Ethiopian Journal of Water Science and Technology (EJWST)

DOI: https://doi.org/10.59122/16519g6

Vol. 6 , 2023, pages: 1~16 ISSN(Print): 2220-7643

Water Quality Status of *Washa* and *Borale* Reservoirs Using Physicochemical Parameters and Macroinvertebrates in Ethiopian Central Highlands

[1]Girum Tamire, *[1]Admasu Moges, [2]Bezuayehu Tadesse, [1]Mastewal Hailemariam

[1]Department of Biology, College of Natural and Computational Sciences, Debre Berhan University Debre Berhan, Ethiopia, P.O.Box 445
[2]Department of Chemistry, College of Natural and Computational Sciences, Debre Berhan University Debre Berhan, Ethiopia, P.O.Box 445
***Corresponding author: Email: mogesadmasu@gmail.com, Mobile: +251913487398

ABSTRACT

Washa and *Borale* reservoirs are important in regulating climatic and ecological conditions and providing various economic services. However, water quality and/or ecological health status of reservoirs has not yet been properly assessed in Ethiopia. Therefore, the main purpose of this study was to assess the water quality status of the *Washa* and *Borale* reservoirs/ wetlands located in North Shewa Zone of Ethiopian Central Highlands. Their water quality status was assessed using water physicochemical parameters and macroinvertebrates in December 2020 and November 2021. The results recorded from *Washa* Reservoir showed that the concentration of nitrate, phosphate, ammonia and silica on average was 69 µg/L, 53.52 µg/L, 188.86 µg/L and 14 µg/L, respectively. Similarly, the concentration of nitrate, phosphate, ammonia and silica obtained from *Borale* Reservoir on average was 43.5 µg/L, 32.6 µg/L, 50.0 µg/L and 109.8 µg/L, respectively. The concentration of ammonia was found to be high in both reservoirs indicating the presence of organic contamination. The total number of macroinvertebrates collected from *Washa* and *Borale* reservoirs were 519 and 789, respectively. Eight families belonging to three orders were recorded in *Washa* Reservoir whereas seven families belonging to four orders were recorded in *Borale* Reservoir. Order Hemiptera was represented by 5 families, Coleptera by two and Ephemeroptera by one in *Washa* Reservoir. Similarly, Hemiptera was represented by four families compared to other orders in *Borale* Reservoir. High dominance of tolerant macroinvertebrate families and absence of sensitive families indicated ecological instability and pollution in *Borale* Reservoir. Besides, ecological disturbance and pollution are observed in Washa Reservoir. Hence, human interference and cattle drinking should be regulated before both reservoirs are impaired permanently.

Keywords: Central Ethiopia, Evaluation, Wetlands, Water parameters, Water pollution

Received: 29 Apr 2023 ; accepted 20 May 2023

1. INTRODUCTION

1.1. Background and Justification

Reservoirs are lacustrine wetlands with immense ecological and economic importance. They can help in checking floods, generating electricity, providing storage for drinking water and irrigation etc. Such systems are particularly critical for supporting human livelihoods in Africa (Chapman *et al*., 2001; Rebelo *et al*., 2010). They also play vital roles in retaining runoff and sediments, and in purifying wastewaters so that they serve as sink, runoff receivers, wastewater filters and transformation systems of pollutants. Moreover, they provide many important functions including habitat and food provision for plants and animals, and processing of pollutants derived from extensive agriculture and urban development (Wetzel, 2006). Especially, wetlands are habitats (living areas) to remarkable number of animals, plants, macroinvertebrates and amphibians (U.S. EPA, 2002b). Most of the aquatic flora and fauna depend entirely on wetlands and are attracted by the presence of high habitat qualities (Zedler and Kercher, 2005).

Despite providing such biodiversity conservation and socio-economic services, such lacustrine wetlands have severely been degraded worldwide, particularly in developing nations like Ethiopia. The greatest threats and causes of the wetland degradation and loss are mainly associated with anthropogenic activities. The main anthropogenic activities are cultivation, drainage, plantation, overgrazing, and water extraction and waste discharges (Crecious and Lazarou, 2013; Moges *et al*., 2018). Moreover, development activities such as soil excavation, unplanned construction and urbanization, and excessive exploitation of resources of wetlands (Schuyt, 2005) are the other major pressures to degradation and loss of such reservoirs. Generally, these activities have severely affected the wetland ecosystems by altering their flora composition, physicochemical characteristics of waters, and their physical structures. Furthermore, dumping domestic and industrial wastes predominantly in the urban wetlands (Beyene *et al*., 2009) and adding nutrients via runoff mainly to agricultural wetlands are other sources of pollution and ecological degradation. As a consequence, many wetlands in Ethiopia are under severe threats (Ambelu *et al*., 2013; Moges *et al*., 2018).

