediments. They are important components of the ecosystem as a link base of food chain with the rest of trophic levels in the food chain (Barbour *et al.*,1999). Hence, policies and laws of environmental issues need to be formulated based on the actual local scenario and resource conditions in the country. To this end, comprehensive scientific information and decision support tools should be generated across the country.

2.4**.** Major threats of streams and rivers

River ecosystems are continuously threatened by human impacts due to land use change, degradation of in stream habitat and water quality (Sala, 2000). This makes the human activities one of the main factors influencing the macro invertebrate community structure in the river basin. The macroinvertebrate community composition changes arise due to change that occur in habitat condition and water chemistry of rivers as result of human activities. Waste dumping, clearance of vegetation, damming, and agriculture are the major activities that affect the natural condition river, which in turn affects the macroinvertebrate community (Hughes *et al*.,2007) In tropical countries grate biodiversity loss in freshwater ecosystem due to deforestation (Bailey, 2001).

The impact of humans on water resources takes different forms. It includes physical alteration and pollution from industries and residential areas. Also, it includes changes in riparian vegetation and stream morphology, sedimentation, nutrient additions, organic enrichment and pesticide contamination from agricultural land uses (Chu and Karr, 2001). In Ethiopia land degradation, urban sanitation, industrial and chemical pollution are the major environmental problems (Zinabu Gebre-Mariam and Zerihun Desta, 2002) that cause adverse impact on aquatic resources of the country.

2.4.1. Agriculture

Agriculture is one of the major human activities responsible for nonpoint-source of pollution in streams and rivers of Ethiopia (Aschalew Lakew, and Moog, 2015). Poor agricultural practices around rivers and streams can lead to soil erosion and subsequent runoff of fine sediments, nutrients and pesticides (Lowrance *et al.*, 1984). Studies showed that fine sediment accumulation affect macroinvertebrate assemblages by affecting substrate composition and by favoring only for the tolerant taxa. Suspended sediments accumulation have an impact on stream fauna by interference with filter feeding mechanisms or reducing visual feeding efficiency and by reducing light levels to the point of triggering drift behavior (Waters, 1995). In addition, streams and rivers in Ethiopia serve for cattle watering site and their banks for grazing area due to all year availability of green grasses.

2.4.2. Domestic waste

Domestic sewage contains a wide variety of dissolved and suspended impurities such as organic materials and plant nutrients. The main materials of domestic waste are food and vegetable wastes, plant nutrients come from chemical soaps, washing powders, etc. Domestic sewage is also very likely to contain disease-causing microbes. Most detergents and washing powders that we use to clean our houses and other utensils contain phosphates and other toxic chemicals that affect the health of all forms of life in the water. Domestic waste contained water causes eutrophication, which is the increase in concentration of nutrients. The nitrates, phosphates, and organic matter found in human waste and other organic source serve as a food for algae and bacteria. This causes these organisms to overpopulate to the point where they use up most of the dissolved oxygen and makes the environment anoxic and difficult to survive. Some of the organisms that do overpopulate from this can also be disease-causing microorganisms (planetary Notions, 2002).

2.4.3. River damming

African rivers are being dammed for different purposes. They are important for damming activities and to hydropower generation. Dams stope the natural flow of rivers and affect the ecosystem of the downstream catchment. Downstream the dam, the discharge of rivers drastically changes which resulting water stress in riverine ecosystem (Argaw Amblu *et al.*,2010).

2.4.4. Industry

Industrial effluent can change physical, chemical and biological nature of water body leading to deterioration in water quality that causes high impact on the water chemistry and biological elements (Carr and Neary, 2008).

Ethiopia has few industries and few developed urban areas, water bodies near cities such as Addis Ababa, have shown severe pollution problem (Baye Stotaw, 2006) and the same problem face in Sebeta town, which is recognized as one of the industrial zone of the country. The effects of industrial activities on aquatic environment are becoming evident through the pollution of water bodies and human habitat in the major cities of the country and its rivers and lakes (Seyoum Leta et al., 2003).

The textile industries are one of the largest water users and polluters industries which adverse environmental problems. They have the potential to affect water transparency (Banat et al., 1996). Brewery and alcohol effluent causes oxygen depletion, increase in plant and animal biomass, reduction of the amount of light available for aquatic vegetation, decrease in species diversity and favors the dominance of tolerant biota. Microorganisms gradually break down the organic component of wastewater by consuming the available oxygen which will pollute rivers, lakes, streams and deep-water (Ekhaise and Anyansi, 2005).

3. MATERIALS AND METHODS

3.1. Description of the study area

The Infranz River is located at northwest of Bahir Dar city which is capital city of Amhara national regional state, around 10 kilometers. It is 576 kilometers away from Addis Ababa. The Infranz River originates from Zegie kebele. The upper part of the river is rich with a number of springs. The head of spring is the source of drinking for Bahir Dar city. The river flows into the southwest of Lake Tana and its catchment area is around 198 km^2 (Kidan, 2010). Surface water is the main water source of the Infranz River. This water is directly pumped for Bahir Dar city residents from wells drilled and water tube near the river (Kassahun, 2008). The total population size of Bahir Dar city was 308,877 in 2019 and had a population growth rate of 5% per year (CSA, 2019), which is more than twice as high as the average population growth rate in Ethiopia.

The climate of the watershed of Infranz River categorized into rainy season (July–September), dry season (December–April), pre-rainy season (May–June) and post-rainy season (October–November) (Abrehat Kahsaye *et al.*, 2014). The watershed of Infranz river coverage is around 2500 ha. and inhabited around 24,000 people (Abrehat Kahsaye *et al.*, 2014).

The watershed is mainly used for grazing and agriculture activities (mainly in dry season). Most lands used for grazing cattle and used for extensive agriculture, mainly *Chat* (*Cathiedulis)*, *Mango (Mangifera), Vetch (Vicia sativa), Small millet (Panicum sumatrense)* and *Maize (Zea mays).* The remaining land is occupied by trees, shrubs and human settlement. In addition to this, river intensive irrigation in dry season is mainly applied for growing *Chat* (*Cathiedulis)* and vegetable production. This river also serves as domestic activities, washing, drinking and bathing. Most riparian vegetation was removed due to intensive human activities. The major human activities observed in and around the study area were intensive grazing, farming, vegetation removal, water abstraction, and drainage. The riparian vegetation is diverse and consists of about 27 species of shrubs (Abrehat Kahsaye *et al.*, 2014). The most dominant plant species along the river were found *Scysigiumquinees (dockma), Banana (Musa paradisicum), Cyprus papyrus L. (Cyprus papyrus), Eucalyptus (Eucalyptus globulus),* and *Wanza (Corda African Latm)* were observed. The sampling site is presented in figure 1.

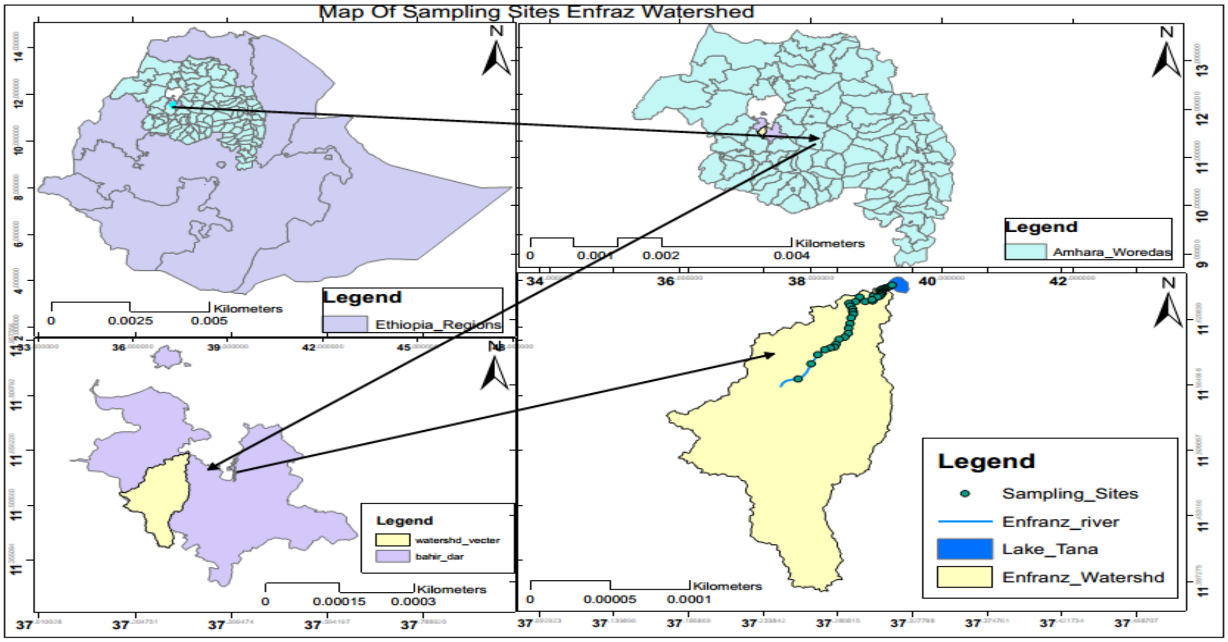


Figure 1. Map of study area (obtained from satellite image)

3.2. Sampling Site Selection and Description

In total 39 sampling sites representing different human land use activities were selected across the study area. The intensity of human disturbance in each site was scored following Barbour *et al.* (1999). Thereafter, the intensity of human disturbances in each sites was classified into low, moderate, and high. Low human impacted sites were surrounded by riparian vegetation at both side of the River. It had minimal vegetation removal, farming, and grazing. It was highly covered by riparian vegetation. They were 12 sampling sites at low human land use activities.

Moderate human land use sites were covered by riparian vegetation at one side. Mainly affected by grazing, vegetation removal and water drainage. They were 14 sampling sites per moderate human land use activities. High human impacted sites were limited riparian vegetation at both sides. They were mainly affected by intensive farming, grazing, deforestation, and drainage (Argaw Amblu, 2010). There were 13 sampling sites at high land use activities. The sampling sites ranged from head water (S1) to the mouth of river (S39). The study sites were mainly affected by cattle watering, grazing, agricultural activities, washing, and different domestic activities were shown in figure 2 (Argaw Amblu,2010). The photos different human disturbance taken by camera man Melese Belew (2019).

Figure 2. Agricultural activities, grazing, cattle watering, and washing

3.3. Data collection

3.3.1. Habitat quality data collection

At each sampling site major anthropogenic activities such as: farming, grazing, tree removal, irrigation, and drainage, the physical habitat condition, and habitat quality were carefully assessed (Barbour *et al.*,1999). Sampling sites were selected along gradient of visible disturbance including low, moderate, and high human disturbance sites. Low human disturbance characterized by high riparian vegetation, canopy cover, inorganic substrate components, minimal debris, minimal sediment deposition, high vegetation protection, and high epi faunal substrate. High human disturbance visually characterized that minimal riparian vegetation, canopy cover, vegetation protection, and contains high large woody debris (Barbour *et al.*, 1999).

