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RESEARCH ARTICLE

A COMPARATIVE STUDY OF TWO BIOLOGICAL MONITORING SYSTEMS IN ASSESSING WATER QUALITY: A CASE OF RIVER BIRIRA, SHEEMA DISTRICT, UGANDA

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ABSTRACT

River Birira stretches through Kitagata town council and near Kitagata hot springs in southwestern Uganda. These areas receive an inflow of people that utilize the hot springs because of the belief of healing associated with the water. This has led to increased human activities along river Birira, which may negatively impact on the ecological integrity of the river. A number of countries have developed biological monitoring systems to assess the water quality of rivers and streams, however non has been developed specifically for Uganda. This study therefore aimed to assess the water quality of river Birira and determine the compatibility and usability of Biological Monitoring Working Party (BMWP) and Tanzania River Scoring System (TARISS) biological monitoring systems in a Ugandan setting. In this study, four sampling sites were selected basing on human activities taking place along river Birira. The sites were assessed for both physico-chemical and biological parameters using standard methods. In this study 9 physicochemical parameters were used in the computation of water quality index (WQI). Findings of this study indicated that sites in close proximity with the bathing pool of Kitagata hot springs were severely impacted and had undesirable water quality. Results also showed that the water of river Birira is generally unsuitable for human consumption, therefore, needs thorough treatment before consumption and domestic use. This study further revealed that both BMWP and TARISS monitoring systems give similar deductions about the water quality of river Birira. Therefore, any one of the monitoring systems can be adopted in assessing the water quality of the River.

KEYWORDS

Bioindicator, Water quality index, Physico-Chemical, River ecological integrity.

1. INTRODUCTION

Rivers and streams in most parts of the world are threatened despite of the benefits and services they provide to humans. For rivers, this is particularly expected in most urbanizing areas with limited municipal infrastructure to handle both industrial and domestic wastes (Qin et al., 2014). In many areas, such waste is usually discharged into local rivers with hope that it will be flushed with minimum negative impact on local environment and biodiversity (Nasrullah et al., 2006). Unfortunately, this is not the case for point source pollution where effluent discharged influences the water chemistry and habitats in ways that reduce their integrity (Jiake et al., 2011). This increases costs of treating water for public supply thus making it expensive especially in developing countries. According to WHO, 844 million people in the world lack a basic drinking water service and 159 million people depend on surface water sources most of which are threatened by human activities (WHO, 2008). The highest proportion of such population is in developing countries including Uganda. In addition, WHO projects that by 2025, half of the world's population will be living in water stressed areas if the threats on water especially human activities are not checked. According to Uganda National Water and Sewerage cooperation, 34% of the villages and 26% of urban areas in Uganda lack access to safe drinking water (NWSC, 2018). Therefore, this population depends on surface water especially river water which in most cases is contaminated. NEMA states that Ugandan water bodies continue to experience reduction in water volume and deterioration in water quality due to human activities (NEMA, 2010).

Over the past decades, countries and organizations worldwide have been developing indicators to identify the stressor effects on water quality (Szczerbinska and Galczynska, 2015). Biological Monitoring Working Party (BMWP) was developed to assess the water quality of European rivers while Tanzania River Scoring System (TARISS) was developed for Tanzanian rivers (Hawkes, 1998; Kaaya et al., 2015). These assign scores to aquatic macroinvertebrates depending on their sensitivity or tolerance to pollution. BMWP has a maximum score of 10 while TARISS has a maximum score of 15 but all have been developed to assess river and stream health. Macroinvertebrates have been widely used for determining natural and anthropogenic influences on water resources and habitat because they respond to stresses from multiple spatial and temporal scales (Hawkes, 1998). Furthermore, the use of aquatic organisms in environmental monitoring studies has proven to be effective than physicochemical parameters because the biotic communities integrate structural and functional characteristics to reflect health of an aquatic system (Resh et al., 1995; Park and Hwang, 2016; Friberg et al., 2011). Moreover, freshwater macroinvertebrates allow objective classification of biological quality of aquatic sites with varying degrees of degradation. In this regard aquatic macroinvertebrate species vary in sensitivity to organic pollution and thus their relative abundances have

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been used to make inferences about pollution loads (Friberg, 2014). Macroinvertebrates such as leeches and certain fly larvae e.g Chironomids indicate polluted conditions of water. These are also classified as pollution tolerant species. On the other hand, pollution sensitive (intolerant) macroinvertebrates include caddis flies, stone flies and may flies (Xu et al., 2014; Rios-Touma et al., 2014; Karrouch et al., 2017; Hellawell, 2012).

Researchers in Uganda tend to adopt biotic indices e.g BMWP and TARISS in monitoring river water quality, however there is no empirical data on the compatibility of the two biological monitoring systems (BMWP and TARISS) in determining water quality of Ugandan streams and rivers given the fact that diversity of aquatic organisms and their tolerance varies from one region to another hence the need for this study. We therefore aimed to determine the compatibility and usability of the two biological monitoring systems (TARISS and BMWP) in assessing water quality of river Birira in a Ugandan setting. In addition, the fact that activities such as agriculture, bathing in pools around Kitagata hot springs and washing of vehicles occur along river Birira. These activities add wastes and pollutants into the river which may have an impact on physico-chemical and biological parameters of river Birira. Therefore, this study also aimed to assess the effect of Kitagata hot springs proximity and human activities on macroinvertebrate diversity of river Birira. This research is expected to serve as baseline in formulation and implementation of better policies and water conservation programs in Uganda and other countries at large. In addition, the information is intended to act as a guideline in developing corrective measures to improve physico-chemical and biological parameters of water so that people are able to obtain safe water for domestic use.

