Distribution and Abundance of Macroinvertebrates in Upper Awash River at Chillimo Forest, West Shoa, Ethiopia

Misgana Dabessa[1], Aschalew Lakew[2], Prabha Devi[3]

[1]Chemical and Construction Inputs Industry Development Institute, Addis Ababa, Ethiopia, email address: misganadabesa32@gmail.com

[2]Ethiopian Institute of Agricultural Research, National Fishery and Aquatic Life Research Centre, Sebeta, Ethiopia, email address: aschalewl@gmail.com

[3]Ambo University, Department of Biology: drlpraba@gmail.com

Abstract

The aim of this study was to analyse the distribution and abundance of benthic macroinvertebrates in the Upper Awash River. The study was conducted for three months from January 2018 to March2018, and macroinvertebrates were collected from five sites using a standard hand net. Physicochemical parameters that can affect the distribution and abundance of benthic macroinvertebrates due to water pollution were measured and analysed. A total of 14,465 individuals belonging to 33 families of aquatic insects, 5 families of the non-insect group were identified. Among all taxa, Diptera was the most abundant and diversified animals in the study area. Macroinvertebrates among the five sites showed variation in species richness, evenness and Shannon Diversity Index. The highly impacted downstream site (UAW4) had the relatively highest H-FBI index (5.15), followed by UAW5 (5.08) indicating that UAW4 and UAW5 were poorer in benthic faunal diversity than other sites. In addition, as habitat and water quality degradation increased, the number and percentage of Ephemeroptera, Plecoptera, and Trichoptera (EPT) decreased. Furthermore, as perturbation increased, species diversity, ETHbios index, Average Score per Taxon , and family richness were decreased, while the percentage of Chironomidae, Diptera, Dominant Taxa and Hilsenhoff Family-Level Biotic Index were increased indicating that tolerant species become abundant in UAW4 and UAW5. Based on the current study, we recommend that sustainable management of the Upper Awash River by environmental protection agencies of governmental and non-governmental organizations should take strict remedy to tackle anthropogenic activities resulting in water pollution.

Keywords: Benthic macroinvertebrates, biotic indices, pool, riffle, physicochemical parameters

1. Introduction

1.1. Background and justification

Ethiopia, like other developing countries, is experiencing an increasing deterioration in river quality resulting in adverse effects on human health, increased water treatment costs and reduction in yields from river fisheries [2, 3, 4]. Such a problem is also due to anthropogenic (and, in some cases, natural) changes in the physical and chemical habitat of freshwaters that bring diverse biological effects both subtle and severe [5]. Such changes indicate that the ecosystem and its associated organisms are under stress. These changes in the aquatic environment can be used to indicate the pollution level of the water body and even possible risks to human health [6]. Each aquatic organism has particular requirements with respect to the physical, chemical and biological conditions of its habitat. Therefore, perturbations in these conditions can result in the reduction in species numbers, a change in species dominance or total loss of sensitive species [7].

Freshwater is a vital resource for people all around the world that provides many provisioning, regulatory and cultural ecosystem services [1]. Currently, conventional physicochemical methods are used in some rivers of Ethiopia for monitoring the river water quality. However, the effects of a variety of stressors cannot be detected through these methods, and water management decisions may suffer under the scarcity of knowledge of the environmental consequences. Monitoring water quality is essential to determine the water quality status and to improve the environmental conditions and the related public health [8]. Macroinvertebrates have proven to be useful bio-indicators to determine the integrity status of freshwater ecosystems, as their community consists of a broad range of species with different tolerances to water pollution [3]. In addition, macroinvertebrates: (i) respond very rapidly to pollution, (ii) are ubiquitous, abundant and easy to collect, (iii) are representative of the local conditions due to their relative sedentary behavior, and (iv) have long life spans, which provide an integrated temporal record of water quality [9]. For these reasons, benthic macroinvertebrates are often the taxa of choice for biomonitoring in streams and rivers [10, 11]. They are good indicators of several anthropogenic pressures such as water pollution [12] and geo-morphological alterations [13].

Recently, biological indicators such as macroinvertebrates and diatoms are getting more acceptance as routine monitoring tools especially in developed countries [5]. In the last one decade, many studies have been conducted in Ethiopia using benthic macroinvertebrates as bioindicators [15, 16, 17, 18, 19, and 20]. However, there is no study conducted on macroinvertebrates indicators to evaluate the specific effect of water pollution on benthic macrofauna. Therefore, the aim of this study was to analyse the distribution and abundance of macroinvertebrates in the Upper Awash River at Chillimo forest, West Shoa, Ethiopia.

1.2. Objectives

1.2.1. General objective

- ✓ To investigate the distribution and abundance of macroinvertebrates in the Upper Awash River.

1.2.2. Specific objectives

- ➢ To assess macroinvertebrates community structure and distribution at selected sampling sites.
- ➢ To determine the level of relationship between the diversity of benthic macroinvertebrates and habitat composition.
- ➢ To examine the values of selected physico-chemical parameters of the water at the different sampling sites.

2. Materials and Methods

2.1. Study Area.

The AwashRiver is located in the Dandi District of West Shewa Zone, Oromia Regional State, Ethiopia, at 9° 5′ N latitude and 38° 10′ E longitude. The district's capital, Ginchi, is located 75 km west of Addis Ababa, the capital of Ethiopia. The district has a total area of 109,729 ha ranging from 2000-3200 m.a.s.l. Based on the 2007 Ethiopian Central Statistical Agency population census; the total population of the Dandi district has been estimated to be 165,803. The favourable climatic condition for both crops and livestock production has been attributed to the large population in the District. The district has some natural endowments to attract tourists and researchers. Among these, Chilimo-Gaji Forest is one of the 58 National Forest Priority Areas of Ethiopia. The forest represents the remnants of the dry Afro-montane forests in the central plateau of Ethiopia. This district is also well known for its rich water resources among which the Awash River basin and Lake Dandi are the most important natural resources [21]. Lake Dandi is a highland lake with high tourist potential. The Awash River originates from a high plateau of the district near Ginchi town, about 80 km west of Addis Ababa and flows along the rift valley into the Afar triangle and ends in saline Lake Abbe [4]. Near to Upper Awash River, there is a paper factory that was established in 2009 to produce paper products from used paper collected from different parts of the country. The processed effluent from the mill section has directly been discharged to the Upper Awash River [22].

In the study area, rainfall distribution is bimodal: a short rainy season from March to April and the main rainy season from June to September with total annual rainfall above 1000 mm. The discharge of the Upper Awash River fluctuates concurrently with the rainfall intensity. For example, average discharge measured at Ginchi town from 2001 to 2009 indicates that maximum discharges were from July to September with the highest peak in August (16.7 m^3/s), and the minimum from November to May with the lowest in December (0.16 m^3/s) [4].