Nearly 690 households are living in the present study area (01 kebele) of *Debre Birhan Town.* Of which 58 and 149 households, belonging to *Washa* and *Borale*, respectively, have irrigable lands at downstream and harvest various vegetables and cereal crops at least twice a year by drawing water directly from the reservoirs. Moreover, these reservoirs provide water for domestic uses and animal drinking and recreational services to the surrounding communities. The reservoirs also support different kinds of birds besides aquatic vegetation. Moreover, farming and grazing activities are practiced in the catchments of these reservoirs. As a result, these two reservoirs are under threats like that of other surface water bodies found in Ethiopia owing to water extraction for irrigation at downstream and livestock drinking, faming, and grazing practices. Thus, this situation calls for immediate assessment of water quality of the two reservoirs. For evaluating the water quality/pollution extent of the two reservoirs, physicochemical parameters and macroinvertebrates are used because the integrated use of physicochemical characteristics and biological communities in surface water of wetlands/ reservoirs helps to determine their condition or health (U.S. EPA, 2002a) in a better way. Sharma and Rawat (2009) also reported that macroinvertebrates and water quality are interrelated as they are indicators of water quality and they easily respond to pollutants and eutrophication. Thus, the major physicochemical parameters and macroinvertebrate communities are analyzed for evaluating the water quality of the present reservoirs. Therefore, the specific objectives of this study are to: (1) analyze the major water quality parameters, (2) calculate the macroinvertebrates composition, abundance and diversity using various Shannon-Weiner diversity indices, and (3) determine the water quality status of the two reservoirs based on the results of both water quality parameters and various indices for macroinvertebrate communities.

2. MATERIALS AND METHODS

2.1. Description of the study area

This study was carried out in *Washa* and *Borale* Reservoirs/ wetlands located at the periphery of Debre Berhan town, but now included to be the part of 01 Kebele (which is the smallest governmental administrative unit in Ethiopia) of DBU of North Shewa Zone, Ethiopian Central Highlands (Figure 1). The *Washa* and *Borale* sites are 10 and 15 km far from the center of the town, with altitudes of 2763 and 2832 meters above sea level, respectively. The *Washa* site is positioned at 9^{0}39’45” latitude and 39^{0}32’45” longitude; whereas the *Borale* site is located at 9^{0}39’62” latitude and 39^{0}32’36” longitude. The temperature of DBT ranges from the mean annual minimum temperature of 2.3^{0}c to the mean annual maximum temperature of 22^{0}c. The mean annual rainfall of the study area is 906 mm.