The measure of human disturbance was obtained by assessing hydrological modification, habitat alteration, and land use practice. Hydrological modification includes damming and water abstraction. Habitat alteration includes grazing, vegetation removal, and tree plantation. Land use practice in station includes farming and waste dumping. Other human activities were bathing, swimming, agricultural biocides, and water abstraction. Protocol described by Ayenew Gezie (2004)) to categorize human disturbance was used. Score 1 was assigned to no or minimal land use human impacted sites, score 2 moderate, and score 3 to high human disturbance. The overall disturbance from each site was calculated summing individual values of eight different factors. The human influence ranges from 8 to 14 to low, 15 to 18 moderate and 19 to 24 to high impacted sites. For each human disturbance check lists were prepared and points given listed above and average human impact score was given to each study site (Appendix 2).

3.3.2. Physicochemical data collection

Environmental data were collected at 39 sampling sites along the Infranz River, starting from the head of the River up to the mouth of the River. A composite sampling technique to take water samples at three sampling points across the width of the rivers for chemical analysis was carried out. Physicochemical parameters were measured both on-site and in the laboratory. The materials used in sampling were clean plastic bottles, dark plastic, marker, and kit container. Dark plastic was used to keep the sample at low temperature, prevent direct solar radiation and thus avoid the fluctuation of the water parameters. Water samples were collected at each sampling station

(Baldwin *et al.*, 2005). Latitude, longitude, and altitude were determined with the help of global position system (GPS) instrument to identify location of study sites. Substrate composition of each site was visually estimated in accordance with particle size: boulder (>256 mm), cobble (64-256 mm), grave (2-64 mm), sand (0.06-2 mm), and silt (0.004-0.06 mm), and clay (<0.004 mm). The water depth and sediment depth were measured at each sampling site by using graduated stick and the average of each measurement was considered as final value (Ayenew Gezie *et al.*, 2017). The flow velocity was measured by meter model 1100. Physical parameters such as sediment depth, water depth, turbidity, electric conductivity, pH, water temperature, oxygen saturation, and dissolved oxygen were measured on-site using portable plain test multiple parameter method was shown in figure 3 (Aschalew Lakew). The onsite measurement of physicochemical parameters the photos taken by camera man Melese Belew (2019).

Figure 3. Onsite measurements of physicochemical parameters

Two Litter of water sample was collected at each sampling site and stored dark plastic in the field and transported to Bahir Dar University Polly compass SCWRE water quality and treatment research center laboratory for analysis of ammonium, nitrate concentration, total suspended solid (TSS), Total dissolved solid (TDS), calcium carbonate, phosphate, iron, and hydrogen bicarbonate following the standard procedures as outlined in APHA (1998).

3.3.3. Macroinvertebrate data collection

Macroinvertebrates were collected at each human disturbance site along the study site, starting from the head of the river up to the mouth of the river. Macroinvertebrate samples were collected using the kick-sampling technique with a D-frame net width 20 cm by 30 cm having a mesh size of 300 μm. Kick-sampling was carried out along a 10-meter stretch of the river for five minutes, including all the microhabitats within the sampling reach (Gabriels *et al.,* 2010). Sampling was started at downstream end of reach and proceeds upper stream against current. During sampling, the river bed was thoroughly disturbed by feet to dislodge the macro invertebrates from the substrate. The collected samples were sorted by needles and preserved in 96 % ethanol, labeled, and placed in side of plastic bottle marked with date, stream name, and site code by pencil. The same information was also labeled on the outside of container with water proof marker. All macroinvertebrates were transported to Bahir Dar University research center of zoology laboratory and examined using stereomicroscope. In the laboratory, the sorted macroinvertebrates were identified at family level using different identification keys (Gerber and Gabriel, 2002, Bouchard, 2012). The methods field sampling and sorting of macroinvertebrates followed quality control procedures are showed in figure 4 (Barbour *et al*.,1999)

Figure 4. Field sampling and sorting of benthic macroinvertebrates

The macroinvertebrate samples collected and preserved in the field were subjected to process in the laboratory for further analysis. Before processing, the information in the sample container was copied to data sheet. By placing the sample in the Petri dish, sorting was performed through naked eye. Macroinvertebrates were trapped in smaller fraction of the sieve and sorted with help of light microscope. In some sampling unit the density of some taxa was very high such as, Gomphidae, Chironomidae, Platycnmidae, and Melanopsidae. Identifications were performed using Aquatic Invertebrates of South African Rivers (2002) field guide.

In the laboratory, like other macroinvertebrates, Chironomids were properly sorted, counted and preserved in 96% ethanol. Identification was made under compound microscope with the help of identification keys (Getachew Benebru, 2013). The macroinvertebrate sample processing and sorting in laboratory was showed in figure 5 followed (Barbour *et al*.,1999).

Figure 5. Benthic macroinvertebrate sample processing and sorting

3.4. Data analysis

The data was analyzed using different statistical software such as SPSS version 20, PAST and Excl. Box and whisker plots were used to visualize the relationships of biological attributes with water environmental variables. ANOVA was performed to test relationships of human disturbance with environmental parameters.

Spearman rank correlation was calculated to examine the extent of correlation of the selected attributes of macroinvertebrates' metrics with water quality parameters. Microsoft excel was used to calculate the metrics. The relationship between discriminative metrics and environmental variables were determined by calculating the Spearman rank correlation coefficients.

Family biotic index, BMWP, Shannon winner diversity index, and Average scoring per taxon were calculated by the following formula.

Hilsenhoff family biotic index (FBI)= $\frac{\sum n_{it_i}}{N}$ (Hilsenhoff,1988)

Where n_i= abundance of taxa, t_i is tolerance value of individual and N = total number of individual in sample. Tolerance value provides measure of sensitivity of macroinvertebrates to anthropogenic disturbances (Yhuna, 2006). Tolerance value each benthic macroinvertebrate methods for estimated the relationship between given and anthropogenic stressor gradient (Yhuna, 2006).

H'=-$\sum p_{ilogp_i}$ where p_i is proportion of abundances of tax ($\frac{n}{N}$) (Shannon 1948). Where H' = Shannon winner diversity index

BMWP=$\sum TV$ where BMWP is biological working part and TV is tolerances value of taxa (Armitage *et al*., 1983)

ASPT=$\frac{\text{BMWP}}{No,taxa}$ where ASPT is average scoring per taxa, No, tax.is number of taxa.

3.5. Benthic macroinvertebrate(metrics) selection and calculations

Metrics are biological attributes that reflect the impact of human induced activities and give response in predictable way. The response given to different human land use activities within Infranz River about 21 metrics were selected and calculated using Microsoft excel (Appendix 3). The tolerance value of benthic macroinvertebrate family biotic index, biological monitoring working party (BMWP), average scoring per taxa (ASPT), and Shannon winner index (H`) were calculated according to the value awarded to each benthic macroinvertebrate.

4. RESULTS

4.1. Environmental parameters

The most of physicochemical parameters measured in the field and laboratory showed significance difference between at different human disturbance sites (Table 1). The water temperature tends to increase with increasing human disturbance but dissolved oxygen was decreased (Table 1). There was no significance difference ($p > 0.05$) in water temperature between human disturbance sites. But, water temperature at low human disturbance low compare to moderate and high human disturbance. There was significance difference ($p<0.05$) transparency between human disturbance sampling sites. The highest transparency recorded at low human disturbance (91.5-98.66cm) while the lowest recorded was at high human disturbance (31.44-93.32cm). There was no significance difference ($p > 0.05$) in dissolved oxygen between human disturbance. But, the higher dissolved oxygen recorded at low land use sites with ranges 0.081- 0.083mg/l than high human land use sites (0.0803- 0.0806Mg/l). There was no significance difference ($p > 0.05$) in pH, turbidity, electrical conductivity and total dissolved solids between human disturbance sites. But, there were highest recorded at high human disturbance than low and moderate disturbance (Table 1). There was significance difference ($p < 0.05$) in canopy and vegetation cover between human disturbance sites. But, there was the highest recorded of canopy and vegetation cover at low land use activities (76.78% and 85.149%) compare to high human land use sites (14.840% and 32.192%) respectively. There was significance difference ($p < 0.05$) in habitat alteration, land use and hydrological modification between human disturbance sites. But, there was higher recorded at high human disturbance than moderate and low land use activities (Table 1). There was no significance difference ($p < 0.05$) in the calcium carbonate, ammonia, and phosphate concentration between human disturbance sites. But, there was highest recorded at high disturbance than low and moderate human disturbance (Table 1). The Epifunal substrate was significance difference ($p < 0.05$) between human disturbance with highest recorded at low disturbance than moderate and high human disturbance (13-19.56, 7-16 and 5.82-15.42) respectively.

Table1. Average values and standard deviation of environmental variables measured in Infranze River.

Variables	Human disturbances		
	Low (n=12) (mean $\pm SD$)	Moderate (n=14) (mean $\pm SD$)	High (n=13) (mean $\pm SD$)
PH	7.20 ± 0.35	7.50 ± 0.34	7.58 ± 0.28
WT (°c)	19.10 ± 0.60	19.17 ± 0.75	19.33 ± 1.19
DO (mg/L)	0.08 ± 0.03	0.08 ± 0.02	0.08 ± 0.01
EC (µS)	0.18 ± 0.08	0.16 ± 0.04	0.190 ± 0.07
Turbidity (NTU)	5.93 ± 4.65	11.19 ± 7.41	8.97 ± 5.89
Transparency (cm)	95.08 ± 3.58	66.79 ± 37.03	62.38 ± 30.94
WD (cm)	58.23 ± 25.77	67.71 ± 35.97	72.84 ± 45.66
SD (cm)	4.92 ± 8.83	8.48 ± 9.23	7.32 ± 7.08
TSS (mg/L)	0.01 ± 0.05	0.02 ± 0.04	0.04 ± 0.02
TDS (mg/L)	0.34 ± 0.10	2.23 ± 7.13	4.64 ± 10.81
CaCO3(mg/L)	34.83 ± 31.75	46.21 ± 43.63	39.86 ± 40.81
DOS (%)	0.08 ± 0.01	0.08 ± 0.03	0.083 ± 0.02
Discharge(m^3/**S)**	1.07 ± 0.49	1.14 ± 1.02	1.37 ± 0.88
Canopy (%)	56.00 ± 20.78	24.50 ± 22.45	5.38 ± 9.45
NH4 (mg/L)	0.38 ± 0.36	0.42 ± 0.38	0.45 ± 0.48
PO4 (mg/L)	0.13 ± 0.12	0.41 ± 0.44	0.36 ± 0.39
Habitat alteration	14.48 ± 0.86	18.06 ± 8.80	20.13 ± 0.58
Land use	14.44 ± 1.64	17.82 ± 15.00	20.15 ± 0.66
H. modification	11.54 ± 2.35	17.52 ± 3.60	19.38 ± 5.27
Vegetation cover	71.000 ± 14.15	37.14 ± 11.80	23.31 ± 8.88
Epifunal substrate	16.25 ± 3.31	11.64 ± 4.46	10.62 ± 4.80

Key: - SD (standard division), WT (water temperature), DO (dissolved oxygen), EC (electrical conductivity), WD (Water depth), SD (sediment depth), TSS (total suspended solid), TDS (total dissolved solid), DOS (%) (Dissolved oxygen saturation), n=number of sampling sites, H= Hydrological

4.2. Benthic Macroinvertebrate abundance and occurrence

A total of 1052 macroinvertebrates belonging to 55 families and 11 orders were recorded as shown in Table 2. The most dominant orders were Odonata which consisted of six families with relative abundance of 43%. Among the Odonata Gomphidae and Platycenmididae were the most frequently occurring families which were found in 81.26% of this order. The second dominant order was Dipterans which consists of four families with relative abundance of 16.6%. Chironomidae was the most frequently occurring in order Dipterans which found in 94.8% and 15.6% in the study site. Mollusca were the third order with 13 families and relative abundance 11.5%. Among Mollusca the most frequently occurring was Melanopsidae which consists 28% in this order.