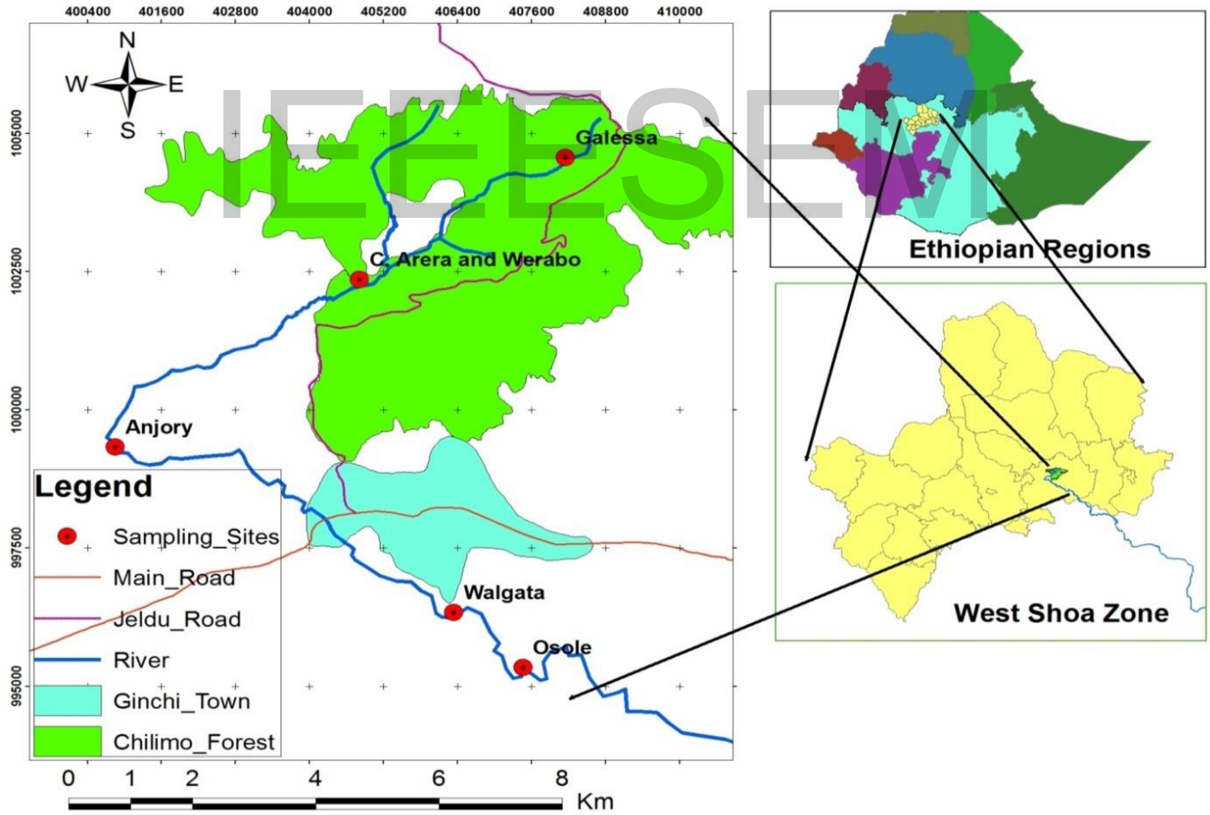

Fig. 1 Location of the study sites (Galessa=UAW1, Arera=UAW2, Anjory=UAW3, Walgata =UAW4, Osole =UAW5)

2.2. Data collection.

Sampling sites were selected based on their vegetation cover and exposure to various human activities such as agricultural practices, laundry, bathing, animal grazing, watering and drainage of chemical fertilizers from the surrounding lands and discharges of untreated waste that pollute the river. Moreover, sites selection was carried out based on the physical, chemical, and biological and land-use pattern. Accordingly, five sampling stations were selected following the rapid bio-assessment protocol criteria [23], where different levels of anthropogenic impacts are observed: forest areas with less human impact (UAW1, location-latitude=38^{o}9’4”, longitude=9^{o}4’48”, altitude=2475 masl), scattered grazing and agricultural activities (UAW2, location-latitude=38^{o}7’5”, longitude=9^{o}3’57”, altitude=2346 masl), more grazing and agricultural activities (UAW3, location-latitude=38^{o}5’48”, longitude=9^{o}2’18”, altitude=2252 masl), paper mill, industrial wastes and domestic wastes (UAW4, location-latitude=38^{o}8’5”, longitude=9^{o}0’42”, altitude=2200 masl), and influenced by discharges from the paper mill and agricultural activities (UAW5, location-latitude=38^{o}9’2”, longitude=9^{o}0’04”, altitude=2176 masl) (Fig. 2).

These all five riverine sites were further divided into pool and riffle based on the movement of water since the diversity and abundance of macroinvertebrates in fast-flowing and still water are different, The Multi-Habitat Sampling (MHS) scheme was used to collect benthic macroinvertebrates larvae, [24]. Benthic macroinvertebrates were collected using a standard hand net (625 cm^2, net with mesh size of 500 μm from multi-habitat units) monthly from January 2018 to March 2018.

Composite samples consisting of 20 sampling units were taken from each of the five sites (20 samples were for both riffle and pool of one site). These 20 sampling units taken for one site at a time was repeated for three times per site and the average was taken at last. A sampling unit was performed by positioning the net and disturbing the substrate in a quadratic area that equals the frame area of the net. Sampling started at the downstream end and proceeded upstream against the current. In places where the current was low, hand stirrings were used to create local currents to push the organisms into the net. Megalithal (>40cm and bedrock) stones were sampled by brushing the surface approximately equal to the size of the sampling net. Macrolithal (20-40cm) stones were picked by hand and their surfaces were brushed to dislodge clingers and sessile organisms. After every 3 samplings, the net was rinsed by running clean stream water to avoid clogging. Before preservation, quick identification of macroinvertebrates taxa was performed. Samples were then preserved in 4% formaldehyde for further analysis. Proper records were maintained with details such as stream name and site identity code. The same information was also marked on the container with waterproof markers. Along with the collection of macroinvertebrates, Microhabitat of the study sites in the river of study sites was visually observed and categorized per particle size: psammal (<0, 2cm), akal (0, 2-2cm), Macrolithal (2-6cm), mesolithal (6-20cm), macrolithal (20-40cm), and megalithal (>40cm and bed rock).

The preserved macroinvertebrates samples were brought to Ambo University, Environmental Science laboratory for further analysis. It was then passed through a set of sieves (2000, 500 and 250 µm mesh size) to remove formalin and separate size classes of macroinvertebrates groups under tap water [4]. Macroinvertebrates trapped in the coarse fraction of the sieve were sorted out and organisms trapped in the smaller fraction of the sieve were sorted with the help of a light microscope and naked eye. Further identification up to the family level was performed using the Aquatic Invertebrates Identification key [25, 26, 27]. The identified benthic macroinvertebrates were preserved in plastic vials with 70% alcohol for further uses.

Water samples for physicochemical parameters were taken at the same location and almost simultaneously with the samples for macroinvertebrates. Dissolved oxygen (DO), Electrical conductivity, pH and water temperature were measured *in situ* using a multi-probe (Model HQ40d, HACH Instruments) before sampling the macroinvertebrates. Water samples were collected in 1L polyethylene bottles and stored in an icebox and transported to Ambo University for the analysis of total phosphorous (TP) and Nitrate. Nitrate concentration and total phosphorus ere determined by Phenoldisulphonic acid method using double beam UV-spectrophotometer (ELICO SL-160) and colorimetric methods respectively.

2.3. Data analysis.

Data were analysed by using descriptive and inferential statistics. In addition, the following biological indices that had been suggested by Rosenberg and Resh [11] were used to evaluate benthic macroinvertebrates communities and to assess pollution effects on them.

Shannon-Weiner Diversity Index (SDI) was used to calculate species diversity in a community.

$$H' = -\sum_{i=1}^{s} Pi \ln pi$$

Where S= number of families represented by n, N = total number of individuals, Σ = Sum, Pi= n/N

Hilsenhoff Family-Level Biotic Index (H-FBI) was used to estimate the tolerance value of the community in the study area. This metric is a biotic index that is calculated by multiplying the number of individuals of each family by an assigned tolerance value, summing these products, and dividing by the total number of individuals. It is a weighted measure of individuals in a population.

H-FBI = Σ (Xi*ti)/ (n)

Where, Xi = number of individuals within taxa, ti = tolerance value of taxon, n = total number of organisms in the samples

Family-Level richness (RICH) was used to evaluate the number of different families found in the sample. It was done by Margalef index formula d = (S-1)/lnN where, d = Family level richness or Margalef index, S = number of families, and N = total number of individuals in the sample.

Percentage of Ephemeroptera, Plecoptera, Trichoptera index (%EPT) was used to calculate the proportion of individuals of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddis flies) found in the samples.

%EPT = n/N X 100 Where n = number of individual EPT in the sample, N = total number of individuals in the sample.

Percentage of Chironomidae (%CHIR) was used to investigate percentage of Chironomidae in a sample. **%**CHIR = n/N X 100 Where n = number of Chironomidae in the sample, N = number of individuals in the sample.

Percentage of dominant taxa (%DT) was used to measure community balance or evenness of the distribution of individual families. The index was used to evaluate the abundance of numerically dominant family relative to the others as indication of community balance.

ETHbios was used to calculate the sum of sensitivity score of each taxon present in a sample.

$$ETHbios = \sum_{i=1}^{n} scorei$$

The average score per taxon (ASPT) is calculated as ETHbios divided by the total number of taxa considered in the calculation.