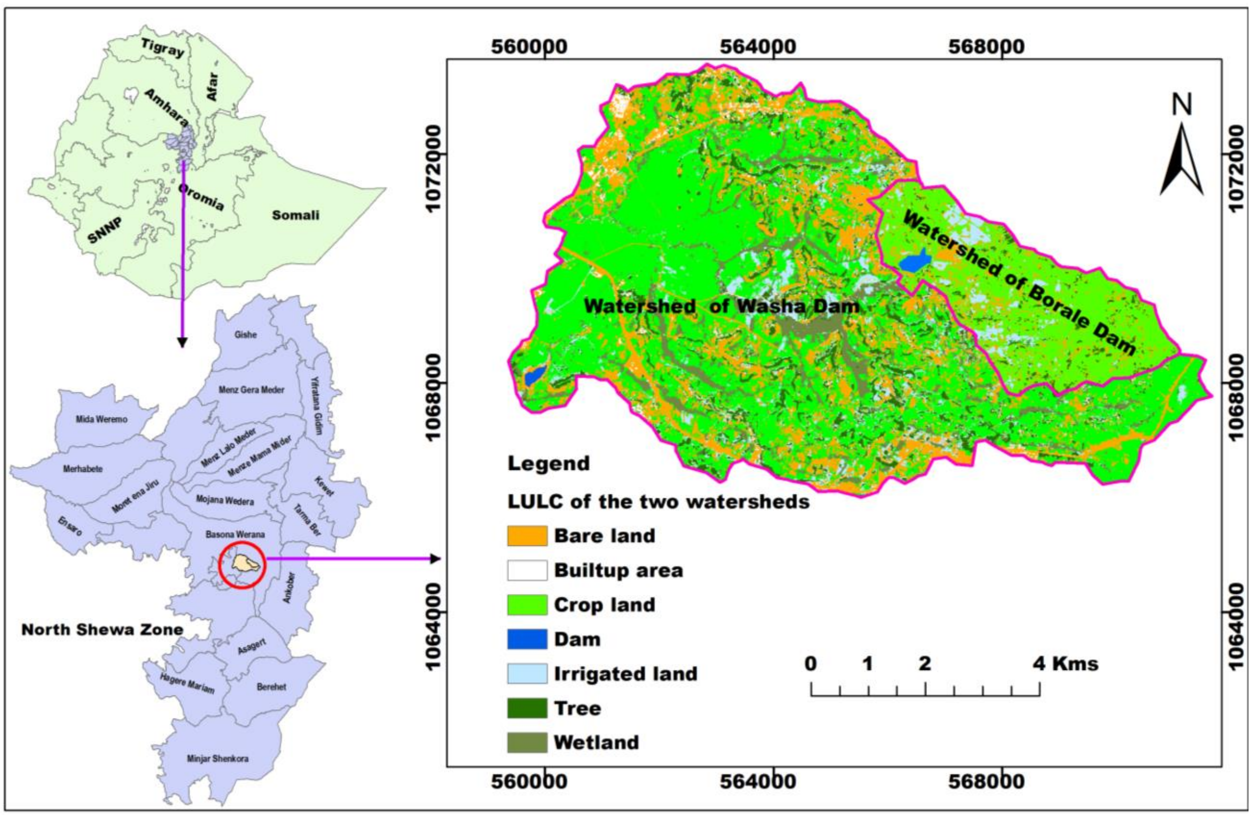

Figure 1: A map of the study area (Source: Moges and Mebrate 2022)

2.2. Study design and sampling

Preliminary survey was conducted on both reservoirs in November, 2020 to gather general information on the physical characteristics of the study area such as watershed features, littoral vegetation, and human pressures. Accordingly, the sites for habitat quality assessment were selected purposively in both reservoirs based on the stressor types (distance from human settlements and anthropogenic effects) and accessibility for quantitative study. For habitat quality assessment, three habitat plots: hab-plot "A'', hab-plot " B'' and hab-plot "C'' were selected following Lake Habitat Survey (LHS) procedure as outlined in McGoff and Irvine (2009). Each hab-plot covered approximately 100 m of shoreline length. The assessment was done visually and scored through observation.

2.3. Sampling sites of the two wetlands

2.3.1. Sampling sites of *Washa*

Hab-Plot ''A'': This plot is located in the Northwest of *Washa* Wetland. The site is characterized by sparsely distributed emergent macrophytes and highly exposed to animal interactions.

Hab-Plot ''B'': This site is bordered by agriculture land. The topography of the site is slant.

Hab-Plot ''C'': This site is characterized by stony bedrock or sediment and relatively sheltered by the dam.

2.3.2. Sampling sites of *Borale* Wetland

Hab-Plot ''A'': This plot has no buffer and characterized by cattle watering, agriculture practices, high rate of siltation.

Hab-Plot ''B'': No agricultural activity is observed in this site. Relatively, it is vegetated and has a buffer. More cattle watering is observed.

Hab-Plot ''C'': This site is characterized by stony bedrock or sediment and relatively protected.

2.4. Sampling procedures and laboratory analysis of water and macroinvertebrate samples

Sampling was done in December 2020 and November 2021. Each wetland was sampled two times: first in a dry season and second in a wet season. Dissolved oxygen, electrical conductivity, water temperature, and pH were measured *in situ* using pre-calibrated multimeter hand-held probe, model HQ40D. Replicated composite water samples were collected with a 1L plastic bottle from each site, labeled with collection point, stored in an ice box prior to analysis and transported to Addis Ababa Limnology Laboratory. In the laboratory, water samples were filtered through 0.45 µm glass fiber filters (GF/F). Then Nitrate (μgL^{-1}) was measured using cadmium reduction and phosphate (μgL^{-1}) was measured using ascorbic acid methods according to spectrophotometer (HACH, DR/2010, USA) procedures as outlined in APHA (1999). Then concentrations of nutrients were calculated. Ammonia was analyzed by the Phenate Method whereas Dissolved SiO_2 (only Molybdate reactive Silica) was analyzed using Molybdosilicate method following APHA et al. (1999) guideline.