2. Materials and Methods

2.1 Study Area

River Birira is found in Kitagata Sub County Sheema district, South western Uganda (Figure 1). This is crossed by Kitagata-Kabwohe road and Ishaka-Ntungamo road at a distance of approximately 16 km from Ishaka town and 0.8 km from Kitagata trading Centre respectively. This river passes through Oruya gorge in Kitagata town council and near a component of Kitagata hot springs known as Mulago hot spring, which pours its water into the river. About 300 m away from Mulago hot spring is another hot spring called Omugabe pool. Both hot springs are marked by human activities such as bathing and washing of clothes. There are various human activities carried out around river Birira which include livestock rearing, crop husbandry and washing of vehicles and clothes among others. These activities may add pollutants into the river for example fertilizers from gardens, wastewater from the hot springs and domestic wastes. In this regard this may impact on the biological and physico-chemical parameters of river Birira which is an eminent source of water in Kitagata Sub County (Bahati et al., 2005).

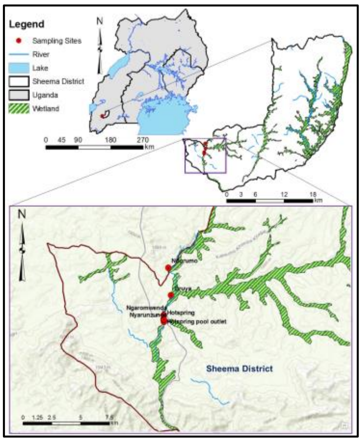

Figure 1: Map of Uganda and Sheema district showing location of river Birira and sampling sites (Source: Drawn from ESRI Arc GIS ver 10.5)

2.2 Water sampling and Laboratory Analysis

2.2.1 Physical chemical parameters

Sampling sites were selected on the basis of human activities taking place along the river (Table 1). A total of four sampling sites were established along the river (Oruya, Ndurumo, Ngaromwenda and Nyaruzinga) whereas two sampling points were established at the hot springs (Centre point of hot spring and hot spring outlet). Water sampling for physico-chemical analysis at the selected sites was done randomly and in replicates of five samples per selected sampling site spanning from January 2019 to March, 2019. Water quality parameters such as pH, Electrical conductivity (E.C), Total Dissolved Solids (TDS) and temperature were determined *in-situ* at the sampling site using a combo pH/Conductivity/TDS Tester (Hanna HI98130®). On the other hand, Dissolved Oxygen (DO) was determined using a portable DO meter (Lutron DO-5510®). In addition**,** five samples were randomly collected into 500 ml clean plastic water sampling bottles from various sampling points at each sampling site. The bottles were appropriately labeled and then samples transported in an Ice box with ice packs to National Water and Sewerage Co-operation (NWSC) station, Bushenyi district for analysis of Total Phosphates, Chlorides, Nitrates, Turbidity and Total hardness using standard methods for the examination of water and waste water as described by American Public Health Association (APHA) (Baird et al., 2012).

Table 1: Description of the Sampling Sites along River Birira

Sites	Description
Oruya	Cattle grazing and crop cultivation on Kagari hills are the main activities carried around this section of the river. The water flow is rapid compared to other sites of the river. The site is located at **0.670611^{0}S** and **30.16375^{0}E**
Ndurumo	This is located in a relatively flat area with limited human activities. The river at this point is surrounded by thick riparian vegetation with un cultivated grassland. This part of the river is characterized by slow flowing water. The site is located at **0.659556^{0}S** and **30.16275^{0}E**
Ngaromwenda	This site is surrounded by shops that facilitate people who visit the hot springs. Washing of clothes and motor vehicles also take place in addition to inflow of water from Omugabe hot spring bathing pool. The location of this site is **0.678389^{0}S** and **30.160917^{0}E**
Nyaruzinga	This section of the river receives wastewater from the Mulago hot spring bathing pool. The riparian vegetation around this section of the river has been greatly reduced mainly by crop cultivation. The site is located at **0.68125^{0}S** and **30.16083^{0}E**

2.3 Computation of Water Quality Index WQI

Water quality index (WQI) offers a numerical value that expresses overall water quality of a particular water body centered on several water quality parameters. In this study WQI was computed by relating the measured value of each parameter to the standard values from Uganda National Bureau of Standards and World Health Organization guidelines for drinking water (UNBS, 2014; WHO, 2017). For the case of dissolved oxygen where no guideline value was stated by WHO/UNBS, a desirable value was adapted from Helmer and Hespanhol (Helmer and Hespanhol, 1997). A total of 9 physical chemical parameters were considered in computation of WQI. The parameters were assigned different weights (w_i) on a scale of 1-5 in ascending magnitude of impact on water quality with 1 indicating least impact on water quality while 5 indicating greatest impact on water quality (Ahmed et al., 2019; Singh et al., 2016; Sutadian et al., 2018). see Table 5. The WQI was computed using the following formulae (1-4).