ASPT= ETHbios/n

Where score i is the score of taxon i and n is the number of taxa considered in the calculation. A high score value of the macroinvertebrate indicator taxon indicates high sensitivity to stressors and a taxon with low scores indicate high tolerance to stressors. The ecological status of the sampling sites was tested based on the threshold values of ETHbios established for Ethiopian highland streams and rivers [28].

In addition to biological indices, data collected for benthic macroinvertebrates and physicochemical parameters were statistically analysed by using an Excel spreadsheet, and SPSS version 21. Bivariate Spearman correlation was used to analyse benthic macroinvertebrates abundances, their diversity indices and physicochemical parameters and 0.05% were taken as the significance level.

3. Results

3.1. Composition and abundance of macroinvertebrates

A total of 14,465 individuals of macroinvertebrates, representing eight orders of insects and five classes of non-insects having 37 families were collected and identified from the study area (Table 1, 2, and Fig. 3). Eight orders of insects namely Ephemeroptera, Plecoptera, Diptera, Trichoptera, Coleoptera, Heteroptera, Odonata and Hemiptera, and five non-insect classes (Gastropoda, Decapoda, Turbellaria, Oligochaeta and Hirudinea) were collected during the study period. Among insects, Diptera was highly diversified order having eight families followed by Hemiptera with six families. However, some non-insect taxa were not identified to the family level.

Table 1 Total number of macroinvertebrates collected from Upper Awash River at Chillimo Forest

, West Shoa

Study sites		No. of Orders/Taxa	No. of family	Individuals/m^2
	Pool	8	19	662
UAW1	Riffle	7	15	2026
	Pool	9	19	683
UAW2	Riffle	8	19	2098
	Pool	9	19	776
UAW3	Riffle	8	19	2703

	Pool	9	16	596
UAW4	Riffle	10	19	1842
	Pool	9	19	868
UAW5	Riffle	10	19	2211

In the present study, eight orders of insects and one order of non-insects were identified from UAW1 riffle and pool during the study period. Seven orders of insects and one order of non-insects were identified from the UAW1 pool area. In addition, three families of each Ephemeroptera and Coleoptera, two families of each Hemiptera and Trichoptera, six families of Diptera and one family of each Plecoptera and Heteroptera were collected from this site.(table: 2) Diptera was the most diversified from insects and Decapoda from non-insect. The benthic macroinvertebrates of UWA1 riffle were composed of 13 families of insects and two families of non-insects. The area was inhabited by more insects of which Diptera, Ephemeroptera and Trichoptera were represented by five, three and two families respectively and each of Odonata, Coleoptera and Plecoptera were represented by one family. Among non-insects, each Turbellaria and Decapoda was represented by one family. Diptera was again the most diversified animal of the area.

From pool and riffle part of UAW2, 21 families of insects and two families of non-insects were identified. Pool area of UAW2 was represented by four families of each Diptera and Ephemeroptera, three families of Coleoptera, two families of each Trichoptera and Odonata, one family of each Hemiptera and Hetroptera. Among non-insect, Oligochaeta and Hirudinae were identified from the pool region. UAW2 riffle part registered seven orders of insects and one order of non-insect. Insects were represented by five families of Diptera, four families of Ephemeroptera, three families of each Coleoptera and Trichoptera, one family of each Odonata, Hetroptera and Plecoptera. Only an order of Classes Oligochaeta was identified from non-insects. Diptera was the most diversified group followed by Ephemeroptera, Coleoptera and Trichoptera.

In general, 23 families of insects, two families and one class of non-insects were identified from pool and riffle parts of UAW3 during the study period. UAW3 pool region contained seven orders of insects and two orders of non-insects. Insects were represented by four families of Odonata, three families of each Ephemeroptera, Diptera and Hemiptera, two families of Coleoptera and each one family of Trichoptera and Heteroptera. From non-insect groups, two families of Gastropoda and order of Oligochaeta were identified. Odonata was the most diversified family for this site. Furthermore, 18 families of insects and one non-insect class were collected from the UAW3 riffle area. Diptera was represented by six families, Ephemeroptera by four families, Hemiptera by three families, each Coleoptera and Odonata by two families and each Trichoptera and Heteroptera was represented by one family. However, Oligochaeta was the only identified class of non-insect macroinvertebrates.

From the pool and riffle of UAW4, a total of 16 families of insect and three families of non-insects were collected during the study period. UAW4 pool area contained 13 families of insects and three families of non-insects. Insects were represented by five families of Diptera, two families of each Ephemeroptera and Odonata, one families of each Hemiptera, Coleoptera and Hetroptera. Among the non-insect group, two families of Gastropoda and class Oligochaeta were identified. Among insects group Micronectidae were the most abundant followed by Chironomidae. Likewise, 15 families of insects and four families of non-insects were identified from riffle part of UAW4. The insects were represented by five families of Diptera, three families of Odonata, and two families of each Ephemeroptera and Coleoptera, one family of each Trichoptera, Hemiptera and Heteroptera. However, non-insects were represented by two families of Gastropoda, one family of each Decapoda and Oligochaeta. Diptera was the most diversified animals of this site followed by Odonata, Coleoptera and Ephemeroptera.

From UAW5 (pool and riffle), collectively three families of non-insects and 19 families of insects were identified during the study period. UAW5 pool part contained 16 families of insects and three families of non-insect groups. Insects were represented by five families of Diptera, three families of Odonata, two families of each Ephemeroptera, Hemiptera, Coleoptera, Heteroptera and one family of Trichoptera. Among the non-insect groups, two families of Gastropoda, and Oligochaeta order were identified. In the UAW5 riffle part, the macroinvertebrates identified belonging to 16 families of insects and three families of non-insects. Insects were represented by five families of Diptera, three families of Odonata, two families of each Ephemeroptera and Hemiptera, one family of each Trichoptera, Coleoptera and Heteroptera, and non-insects were represented by one family of each Decapoda, Gastropoda, and Oligochaeta. Diptera was the most diversified and abundant group followed by Odonata, Ephemeroptera and Hemiptera (Table 2).

Table 2 Taxa identified from the five sampling sites of Upper Awash River at Chillimo Forest during the study period

Major Taxon/ family/	Composition of species (individual/m^2)				
	UAW1	UAW2	UAW3	UAW4	UAW5
PLECOPTERA					
Perlidae	61	2	--	--	--
EPHEMEROPTERA					
Baetidae	686	800	328	162	197
Caenidae	270	608	866	583	602
Heptagenidae	252	87	54	--	--
Tricorythidae	--	2	1	--	--
ODONATA					
Aeshnidae	2	20	4	2	2
Libellulidae	--	--	--	--	29
Coenagrionidae	--	2	83	14	35
Gomphidae	--	--	1	3	2
Corduliidae	--	--	1	--	--
HEMIPTERA					
Belostomatidae	--	2	5	--	2
Gerridae	--	--	3	--	3
Nepidae	--	--	1	--	--

Naucoridae	--	--	9	9	10
Notonectidae	2	--	--	--	--
Velidae	2	--	2	--	--
TRICHOPTERA					
Hydropschidae	435	413	953	562	353
Leptoceridae	--	3	--	--	--
Lipidostomatidae	301	169	--	--	--
COLEOPTERA					
Dytiscidae	8	18	21	--	--
Elmidae	2	3	13	3	2
Gyrinidae	24	4	--	2	2
Hydrophilidae	--	--	3	--	--
Helodidae	--	2	--	--	--
DIPTERA					
Chironomidae	108	459	393	589	687
Ceratopogonidae	3	--	--	3	4
Tipulidae	74	81	3	2	--
Athericidae	23	6	4	--	--
Simuliidae	381	51	140	46	183
Muscidae	--	--	18	7	59
Tabanidae	23	4	8	3	33

Syriphidae	--	--	--	--	2
HETROPTERA					
Micronectidae	14	41	94	401	482
GASTROPODA					
Physidae	--	--	81	3	3
Planorbidae	--	--	379	4	206
OLIGOCHAETA					
Oligochaeta	--	2	14	38	179
HIRUDINAE					
Hirudinea	--	2	--	--	--
DECAPODA					
Potamonautidae	3	--	--	2	2
TURBELLARIA					
Planaria	14	--	--	--	--

In the present study, there were high numbers of individual insects in the study area when compared to non-insect macroinvertebrates (Table 3). In addition, the abundance of individuals varied among the study sites with the lowest at UAW4 (2438), although there was no significant difference among the sites ($p = 0.289$, $p > 0.05$).