Benthic macroinvertebrates were sampled using D-frame net with mesh size of 500µm (Baldwin *et al*., 2005). The net was moved in a vigorous action for 5 minutes at each site to dislodge macroinvertebrates attached to substrates (Baldwin *et al*., 2005). Macroinvertebrates were sorted out from other debris and then were preserved using 4% formalin, placed into polyethylene plastic bags, labeled and transported to Zoological Sciences Laboratory of Debre Berhan University (DBU) for identification and enumeration. Macroinvertebrates in the samples were identified by family level using combination of keys (Gerber and Gabriel, 2002; Bouchard, 2012) and a dissecting microscope. Subsequently enumeration was done following Baldwin *et al*. (2005).

2.5. Data analysis

The presence of significant variations between the sites in terms of measured physico-chemical parameters and abundance of macroinvertebrates was tested using one-way ANOVA followed by TUKEY test for significant variations.

3. RESULTS

3.1. Physico-chemical parameters of the reservoirs

Concentration of nitrate, phosphate, ammonia, and silica ranged between 44.86- 89 µg/L, 38.8-72.7 µg/L, 131.57- 280 µg/L and 11.02- 22 µg/L (Table 1) in *Washa* Reservoir, consecutively. whereas, At *Borale* Reservior, however, the concentration was different: 3.4- 89.14 µg/L, 0.8-52.8 µg/L, 20- 93 µg/L and 17.7- 131 µg/L (Table 2). All measured physico-chemical variables in both reservoirs showed significant variations seasonally. High concentration was noticed during post-rainy season (Table 3 and 4**)**. However, phosphate (SRP) and nitrate ($P<0.05$) showed significant spatial variation in *Washa* Reservoir; whereas, these variations were brought due to Nitrate, Silica, and DO ($P<0.05$) in *Borale* Reservoir. Spatial comparison between sites indicated higher concentration of soluble reactive phosphate (SRP), DO, and ammonia in Hab-Plot A at *Washa* Reservoir, while nitrate was higher in Hab-Plot B (Table 3). Dissolved Oxygen level was the lowest in Hab-Plot B (Table 3). In *Boral*e Reservior, Hab-Plot C showed significantly higher nitrate ($P<0.05$) and lower Silica ($P<0.05$) than the other two sites (Table 4). Dissolved oxygen was significantly highest at Hab-Plot A compared to the other two sites (Table 4). The other parameters didn't show significant variations among sites in both reservoirs. Conductivity and pH were relatively higher in *Borale* Reservoir. However, temperature and dissolved oxygen level were comparable in these two reservoirs (Table 3 and 4).

Table 1: Physicochemical parameters of *Washa* Wetland

Parameters	Min	Max	Average	Standard deviation
Nitrate (µg/L)	44.86	89	69	14.8
Phosphate(µg/L)	38.8	72.7	53.52	10.36
Ammonia(µg/L)	131.57	280	188.86	46.8
Silica(µg/L)	11.02	22	14.9	3.99
pH	6.2	8	7	0.9
Temperature (^{o}C)	16.3	20	18.4	1.9
DO (mg/L)	6.5	10	7.9	1.8
Conductivity (µS/cm)	18.64	21.12	19.9	1.2

Table 2: Physico-chemical parameters of *Borale* Wetland

Parameters	Min	Max	Average	Standard deviation
Nitrate (µg/L)	3.43	89.14	43.5	32.65
Phosphate (µg/L)	0.8	52.8	32.6	16.78
Ammonia (µg/L)	20.14	93	50	24.22
Silica (µg/L)	17.7	139.1	109.8	39.85
pH	6.27	8.5	7.9	0.8
Temperature (^{o}C)	10.5	21	16.4	3.7
DO (mg/L)	3.8	8.5	6.7	1.8
Conductivity (µS/cm)	55	86.4	73.2	10.2

Table 3: Physicochemical parameters during dry and wet season taken in *Washa* Wetland

	Parameters	Dry Season			Wet Season		
		Plot A	Plot B	Plot C	Plot A	Plot B	Plot C
1	SRP (µg/L)	58.4	45.1	41.8	70.5	55.6	49.35
2	Nitrate (µg/L)	45.6	64.3	65.5	66	85	87.5
3	Ammonia (µg/L)	178.76	151	134	216	211.5	211.5
4	Silica (µg/L)	11.75	12.5	11.6	15	17	21.5
5	pH	7.1	6	7.8	6.7	6.4	8.2
6	Temperature (^{0}C)	17	19	22	14.9	17	18
7	DO (mg/L)	8	6.5	7	10	7.5	8.5
8	Conductivity (µS/cm)	21	23	19.2	19	20.6	18

Table 4: Physicochemical parameters measured during dry and wet season in *Borale* Wetland