The relative weight (W_i) calculated using the formula

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (1)$$

Where: W_i is the relative weight, w_i is weight assigned to parameter, and n is the number of parameters.

Consquently, a quality rating scale (Qi) for each parameter was computed using the formula:

$$Q_i = \frac{C_i}{S_i} x100 \quad (2)$$

Where: Q_i is the quality rating, C_i is the measured value of each physico-chemical parameter of the water and S_i is the UNBS/WHO standard value for each physico-chemical paramter according to the WHO and UNBS guidelines for drinking water.

Sub Index (SI) was computed for each parameter using the formula:

$$SI_i = W_i \text{ x } Q_i \quad (3)$$

Where SI_i is the sub index of each parameter, Qi is the quality rating score of each parameter.

WQI was computed using formula 4

$$WQI = \sum_{i=1}^{n} SI_i \quad (4)$$

2.2.2 Macroinvertebrate Sampling

Macroinvertebrates were collected using kick sampling method (Moore and Murphy, 2015). Sampling procedure involved using a scoop net of 20 cm diameter and mesh size 1 mm attached to a handle of a 1.5 m length. The scoop net was placed on the riverbed against the river flow, the substratum upstream was agitated by vigorous kicking and brushing of the scoop net against the riverbed. Macroinvertebrates, organic matter and debris were then swept into the net by the river flow. Furthermore, large stones and macrophytes were hand-picked out at the sampling points and washed into the collecting tray using river water to remove any attached macroinvertebrates. This procedure was carried out at each of the four selected sites (Ndurumo, Oruya, Ngarowenda and Nyaruzinga) along the river with a uniform sampling effort of 60 minutes per sampling site. The macroinvertebrates were sorted, enumerated and transferred, into 200 ml plastic sampling containers having 70 % ethanol for preservation. The samples were appropriately labeled and transported to biology laboratory at Mbarara University of Science and Technology for further identification. Macroinvertebrates were identified to family level using detailed identification keys by (Oscoz et al., 2011; Thorp and Covich, 2009; Kriska, 2013; Heckman, 2006; Thorp and Rogers, 2010; Gerber and Gabriel, 2002; Mann, 2013). Tanzania River Scoring System (TARISS) scores and Biological Monitoring Working Party Index (BMWP) scores were assigned to each family and the Average Score Per Taxon (ASPT) computed for each site using the formula (Zeybek et al., 2014):

$$ASPT = \frac{\text{Sum Scores of all families in a sample(BMWP or TARISS)}}{\text{Number of famlies scored in a sample}}$$

2.3 Data analysis

Data was analyzed using descriptive statistics and presented as Mean ± Standard Error of Mean (SEM). Macroinvertebrates diversity was determined using diversity indices such as the Shannon-Weiner index (H), evenness, dominance using PAST Ver. 3.16. Comparison between physico-chemical and biological parameters among the selected sampling sites was analyzed using One-way ANOVA in SPSS Ver. 20 at 5 % level of significance and consequently LSD post-hoc analysis for multiple comparison. Regression between physico-chemical and biological parameters was performed using general linear model in SAS JMP Version 11.0. Pearson's correlation coefficient was performed to establish the relationship between physico-chemical parameters and biological indices such ASPT in SPSS Ver. 20 at 5 % level of significance.

3. Results and Discussion

3.1 Physico-chemical parameters

3.1.1 pH

pH is known as one of the most important functioning water quality parameters. Processes such as respiration, photosynthesis and chemical decomposition bring about changes in the pH of the water. Chronically low pH levels exert stress on aquatic life (Driscoll et al., 2003). Uganda National Bureau of Standards (UNBS) set recommended pH within a range of 6.5-8.5. The overall pH value recorded in this study lies within the recommended range (Table 2).

3.1.2 Dissolved Oxygen

Dissolved Oxygen is a vital parameter and indicator in water quality assessment because of its indispensable role in the survival of aquatic life. Different aquatic organisms have varying oxygen requirements with some able to survive under hypoxic conditions. DO level of water is often affected by number of aspects such as temperature, chemical and biological processes occurring in the aquatic system (Khatri and Tyagi, 2015). The mean DO recorded in this study ranged from 3.18- 7.00 mg/l with Oruya site and Nyaruzinga site having the highest and lowest mean DO values respectively (Table 2). The overall DO levels in river Birira is above the recommended level of 5.0 mg/l by Helmer and Hespanhol (Helmer and Hespanhol, 1997).

3.1.3 Temperature

In a conventional aquatic system, water temperature controls the rate of all chemical reactions. Therefore, radical temperature changes can impact negatively on aquatic life. River systems naturally show changes in temperature daily and seasonally due to different activities that can contribute to changes in surface water temperature (Tripathi et al., 2014). In this study the lowest temperature was obtained at Oruya site, this is probably due to shading effect by riparian vegetation and low human activities at this site. On the other hand, Nyaruzinga site presented the highest temperature values (Table 2) because of its close proximity to the hot spring pool outlet that consequently had a very high temperature (Table 3).