The most diverse and abundance of macroinvertebrate occurs at low human land use activities which consists nine taxa and 443 individuals than moderate and high land use activities (seven taxa, 374 and five taxa, 235 individuals) respectively. The highest number of Odonata 214 were register at low land use activities than moderate 184 and high 61 land use activities. Dipterans were more or less found from low to high human impacted sites. But the highest number Diptera (67) were recorded at high land use activities. Pollution sensitive to environmental disturbance orders were Ephemeroptera which consist of Ephemerellidae, Baetidae, and Caenidae, Trichoptera which consisted Perlodidae and Chloroeiphidae and Plecoptera which including Hydropsychidae and Ecnomidae were distributed mostly at low human land type use activities (77). However, these EPT (Ephemeroptera, Plecoptera, and Trichoptera) orders were declined at high human land use sites (24). The highest number of Mollusca (52) was recorded at low human impacted sites. In contrast the lowest numbers (24) of Mollusca were recorded at high human disturbance site. The most Decapoda and Hemiptera were frequently occurred at low human land use activities than high human impacts sites. The major macroinvertebrate family identified during data collection of their photographic picture and their family name were shown in appendix 1.

Table 2. Overview of relative abundance of macroinvertebrates taxa in the study Infranz River

Taxa	Human disturbance	Total

	Low (n=12)	Moderate (n=14)	High (n=13)	n=39
Odonata	214	184	61	459
Ephemeroptera	34	0	14	48
Plecoptera	2	1	1	4
Coleopteran	13	52	38	103
Trichoptera	41	10	9	60
Hemiptera	22	18	18	58
Hirundae	0	3	2	5
Mollusca	52	45	24	121
Gastropoda	0	1	0	1
Decapoda	14	3	1	18
Diptera	51	57	67	175
Relative abundance	443	374	235	1052

As shown in Table 3, the mean value of benthic macroinvertebrate metrics varied across different human disturbance sites. At low human disturbance sites the mean value of biological monitoring working party, average scoring per taxa, family richness, Shannon winner diversity index, Ephemeroptera and Odonata richness, and percentage of Ephemeroptera, Plecoptera, and Trichoptera (EPT) were higher compared to sites with moderate and high human land use activities (Table 3) In contrast to family biotic index, percentage of dominant taxa and percentage *Diptera* was higher at sites with high land use activities. The Gomphidae, Chironomidae, Platycnmidae, and Chloroeiphidae were the most frequently occurring families at all human disturbed sites (Appendix 5).

Table 3. Average value of macroinvertebrate metrics in Infranz River

Biotic metrics	Human disturbance

	Low (n=12)	Moderate (n=14)	High (n=13)
FBI	3.33	3.89	4.93
BMWP	34.33	18.50	17.15
ASPT	4.62	2.98	1.34
Shannon winner index	1.75	1.45	0.12
Family richness	0.16	0.11	0.108
EO richness	20.25	11.85	7.92
Number of taxa	9.00	7.00	5.00
No.Trichoptra	41.00	10.00	8.00
% dominant taxa	35.33	41.00	45.25
% EPT	68.76	21.42	9.82
% Dipterians	29.1	32.6	38.3
% Chironomidae	21	33	46

Key: - FBI=family biotic index, BMWP= biological monitoring working party, ASPT= average scoring per taxa, EO = Ephemeroptera and Odonata, EPT = Ephemeroptera, Plecoptera, and Trichoptera.

4.3. The relationship between environmental parameters and macroinvertebrate metrics

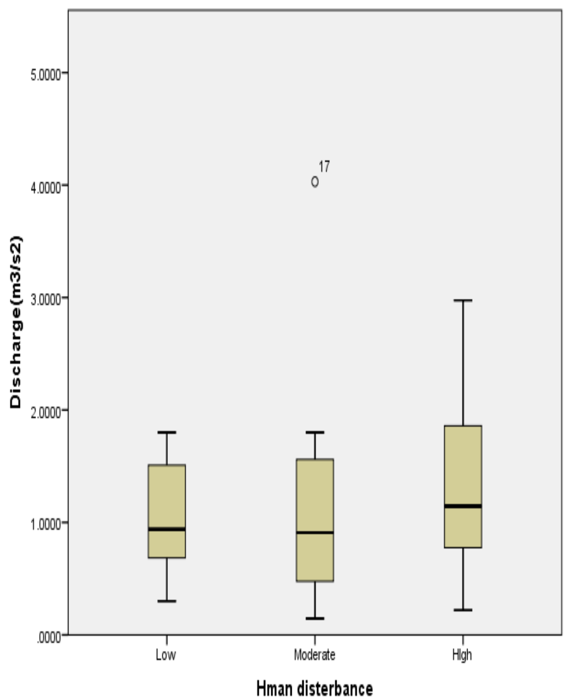
The correlation between environmental parameters and macroinvertebrate metrics was shown on Table 4. The Spearman's rank order correlation indicated that the most environmental parameters were significantly correlated with macroinvertebrate metrics. Highly sensitive macroinvertebrate metrics were significantly correlated with environmental variables. Abundance, biological monitoring working party, and average scoring per taxa were positively correlated with vegetation cover ($p<0.05$). However, abundance, biological monitoring working party, average scoring per taxa, Ephemeroptera and Odonata richness, and Shannon winner index were negatively correlated with habitat alteration, land use, turbidity, and total suspended solid ($p<0.05$). Family richness was positively correlated with transparency and vegetation cover. In contrast, it was negatively correlated with pH, electrical conductivity, turbidity, total suspended solid, and dissolved oxygen saturation ($p<0.05$). Family biotic index and Dipterans were positively correlated with land use and habitat alteration and waste damping ($p <0.05$). The pH and dissolved oxygen saturation were positively associated with turbidity and total suspended solid. In contrast they were negatively associated with electrical conductivity and total suspended solid ($p<0.05$). Electrical conductivity was positively correlated with total suspended solid and total dissolved solids. But, it was negatively correlated with turbidity and dissolved oxygen saturation ($p<0.05$).

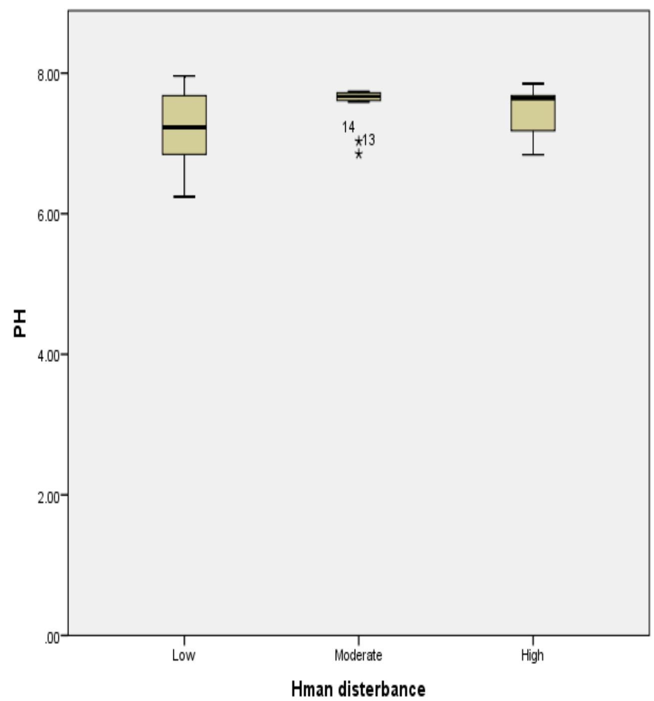
Table 4. spearman's Correlation between environmental variables with biological metrics

	Ab.	FBI	BMWP	ASPT	Sh.I.	FR	EOR	Ch.	EC	TU	TSS	DOS	HA	LU	VC	TDS	WD
Ab.																	
FBI	-0.33*																
BMWP	0. 53**	-0.30															
ASPT	0.35*	-0.17	0. 87**														
Sh.I.	0.34*	-0.42*	0. 67**	0.37*													
FR	0. 47**	-0.27	0. 41*	0. 35*	0.21												
EOR	0. 75**	-0.43**	0.50**	0.31	0. 43**	0.15											
Ch.	-0.31	0. 36*	0.13	-0.09	-0.08	0.11	-0.48**										
EC	0.01	0.23	0.16	0.21	0.09	-0.56**	-0.05	-0.63**									
TU	-0.02	0.03	-0.33*	-0.48**	-0.02	-0.47**	-0.24	0.01	0. 52**								
TSS	-0.08	-0.16	-0.30	-0.38*	-0.06	-0.49**	-0.07	-0.01	0. 56**	-0.60**							
DOS	-0.08	-0.37*	-0.23	-0.28	0.06	-0.53**	0.08	-0.01	0.28	-0.53**	0. 54**						
HA	-0.46**	0.45**	-0.52**	-0.39*	-0.35*	-0.32*	-0.51**	0.36*	0.17	-0.04	0.27	0.24					
LU	-0.41**	0.43**	-0.50**	-0.40**	-0.23	-0.26	-0.44**	0.31*	0.01	0.10	0.08	0.05	-0.13				
VC	0.44**	-0.22	0.51**	0.48**	0.15	0.38*	0.42**	0.32*	0.24	0.17	-0.37*	-0.36*	-0.07	-0.85**			
TDS	-0.13	0.18	-0.07	0.19	-0.02	-0.17	-0.15	-0.24	-0.52**	0.58**	-0.42**	-0.35*	-0.18	0.20	0.28		

FBI=family biotic index, BMWP=Biological monitoring working party, ASPT=Average scoring per taxa, Sh.i=Shannon winner diversity index, F.R=family richness, EOR= Ephemeroptera and Odonata richness, Ch= Chironomidae, TU=turbidity, HA=habitat alteration , LU=land use, VC=vegetating cover, WD=waste dumping, TSS= total suspended solid, TDS =total dissolved solid, DOS =dissolved oxygen saturation, ** significant at 0.01, * significant at 0.05

The box and Whisker plots showed that water quality parameters such as pH, total suspended solid, discharge and land use were differently between three human impact class. The mean of discharge was slightly higher at high human disturbance than low and moderate human disturbance. The reliability was higher on high human disturbance than others. The mean value of land use was higher at high human disturbance than low and moderate human disturbance. The land use slightly increases with increasing human disturbance. The box plots indicated that mean pH value of water were higher at high land use activates compare to low and moderate disturbance. Low human disturbance had good water quality than high and moderate human impacted sites (Figure 6).