	Parameters	Dry Season			Wet Season		
		Plot A	Plot B	Plot C	Plot A	Plot B	Plot C
1	SRP (µg/L)	32.8	48.2	1	45.8	39.8	29.5
2	Nitrate(µg/L)	14.85	23	88.7	77.71	51.3	4.9
3	Ammonia(µg/L)	32.5	72.1	31.1	89.1	36.3	38.7
4	Silica (µg/L)	13.7	12.5	24.9	12.6	12.9	11.8
5	pH	8	8	7.1	8.6	8.6	7.7
6	Temperature (^{0}C)	19	18.9	17.7	17	15.1	16.6
7	DO (mg/L)	7.8	7	3.8	8.5	7.8	6
8	Conductivity (µS/cm)	70	88	82	76	85	78

3.2. Macroinvertebrate distribution in *Washa* and *Borale* Reserviors

The total number of macroinvertebrates collected in this study was 519 (in *Washa*) and 789 (in Borale). Eight families which belonged to three orders were recorded in *Washa* Reservoir (Table 5), whereas seven families belonging to four orders were recorded in *Borale* Reservoir (Table 6). Order Hemiptera was represented by 5 families, Coleptera by two and Ephemeroptera by one in *Washa* Reservior. Similarly, Hemiptera were represented by four families compared to other orders in *Borale* reservoir, whereas Coleptera, Tricoptera and Class Hirudinea were represented by one family each. Corixidae and Chironomidae comprised 64.5% of the total individuals in *Washa* Reservior (Figure 2), whereas Belostomatidae and Chironomidae comprised 90% in *Borale* Reservior (Figure 3). These results indicated a high dominance of the two pollution resistant families in both Washa and Borale reservoirs. This, in turn, showed the presence of higher pollution contaminants in both reservoirs. Pleidae, Veliidae, and Notonectidae were rarely (<5% each) observed in *Washa* while Philipotamidae, Velidae, Corixidae, and Leeches were rarely observed in *Borale* Reservior.

Among the identified families in *Washa* Reservior, seven of them were observed in Hab-Plot C (Table 7). Similarly, Corixidae and Chironomidae families were abundant in this site. . Belostomatidae was abundant at Hab-Plot C during the dry season. Nevertheless, Chironomidae was abundant at Hab-Plot A (Table 8).

Table 5: Macroinvertebrate family identified in *Washa* Wetland and their relative abundance

Family	Abundance (sum)	Relative abundance
Corixidae	227	0.451
Chironomidae	108	0.215
Haliplidae	48	0.095
Veliidae	16	0.032
Baetidae	42	0.083
Belostomatidae	37	0.074
Pleidae	19	0.038
Notonectids	6	0.012

Table 6: Macroinvertebrate family identified in *Borale* Wetland and their relative abundance

Family	Abundance	Relative abundance
Chironomidae	216	0.276
Belostomatidae	494	0.631
Philapotamidae	32	0.041
Corixidae	14	0.018
Notonectidae	19	0.024
Leeches	4	0.005
Velidae	4	0.005