Table 2: Mean ±SEM value of physico-chemical parameters of river Birira

Parameter	Site					UNBS/WHO Guideline Value
	Ndurumo	Oruya	Ngarowenda	Nyaruzinga	Overall	
PH	6.70±0.03^a	7.32±0.07^b	6.20±0.11^c	6.92±0.02^d	6.79±0.10	6.5-8.5
Temp. (°C)	22.04±0.13^a	19.98±0.28^b	23.94±0.27^c	24.50±0.52^c	22.62±0.43	_
DO (mg/l)	6.88±0.037^a	7.00±0.07^a	4.76±0.05^b	3.18±0.10^d	5.46±0.37	5
E.C (µs/cm)	53.20±0.73^a	55.20±0.58^a	93.40±2.06^b	895.40±1.29^c	274.30±82.35	1500
TDS (mg/l)	47.96±0.25^a	48.64±0.18^a	60.40±0.29^b	225.70±0.68^c	95.68±17.26	600
T.H (mg/l)	121.64±0.12^a	95.56±0.12^b	243.72±0.88^c	420.24±0.10^d	220.29±29.43	300
Turb. (NTU)	121.54±1.24^a	104.92±1.55^a	173.62±24.18^b	421.60±0.63^c	205.42±29.74	5
Cl (mg/l)	22.84±0.89^a	22.14±0.81^a	41.84±0.79^b	55.00±0.70^c	35.46±3.18	250
NO_3^- (mg/l)	5.18±0.25^a	4.46±0.26^a	9.98±0.29^b	20.86±0.61^c	10.12±1.51	50
PO_4^{3-} (mg/l)	5.90±0.46^a	3.84±0.08^b	15.86±0.68^c	30.54±1.01^d	14.04±2.44	2.2

UNBS-Uganda Bureau of Standards, WHO-World Health Organization, Temp.-Temperature, E.C- Electrical Conductivity, TDS-Total Dissolved Solids, T.H-Total Hardness, Turb.- Turbidity, Cl-Chloride, NO_3^- Nitrate, PO_4^{3-} Phosphate. In rows values with similar superscripts are not significantly different at p = 0.05 LSD Post-Hoc test.

3.1.4 Electrical conductivity

Electrical conductivity is the measure of the ability of water to allow electrical current to flow through it. Significant variations in conductivity may indicate that a discharge/contaminant has entered the water body (Singh and Hussian, 2016). In this study, conductivity of water samples from river Birira ranged from 53.20- 895.04 µs/cm with Nyaruzinga site recording the highest EC values (Table 2). The high ion concentration at this site may be due to wastewater entering into the river from the hot spring bathing pool outlet as indicated in Table 3. In addition, human activities like motorcycle washing and farming practices like use of artificial fertilizers add conducting ions into the river.

3.1.5 Total Dissolved Solids (TDS)

Total dissolved solids comprise inorganic salts and small amounts of organic matter that are dissolved in water (WHO, 2017). The lowest TDS value was obtained at Ndurumo site (Table 2), this is probably due to low reduced surface runoff into the river owing to high vegetation cover at the river bank which absorb excess mineral ions for example phosphates and nitrates introduced into the river at Ndurumo site. The TDS values recorded in the study area ranged from 47.96-225.70 mg/l and were within the recommended levels of WHO (WHO, 2017).

3.1.6 Total Hardness

Hardness in water is caused by dissolution of various metal ions, mainly magnesium and calcium ions. The hardness value recorded along the river ranged from 95.6-420.4 mg/l (Table 2) with the highest value being recorded at Nyaruzinga site. This was above WHO recommended value (300 mg/l) (WHO, 2017). However, the overall value of the river was within the WHO recommended value.

3.1.7 Turbidity

Turbidity indicates presence of suspended materials such as clay, silt, organic and inorganic matter, plankton and microorganisms in water. Water clarity reduces with increasing turbidity due to reduction in transmission of light (Khatri and Tyagi, 2015). Changes in turbidity of river Birira may be due to daily disturbance of the river by washing vehicles and surface runoff. Results show that all sites on the river had turbidity levels above the WHO recommended value of 5 NTU (WHO, 2017). However, turbidity was highest at Nyaruzinga (Table 2), this may be attributed to increased human activities like car washing, poor cultivation of nearby farmlands which increase surface runoff into the river and close proximity to the Kitagata hot springs. This is evidenced by alarming increase in turbidity of water coming from the heart of the hot spring as it leaves the spring through the pool outlet (Table 3). The high turbidity values reported in this study indicate that the entire river was generally disturbed and posing problems to aquatic lives.

3.1.8 Chlorides

The presence of chloride in water sources can be attributed to the dissolution of calcium, sodium, potassium and magnesium chloride salt deposits. Effluents from chemical industries, sewage may result in local contamination of surface water with chlorides (Simpi et al., 2011). Chloride concentration recorded along river Birira ranged from 22.14-55.0 mg/l. Overall concentration of chlorides in the river is way below the recommended level of 250 mg/l.