Table 3 Numeric and percentage abundance of benthic macroinvertebrates in the study sites

Types of Taxa	UAW1	UAW2	UAW3	UAW4	UAW5
Insect	2671 (99.37%)	2777 (99.86%)	3005 (86.38%)	2391 (98.07%)	2689 (87.33%)
Non Insect	17 (0.632%)	4 (0.14%)	474 (13.62%)	47 (1.93%)	390 (12.67%)
Total	2688 (100%)	2781 (100%)	3479 (100%)	2438 (100%)	3079 (100%)
P-value		p = 0.289, df = 4, p > 0.05			

3.2. Abundance of major orders of benthic macroinvertebrates.

Relative abundance of the eight orders of insect taxa and five non-insect taxa were computed and summarized in Table 4. The benthic macroinvertebrates population density showed variations among sampling sites. The highest population density was recorded for Order Ephemeroptera whereas order Hirudinae was the least. Gastropoda was higher at UAW4 than other sites. Population density of Oligochaeta was highest at UAW5 ($p = 0.035$, $p < 0.05$).

Table 4 Relative abundances of insect orders and non-insect taxa at the five study sites

	UAW1		UAW2		UAW3		UAW4		UAW5	
	Riffle	Pool	Riffle	Pool	Riffle	Pool	Riffle	Pool	Riffle	Pool
	%	%	%	%	%	%	%	%	%	%
Taxa										
Gastropoda	--	--	--	--	4.08	9.14	0.12	0.16	5.85	0.94
Potamonautidae	0.07	0.04	--	--	--	--	0.08	--	0.07	--
Turbellaria	0.52	--	--	--	--	--	--	--	--	--
Hirudinea	--	--	--	0.07	--	--	--	--	--	--
Oligochaeta	--	--	0.04	0.04	0.06	0.34	1.39	0.16	2.73	3.09
Plecoptera	1.56	0.71	0.07	--	--	--	--	--	--	--
Ephemeroptera	30.31	14.63	33.33	20.49	34.58	1.32	26.57	3.98	22.70	3.25
Odonata	0.07	--	0.65	0.14	1.26	1.29	0.61	0.16	1.04	1.17
Hemiptera	--	0.15	--	0.07	0.23	0.26	0.08	0.29	0.26	0.23
Trichoptera	24.74	2.64	20.35	0.68	27.36	0.03	22.72	0.33	11.37	0.09
Diptera	17.29	5.47	20.24	1.37	9.37	6.89	20.38	6.28	27.38	4.06

Heteroptera	--	0.52	0.04	1.44	--	2.70	3.40	13.04	0.36	15.29
Coleoptera	0.78	0.48	0.72	0.25	0.75	3.16	0.16	0.04	0.06	0.06

The abundance of macroinvertebrate collected in February significantly varied among the sites being higher (1392 individuals) at UAW3 ($p<0.05$, df = 4) than in other sites. However, the highest number (1779) of macroinvertebrate was counted in January. In addition, the highest family richness for the current study was recorded in February (22) at UAW5 ($p<0.05$, df = 4) (Table 5).

Table 5 Monthly variations of abundance and family richness by one sample test option

		UAW1	UAW2	UAW3	UAW4	UAW5	95% Confidence Interval of the Difference	
							Lower	Upper
Abundance	January	1302	1779	1496	786	721	650.2804	1783.3196
	February	961	961	1392	945	1196	845.2085	1336.7915*
	March	425	354	590	107	162	83.0795	572.1205
Family richness	January	18	16	16	12	14	12.3686	18.0314
	February	16	21	21	17	22	16.0452	22.7548*
	March	17	21	21	16	19	15.9686	21.6314

*Significance level at 0.05 was used ($p<0.05$, df = 4)

3.3. Shannon-Weiner Diversity Index.

Comparison of benthic macroinvertebrates among the five sites showed variation in species richness, evenness and Shannon-Weiner Diversity Index. UAW1 showed the largest value of Shannon diversity index ($H^{'}$= 2.16), followed by UAW3 ($H^{'}$ = 2.06), UAW2 ($H^{'}$ = 1.93), UAW4 (1.79), and UAW5 ($H^{'}$ = 1.68). The highest value of family richness was recorded for UAW3 (d = 3.33), followed by UAW2 (d = 2.99), UAW5 (d = 2.93), UAW1 (d = 2.83) and the least was recorded for UAW4 (d = 2.44). In addition, the highest values of Evenness were computed for UAW1, followed by UAW3, UAW2, UAW4 and UAW5, with the values of 0.274, 0.253, 0.245, 0.228 and 0.209 respectively (Fig. 4).

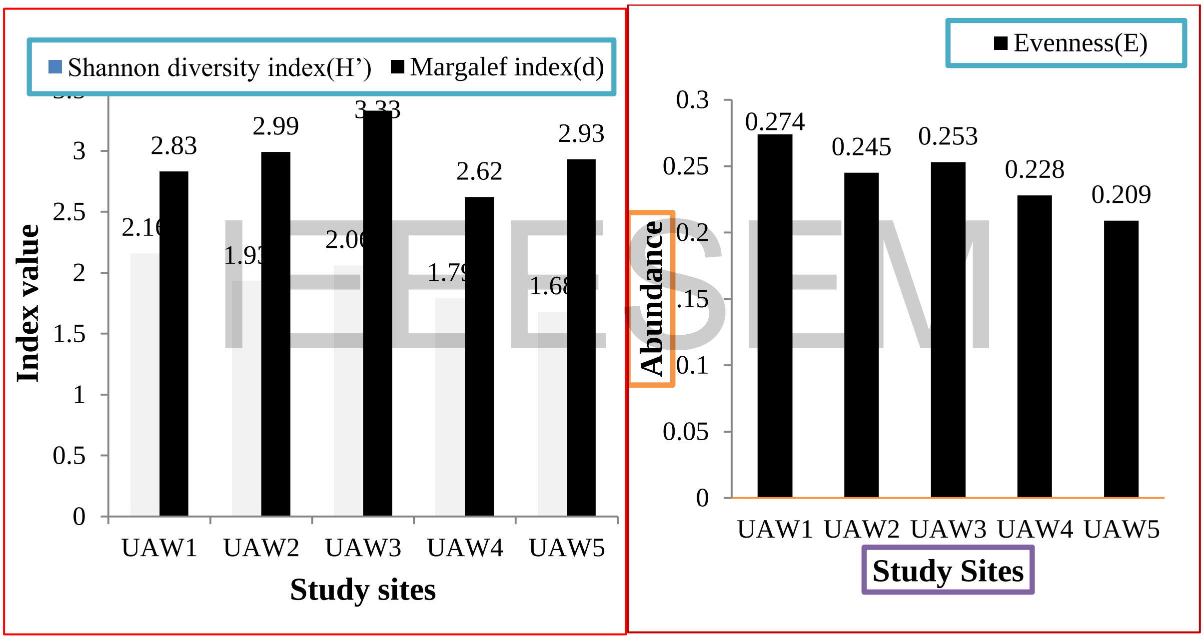

Fig. 2 Value of Evenness and Shannon diversity indices for benthic macroinvertebrates

3.4. H-FBI, % EPT, Family-level Richness, %Chironomidae, ETHbios and ASPT Indices.

In the current study, biotic indices have been summarized and presented in Table 6. The result showed that UAW4 had the relatively highest H-FBI index (5.15), followed by UAW5 (5.08), UAW2 (4.97), UAW3 (4.92) and then UAW2 (4.09), thereby indicating that UAW4 and UAW5 are poorer in benthic faunal diversity than other sites. In general, the H-FBI values for the entire sample sites scored 4.842 which indicate there is some organic pollution and good water quality.