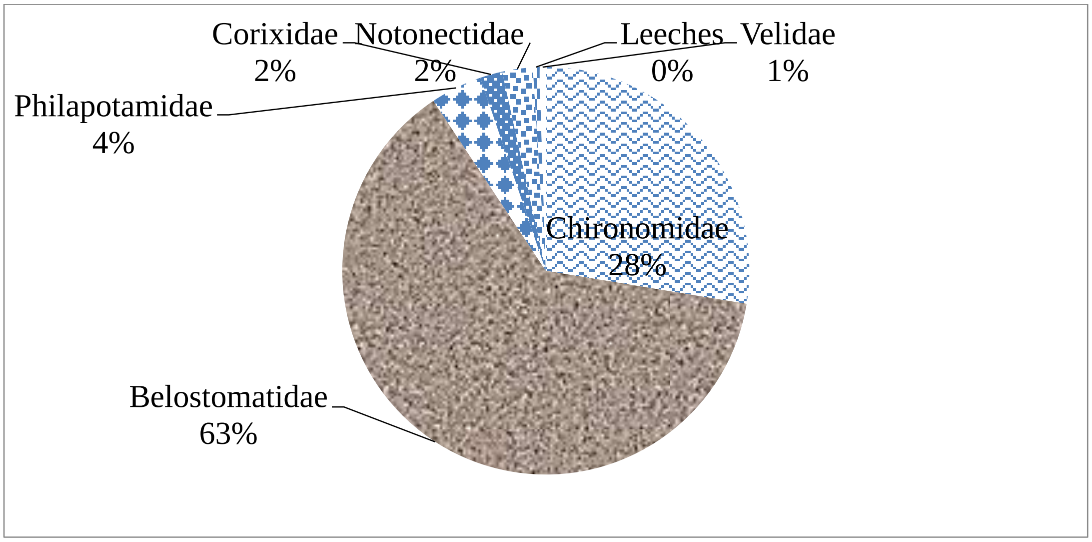

Figure 2: Macoinvertebrate families' percentage in *Wash* Wetland

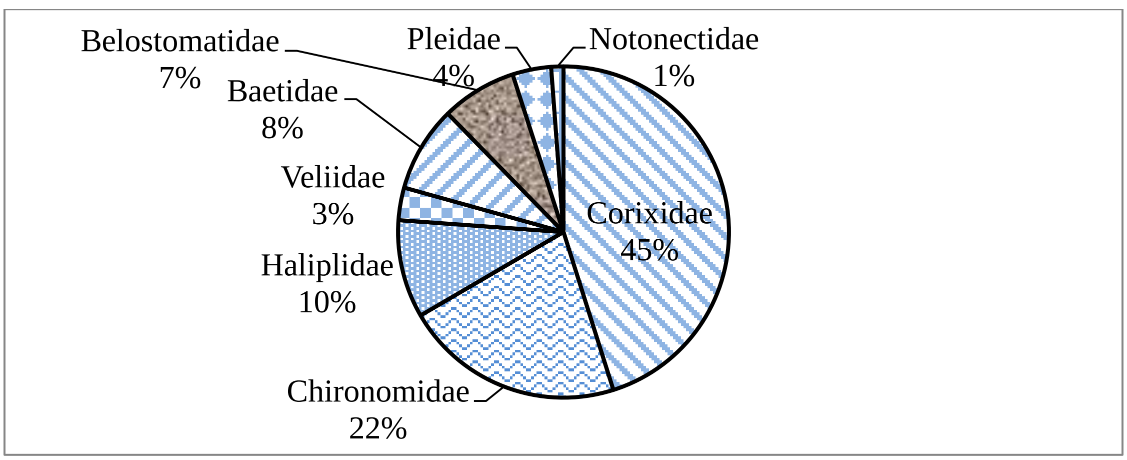

Figure 3: Macoinvertebrate families' percentage in *Borale* Wetland

Table 7: Abundance of macroinvertebrate families across the three plots in dry and wet seasons in *Washa* Reservoir

	Family	Dry Season			Wet Season		
		Plot A	Plot B	Plot C	Plot A	Plot B	Plot C
1	Chironomidae	57	26	5	77	46	5
2	Belostomatidae	18	92	137	28	82	13
3	Philapotamidae	4	2	0	14	12	0
4	Corixidae	2	0	0	12	0	0
5	Notonectidae	0	9	5	0	0	5
6	Leeches	0	2	0	0	2	0
7	Velidae	0	0	2	0	0	2

Table 8: Abundance of macroinvertebrate families across the three plots in dry and wet seasons in *Washa* Reservoir

	Family	Dry season			Wet season		
		Plot A	Plot B	Plot C	Plot A	Plot B	Plot C
1	Corixidae	27	8	82	35	10	65
2	Chironomidae	10	9	17	43	13	16
3	Haliplidae	6	5	6	10	0	21
4	Veliidae	6	0	0	10	0	0
5	Baetidae	0	3	11	0	5	23
6	Belostomatidae	0	10	1	0	23	3
7	Pleidae	0	14	5	0	0	0
8	Notonectids	0	0	6	0	0	0

4. DISCUSSION

Most of the measured physico-chemical parameters in this study revealed that both reservoirs had moderate water quality though there was spatial difference with respect to water quality among the sites. All the measured parameters in this study were found to be lower when compared to the same parameters in Koka Reservoir, except Ammonia (Habtamu, 2019) and Angrehb Reservoir except for DO (Alebachew, 2018).

The safe range of pH for drinking water is from 6.5 to 8.5 for domestic use and living organisms need (WHO, 2011). In this regard, it is fair to consider the mean pH level of both reservoirs if it serves the aforementioned purpose. DO level of *Washa* Reservoir is suitable for productivity of aquatic organisms more particularly for fish. Fish species such as *Cyprinus carpio* can survive in such environment as they can tolerate lower temperature. However, ammonia level was highest compared to the reservoirs mentioned, more particularly in *Washa* Reservoir. High level of ammonia in aquatic system is often an indication of fecal contamination (WHO, 2011). In this case, the water may be contaminated with fecal matter from nearby livestock. On the other hand, lower level of nitrate was recorded in both reservoirs compared to Angrheb and Koka Reservoirs. This indicated that the pollution extent of the two reservoirs' water was relatively low compared Angrheb and Koka reservoirs, but still there was pollution in Washa and Borale reservoirs, as there was high level of ammonia in the reservoirs. Hence, there were less abundant sensitive macroinvertebrate families.