3.1.9 Nitrates

High nitrate concentrations in freshwater water systems has been shown to negatively impact on aquatic animal populations including amphibians, macroinvertebrates and fish (Camargo and Alonso, 2006; Leszczynska et al., 2017). Furthermore, ingestion of water with high levels of nitrates can lead to methemoglobinemia in humans especially infants (WHO, 2011). Thus WHO sets recommended levels of nitrate in portable water at 50 mg/l (WHO, 2017). In this study, nitrate levels in samples collected from different sampling sites on river Birira varied from 4.46-20.86 mg/l (Table 2). Water samples from Nyaruzinga site showed the highest nitrate concentration (Table 2). Presence of considerable levels of nitrates in the water samples may be attributed to agricultural runoff, domestic and animal waste.

3.1.10 Phosphates

Phosphates are an important nutrient source for aquatic plants, therefore presence of high phosphate concentration in a water body may trigger a significant algal growth. In some cases, algae can be hazardous to human health especially when toxic algae is present in drinking water (Otten and Paerl, 2015). Geology, agricultural runoff, domestic and industrial waste often influence phosphate level of an aquatic system. Uganda National Bureau of Standards sets the permissible limit of phosphates at 2.2 mg/l. The concentration of phosphates in water samples collected from different sites along river Birira ranged between 3.84 and 30.54 mg/l (Table 2). The highest phosphate concentration was recorded at Nyaruzinga site probably due to high surface runoff from the town and gardens around the river and a point source waste water from hot spring bathing pool which joins already disturbed river water from Ngaromwenda site.

Table 3: Physico-chemical parameters of water joining river Birira from the hot spring

Parameters	Centre point of spring	Hot spring outlet
pH	7.134±0.11	6.942±0.03
E.C (µs/cm)	964.12±2.41	1119.2±0.84
TDS (mg/l)	224.82±0.33	429.62±0.32
Total hardness (mg/l)	119.62±0.45	346.88±4.22
Chlorides (mg/l)	47.74±0.70	65.78±3.59
Phosphates (mg/l)	16.52±0.23	26.94±1.13
Temperature (°c)	59.9±0.16	32±0.38
Nitrates (mg/l)	15±0.20	23.6±0.53
Turbidity (NTU)	224.24±0.92	430.58±1.03
DO (mg/l)	0.78±0.08	1.74±0.09

3.1.11 Correlation between physico-chemical parameters

The degree of line of association between any two of the physico-chemical parameters is measured by the correlation coefficient (r) as indicated in Table 4. Temperature showed strong positive correlation with EC, weak positive correlation with chlorides and a strong negative correlation with dissolved oxygen. The dissolved oxygen showed strong negative correlation with all other parameters except pH. TDS showed strong positive correlation with electrical conductivity indicating the effect of increased ion concentration on conduction of electrical current. Turbidity showed strong positive correlation with nitrates, phosphates and chlorides.

Table 4: Correlation between physico-chemical parameters

Parameters	pH	Temp. (°C)	DO (mg/l)	E.C (µs/cm)	TDS (mg/l)	T.H (mg/l)	Turb. (NTU)	Cl (mg/l)	NO_3^- (mg/l)
Temp. (oC)	-0.579**								
DO (mg/l)	0.287	-0.834**							
E.C (µs/cm)	0.150	0.602**	-0.849**						
TDS (mg/l)	0.134	0.613**	-0.859**	1.000**					
T.H (mg/l)	-0.206	0.816**	-0.984**	0.918**	0.926**				
Turb. (NTU)	-0.013	0.683**	-0.902**	0.969**	0.972**	0.952**			
Cl (mg/l)	-0.296	0.828**	-0.989**	0.838**	0.850**	0.978**	.892**		
NO_3^- (mg/l)	-0.092	0.761**	-0.955**	0.953**	0.959**	0.986**	0.970**	0.951**	
PO_4^{3-} (mg/l)	-0.195	0.786**	-0.978**	0.914**	0.922**	0.992**	0.939**	0.969**	0.976**

**. Correlation is significant at the 0.01 level (2-tailed).

Temp.-Temperature, E.C- Electrical Conductivity, TDS-Total Dissolved Solids, T.H- Total Hardness, Turb.-Turbidity, Cl-Chloride, NO_3^- Nitrate, PO_4^{3-}

3.2 Water Quality index (WQI)

The overall WQI of river Birira was 448.22 which indicated that water from river Birira is unsafe for drinking. Oruya site had the lowest WQI (224.17) this indicated that water was very poor while the highest WQI (881.35) was obtained at Nyaruzinga thus water at this site is unsuitable for drinking as shown in Table 6. Water quality of river Birira could be mainly deteriorated by various organic inputs along the river course through various inputs which consists of domestic wastes, sewage discharges without treatment, municipal waste from Kitagata town and garbage wastes at the river bank.