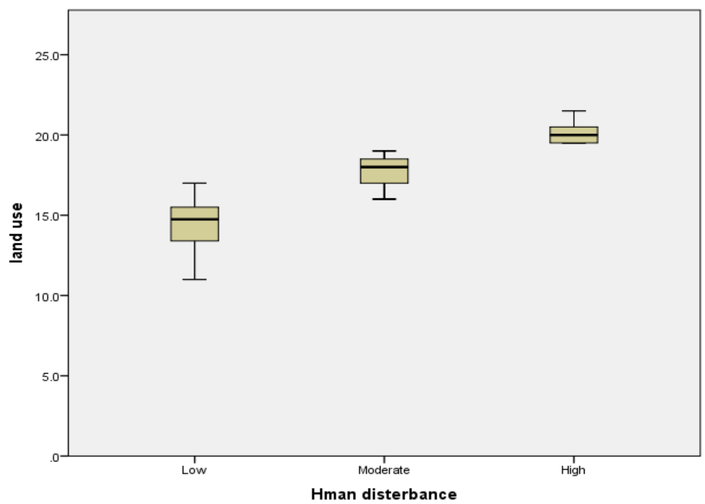
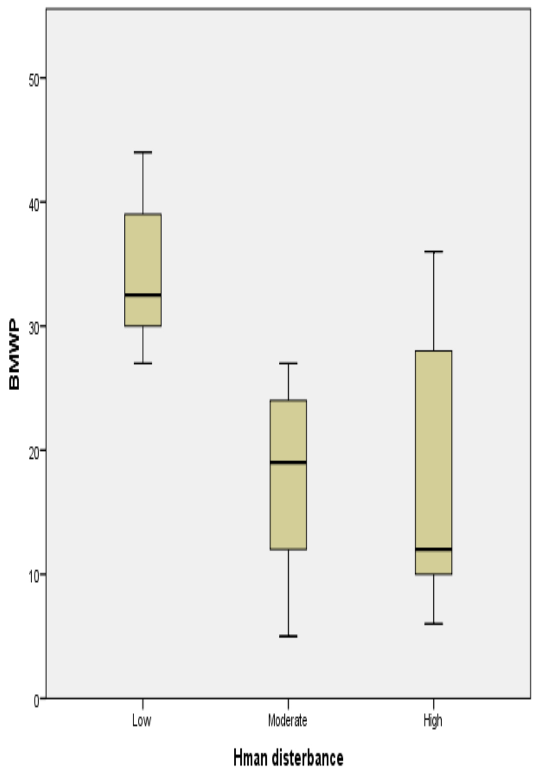


Figure 6. Box and whisker plots of water quality variables for the Low, Moderate and high human disturbance in the Infranz river

4.4. The relationship of macroinvertebrate metrics with human disturbance

The box and Whisker plots showed that mean abundance and standard deviation was higher at low human disturbance than moderate and high disturbance. The mean value of number of taxa was higher on low human disturbance than moderate and high disturbance. The mean value of biological monitoring working party was higher at low human disturbance than moderate and high disturbance but standard deviation was low. The higher mean value of family richness, average scoring per taxa, and Ephemeroptera and Odonata richness were at low human disturbance than moderate and high disturbance and they high have higher standard deviation. The family biotic index and dominant taxa was higher at high human disturbance compare to moderate and low human disturbance but standard deviation of family biotic index was lower. The box plot indicated that biological monitoring working party, family richness, No. of taxa, Ephemeroptera and Odonata richness, abundance and average scoring per taxa were decreased with increasing human disturbance. In contrast mean value of these metrics increased with decreasing human disturbance. But family biotic index and % dominant taxa score was increased with increasing human disturbance (Figure 7).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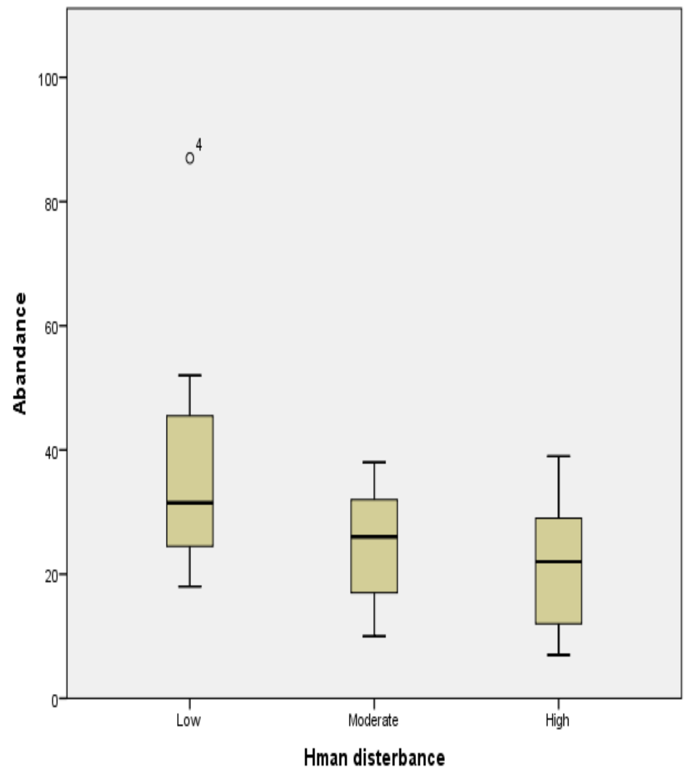
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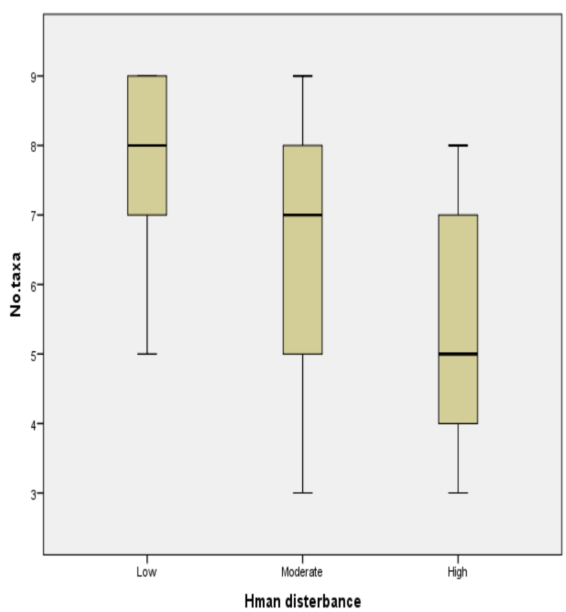
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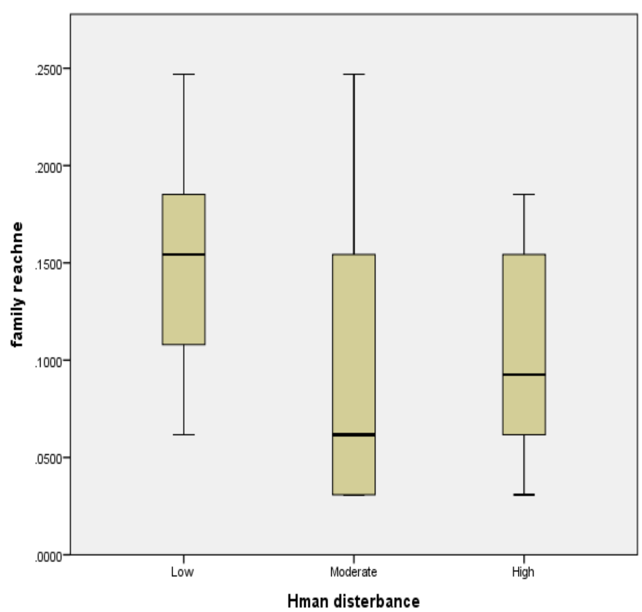
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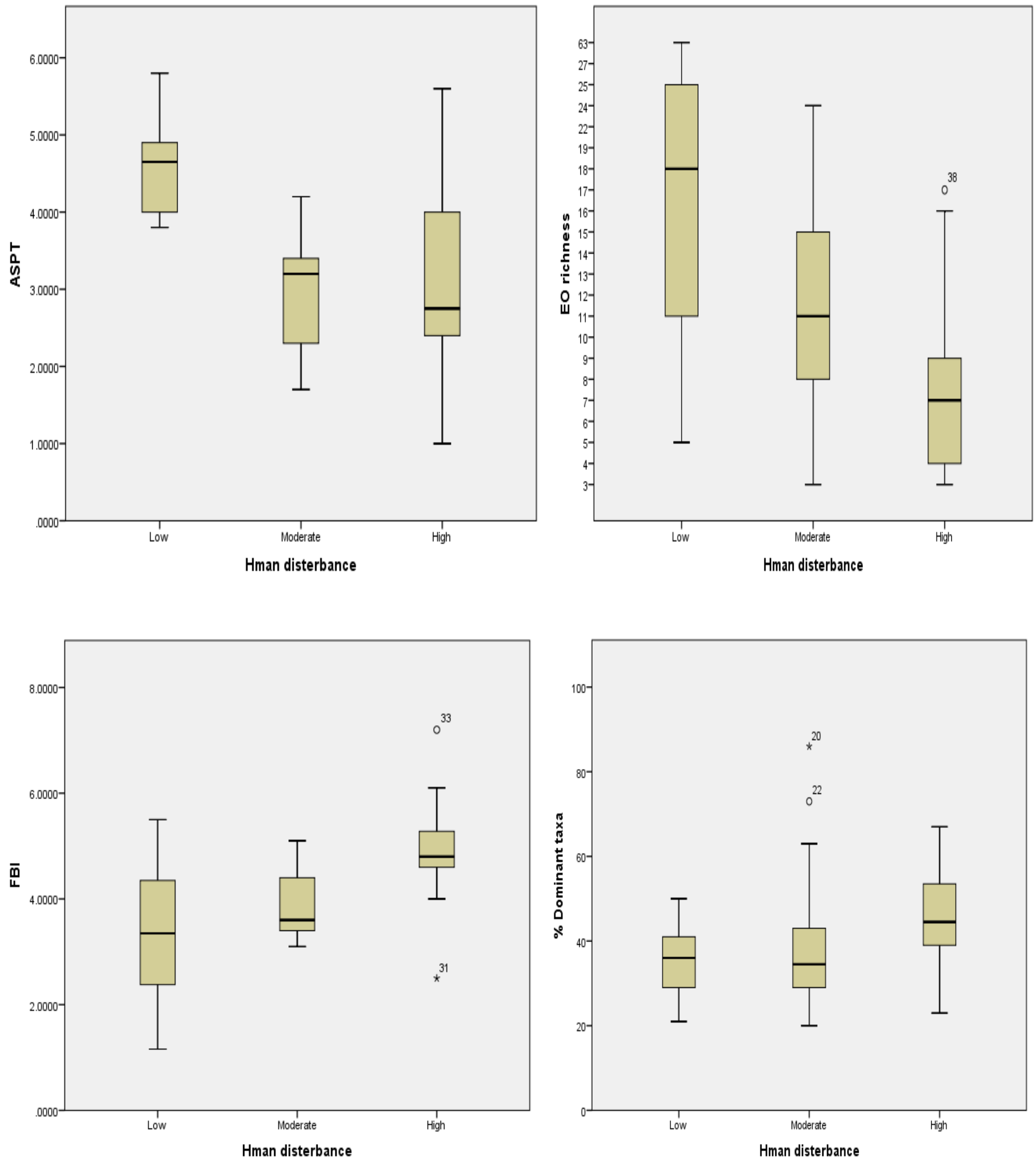

Figure 7. Box and whisker plots of macroinvertebrate metrics for the low, Moderate, and high Human impact classes in the Infranz River.