The highly impacted site (UAW4) recorded a high percentage of Chironomidae (24.16%), followed by slightly impacted sites, UAW5 (22.31%), UAW2 (16.51%), UAW3 (11.29%) and UAW1 (4.02%) respectively. The %EPT increased from the highly impacted site (UAW4) to a low impacted site (UAW1). The largest %EPT was registered for UAW2 with a value of 74.94%, followed by UAW1 with value of 74.59%, UAW3 (63.29%), UAW4 (53.61%), and the least (37.41%).

In this study, ETHbios value was highest in UAW2 (111) and UAW1 (107), whereas the least value was observed in highly impacted UAW4 found below the paper mill factory. A low value may prove good indicators of increased pollutants. A high value of ASPT scores was recorded in UAW1 (5.95), followed by UAW2, UAW3, UAW4 and UAW5 with the values of 5.84, 5.22, 5 and 4.5 respectively.

Table 6 Biotic indices calculated from all sampling sites

Metrics	**UAW1**	**UAW2**	**UAW3**	**UAW4**	**UAW5**
Family-level Richness	21	23	27	20	23
H-FBI	4.09	4.97	4.92	5.15	5.08
%EPT	74.59	74.94	63.29	53.61	37.41
Abundance (Individuals/m^2)	2688	2781	3479	2438	3079
%Chironomidae	4.02	16.51	11.29	24.16	22.31
ETHbios	107	111	105	84	91
ASPT (ETHbios)	5.95	5.84	5.22	5	4.5

3.5. Percent of dominant taxa (%DT).

The dominance of taxa for the distribution of individual families was calculated (Fig. 5). Accordingly, Baetidae was the most dominant in both UAW1 and UAW2 with the value of 25.52% and 28.77% respectively. However, Hydropschidae were the most dominant in UAW3 with a value of 27.39%, and Chironomidae was the most dominant in both UAW4 and UAW5 accounting for 24.17% and 22.31% respectively.

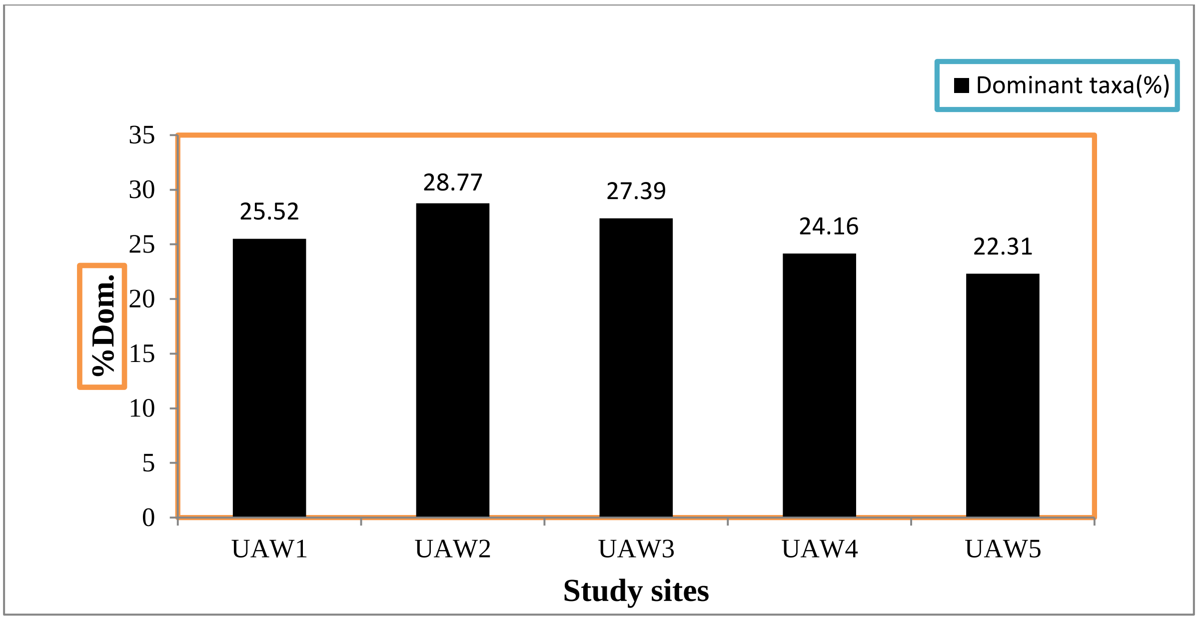

Fig. 3 Percentage of dominant taxa in study sites

3.6. Environmental parameters.

Environmental variables measured in the field and laboratory during the sampling period are summarized in Table 7. The maximum average concentration of DO was recorded at UAW1 (7.69±0.13), followed by UAW2 (7.68±1.03 mg/L) and the minimum value was recorded at UAW4 (7.26±0.5 mg/L). The highest mean pH was recorded at UAW1 (8.78±0.51), while the lowest value was from UAW2 (8.57±0.28). The maximum mean total phosphorous (0.28±0.41 mg/L) and the maximum average N-NO_3^- concentration (0.83±0.08mg/L) was recorded at UAW3 where agricultural activities are intense.

Table 7 Means and ranges for environmental parameters collected from study sites

Parameter	**Sampling sites**				
	UAW1	UAW2	UAW3	UAW4	UAW5
pH	8.78 ± 0.51	8.57 ± 0.28	8.72 ± 0.62	8.69 ± 0.45	8.58 ± 0.25
EC (µS/ cm)	187.04 ± 20.11	297.78 ± 24.06	370.77 ± 5.65	465 ± 32.97	472 ± 31.57
DO (mg/L)	7.69 ± 0.13	7.68 ± 1.03	7.39 ± 0.85	7.26 ± 0.5	7.4 ± 0.53

DO (%)	96.86 ± 1.72	100.49 ± 2.49	108.78 ± 20.43	113.7 ± 10.69	125.4 ± 19.38
H_2O (°C)	12.49 ± 1.17	14.9 ± 2.03	20.79 ± 3.59	23.12 ± 1.2	21.25 ± 5.41
Total TP (mg/L)	0.06 ± 0.01	0.05 ± 0.01	0.28 ± 0.41	0.06 ± 0.01	0.027 ± 0.05
No_3^-N (mg/L)	0.12 ± 0.06	0.37 ± 0.24	0.83 ± 0.08	0.38 ± 0.22	0.48 ± 0.39

EC=electrical conductivity, DO=dissolved oxygen (mg/l), TP=total phosphorous, No_3^-N= nitrate-nitrogen, pH= acidity or alkalinity, % DO= percentage of dissolved oxygen, H_2O (°C) = water temper

4. Discussion

Rivers can exhibit different habitat conditions due to natural variations as well as anthropogenic influences thereby resulting in different faunal composition [5]. In the current study, a total of 14,665 benthic macroinvertebrates belonging to 13 orders (eight insects and five non-insects) and 37 families were reported. The overall benthic macroinvertebrates recorded in the study revealed significant variation in composition, distribution and abundance across different sites of Upper Awash River with the highest number of total family recorded in UAW3(3478 ind/m^2 followed by UAW5(3079 ind/m^2) . The differences might be due to the influence of anthropogenic factors including farming (UAW3) and industrial wastes (paper mill site 4 and 5), and the tolerance value of benthic macro fauna. The difference generally might be due actual situation of study area (forest areas with less human impact (site1 (UAW1), scattered grazing and agricultural activities (UAW2), more grazing and agricultural activities (UAW3), paper mill, industrial wastes and domestic wastes (UAW4,) and influenced by discharges from the paper mill and agricultural activities (UAW5).

In the present study, the numbers of taxa also varied between riffle and pool habitats. Riffle habitat showed higher population density and family richness than pool habitat. In the riffle, microlithal, mesolithal and macrolithal combined with organic substances such as plant roots and fallen leaves were observed to be dominant which might facilitate the suitable substratum for the benthic macroinvertebrates. However, in the pool section, the stream bed is dominated by sand and mud where few taxa with special adaption features might survive. In the current work, Corduliidae, Leptoceridae and Hirudinae were identified in the pool only while Planaria and Syrphidae were identified in riffle only. Such macroinvertebrate taxa differences between both habitats were also reported in earlier studies [29, 31]. Other studies identified that differences in taxa richness between riffles and pools have been associated with habitat stability [29, 30], peak annual discharge, and reach gradient; however, sampling method and taxonomic resolution also are important factors [31].