Table 5: Water quality index classification

WQI Value	Water quality status
<50	Excellent
51-100	Good
101-200	Poor Water
201-300	Very Poor Water
>300	Water Un Suitable For Drinking

Table 6: WQI computation at different sites along river Birira

Sites		Parameters										
		pH	E.C (µs/cm)	DO (mg/l)	TDS (mg/l)	T.H (mg/l)	Turb. (NTU)	Cl (mg/l)	NO_3^- (mg/l)	PO_4^{3-} (mg/l)		
	UNBS/WHO	8.5	1500	5	600	300	5	250	50	2.2		
	w_i	3	2	5	2	2	2	2	5	3		
	W_i	0.115	0.077	0.192	0.077	0.077	0.077	0.077	0.192	0.115	**WQI**	**Interpretation**
Ndurumo	Value	6.70	53.2	6.88	47.96	121.64	121.54	22.84	5.18	5.9		Very Poor water
	Qi	78.80	3.55	137.60	7.99	40.55	2430.80	9.14	10.36	268.18		
	SI	9.09	0.27	26.46	0.61	3.12	186.98	0.70	1.99	30.94	**260.18**	
Oruya	Value	7.32	55.2	7	48.64	95.56	104.92	22.14	4.46	3.84		Very Poor water
	Qi	86.12	3.68	140.00	8.11	31.85	2098.40	8.86	8.92	174.55		
	SI	9.94	0.28	26.92	0.62	2.45	161.42	0.68	1.72	20.14	**224.17**	
Ngaromwenda	Value	6.2	93.4	4.76	60.4	243.72	173.62	41.84	9.98	15.86		Unsuitable for drinking
	Qi	72.94	6.23	95.20	10.07	81.24	3472.40	16.74	19.96	720.91		
	SI	8.42	0.48	18.31	0.77	6.25	267.11	1.29	3.84	83.18	**389.64**	
Nyaruzinga	Value	6.92	895.4	3.18	225.7	420.24	421.6	55	20.86	30.54		Unsuitable for drinking
	Qi	81.41	59.69	63.60	37.62	140.08	8432.00	22.00	41.72	1388.18		
	SI	9.39	4.59	12.23	2.89	10.78	648.62	1.69	8.02	160.17	**858.39**	
Overall	Value	6.78	22.62	5.46	274	95.68	220.29	205	35.46	10.12		Unsuitable for drinking
	Qi	79.82	1.51	109.10	45.72	31.89	4405.80	82.17	70.91	460.00		
	SI	9.21	0.12	20.98	3.52	2.45	338.91	6.32	13.64	53.08	**448.22**	

w_i-Weighted Factor, W_i- Relative Weight Factor- Value= Average of each parameter per sampling site. Qi= Quality rating score and SI= Sub Index, WQI-Water Quality Index

Table 7: Diversity and abundance of macroinvertebrates of river Birira

Taxa	Ndurumo				Oruya				Ngaromwenda				Nyaruzinga				
Family	Site 1	Site 2	Site 3	**Total**	Site 1	Site 2	Site 3	**Total**	Site 1	Site 2	Site 3	**Total**	Site 1	Site 2	Site 3	**Total**	**Overall**
Gerridae	1	0	1	**2**	16	1	1	**18**	1	1	1	**3**	0	1	0	**1**	**24**
Hydrophilidae	0	0	0	**0**	2	5	2	**9**	1	1	1	**3**	0	0	6	**6**	**18**
Ceratopogonidae	0	0	0	**0**	2	3	1	**6**	0	0	0	**0**	0	0	0	**0**	**6**
Dytiscidae	2	1	1	**4**	4	2	3	**9**	0	2	0	**2**	1	0	0	**1**	**16**
Libellulidae	0	0	0	**0**	5	0	1	**6**	2	3	1	**6**	0	0	0	**0**	**12**
Scirtidae	0	0	0	**0**	1	1	1	**3**	0	0	0	**0**	0	0	0	**0**	**3**
Planorbidae	0	0	0	**0**	16	3	1	**20**	2	4	0	**6**	2	7	5	**14**	**40**
Lymnaeidae	0	0	0	**0**	7	1	1	**9**	0	0	0	**0**	0	0	0	**0**	**9**
Notonectidae	2	0	5	**7**	13	3	6	**22**	1	6	2	**9**	3	1	0	**4**	**42**
Platycnemidae	0	0	0	**0**	2	6	5	**13**	0	0	0	**0**	0	0	0	**0**	**13**
Corixidae	0	0	5	**5**	2	0	1	**3**	0	0	1	**1**	0	0	1	**1**	**10**
Chironomidae	8	70	11	**89**	3	3	1	**7**	0	1	0	**1**	3	10	3	**16**	**113**
Caenidae	0	0	0	**0**	6	6	20	**32**	6	3	21	**30**	0	0	0	**0**	**62**
Hirudunae	0	0	5	**5**	2	2	0	**4**	0	0	0	**0**	0	0	0	**0**	**9**
Simulidae	0	0	0	**0**	1	0	11	**12**	0	0	0	**0**	0	0	1	**1**	**13**
Culicidae	8	4	6	**18**	3	3	0	**6**	3	3	2	**8**	2	23	3	**28**	**60**
Coenagrionidae	0	0	0	**0**	7	7	6	**20**	4	1	6	**11**	5	0	0	**5**	**36**
Physidae	0	0	0	**0**	0	0	0	**0**	3	3	3	**9**	0	0	0	**0**	**9**
Aeshnidae	0	0	0	**0**	0	0	0	**0**	1	0	0	**1**	0	0	0	**0**	**1**
Naucoridae	2	1	0	**3**	0	1	0	**1**	1	0	0	**1**	0	0	0	**0**	**5**
Oligochaetae	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	1	0	7	**8**	**8**
Gyrinidae	1	1	3	**5**	6	1	1	**8**	3	2	0	**5**	0	3	0	**3**	**21**
Syriphidae	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	1	0	0	**1**	**1**
Baetidae	0	1	1	**2**	0	0	0	**0**	0	2	0	**2**	0	0	0	**0**	**4**
Emphemeridae	0	0		**0**	0	2	3	**5**	0	0	**0**	**0**	0	0	0	**0**	**5**
Nepidae	1	0	0	**1**	1	0	1	**2**	0	0	0	**0**	0	0	0	**0**	**3**
Notonemouridae	0	0	0	**0**	0	0	1	**1**	0	0	0	**0**	0	0	0	**0**	**1**
Elmidae	0	0	0	**0**	2	1	4	**7**	0	0	0	**0**	0	0	0	**0**	**7**
Belostomatidae	2	2	2	**6**	3	6	1	**10**	5	1	0	**6**	3	1	2	**6**	**28**
Vellidae	0	0	0	**0**	1	0	2	**3**	0	0	0	**0**	0	0	0	**0**	**3**
Hydropsychidae	0	0	0	**0**	0	0	1	**1**	0	0	0	**0**	0	0	0	**0**	**1**
Oligoneuridae	0	0	0	**0**	0	0	1	**1**	0	0	0	**0**	0	0	0	**0**	**1**
Hydraenidae	0	0	0	**0**	0	0	1	**1**	0	0	0	**0**	0	0	0	**0**	**1**
Tipulidae	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	1	0	**1**	**1**
Muscidae	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	1	1	0	**2**	**2**
Heptagenidae	0	0	0	**0**		0	0	**0**	0	0	4	**4**	0	0	0	**0**	**4**
Ecnomidae	1	0	0	**1**	6	4	1	**11**	0	0	0	**0**	0	0	0	**0**	**12**