Among human disturbance land use and vegetation removal were important predicators for abundance (R^2 =0.421, p=0.03 and R^2=0.208, p=0.04) respectively shown in Table 5. Vegetation removal was important predicators for biological monitoring working party (R^2 =0 .447, p = 0.001). Vegetation removal was the main factor for average scoring per tax ($R^{2=}$ 0.286 and p = 0.001). Grazing, sediment deposition, and Epifunal substrate were the main predicator for Shannon winner diversity index (R^2=0.523, p=0.03, $R^{2=}$0.631, p=0.037, and $R^{2=}$0.214, p=0.05) respectively. Epifunal substrate was the major factor for family richness (R^2=0.230, p=0.02). Habitat alteration was important predicators for EO richness (R^2=0.289, p=0.01). Land use was the most important predicators for No. of Trichoptera and Ephemeroptridae individual (R^2=0.223, p=0.031 and R^2=0.239, p=0.032) respectively.

Table 5. Stepwise regression model showing the relationship between human disturbance and macroinvertebrate metrics in Infranz River.

Biotic index	R^2	Adjusted R^2	F value	P value	Predictor	Partial correlation
Abundance	0.421	0.389	13.08	0.034	Land use	
	0.208	0.183	9.485	0.004	Vegetation removal	-0.115
Ephemeroptridae	0.153	0.133	5.678	0.023	Grazing	
Trichoptera	0.223	0.202	10.647	0.002	Land use	-0.062
BMWP	0.447	0.432	29.921	0.001	Vegetation removal	-0.147
ASPT	0.286	0.266	14.792	0.001	Vegetation removal	
Shannon winner index	0.214	0.194	8.905	0.05	Epifunal substrate	
	0.382	0.348	11.121	0.02	Mud	0.483
	0.523	0.482	12.770	0.03	Grazing	-0.477
	0.631	0.576	11.308	0.037	Sediment deposition	-0.354
Family richness	0.2030	0.209	9.459	0.037	Epifunal substrate	
EO richness	0.289	0.270	15.024	0.001	Habitat alteration	

5. DISCUSSION

Human activities on land use like farming, grazing, vegetation removal, cattle watering, irrigation, and drainage were negatively correlated with water quality and assemblage of benthic macroinvertebrate communities in the Infranz River. Similar findings in Gilgel Gibe river basin (Argaw Ambelu, 2010) showed that different human activities are the main cause of water quality and macroinvertebrate community changes.

The significantly lower temperature was recorded at low human land use activity which was highly covered by riparian vegetation. This contributes to reducing solar radiation directly reaching water surface. In this case, water the temperature was declined at low land use activities. The same studies conducted by Masses *et al.* (2010), Champman (2013), Aschalew Lakew (2014), and Fireo *et al*. (2017) who reported that low temperature was registered in forested head of water. In current study the highest temperature was recorded at sites with high human disturbance. It might be due to loss of riparian vegetation which results direct heating of water by solar radiation. The same findings reported by Mases *et al*. (2010) stated that highly human impacted sites are affected by the highest temperature due to loss of riparian vegetation. The pH was an important parameter to determine water quality. In the present study p^H value was increased more at sites with high land use activities than low land use activities. The activities which increase the pH values were intensive farming, cattle watering, over grazing, and drainage. Due to intensive farming, high amount of acidic soil might be directly added to river, which led to the water quality to become more acidic. In contrast at low human land use activities, the pH value of water was low. This is because of the presence of riparian vegetation that prevents direct entering of soil to the water. An increasing or decreasing of the pH value had an impact on assemblage of benthic macroinvertebrate (Aschalew Lakew, 2012).

Dissolved oxygen (DO) was a requirement for survival of benthic macroinvertebrates. However, in the present study dissolved oxygen was relatively lower at sites with high land use activities than the moderate and low land use activities. Because of the application of intensive farming, grazing, removal of riparian trees and cattle watering, high amount of organic waste, total suspended solids and dissolved solids was added to water. To breakdown different organic wastes, total dissolved solids, total suspended solids and large woody debris high amount of oxygen was required and dissolved oxygen was decreased. Due to this reason, the diversity and distributions of most of the macroinvertebrates were influenced. The findings conducted by Aschalew Lakew (2016) reported that, the same results with the present study.

The highest electrical conductivity was recorded at site with high land use activities compare site with low land use activities. At sites with high intensive farming, removal of vegetation, and cattle watering, high amount of different loaded suspended ions directly entered to water. Thus results increasing water electrical conductivity, in contrast, at sites with low intensive farming, removal of vegetation, and cattle watering, the electrical conductivity of water decreased. The same findings were reported by Kasangaki *et al.* (2007), Mass *et al*. (2010), Sirisinthuma *et al.* (2016), and Fierro *et al.* (2017).

In current study, the highest turbidity was recorded at sites with high land use activities which were influenced by intensive farming, vegetation removal, and high detritus removal. Similar findings conducted by Kasangaki *et al.* (2007) showed that turbidity increased at degraded sites. The highest amount of total dissolved solids and suspended solids which affect the reduction of dissolved oxygen were registered at sites with high human influenced compare to moderate and low human influenced sites. The same findings conducted by Kasangaki *et al.* (2007), Sirisinthuma *et al.* (2016), and Fierro *et al.* (2017) showed that the amount of oxygen was relatively very low at sites which contain high amount of total dissolved solids and suspended solids. The transparency of water was very low at sites with high total suspended solids and dissolved solids. Because it prevents the penetration of light and hydrolysis process that results in decreasing the amount of dissolved oxygen. Similar studies in rain forest streams by Kasangaki *et al.* (2007) showed that, higher water transparency was recorded at sites with low human land use. Due to intensive farming, nitrates and phosphates that eroded to water, in present study the concentration of calcium carbonate, ammonia, and phosphate were more recorded at highly human land use activities. The study conducted by Egler *et al.* (2012) showed that, increasing of nitrate was caused by excessive use fertilizers in agricultural activities. Other similar findings conduct around the Gilgel Gibe river basin (Argaw Amblu, 2010) showed that application of fertilizers, grazing and deforestation by the local community were responsible for the increasing concentrations of nutrients and suspended solids in the river.

In response to human induced activities on land use and water quality conditions, benthic macroinvertebrate community assemblages were varying from low to high human impacted sites. This study showed that the dominant benthic macroinvertebrates were Odonata, Diptera, and

Coleopteran. They were tolerant to pollution and habitat degradation. Similar studies conducted in Enda Grab stream by Tesfaye Selemon *et al*. (2016) showed the same findings with the current study. In current study, the most diverse and abundant benthic macroinvertebrate occurred at sites with low human land use. The same result was shown in study conducted by Sirisinthuma *et al.* (2017) in Phong River. The Ephemeroptera (Caenidae, Baetidae, and Ephemerellidae), Plecoptera (Perlodidae), and Trichoptera (Ecnomidae) were the most abundant at sites with low human influenced sites. But, they were relatively low at sites with high land use activities, such as tree removal, grazing, farming, and river bank deformation. Similar findings on Ephemeroptera, Plecoptera, and Trichoptera at Tikur Wuha river, Moiben river, and around Sebeta river by Birnesh Abaye (2007), Masess (2010), and Amare Mezegbu (2017) respectively showed that habitat quality, bank erosion, animal watering, and cultivation greatly affect the distribution and abundance of Ephemeroptera, Plecoptera, and Trichoptera. According to the result of present study, the family Gyinidae, Dysidae, Hydropsychidae, Aeshendiae, and Gomphidae were highly distributed at sites with low human land use activities. Nearly the same result was also shown in study conducted by Amare Mezegbu (2017) around Sebeta River.

The assemblages of Dipterians were the most dominant at sites with high land use activities according to the current study. The studies carried out by Masess *et al.* (2010) and Karaouzes *et al.* (2015) stated that, Dipterians were increased at degraded, grazing, and cattle watering sites. Furthermore, the total number of families (55) reported in the present study was low compared to the studies conducted by Masses *et al*. (2010) and Sirisnthuma *et al*. (2016).

In the current study, Shannon winner diversity index was positively correlated with dissolved oxygen and negatively with total dissolved solids, turbidity, and electrical conductivity. Similar findings conducted by Aschalew Lakew and Moog (2015) stated that, Shannon Winner diversity index had positive correlation with dissolved oxygen and negatively correlated with total dissolved solid. Biological monitoring working party was positively correlated with vegetation cover and dissolved oxygen. The same finding was reported by Argaw Ambelu (2010) in Gilgel Gibe river basin.

According to Wilhm and Dorries (1968), Shannon diversity index value less than one indicates highly polluted, 1-3 moderately polluted, and greater than 4 (four) indicates unpolluted water. Based on these findings in the current study at high human land use activities Shannon diversity index was less than one and it was highly polluted. But, sites with low land use activities Shannon diversity index (1.75) the water bodies were moderately polluted. Other studies carried out by Baye Stotaw (2006), Birinesh Abaye (2007) and Enawagaw and Lemma (2019) showed that decreasing of Shannon diversity index along impacted sites.

According to Barbour *et al.* (1996) the percent of dominant taxa greater than 45 indicates impair, 40_45 possible impair, and less than 40 pure water condition. Based on this criterion in the present study, the percent of dominant taxa at high human impacted sites was greater than 45 that indicated highly polluted of water. In contrast sites with low human disturbance percent of the dominant taxa was less than 40 that showed high water quality and it contains high diversity of families.

Hilsenhoff family biotic index (HFBI) is used to detect organic pollution. Lower family biotic index was registered at low human impacted sites that: suggesting comparatively higher water quality. High family biotic index was calculated at highly degraded sites and lower water quality. The family biotic index values 0 to 3.75 indicating excellent water quality, 3.76 to 4.25 very good water quality, and 4.26 to 5 poor water quality (Hilsenhoff, 1988). Based on these findings, in the current study, the family biotic index at high human land use activities was the highest (4.94) that indicates poor water quality. The present study suggested that, Infranz River along the whole length from low human to high human land use activities was highly impacted (Masse *et al.,* 2013).

6. CONCLUSION AND RECOMMENDATION

6.1. Conclusion

The results of this study showed that, study sites with high human activities in and around Infranz River such as, intensive grazing, farming, vegetation removal, cattle watering and water abstraction deteriorate water quality and decrease assemblage of benthic macroinvertebrates. Most physicochemical parameters such as turbidity, pH, total dissolved solid, total suspended solid, electrical conductivity, ammonia, phosphate, nitrate, and water temperature showed that increasing variation as human land use activities increased, but from low human land use activates dissolved oxygen and transparencies were increased. The most taxa richness, abundance, biological monitoring working party, Shannon Winner index, family richness, Ephemeroptera and Odonata (EO) richness and average scoring per taxa metrics were high at low human disturbed sites. In reverse, these metrics declined at high human disturbed sites. Order Ephemeroptera, Plecoptera, Trichoptera, and Odonata were dominantly found at low human impact sites. However, pollution sensitive EPT (Ephemeroptera, Plecoptera, Trichoptera) were declined at sites which were highly influenced by human activities. The wide distribution of benthic macroinvertebrate indicates the tolerance variation to human disturbance. Tolerant taxa metrics like the percentage of Dipterans, dominant taxa, and the percentage of Chironomidae were high at sites with high human disturbance.