The abundance of individuals was lowest in UAW4 (relative to all respective sites which slightly showed a poor quality and dominated with tolerant taxa as the site was impacted by paper mill, agricultural activities, car washing, cattle grazing, washing clothes, bathing and other human activities. This result was in accordance with macroinvertebrate community structure reported in Upper Awash River previously by Aschalew Lakew [32]. Human activities such as cattle watering, washing, domestic waste disposal, agricultural activities and siltation might result in reduced animal diversity and abundance compared to the least impacted sites in the Upper Awash River. The upper part of the river becomes pristine and unimpacted, most fauna can inhabit it, and there will be high competition, and can thus support fewer invertebrates than the lower part of the River.

The result showed that macroinvertebrate community composition varied among all sites due to different activities. For example, at UAW4 and UAW5, which impacted by different anthropogenic activities, red Chironomidae was the most abundant and dominant taxon throughout the study. Comparatively, Oligochaeta was also the most abundant animal at UAW4 (38) and UAW5 (179). This finding agrees with the accepted view that tolerant species become abundant in degraded streams and rivers [19, 33, 34]. Likewise, the percentage of the dominant taxa (%DT) increased from the least impacted site to the more impacted sites while the percentage of Chironomidae (%Chironomidae) inversely decreasing from more impacted sites to the least impacted site where the river channel consisted of more natural forest coverage and vegetation canopy. The high abundance of Chironomidae at UAW4 and UAW5 might be an indication of organic pollution and nutrient enrichment, because, Chironomidae increases with decreasing water quality. In agreement with the present result, Weigel et al. [35] reported that Chironomidae is abundant in water where severe pollution exists. Furthermore, several studies have shown that a high abundance of tolerant benthic macroinvertebrate and low diversity of sensitive taxa were registered in impacted streams [36, 37]. However, not all studies have shown such clear trends [38, 39].

Insect species including Baetidae, Caenidae and Hydropschidae were numerically dominant at UAW1, UAW2 and UAW3 where agricultural activities were available. The result showed that Baetidae was the most dominant taxa both at UAW1 and UAW2 with the value of 25.52 % and 28.77% respectively and Hydropschidae were the most dominant taxa at UAW3 with the value of 27.39 %. The mean composition of EPT taxa was maximum at UAW2 (74.94%) followed by UAW1 (74.59%) and the lowest was at UAW4 (53.61%) and UAW5 (37.4%) indicating that there was an impact from human activities including industrial, agricultural, car washing,. Diptera composition was highest accounting to 31.44% and 26.66 in the impacted site, UAW5 and UAW4 respectively. These findings agree with the previous reports in the Upper Awash River [32, 40].

The benthic macroinvertebrate density was found to vary between months. The total abundance of benthic macroinvertebrates was found to be high during January. The presence of a particular population is governed by a specific set of ecological conditions prevailing at that period. The abundance and diversity of benthic fauna mainly depend on the physical and chemical properties of its habitat as it responds quickly to any change in water quality [41]. For example, water temperature has a pronounced influence on their life cycle [42, 43] as it changes seasonally.

The Average Score Per Taxon (ASPT) and ETHbios were recorded in all sites during the study period. In addition, the description of water quality was done based on ASPT and ETHbios values in each site. According to the suggested ETHbios threshold values ([34], the highest ETHbios scored in UAW1 (107) and UAW2 (111), with ASPT value greater than 5 which indicated good ecological water quality class and slight ecological degradation. However, UAW3, UAW4 and UAW5 have ASPT value less than 5 that is categorized under moderate ecological water quality class and significant ecological degradation. This finding agreed with Ayana Chimdo [44] who reported good water quality class at Chilimo site or UAW1 and poor ecological quality at paper mill site or UAW4.

The current result showed that as habitat and water quality are degraded, the number and percentage of EPT decreased, while percentages of Diptera and blood-red Chironomids increased. Moreover, there were significant correlations between macroinvertebrates and most environmental parameters. Such correlation is in agreement with the study of Baye

Sitotaw, [15, 32]. In addition to this, H-FBI was increased with increasing organic pollution. According to Hilsenhoff [45], it is evident that UAW3 (4.92), UAW2 (4.97), UAW4 (5.15) and UAW5 (5.08) is categorized under moderate water quality class, while UAW1 part is good water quality class. As a whole, the H-FBI values for the entire sample sites indicate that some organic pollutants were entering the river from the human in-stream and catchment activities.

Human activities have led to the depletion of macroinvertebrates. Some anthropogenic activities like agricultural activities, paper mill factory, grazing and water dumping caused changes in physicochemical parameters, which, lead to a severe impact on the benthic invertebrates of the river [5]., there was also some variation in physicochemical parameters in which the benthic population showed an inverse relationship with anthropogenic activities whereby macroinvertebrates declined correspondingly with the increase in anthropogenic activities. The mean pH value of study sites slightly increased from 8.57 ± 0.28 value of UAW2 to 8.78 ± 0.51 value of UAW1 which is within the range of EPA [46] standards for surface water (6.0-9.0). Although benthic macroinvertebrate sensitivities to pH vary, values below 5.0 and greater than 9.0 (which were not recorded for the current study) are considered as harmful [47]. Even though the mean EC value in all sampling sites was lower than the hitherto tested Rivers in Ethiopia [15, 17, 48] and the standard value of EC in surface waters [46], it was in the range of EC reported for general freshwaters (10-1000 μS/cm) [5]. Relatively, higher values of EC in the down reach of the river at UAW4 (465 μS/cm) and UAW5(472 μS/cm) might be associated with paper milling, agricultural activities, car washing, cattle grazing, washing clothes, bathing and other human activities. This was due to domestic sewage in nutrient and enrichment of electrolytes from nearby areas or weathering of sediments [40].

The benthic macroinvertebrates have evolved to live within a specific temperature range, which limits their distribution and affects the community structure [42, 43], as it regulates the amount of dissolved oxygen, the rate of decomposition of organic matter, photosynthesis and ionization of ammonia [49]. Natural variation in water temperatures mainly occurs in response to seasonal and regional climate ([8]. The mean temperatures recorded at all current study sites were found to be within a range of [8] guideline values (12-25°C) for freshwater bodies. The maximum mean water temperature recorded at UAW5 (23.12 ± 1.2°C) might be due to the absence of vegetation cover and the least mean value recorded at UAW1 (12.49 ±

1.17°C) could be related to the presence of some riparian vegetation cover and vegetation within the stream channels.

The amount of dissolved oxygen concentration in the present study was higher than the recommended level of dissolved oxygen content in natural water (5 mg/L), which is optimum for the survival and normal functioning of biological communities [5]. However, the recorded dissolved oxygen value at all sampling sites, UAW1-UAW5, (7.69 ± 0.13, 7.68 ± 1.03,7.39 ± 0.85,7.26 ± 0.5 and 7.4 ± 0.53 respectively) were less than the amount of typical dissolved oxygen concentration in unpolluted natural water (10 mg/L), which showed sign of the river pollution [5]. Relatively, the lowest dissolved oxygen value in UAW5 might be associated with the discharge of organic pollutants from paper milling and urban runoff. Even though the sign of pollution was detected in the current study sites, the result of dissolved oxygen measured in the study area was greater than the result obtained in other Ethiopian rivers, such as Guder River [50] (4.9 + 0.49 mg/L), Modjo River ([15], (6.1 + 4.01 mg/L) and Akaki River [51], (0.3 mg/L), and almost not far from Upper Awash River [32, 40] (6.4 mg/L and 7.35 mg/L).

The maximum average $N\text{-}NO_3^-$ concentration (0.83 ± 0.08 mg/L) was found in UAW3 because of the high agricultural activities in the area, followed by UAW5 (0.48 ± 0.39 mg/L) (below the paper mill factory) and the minimum concentration (0.12 ± 0.06 mg/L) was recorded at UAW1. The records at all sites were also within the permissible limit of EPA [46] standard (10 mg/L). In addition, total phosphorous recorded at the sampling sites along the Upper Awash river was higher than the concentrations in most natural waters (0.006 to 0.02 mg/L) [5]. The higher concentration measured at UAW3 (0.28 + 0.41) might be attributed to the use of phosphorus-based chemicals (especially fertilizers) due to agricultural activities in the area. Agricultural practices such as crop cultivation adjacent to streams can lead to topsoil erosion and subsequent runoff of fine sediments, nutrients and pesticides [32, 52, 53]. Moreover, runoff from agricultural farmlands is rich in nitrates and phosphates that lead to eutrophication. Siltation caused by erosion from the unprotected watershed is another stressor in the area ([4].