3.3 Biological parameters

3.3.1 Biological indices

A total of 616 macroinvertebrates were recorded in this study. Results of the study indicate that Chironomidae is the most abundant family in river Birira (Table 7). Chironomidae is a known pollution tolerant family with BMWP and TARSS score of 2. Therefore, abundance of such a less sensitive taxon could be linked to their high tolerance of anoxic conditions (Odume et al., 2012). Thus, this finding indicates that the water of river Birira is of poor quality. This is further supported by the general WQI result in Table 6. The least abundant families recorded in the study area were Aeshnidae, Syriphidae, Notonemouridae, Hydropsychidae, Oligoneuridae, Hydraenidae and Tipulidae with only 1 individual each. The Shannon – Weiner index obtained revealed that there was high diversity of macroinvertebrates at Oruya compared to other sites of the river. This is attributed to the fact that Oruya had better water quality as indicated by highest BMWP and TARSS ASPT values (Table 8 and 10). This is probably due to less human disturbance, heavy riparian vegetation that provide much shading effect and at the same time hold, breakdown and utilize nutrients like phosphates and nitrates (Canning and Stillwell, 2018). More so abundance and distribution of aquatic macroinvertebrates can be affected by sedimentation and land use practices in the catchment area of the river (Atwongyeire et al., 2018). Increased anthropogenic activities especially around water bodies and urban development, in this case Kitagata town council, produce non-point source contaminants which are then washed down the slope into river Birira. These reduce water quality and impact on macroinvertebrate diversity abundance and distribution.

Table 8: Mean±SE of biological indices of collected Macroinvertebrates

Biological Parameters	Site					P-value
	Ndurumo	Oruya	Ngaromwenda	Nyaruzinga	Overall mean	
Dominance index	0.37±0.35	0.09±0.02	0.17±0.11	0.23±0.03	0.21±0.19	0.344
Shannon-Weiner index	1.52±0.82	2.69±0.04	2.178±0.43	1.74±0.06	2.03±0.61	0.060
Evenness index	0.57±0.28	0.69±0.12	0.74±0.17	0.67±0.13	0.67±0.17	0.749
ASPT-TARISS	3.41±0.38	5.21±0.55	2.89±0.31	1.59±0.06	3.27±1.39	0.000
ASPT-BMWP	3.72±0.42	4.48±0.18	3.41±0.26	1.82±0.1	3.36±1.0	0.000

3.4 Relationship between physico-chemical and biological parameters

ASPT for both BMWP and TARISS showed negative correlation with total hardness, electrical conductivity, temperature, nitrates, phosphates and chlorides (Table 9 and Figure 2). On the other hand, ASPT showed a strong positive correlation with dissolved oxygen. Regression analysis indicated that 76.74 % variation in ASPT using TARISS can be explained by variation in dissolved oxygen (Figure 2). Specific macroinvertebrates have specific oxygen requirements for their growth and with more macroinvertebrates requiring more oxygen. Therefore, increased oxygen levels in the aquatic habitant favor survival of sensitive macroinvertebrates that consequently give rise to high scores in biological assessment indices.