6.2. Recommendations

Based on the result and observation during the study the following recommendations were suggested.

- Agricultural extension should create awareness to the local community on the best agricultural practices to prevent excessive nutrients from farm land into water and training farmers to proper application of farm, use fertilizers, and dam construction to prevent soil erosion.
- Protection of the remaining riparian vegetation and establishment of vegetation on both sides of the river could help to restore the deteriorated habitat and thus improve the water quality and the macroinvertebrate diversity.
- It is important to undertake remedial actions that should involve prohibition of deforestation of riparian vegetation and agricultural activities close to the rivers.
- Elders of local community should discuss with their locality farmers how to minimizes cattle grazing around Infranz river.
- Bahir Dar city administration should support by finance, giving education for local people about disadvantage of intensive grazing and farming, and in and around Infranz river, preparing rules and regulations about water quality.
- Further studies should be carried out at Infranz River on investigation of effects of human activities on Lake Tana biodiversity.

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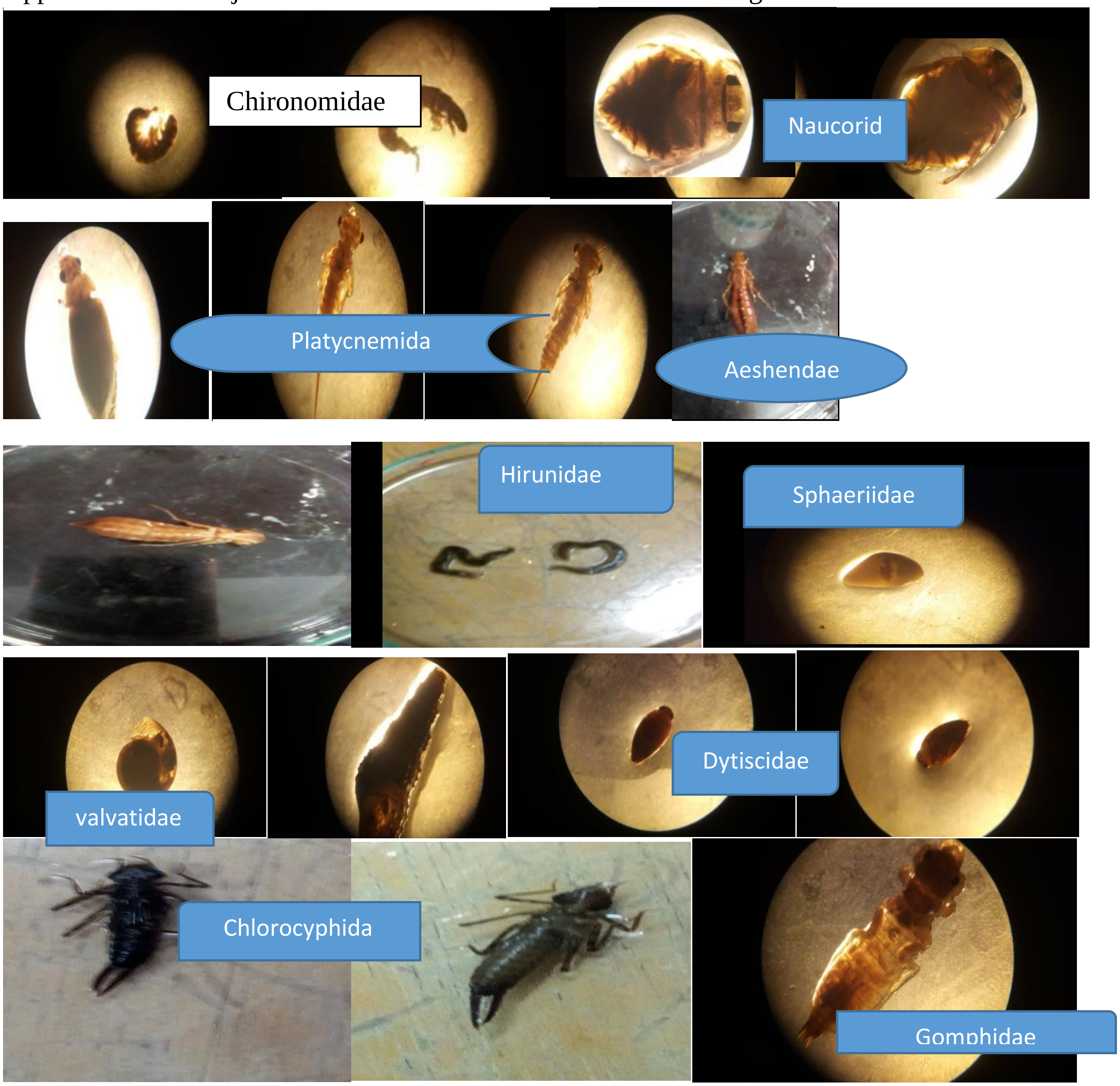
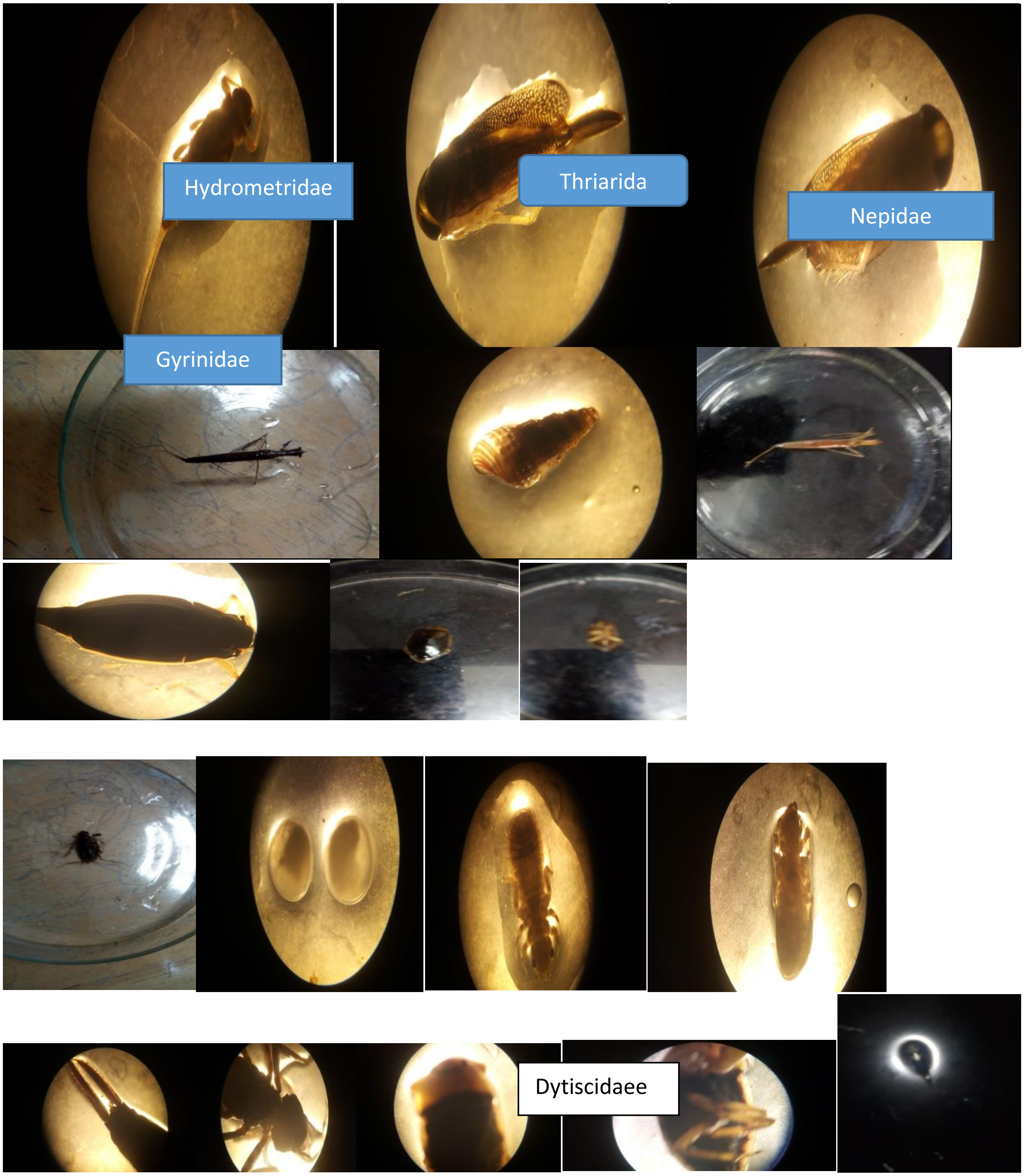
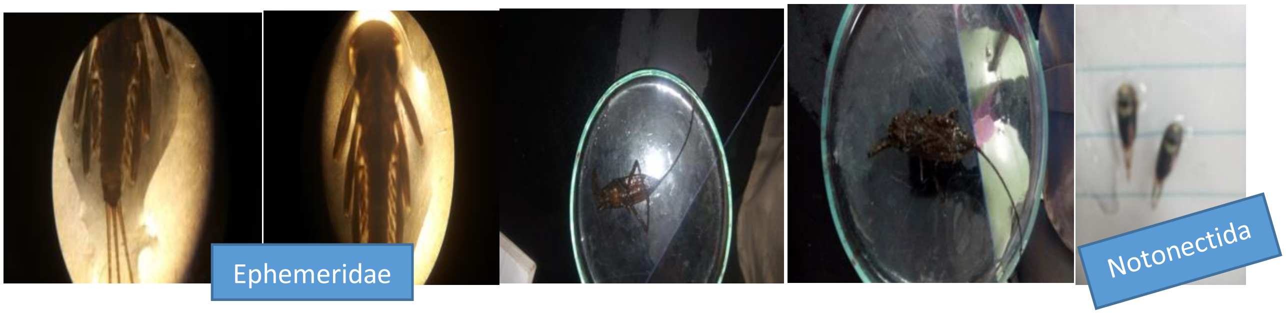
Appendix 1. The major macroinvertebrate families identified during data collection