Significant variation in SRP and ammonia concentration in Hab-Plot A site could be due to exposure to cattle and human interaction. However, a relatively stony edge (Dam) around Hab-Plot C might serve as buffer zone and could be the reason for lower level of the mentioned parameters. In *Borale* Reservior, cattle watering, agriculture practices, the absence of buffer, and high rate of siltation could contribute to lower oxygen level at Hab-Plot A. A lower oxygen concentration in a site ensures the presence of pollution resistant macroinvertebrate families.

The total number of macroinvertebrate individuals and taxa were much lower compared to similar other works (Ambelu *et al,* 2013; Alebachew, 2018; Yirga and Brook, 2019). Taxa richness is the measure of community's diversity and number of different families found in samples of each site. Reduction in community diversity is commonly associated with various forms of environmental pollution, including nutrient loading, toxic substances, and sedimentation (Yirga and Brook, 2019).

Reservoirs have generally a reduced diversity of benthic fauna as compared with natural lakes. Pamplin *et al*. (2010) observed the occurrence of few faunistic groups with low species number in each group and the majority of the species occurring with very low abundance in Americana Reservoir. In addition to the environmental degradation, the low abundance of insects in sediment of these reservoirs could be due to the preference of these organisms for free floating vegetation banks, especially *Eichhornia crassipes*, *Pistia stratiotes*, *Salvinia auriculata and Polygonum spp* (Tavares *et al*., 2004) which are absent in these reservoirs. These plants provide diversified habitats for macroinvertebrates, with wide food resources, breeding places and refugia (shelters) against predators.

The dominance of Hemiptera in these reservoirs indicated the presence of pollution as Hemipterans are relatively tolerant of many forms of pollution (Gooderham and Tysrlin, 2002). Both reservoirs were dominated by tolerant taxa such as Belostomatidae (10), Corixidae (9), and Chironomidae (8) which were good indicators of instability and highly modified with shoreline modification. With increased water pollution, some sensitive groups like EPT taxa will disappear being replaced by more hardy and tolerant groups (for example, Chironomids, Oligochaetes, Syrphidae) (Richard *et al*., 1997). The high percentage of a single or some common taxa at sites might be due to instability or high water-level fluctuation in the system. Sellam et al. (2017) also reported that the abundance of tolerant groups (Diptera, Chironomidae, and Hirudinea) increased with habitat disturbances.

5. CONCLUSIONS

Although most of the measured water quality parameters level was in the permissible range for both reservoirs, the concentration of ammonia was found to be at higher level than the normal range which indicated the presence of contamination in these reservoirs. There was also significant spatial variation in the reservoirs. The exposure of the plot sites to human intervention in the two reservoirs showed a relatively lower water quality whereas the relatively protected plot sites showed the opposite. The dominance of tolerant macroinvertebrate families and total absence of sensitive families indicated the presence of ecological instability and pollution in these systems. Hence, human interference and cattle drinking should be regulated before both systems are impaired permanently.

Conflict of interest

There is not any conflict of interests among authors and between authors and funding organization.

Acknowledgement

The authors would like to thank Debre Berhan University for covering this research budget. Moreover, they extend their great appreciation to 01 Kebele administrative officials and experts of Urban Agricultural Office of Debre Berhan Town and Agricultural Department of North Shewa Zone for facilitating and providing us with information during this research work.

REFERENCES

Alebachew, T.S. 2018. Distribution and abundance of benthic macroinvertebrates in Angereb Reservior ecosystem in Gondar, Ethiopia. Entomology, 43:53-60.

Ambelu A., Lock K., Goethals P.L. 2013 Hydrological and anthropogenic influence in the Gilgel Gibe I reservoir (Ethiopia) on macroinvertebrate assemblages. Lake and reservoir management 29: 143-150

APHA 1999. *Standard Methods for the Examination of Water and Waste Water*. 20th edition, American Public Health Association, New York, NY.

Baldwin D.S., Nielsen D.L., Bowen, P.M. and Williams, J. 2005. Recommended methods for monitoring floodplains and wetlands. MD BC Publication no. 70/24.

Beyene, A., Legesse W., TriestL. Kloos H., 2009. Urban impact on ecological integrity of nearby rivers in developing countries: the Borkena River in highland Ethiopia. *Environmental Monitoring and Assessment* 153(1–4): 461–476.