5. Conclusion

The study depicted the negative impacts of anthropologic activities on water quality and composition, diversity and distribution of benthic macroinvertebrates in the Upper Awash

River. Agricultural activities, destruction of riparian forest, the discharge of sewage and poor solid waste management were the major environmental stressors responsible for the deterioration of the water. Since the Upper Awash River is used for a variety of purposes such as irrigation, cattle drinking, bathing, washing the clothes and domestic purposes, the river showed increased deterioration at downstream sites as anthropogenic activities including agricultural activities, paper mill, industrial wastes, and domestic wastes were observed to increase as one move from UAW1 to UAW5. A change in physicochemical water quality parameters driven mainly by anthropogenic activities harmed benthic macroinvertebrates. As a result, the population of macroinvertebrates showed variation among sites. As habitat and water quality are degraded, the number of EPT, spatial diversity, ETHbios and ASPT decreased, while percentages of dominant taxa (%DT) and the %Chironomidae were decreasing from more impaired site UAW5 to the least impaired UAW1. Conversely, the percentage of Ephemeroptera, Plecoptera and Trichoptera (%EPT) increased from more impaired site to least impaired sites. Hilsenhoff-Family Biotic Index (H-FBI) increased as pollution increased, which showed the impact of multiple human activities on the flowing water. Based on the current result, we recommend that sustainable management of the Upper Awash River by environmental protection agencies should take remedy to tackle anthropogenic activities resulting in water pollution.

6. Appendices

Appendix 1: Evaluation of water quality and degradation of organic pollution from area of environment using biotic index values of all sites

Family biotic index	Water quality	Degree of organic pollution
0.00-3.50	Excellent	Organic pollution unlikely
3.51-4.50	Very good	Possible slightly organic pollution
4.51-5.50	Good	Some organic pollution probably
5.51-6.50	Fair	Fairly substantial pollution likely
6.51-7.50	Fairly poor	substantial pollution likely
7.51-8.50	Poor	Very substantial pollution likely
8.51-10.00	Very poor	Sever organic pollution likely

Source: (Hilsenhoff, 1987)

Appendix 2: Water quality assessment based on suggested ETHbios threshold values.

River quality class	Color	ETHbios score	ASPT-ETHbios	Interpretation
1	Blue	>115	>6.5	High water quality; low level of degradation
2	Green	65-114	5.01-6.4	Good water quality; slight ecological degradation
3	Yellow	45-64	4-5	Moderate water quality; significant ecological disturbance
4	Orange	12-44	2.4-3.99	Poor water quality; major degradation
5	Red	<12	<2.4	Bad water quality; heavily degraded

Source: Aschalew Lakew and Moog, O. (2015b).

Appendix3: Anova table for Number of taxa of all sites and Number of family of all sites

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Number of taxa of all sites	Between Groups	2.700	2	1.350	1.080	.481
	Within Groups	2.500	2	1.250		
	Total	5.200	4			
Number of family of all sites	Between Groups	9.200	2	4.600	.920	.521
	Within Groups	10.000	2	5.000		

7. Acknowledgement

First and for most, I would like to thank my almighty God for giving me health and strength for the completion of the study.

Next, I wish to express my absolute gratitude and deep sense of reverence to my major advisor Dr. Aschalew Lakew whose guidance, mentorship, inputs, timely advice , constructive comment and encouragements which served as a pillar upon which this entire thesis rest from the beginning through completion.

I am highly indebted to my co- advisor Dr. L. Prabha Devi, for her significant and constant support, guidance sincere advice, follow up, constructive suggestions and encouragement during my study..

8. References

[1] B. Aylward, J. Bandyopadhyay, J. C. Belausteguigotia, 2005. “Freshwater Ecosystem Services,” *Ecosyst Hum Well Being Policy Responses* vol. 3, pp. 213-254.

[2] Z. Gebremaria and E. Dadebo, 1989. “Water resources and fisheries management in the Ethiopian rift valley lakes,” *SINET: Ethiopian Journal of Science,* vol. 12, pp. 95-109.

[3] S. T. Mereta, P. D. Boets, L. Meester, and P. L. M. Goethals, 2013. “Development of a Multimetric Index Based on Benthic Macroinvertebrates for the Assessment of Natural Wetlands in Southwest Ethiopia,” *Ecological Indicators,* vol. 29, pp. 510-521.

[4] A. Lakew, 2014. “Development of biological monitoring systems using benthic invertebrates to assess the ecological status of central and southeast highland rivers of Ethiopia,” PhD Thesis, University of Natural Resources and Life Sciences, Vienna, Austria, pp.163,

[5] D. Chapman, and V. Kimstach, 1996 *.Selection of Water Quality Variables*, In: Water Quality Assessments. A guide to the use of biota, sediments and water in environmental Monitoring, pp. 243-318, Cambridge.

[6] J. Bartram, and R. Balance, 1996. *Water quality monitoring-A practical guide to the design and implementation of freshwater quality studies and monitoring programmes,* NEP/WHO.

[7] W. Legesse, P. S. Giller, and J. O’Halloran, 2000. *Physicochemical and Biological assessment of the Kebena River*, Addis Ababa, Ethiopia.

[8] World Health Organization, 1995. “Water supply and Sanitation operation and maintenance of urban water supply and sanitation systems: A guide for manager,” *WHO Bulletin*, vol. 63, no. 2, p. 273.

[9] J. L. Metcalfe, 1989 “Biological Water Quality Assessment of Running Waters Based on Macroinvertebrate Communities: History and Present Status in Europe,” *Environmental Pollution,* vol. 60, pp. 101-113.

[10] J. M. Hellawell, 1986. *Biological Indicators of Freshwater Pollution and Environmental Management*, pp. 546, Elsevier, London.

[11] D. M. Rosenberg, and V. H. Resh, 1993. *Introduction to freshwater biomonitoring and benthic macroinvertebrates,* In: D. M. Rosenberg, V. H. Resh, (ed.), Freshwater

biomonitoring and benthic macroinvertebrates, pp. 1-9, New York, London, Chapman and Hall.

[12] P. D. Armitage, D. Moss, J. F. Wright, and M. T. Furse, 1983. “The performance of a new biological water quality score system based on macroinvertebrates over a wide range of unpolluted running-water sites,” *Water Research*, vol. 17, pp. 333-347.

[13] J. N. Negishi, M. Inoue, and M. Nunokawa, 2002 . “Effects of channelization on stream habitat in relation to a spate and flow refugia for macroinvertebrates in northern Japan,” *Freshwater Biology*, vol. 47, pp. 1515-1529.

[14] K. J. Donald, et al. 2002. "Methods development and use of macroinvertebrates as indicators of ecological conditions for streams in the Mid-Atlantic Highlands Region." *Environmental Monitoring and Assessment*, vol. 78, no. 2, pp. 169-212.

[15] B. Sitotaw, 2006. “Macro-invertebrates assemblage structure in relation to environmental degradation in some Ethiopian Rivers,” M. Sc. Thesis, School of Graduate Studies, Addis Ababa University, Ethiopia.

[16] S. Akalu, S. Mengistu and S. Leta, 2011. “Assessing human impacts on the Greater Akaki River, Ethiopia using macroinvertebrates,” *SINET: Ethiopian Journal of Science*, vol. 34, no. 2, pp. 89-98.

[17] A. Tassew, 2007. “Assessment of Biological Integrity Using Physico-chemical Parameters and Macro-invertebrate Community Index along Sebeta River, Ethiopia.

[18] A. Lakew, 2007. “Applicability of bio-assessment methods using benthic Macro-invertebrates to evaluate the ecological status of highland streams and Rivers in Ethiopia” M. Sc. thesis, UNESCO-IHE Delft, Netherlands .

[19] B. Abay, 2007. “Assessment of Downstream pollution profiles of Awassa Textile Factory Effluent along Tikurwuha River Using physico-chemical and Macro-invertebrate Indicators, Ethiopia,” M Sc Thesis, Addis Ababa University, Ethiopia, pp. 67.