Hydrometridae
Thriarida
Nepidae
Gyrinidae
Dytiscidaee


Ephemeridae
Notonectida

Appendix 2. Human disturbance data from Infranz River

Site	Grazing	Vegetation planation	Tree plantation	Farming	Damming	Vegetation re	Agricultural biocide	Waste dumping	Total	Average	Human disturbance scale
S1	14	11	20	14	8	8	8	8	91	11.4	Low
S2	15	12	19	14	8	8	8	8	92	11.5	Low
S6	16	17	18	15	8	8	8	8	98	12.25	Low
S9	15	14	20	14	8	14	8	8	97	12	Low
S11	14	15	21	12	8	8	8	8	94	11.75	Low
S12	15	14	20	13	8	10	8	8	96	12	Low
S14	15	14	13	14	8	8	8	14	94	11.75	Low
S16	14	13	18	15	8	14	13	14	109	13.6	Low
S20	14	15	19	14	8	13	8	8	99	12.4	Low
S24	16	15	8	13	8	14	8	8	90	11.25	Low
S25	15	16	18	10	8	8	8	8	91	11.4	Low
S30	15	13	14	12	8	8	8	8	86	10.75	Low
S3	17	18	15	17	10	18	17	16	128	16	Moderate
S10	18	18	16	18	16	10	16	14	121	15.125	Moderate
S13	17	18	14	18	10	10	17	15	118	15	Moderate
S23	18	21	13	20	14	14	15	15	130	16.25	Moderate
S26	20	19	11	15	14	18	8	8	120	15	Moderate
S27	19	19	11	18	17	17	17	15	133	16.625	Moderate
S28	20	21	13	21	8	15	8	16	122	15.25	Moderate
S31	19	20	11	20	8	8	15	20	121	15.25	Moderate
S32	21	20	16	19	8	8	16	17	123	15.5	Moderate
S34	16	19	16	21	8	8	17	19	124	15.6	Moderate
S35	18	17	14	18	8	18	19	8	120	15	Moderate
S36	20	18	11	18	8	17	18	17	127	16	Moderate
S37	21	20	14	18	18	8	17	18	132	16.5	Moderate

S38	24	21	13	18	8	18	15	15	132	16.5	Moderate
S4	21	21	15	23	16	15	24	19	153	19	High
S5	24	23	15	24	15	15	21	20	157	20	High
S7	24	23	15	24	20	20	15	18	160	20	High
S8	22	21	13	23	25	19	19	19	157	19.6	High
S15	24	24	14	24	20	15	14	19	154	19.25	High
S17	24	24	17	23	20	21	20	20	164	21	High
S18	24	23	15	19	8	19	22	23	153	19	High
S19	24	24	18	22	8	19	23	20	153	19	High
S22	21	20	15	24	19	20	19	22	160	20	High
S21	24	23	16	23	16	23	15	15	154	19	High
S29	24	22	15	21	19	19	21	19	179	22.4	High
S33	23	24	16	24	19	17	19	19	161	20.1	High
S39	24	24	14	20	8	16	19	19	170	21	High

Appendix 3. Metrics in Infranz river exposed to different anthropogenic impacts

Site	No.ta	Noepe	No.Tr.ind	No.co.in.	No.of ET.in.	N.CTE	No. of Chiro.ind	No.of tolerant	No.of Diptera	% Trichoptra	%EPT	% Diptera	%CTE ind.	% Tolerance	% D. tax	%Chironomidae	FBI	BMWP	ASPT	H''	EO
1	6	0	0	0	0	0	2	20	2	0	0	9	0	69	41	9	3.4	27	4.5	1.6	17
2	7	4	0	0	4	4	2	27	2	0	12	6	12	68	21	6	3.14	28	4	1.4	25
3	4	0	0	0	0	0	3	9	3	0	0	19	0	56	43	19	3.3	12	3	1.28	11
4	7	1	0	0	1	1	4	12	5	0	13	33	7	80		27	4.8	36	5.14	1.8	7
5	4	0	0	12	1	12	0	14	0	0	0	0	39	45	39	0	4.67	9	2.25	1.2	13
6	9	1	0	2	1	3	1	26	1	0	2	2	6	50	42	2	2.46	36	4	1.8	27
7	5	0	0	0	0	0	4	6	4	0	0	57	0	86	57	57	5.28	12	2.4	1	5
8	3	0	0	1	0	1	8	9	8	0	0	67	8	75	67	67	4.9	11	3.66	0.82	3
9	9	14	5	1	19	20	13	47	13	6	20	15	23	55	33	15	3.9	43	4.8	2.9	63
10	8	0	0	1	0	1	1	19	1	0	0	4	4	68	29	4	4.2	27	3.4	1.8	13
11	7	2	15	0	17	17	0	18	0	41	46	0	46	49	41	0	5.5	35	5	1.34	19
12	8	0	0	2	0	2	1	14	1	0	0	6	11	78	39	6	1.16	31	3.8	1.8	8
13	5	0	7	0	7	7	7	7	13	27	27	23	27	27	27	27	3.7	19	3.8	1.5	8
14	5	7	2	0	9	9	4	11	4	8	36	16	36	52	28	16	4.4	29	5.8	1.6	15
15	5	5	1	0	6	6	0	2	0	13	75	0	75	25	50	0	2.5	28	5.6	1.4	6
16	8	0	3	0	3	3	12	16	12	13	21	50	13	67	50	50	4.7	44	5.5	1.7	5
17	4	0	0	10	0	10	8	18	8	0	0	36	45	82	45	36	6.1	11	2.75	1.14	4
18	7	0	0	6	0	6	11	24	12	0	0	43	21	78	39	39	7.2	32	4.6	1.8	7

19	4	0	7	0	7	7	11	21	11	30	31	48	30	91	48	48	5.1	14	3.5	1.2	7
20	9	0	0	5	0	5	3	30	3	0	0	7	11	68	36	7	3.3	42	4.7	1.9	24
21	5	0	0	0	0	0	5	7	5	0	0	26	0	78	58	36	6.1	6	1.2	1.02	3
22	7	0	0	6	0	6	3	18	3	0	5	14	27	82	32	14	4.2	6	1	1.76	9
23	5	0	0	4	0	4	2	7	2	0	0	20	40	70	20	20	3.5	11	2.2	1.47	3
24	7	0	13	1	13	14	10	31	10	28	32	21	30	66	27	21	4.3	32	4.6	1.5	14
25	7	4	3	1	7	13	3	15	3	13	13	13	35	72	30	13	1.4	33	4.7	1.77	8
26	8	0	0	12	0	12	5	31	5	0	0	14	33	86	28	14	5.1	19	2.4	1.77	10
27	7	0	0	2	0	2	7	26	7	0	0	18	5	68	37	18	3.1	24	3.4	1.3	22
28	7	0	0	6	0	6	1	26	1	0	0	3	19	81	41	3	3.5	24	3.4	1.58	19
29	6	0	0	2	0	2	10	25	10	0	4	34	7	86	41	34	4.6	16	2.7	1.35	16
30	8	0	0	1	0	1	1	16	1	0	0	4	4	62	36	4	2.3	32	4	1.7	18
31	3	0	2	0	2	2	0	12	0	14	14	0	14	86	86	0	4.4	5	1.7	0.509	12
32	5	0	0	22	0	22	0	8	0	0	0	0	73	27	63	0	4.9	19	3.8	1.029	7
33	8	8	0	1	8	9	9	30	9	0	0	23	23	77	23	23	4.7	32	4	1.76	7
34	4	0	0	2	0	2	0	21	0	0	0	0	8	81	73	0	4.9	9	2.3	0.83	4
35	6	0	1	0	1	1	0	13	0	4	4	0	4	52	32	0	3.8	25	4.2	1.7	15
36	8	0	0	2	0	2	2	22	2	0	0	6	6	68	41	6	3.5	27	3.4	1.8	24
37	7	0	0	0	0	0	5	15	5	0	0	29	0	88	29	29	3.2	18	2.6	1.8	8
38	9	0	0	1	0	1	4	14	5	0	0	24	5	21	29	19	3.4	20	2.2	1.94	10
39	4	0	0	0	0	0	4	6	4	0	0	44	0	67	44	44	4	10	2.5	1.2	3

Appendix 4. Physicochemical raw data obtained from Infranz river

Va.	PH	WT(°c)	DO(mg/L)	EC(µs)	Tu.(NTU)	Tran(cm)	WD(cm)	SD(cm)	Cl(mg/l)	TSS(mg/l)	TDS(mg/l)	Caco3(mg/l)	DOS(%)	Hco3(mg/L)	Ca(mg/l)	Discharge(m3/s2)	Current velocity(m/s)	Altitude(m)	Canopy %	% Riffle	NO2(mg/l)	NH4(mg/l)	PO4(m/l)
S1	7.2	21	0.0816	0.18	2.8	99	50	0	4.1	0	0.3	26	0.0816	110	10	0.8	0.18	1809	97%	5%	0.003	0.17	0.04
S2	6.24	22	0.0799	0.23	2	98	35.3	0	5.8	0.001	0.4	20	0.08	115	8	0.85	0.16	1808	25%	60%	0.023	0.8	0
S6	7.26	19	0.0811	0.17	3.35	99	30	12	10.5	0.001	0.37	23	0.0812	120	9	0.3	0.25	1809	50%	75%	0.036	0.12	0.21
S9	6.66	19	0.08329	0.28	4.46	97	80	2	29	0.0011	0.53	26	0.0834	125	10	1.52	0.15	1809	0%	50%	0.06	0.13	0.23
S11	7.03	19	0.0833	0.16	3.97	96	55	0	1.9	0.0007	0.33	28	0.0804	90	11	1.8	0.2	1811	50%	50%	0.06	0.08	0.04
S12	7.12	18.5	0.0856	0.22	3.5	95	80	0	2.6	0.0004	0.13	21	0.0806	130	8	0.8	0.2	1809	65%	60%	0.023	0.8	0.29
S14	7.96	18	0.08066	0.16	3.17	95	55	0	3.25	0.0004	0.33	34	0.0807	120	14	1.03	0.19	1800	10%	60%	0.023	0.02	0.27
S16	6.61	17	0.0804	0.23	2.8	96	40.5	9	4.2	0.001	0.48	33	0.0805	120	13	0.57	0.6	1813	75%	70%	0.197	0.08	0
S20	7.68	20	0.08	0.18	14.9	91	90	0	2.1	0.013	0.36	9	0.0813	155	4	1.5	0.14	1804	0%	30%	0.366	0.06	0.27
S24	7.39	18	0.081	0.14	8.2	90	110	30	1.2	0.004	0.31	35	0.0814	100	14	1.5	0.5	1788	40%	60%	0.039	0.8	0.23
S25	7.7	20	0.081	0.12	6.54	97	36	4	1.6	0.005	0.28	30	0.0815	160	12	1.62	0.3	1800	30%	80%	0.059	0.04	0.45
S30	7.68	19	0.0801	0.12	15.5	88	37	2	2.4	0.003	0.27	33	0.0814	90	53	0.555	0.15	1802	50%	80%	0.053	0.8	0.03
S3	6.85	20	0.08043	0.15	3.59	97	45	10	14.1	0	0.6	27	0.0843	85	11	0.17	0.15	1811	50%	55%	0.03	1	1
S10	7.03	19	0.8058	0.26	3.57	95	53	0	9	0.0002	0.54	23	0.0806	120	9	0.477	0.15	1809	90%	50%	0.016	1	0.28
S13	7.59	19	0.0804	0.16	3.8	94	22	0	3.6	0.002	0.31	14	0.0836	125	6	0.55	0.25	1806	100%	60%	0.02	0.15	0.155
S23	7.63	20	0.08	0.16	8.6	93	110	20	1.6	0.011	0.32	21	0.0811	145	8	1.23	0.14	1811	0%	50%	0.043	1	0.17
S26	7.61	19	0.0799	0.13	7.8	90	30	6	2	0.001	0.27	10	0.08	60	4	4.03	0.31	1804	20%	35%	0.06	0.01	0.02
S27	7.61	20	0.0798	0.17	10.6	89	65	16	3.1	0.032	0.26	70	0.083	110	28	1.755	0.3	1807	5%	7%	0.06	0.14	0.09
S28	7.67	20	0.0799	0.13	10.5	89	91	0	0.9	0.031	0.28	61	0.083	160	64	0.59	0.05	1806	5%	40%	0.06	0.06	0.27
S31	7.73	18	0.08	0.17	11.7	76	56	0	3	0.015	0.27	66	0.0815	150	26	0.35	0.16	1799	55%	80%	0.049	1	0.48