Bouchard, W. 2012. Guide to Aquatic Invertebrate Families of Mongolia, Saint Paul, Minnesota, 222pp

Chapman, L.J., Balirwa, J., Bugenyi, F.W.B., Chapman, C., Crisman, T.L., 2001. Wetlands of East Africa: biodiversity, exploitation and policy perspectives. In: Gopal, B., Junk, W.J., Davis, J.A. (Eds.), *Biodiversity in Wetlands: Assessment, Function and Conservation*, Backhuys Publishers, 2:101-131.

Gerber, A., Gabriel, M.J.M., 2002. Aquatic invertebrates of South Africa Rivers. Institute of Water Quality Study, South Africa.

Gooderham,J.,Tysrlin, E.2002. The Water Bug Book. A guide to the freshwater macroinvertebrates of temperate Australia. Australia, CSIRO Publication.

Habtamu G. 2019. Effects of water hyacinth (*Eichhornia crassipes*) on water quality and composition and abundance of phyto and zooplankton in the littoral region of Koka Reservoir, Ethiopia.

McGoff E.,Kenneth Irvine, K. 2009. A test of the association between Lake Habitat Quality Assessment and macroinvertebrates community structure. Aquatic Conservation: Marine and Freshwater Ecosystems. *Aquatic Conservation: Marine and Freshwater Ecosystem*, 19:520–533.

Moges, A., Beyene, A., Triest, L., Ambelu, A., Kelbessa, E., 2018. Imbalance of ecosystem services of wetlands and the perception of the local community towards their restoration and management in Jimma Highlands, Southwestern Ethiopia. Wetlands, 38, 1081-1095.

Moges A., Mebrate T. 2022 "Ecological Conditions and Ecosystem Services of Artificial Wetlands in Semiarid Ethiopian Highlands", *International Journal of Ecology*, https://doi.org/10.1155/2022/7667611.

Pamplin P.A.Z., Almeida T.C.M., Rocha O. R. 2010. Composition and distribution of benthic macroinvertebrates in Americana Reservoir (SP, Brazil). *Acta Limnol. Bras.*, 18(2):121-132.

Rebelo, L. M., McCartney, M. P. and Finlayson, C. M. (2010). Wetlands of Sub-Saharan Africa:distribution and contribution of agriculture to livelihoods. Wetlands Ecology and Management, 18(5): 557-572.

Richards C., Haro R.J., Johnson L.B., Host G.E.,1997. Catchment and reach scale properties as indicators of macroinvertebrate species traits. *Fresh water Biology*, 37: 219-230.

Sellam N, Zouggaghe F., Pinel B., Mimouni A., Moulaï R. (2017). Taxa richness and community structure of macroinvertebrates in rivers of different bioclimatic regions of Algeria. Journal of Material and environmental Science, 8: 1574-1588.

Sharma R.C., Rawat, J.S. 2009. Monitoring of Aquatic Macroinvertebrates as bioindicator for assessing the health of wetlands: A case study in the central Himalyas, India. *Ecological Indicators*, 9: 118-128.

Tavares K.S., Rocha O., Espindola, E.L.G., Dornfeld C.B.2004. Composição taxonômica da comunidade de macrófitas aquáticas do reservatório de Salto Grande (Americana, SP). In: Espíndola, E.L.G.,Leite, M.A. & Dornfeld, C.B. (orgs.) *Reservatório de Salto Grande (Americana, SP): caracterização, impactos e propostas de manejo. Editora Rima, São Carlos.* p.239252

U.S. EPA 2002a. Methods for evaluating wetland condition using vegetation to Assess environmental conditions in wetlands. Office of Water, United State Environment Protection Agent, Washington DC.

U.S. EPA2002b. Methods for evaluating wetland condition: developing an invertebrate index of biological integrity for wetlands. Office of Water, United State Environmental Protection Agent, Washington DC.

Wetzel R.G.,2006. *Limnology: Lake and River Ecosystems*. Academic Press, U.S.A. 1006pp.

WHO 2011. Guidelines for drinking water quality, fourth edition, 564pp.

Yirga, E., Brook L. 2019. Ecological Conditions and Benthic Macroinvertebrates of Lake Tinishu Ababya, Ethiopia. Oceanography and Fishery, 10: DOI; 10.19080/OFOAJ.2019.10.555782

Zedler, J.B., Kercher, S. 2005. Wetland Resources: Status, Trends, Ecosystem Services, and Restorability. *Annual Review of Environment and Resources*, 15 (30). 39-74.