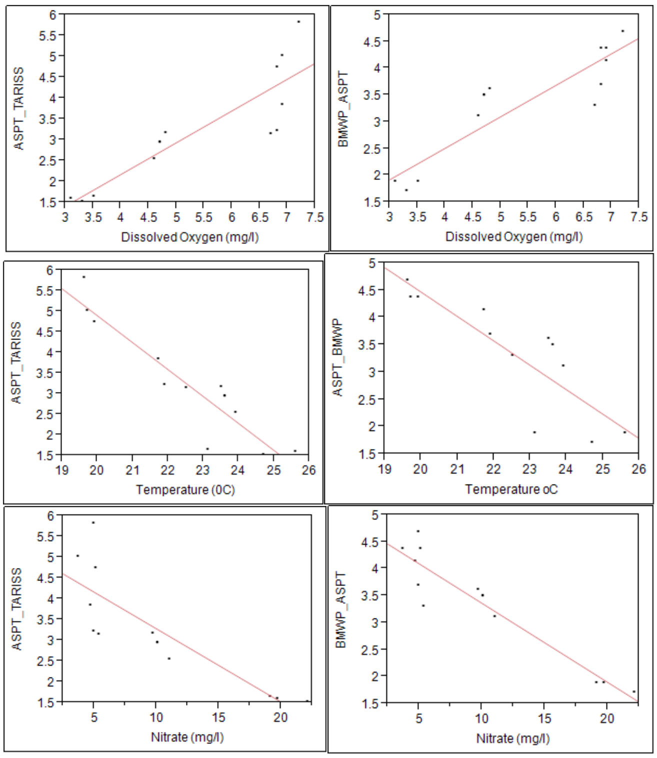

Figure 2: [A] Correlation of ASPT_TARISS and Dissolved Oxygen (r^2=0.76, p=0.000) [B] Correlation of ASPT_BMWP and Dissolved Oxygen (r^2=0.82, p=0.000) [C] Correlation of ASPT_TARISS and Temperature (r^2=0.86, p=0.000) [D] Correlation of ASPT_BMWP and Temperature (r^2=0.73, p=0.000) [E] Correlation of ASPT_TARISS and Nitrate (r^2=0.72, p=0.001) [F]Correlation of ASPT_BMWP and Nitrate (r^2=0.87, p=0.000)

Table 9: Correlations between physico-chemical parameters with ASPT-TARISS and BMWP

Physical chemical Parameters	Biological Parameters	
	ASPT-TARISS	ASPT-BMWP
PH	0.485	0.232
Electrical conductivity (μs/cm)	-0.746**	-0.903**
Total dissolved solids (mg/l)	-0.755**	-0.908**
Total hardness(mg/l)	-0.877**	-0.944**
Turbidity (NTU)	-0.846**	-0.944**
Chloride (mg/l)	-0.865**	-0.909**
Phosphates (mg/l)	-0.857**	-0.932**

**. Correlation is significant at the 0.01 level (2-tailed).

3.5 Compatibility of TARISS and BMWP biological monitoring systems

Results in Table 10 obtained using BMWP classification by Hawkes (1998) and TARISS classification by Kaaya et al. (2015), indicate that the health of river Birira in Kitagata sub county is in the category of very poor quality thus the river is generally highly impacted by anthropogenic activities. Findings of this study indicate that both biological monitoring systems gave similar deduction with regards to water quality of river Birira.

Table 10: Compatibility of TARISS and BMWP in assessing water quality of river Birira

Site	BMWP			TARISS		
	Score	ASPT	Interpretation	Score	ASPT	Interpretation
Ndurumo	110	2.97	Very poor	111	3.00	very poor
Oruya	155	4.19	Poor	170	4.59	Poor
Ngaromwenda	122	3.30	Very poor	117	3.16	very poor
Nyaruzinga	62	1.68	Very poor	54	1.46	very poor
Overall	112.25	3.03	Very poor	113	3.05	very poor

ASPTs as calculated by scoring Overall values from each sampling site

4. Conclusion

Biological monitoring using aquatic macroinvertebrates as bioindicators of water quality is fundamental in assessing ecological integrity of aquatic ecosystems. This study revealed that both BMWP and TARISS biological monitoring systems yielded similar characterization of water quality of river Birira as being very poor. Furthermore, assessing water quality using nine physical-chemical parameters generated an overall water quality index (WQI) score of 448.22 which classifies the water of river Birira as being unsuitable for human consumption. This was in agreement with the characterization by BMWP and TARISS. Thus, any one of the two biological monitoring systems (TARISS or BMWP) can be used to assess the water quality of river Birira. Findings of this study further reveal that the section of river Birira at Nyaruzinga is heavily polluted and highly impacted by human activities mostly arising from the hot springs. We therefore recommend that the waste water from the bathing pools of the hot spring should be treated before its introduction into the river. In addition, communities living around river Birira especially people living around

Kagari hill should be sensitized on how human activities carried out in the catchment area are impacting on the water quality of river Birira. Finally, water obtained from river Birira requires thorough treatment before drinking and domestic use.

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