[20] T. Addis, 2008. “Comparative study of macro-invertebrates and diatoms as Bio-indicators of River Water Quality in Addis Ababa,” M.sc Thesis, Addis Ababa University, Ethiopia.

[21] M. Bekele, 2003 . “Forest Property Right, the role of the state and institutional exigency: The Ethiopian experience,” PhD Thesis, Swedish University of Science, Uppsala, Sweden.

[22] Z. F. Jebessa, E. B. Wondemagegnehu,2018. “Physicochemical Characterization of Upper Awash River of Ethiopia Polluted by Anmol Product Paper Factory,” *International Journal of Water and Wastewater Treatment*, vol. 4, no. 2, pp. 1-10.

[23] M. T. Barbour, J. Gerritsen, B. D. Snyder, and J. B. Stribling,1999. *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish,* U.S. Environmental Protection Agency, Office of Water, Washington, DC, 2nd edition.

[24] O. Moog, and S. Sharma, 2005. *Guidance for pre-classifying the ecological status of HKH rivers,* Deliverable 7b for ASSESS-HKH, European Commission, pp. 27.

[25] A. M. Gerber, and J. M. Gabriel, 2002. *Aquatic Invertebrates of South African Rivers, Field Guide, Institute for Water Quality studies*, Department of Water Affairs and Forestry.

[26] R. W. Merritt, and K. W. Cummins, 1996. *An introduction to the Aquatic Insects of North America*, Kendall/Hunt Publishing, Dubuque, IA, 3rdedition, pp. 862.

[27] K. M. F. Scott, 1983. *On the Hydropschidae (Trichoptera) of South African with keys to Africa genera of maggots, larvae, and pupa and species list*, Annals of the cape provincial Museum, Natural History.

[28] L. Aschalew, and O. Moog, 2015b. "Benthic macroinvertebrates based new biotic score "ETHbios" for assessing ecological conditions of highland streams and rivers in Ethiopia," *Limnologica*, vol. 52, pp. 11-19.

[29] D. L. Mcculloch, 1986. "Benthic macroinvertebrates distributions in the riffle-pool communities of two east Texas streams," *Hydrobiologia*, vol. 135, pp. 61-70.

[30] A. J. Boulton, and P. S. Lake, 1992. "The ecology of two intermittent streams in Victoria, Australia: Comparisons of faunal composition between habitats, rivers and years," *Freshwater Biology*, vol. 27, pp. 99-121.

[31] P. Logan, and M. P. Brooker, 1983. "The macroinvertebrates faunas of riffles and pools," *Water Research*, vol. 17, pp. 263-270.

[32] Aschalew Lakew, 2015c ."Assessing Anthropogenic impacts using benthic macro invertebrates as bio-indicator in central highland streams of Ethiopia."

[33] M. Teferi, Tsegazeabe H/Haileselasie, Tsehaye Asmelash, Haile G/Selasie, Genet Alem, Solomon Amare, Kiros Weldegerima,S. Kiros, G. Equar and L. Bitew, 2013 ."Influence of water quality on the diversity and distribution of macro- invertebrates in highland stream, Northern Ethiopia," *Journal of Agricultural Science*, vol. 2, no. 2, pp. 17-25.

[34] L. Aschalew, and O. Moog, 2015a. "A Multimetric index based on benthic macroinvertebrates for assessing the ecological status of streams and rivers in central and southeast highlands of Ethiopia," *Hydrobiologia*, vol. 751, pp. 229-242.

[35] B. M. Weigel, L. J. Henne, and L. M. Martinez-Rivera, 2002. “Macro-invertebrate based index of biotic integrity for protection of streams in west-central Mexico,” *Journal of the North American Benthological Society*, vol. 21, no. 4, pp. 686-700.

[36] M. J. Hall, G. P. Closs, and R. H. Riley, 2001. “Relationships between land use and stream invertebrate community structure in a South Island, New Zealand, and Coastal stream,” *New Zealand Journal of Marine and Freshwater Research*, vol. 35, pp. 591-603.

[37] C. J. Walsh, A. K. Sharpe, P. F. Breen, and J. A. Sonneman, 2001. "Effects of urbanization on streams of the Melbourne region, Victoria, Australia: Benthic macro-invertebrate communities,” *Freshwater Biology*, vol. 46, pp. 535-551.

[38] P. S. Giller, and H. Twomey, 1993. “Benthic macro-invertebrate community organisms in two contrasting Rivers between-site differences and seasonal patterns,” *Biology and environment: Proceedings of the Royal Irish Academy*, 93B, pp. 114-126.

[39] J. L. Reed, I. C. Campbell, and P. C. E. Bailey, 1994. “The relationship between assemblages and available food at forest and pasture sites in three south-eastern Australian streams,” *Freshwater Biology*, vol. 32, pp. 641- 650.

[40] F. Beksisa, A. Lakew, Prabha Devi and Wolfram Graf, 2016. “Macroinvertebrate Communities in the spring and Stream Sites of Upper Awash River at Chilimo, Ethiopia,” *Innovative Techniques in Agriculture*, vol. 13, pp. 141-151.

[41] A. Kumar, T. A. Qureshi, and P. Alka, 2006. Biodiversity assessment of macroinvertebrates in Ranjit Sagar reservoir, Jammu, J and K, India. *Journal of Aquatic Biology*, vol. 21, no. 2, pp. 39-44.

[42] H. B. N. Hynes, 1960 .*The Biology of Polluted Waters*, Liverpool University Press, Liverpool, England, pp. 202.

[43] B. J. Biggs, I. G. Jowett, J. M. Quinn, C. W. Hickey, R. J. Davies-Colley, and M. Close, 1990. “Ecological characterization, classification, and modeling of New Zealand Rivers: An introduction and synthesis,” *New Zealand Journal of Marine and Freshwater Research*, vol. 24, pp. 277-304.

[44] A. Chimdo, 2016. “Longitudinal zonation patterns of benthic macroinvertebrates along upper Awash River, Dandi district, West Shoa zone, Ethiopia,” M.Sc. Thesis, Addis Ababa University, Ethiopia.

[45] W. L. Hilsenhoff, 1988. “Rapid Field Assessment of Organic Pollution with a Family-Level Biotic Index,” *Journal of the North American Benthological Society*, vol. 7, no. 1, pp. 65-68.

[46] Environmental protection Authority (EPA), 2003. *Guideline Ambient Environment Standard for Ethiopia*, Prepared by Environmental Protection Authority in collaboration with the United Nations Industrial Development Organization, Addis Ababa, pp. 101.

[47] L. L. Yuan, 2004. “Assigning macroinvertebrate tolerance classifications using generalized additive models,” *Freshwater Biology,* vol. 49, pp. 662-677.

[48] S. Leta, F. Assefa and D. Gunnel, 2003. “Characterization of Tannery waste water and assessment of downstream pollution profiles along Modjo River in Ethiopia,” *Ethiopian Journal of Biological Science*, vol. 2, no. 2, pp. 157-168.

[49] J. E. Colt, and J. R. Tomasson, 2001. *Hatchery water supp*ly and *treatment: Fish Hatchery Management*, American Fisheries Society, Maryland, USA, pp. 91-186.

[50] M. Tilahun, 2012. “Study on abundance and distribution of benthic macroinvertebrates in river Guder, Ethiopia,” M. Sc. Thesis, Ambo University, Ethiopia.

[51] D. Mammo, 2004. “An assessment of downstream pollution profile of Sebeta River and its Surroundings,” M. Sc. thesis, Addis Ababa University, Ethiopia.

[52] R. Lowrance, R. Todd, J. Fail, O. Hendrickson, R. A. Leonard, and L. Smussen, 1984. “Riparian forests as nutrient filters in agricultural watersheds,” *Bioscience,* vol. 34, no. 6, pp. 374-377.

[53] J. R., Cooper, J. W. Gilliam, and T. C. Jacobs, 1986. *Riparian areas as a control of non-point pollutants*, In, D.L. Correll (ed.) Watershed Research Perspectives, Smithsonian Institution Press, Washington D.C., pp. 166-190.