S32	7.74	19	0.801	0.13	11.8	66	20	15	1.4	0.018	0.28	82	0.0819	130	33	0.146	0.14	1793	30%	70%	0.06	0.01	0.04
S34	7.72	19	0.082	0.16	13.5	55	84	5.8	0.6	0.007	0.28	88	0.0827	170	35	0.54	0.11	1792	35%	10%	0.06	1	0.29
S35	7.74	19	0.081	0.17	15	45	54	0	3.5	0.009	27	28	0.0819	80	11	1.8	0.33	1793	5%	70%	0.049	0.17	1
S36	7.7	19	0.0818	0.13	15.3	30	90	30	0.7	0.006	0.27	46	0.08824	85	18	1.56	0.12	1797	2%	40%	0.05	0.04	0.08
S37	7.69	18	0.082	0.13	21.1	15	78	30	0.8	0.092	0.26	0	0.0911	55	0	1.4	0.2	1791	0%	0%	0.056	0.01	0.07
S38	7.67	19	0.0798	0.16	20.9	27	150	5	2	0.033	0.28	11	0.0831	80	4	1.315	0.2	1794	0%	30%	0.06	1	1
S4	7.18	18	0.0806	0.18	3.79	95	59	5	6.2	0	0.36	28	0.0806	145	11	0.42	0.1765	1806	10%	40%	0.026	1	0.24
S5	7.04	18	0.08018	0.19	4.4	97	55	19	16.5	0.0002	0.35	14	0.0802	95	6	0.775	0.028846	1807	5%	0%	0.046	0.01	0.31
S7	6.93	18	0.08017	0.23	4.5	98	140	10	12	0.0003	0.47	26	0.0802	115	10	1.86	0.2	1805	0%	50%	0.023	0.03	0.84
S8	6.84	18	0.0806	0.18	4.6	98	45	5	3.7	0.001	0.36	25	0.0807	105	10	2.86	0.27	1808	0%	75%	0.013	0	0.23
S15	7.85	19	0.08	0.14	3.17	95	27	0	0.9	0.011	30	30	0.0811	125	12	1.82	0.75	1807	0%	50%	0.049	1	0.03
S17	7.66	21	0.0801	0.19	3.6	93	30	20	2.3	0.002	0.38	19	0.0803	95	7	1.24	0.375	1805	0%	50%	0.049	0.06	0.1
S18	7.53	20	0.08	0.24	5.6	92	55	0	2.1	0.002	0.58	31	0.0802	135	12	1.1	0.2	1800	0%	25%	0.082	0	0.4
S19	7.77	21	0.08029	0.4	6.7	90	20	2	2.6	0.0021	0.66	104	0.0805	105	42	0.48	0.3	1797	0%	40%	0.095	0.22	0.68
S22	7.63	20	0.081	0.18	9.7	92	120	16	2.1	0.02	0.37	22	0.083	115	9	1.145	0.25	1809	5%	45%	0.046	1	0.12
S21	7.64	20	0.083	0.15	23.4	89	90	2	2.7	0.052	0.3	14	0.0882	150	6	0.22	0.048	1808	20%	10%	0.03	0.07	0.04
S29	7.68	20	0.08	0.13	10.5	87	58	10	2.6	0.015	0.28	10	0.0815	65	4	2.03	0.13	1803	0%	50%	0.063	1	0.09
S33	7.76	18	0.0802	0.13	11.6	30	74	4	1.9	0.004	0.27	150	0.0806	150	60	0.91	0.15	1797	50%	30%	0.053	1	0.01
S39	7.67	20	0.081	0.13	15	5	170	2	1.6	0.024	26	45	0.0834	140	18	2.975	0.05	1792	0%	5%	0.06	0.13	0.68

Appendix 5. Benthic macroinvertebrate data recorded during sampling at Infranz river

family	Calopterygidae	Gomphidae	Protoneuridae	Platycnemidae	Coenagrionidae	Aeshendae	Ephemerellidae	Heptagoniidae	Leptophlebidae	Baetidae	Caenidae	Rhagionidae	Tipulidae	Ephydridae	Chironomidae	Perlodidae	Chloroeiphidae	Dryopidae	Hydrobiidae	Psephenidae
S1	0	9	8	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
S.2	0	1	0	20	0	0	0	0	4	0	0	0	0	0	2	0	0	0	0	0
S.6	0	22	0	4	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0
S.9	7	29	4	0	0	13	0	0	0	0	14	0	0	0	13	0	0	0	0	0
S. 11	0	1	0	1	15	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
S.12	0	1	7	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
S. 14	0	7	0	0	0	1	0	0	0	0	7	0	0	0	4	0	0	0	0	0
S.16	0	3	0	0	0	0	0	0	0	2	0	0	0	0	12	0	0	0	0	0
S. 20	0	8	0	0	0	16	0	0	0	0	0	0	0	0	3	0	0	0	0	1
S. 24	0	0	0	13	0	1	0	0	0	0	0	0	0	0	10	2	0	0	0	0
S 25	0	4	0	0	0	0	0	0	0	0	4	0	0	0	3	0	0	0	0	0
S30	0	9	0	8	0	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0
S3	0	7	0	4	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
S10	0	5	0	6	8	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
S 13	0	2	4	0	0	0	0	0	0	0	0	0	6	0	7	0	0	0	0	0
S 23	0	2	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
S 26	0	4	0	10	0	0	0	0	0	0	0	0	0	0	5	0	0	1	0	0
S 27	0	8	0	14	0	0	0	0	0	0	0	0	0	0	7	1	0	0	0	0
S 28	0	6	0	13	0	0	0	0	0	0	0	0	0	0	1	0	0	0	5	0
S31	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S 32	0	3	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S34	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S35	0	7	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S 36	0	10	0	14	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	0
S37	0	2	2	4	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0

S38	0	4	0	6	0	0	0	0	0	0	0	0	1	0	4	0	0	0	0	0
S 4	0	0	0	4	0	2	0	0	0	1	0	1	0	0	4	0	1	0	0	0
S 5	0	11	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0
S7	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0
S8	0	3	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	1	0
S15	0	1	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0	0	0	0
S17	0	3	0	1	0	0	0	0	0	0	0	0	0	0	8	0	0	0	10	0
S18	0	3	4	0	0	0	0	0	0	0	0	0	0	1	11	0	0	0	5	0
S19	0	0	0	4	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0
S 21	0	2	0	1	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0
S22	0	2	0	7	0	0	0	0	0	0	0	0	0	0	3	0	0	1	0	0
S 29	0	4	0	12	0	0	0	0	0	0	0	0	0	0	10	0	0	0	1	0
S33	0	1	0	8	0	0	0	0	0	8	0	0	0	0	9	0	0	0	0	0
S 39	0	0	0	3	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0

family	Hydraenidae	Gyrinidae	Dytiscidae	Hydropsychidae	Rhyacophilidae	Rhyacophillidae	Ecnomidae	Corixidae	Nepidae	Notonectidae	Naucoridae	Mesovelidae	Hydrometridae	Gerritae	Glossiphoniidae	Erpobdellidae	Hirudinae	Lymnacidae	Neritidae	Ancylidae	Siphlonuridae
S1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	1	0	0
S.2	0	0	0	0	0	0	0	0	0	2	4	0	0	0	0	0	0	0	0	0	0
S.6	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0
S.9	0	0	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S. 11	0	0	0	15	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
S.12	0	2	0	0	0	0	0	0	1	0	0	0	4	0	0	0	0	0	0	0	0
S. 14	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S.16	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S. 20	0	0	4	0	0	0	0	0	0	4	0	1	0	0	0	0	0	0	0	0	0
S. 24	0	0	1	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S 25	0	1	0	0	0	0	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0
S30	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0
S3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S10	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
S 13	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S 23	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S 26	1	0	10	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
S 27	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S 28	0	0	1	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0
S31	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S 32	0	19	3	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
S34	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S35	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0
S 36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
S37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
S38	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0

S 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S 5	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0
S7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
S8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S15	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S18	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
S19	0	0	0	0	0	0	7	0	0	0	0	0	1	0	0	0	0	0	0	0	0
S 21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S22	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S 29	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
S33	0	0	2	0	0	0	0	0	1	0	0	0	9	0	0	0	0	0	0	0	0
S 39	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0

family	Siphlonuridae	Succinedae	Sphaeriidae	Physidae	Planorbidae	Unionidae	Valvatidae	Viviparidae	Lymnaeidae	Melanopsida e	Pleuroceridae	Corbiculidae	Thiaridae	Total
S1	0	0	0	0	0	0	0	3	0	0	0	0	0	3
S.2	0	0	0	0	0	0	0	1	0	0	0	0	0	1
S.6	0	0	0	0	5	0	2	0	4	0	0	0	1	12
S.9	0	0	0	0	1	0	0	0	0	0	0	0	0	1
S. 11	0	0	0	0	0	0	0	0	0	0	0	0	2	2
S.12	0	0	0	0	0	0	0	1	0	1	0	0	0	2
S. 14	0	0	0	0	0	0	0	0	0	0	0	0	4	4
S.16	0	0	0	2	0	0	1	0	0	0	0	0	1	4
S. 20	0	0	0	2	0	0	0	0	0	5	0	0	0	7
S. 24	0	0	0	0	0	0	0	0	0	7	0	0	0	7
S 25	0	0	0	0	0	0	0	0	0	0	0	0	7	7
S30	0	0	0	0	0	0	0	0	0	0	0	0	2	2
S3	0	0	0	0	0	0	0	2	0	0	0	0	0	2
S10	0	2	1	0	0	0	0	0	0	0	0	0	0	3
S 13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S 23	0	0	0	0	0	0	0	0	0	1	0	0	0	1
S 26	0	0	0	0	0	0	0	0	0	1	0	0	0	1
S 27	0	0	0	0	0	1	0	0	0	5	0	0	0	6
S 28	0	0	0	0	0	0	1	0	0	0	0	0	0	1
S31	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S 32	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S34	0	0	19	0	0	0	0	0	0	1	0	0	0	20
S35	0	0	0	0	0	0	2	3	0	0	0	2	0	7
S 36	0	0	0	1	0	0	0	3	0	1	0	0	0	5
S37	0	0	0	0	1	0	0	0	0	0	0	0	1	2

S38	0	0	0	0	0	0	0	0	0	0	1	0	1	2
S 4	0	0	0	0	0	0	0	2	0	0	0	0	0	2
S 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S15	0	0	0	1	0	0	0	0	0	0	0	0	0	1
S17	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S18	3	0	0	0	0	0	0	0	0	0	0	0	0	3
S19	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S 21	0	0	0	0	0	0	0	0	0	11	0	0	0	0
S22	0	0	0	0	0	0	2	2	0	0	0	0	0	4
S 29	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S33	0	0	0	0	0	0	0	0	0	0	0	0	1	1
S 39	0	0	0	0	0	0	0	0	0	0	0	0	0	0