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Application of environmental indexing for water quality assessment – case of Nasolo River, Blantyre

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Abstract Water quality is critical to ecosystem health as it threatens biodiversity when degraded by anthropogenic or geogenic activities. As an urban river, the Nasolo River can be impaired by various anthropogenic activities arising from urbanization and industrialization. This study assessed the effects of the activities above on the Nasolo River in Blantyre, through the application of environmental indexing approaches. Four sampling sites, S1, S2, S3, and S4 sites were purposefully selected to provide an upstream-to-downstream characterization of the river health. Selected water quality variables including pH, electrical conductivity (EC), temperature, salinity, total dissolved solids (TDS), and dissolved oxygen (DO) were measured using a multi-probe AP800 aqua meter. Membrane filtration technique (MFT) was employed to determine fecal and total coliforms, and a hydrotest photometer was used to analyze turbidity and total suspended solids (TSS), nitrate and ammonia. A National Sanitation Foundation Water Quality Index (NSFWQI) was used to depict water quality status and a Stream Assessment Scoring System (miniSASS) biomonitoring technique was employed to collect and identify macroinvertebrates in Nasolo River whose presence or absence reflected varying environmental conditions along the river. Six orders of macroinvertebrates, Ephemeroptera, Diptera, Trichoptera, Annelida, Coleoptera, and Turbellaria were identified in the river. The macroinvertebrates data were interpreted by calculating average scores per taxon (ASPT) to develop a biotic index. Lastly, a correlation analysis between the NSFWQI and macroinvertebrate biotic index (MBI) was performed to quantify the degree to which the two indices are related. The findings showed a significant correlation between the two indices. Both indices have shown that upstream station S1 was mildly contaminated whereas further downstream, sites S2, S3, and S4 were severely polluted. The overall outcome indicated that the water quality in the Nasolo River is poor, posing an ecological risk to aquatic life while rendering the river unable to offer ecological services. Therefore, it is necessary to use good catchment management strategies to improve the quality of the rivers.

Keywords: *Biomonitoring; Human activities; Stream Assessment Scoring System, Malawi, ecology; Catchment management*

1. Introduction

Water is essential to all forms of life (Hossain, 2015), and surface water resources such as rivers offer several ecosystem services. The services include the provision of food and water, soil formation, photosynthesis, nutrient cycling, climate regulation, water purification, carbon sequestration, and flood control; cultural services include recreational, aesthetic, and spiritual benefits (Martin-Ortega et al., 2015). People rely on water for a variety of purposes in this modern industrial period. They use it for industrial production, agricultural output, sand mining for construction, and commercial trading in many localities to meet their requirements (Gichuri, 2018). Population growth, increased human activity, large-scale inadequate or untreated wastewater discharges into rivers, and climate change are all contributing to the contamination of freshwater resources, and as a result, river water quality is declining globally in many regions. (Xue & Shao, 2020). Poor water quality has been linked to the spread of deadly waterborne illnesses such as cholera, typhoid, dysentery, and hepatitis A, all of which are caused by the drinking of polluted water (Ashbolt, 2004). The introduction of invasive aquatic species such as water hyacinths and the mortality of both plants and animals are some of the impacts of pollution on the aquatic environment (Rai, 2008, Ndimele et al., 2011). These effects have devastating impacts on humans as well as aquatic life, which is why it is crucial to routinely assess the water quality. The need for water quality assessment is to verify whether the observed water quality is suitable for its intended uses such as irrigation, domestic water supply, industrial, and other purposes in a watershed, and to determine trends in the quality of the aquatic environment (Haritash et al., 2016). Studies on water quality assessment on rivers are significant because they enable researchers to understand factors affecting water quality and to come up with recommendations on sustainable ways to mitigate such challenges. These measures can then be adopted by the government and other agencies to help improve water quality in these water resources (United Nations Environment Programme, 2018). It is for this reason that this study was conducted to assess the water quality in the Nasolo river. The Nasolo River is one of the rivers in Malawi where human activities for instance urbanization, industry, agriculture, and mining are taking place (Kaonga et al., 2008 & Kuyeli et al., 2009). The river originates from Ndirande Mountain, the most populous location in Blantyre, Southern Malawi, and feeds into the Mudi River. It is surrounded by peri-urban areas; it passes through markets, sand mining sites, agricultural fields, and industries. The industries discharge effluents into nearby streams. The most important economic activities of this area are retail trade, construction, manufacturing of food products, transport, textile manufacturing, motor vehicle sales and maintenance, and public administration (UN-HABITAT, 2011). Cammack (2012) reported that the Nasolo River experiences several water quality problems due to these various activities. The deterioration in water quality in the river has a great impact on the surrounding communities, especially on human and aquatic environmental health.

Physico-chemical and biological analyses are two conventional approaches that are frequently used to evaluate the quality of water (Odume, 2017). Basic water quality indicators including temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), pH, turbidity, electrical conductivity (EC), chemical oxygen demand (COD), nitrates (NO_3), oxidation-reduction potential (ORP), alkalinity, fecal and total coliforms are measured in these methods (Hamid et al., 2016). Nonetheless, in addition to physico-chemical approaches, there are other effective techniques for assessing water quality, such as biomonitoring and ecotoxicology (Mensah et al., 2015 & Vellemu, 2017), and these techniques have not yet been utilized to study rivers in the Malawian context. Biomonitoring is a basic water monitoring technique, employing readily available and inexpensive materials such as aquatic nets to assess water quality (Zakaria & Mohamed, 2019). Moreover, using biomonitoring techniques in conjunction with traditional methods of water quality monitoring can provide a more comprehensive indication of watershed ecological health (Pullanikkatil et al., 2015). Since indices are widely used to classify surface water quality (Bi et al., 2021), this study employed a combination of the National Sanitation Foundation Water Quality Index (NSFWQI) and macro-invertebrate-based biotic index, specifically a mini Stream Assessment Scoring System (miniSASS) version 2. NSFWQI is one of the most commonly used indices for communicating essential information on the quality of water to concerned citizens and policymakers (Made et al., 2019). NSFWQI was proposed by Brown et al. (1970) with the support of the United States National Sanitation Foundation (USNSF). This method uses nine parameters such as DO, Fecal Coliform, BOD, pH, water temperature, Phosphate, Nitrate, Total Suspended Solid (TSS), and turbidity for the calculation of the water quality index based on the weighting from the panel's opinions, water quality management experts across United States of America (USA). NSFWQI has been recommended by several studies for water quality assessments (Mirzaei et al., 2016). For the macro-invertebrate-based biotic index, the updated miniSASS version 2 method was used for the water quality assessment (Graham et al., 2012). MiniSASS uses only 13 classes of aquatic macroinvertebrates allowing simpler identification and assessment of water quality in the ecosystem (Graham et al., 2004). Therefore, the outcomes of this study will act as a baseline for the development of river health and water quality monitoring programs for rivers in Malawi to promote local citizen science participation in catchment management relevant to achieving the Sustainable Development Goal (SDG) 6.

2. Methodology

This study followed an experimental design and utilized descriptive quantitative research method. A single factor study design was employed with the spatial differentiation of the sampling locations the only independent variable investigated.

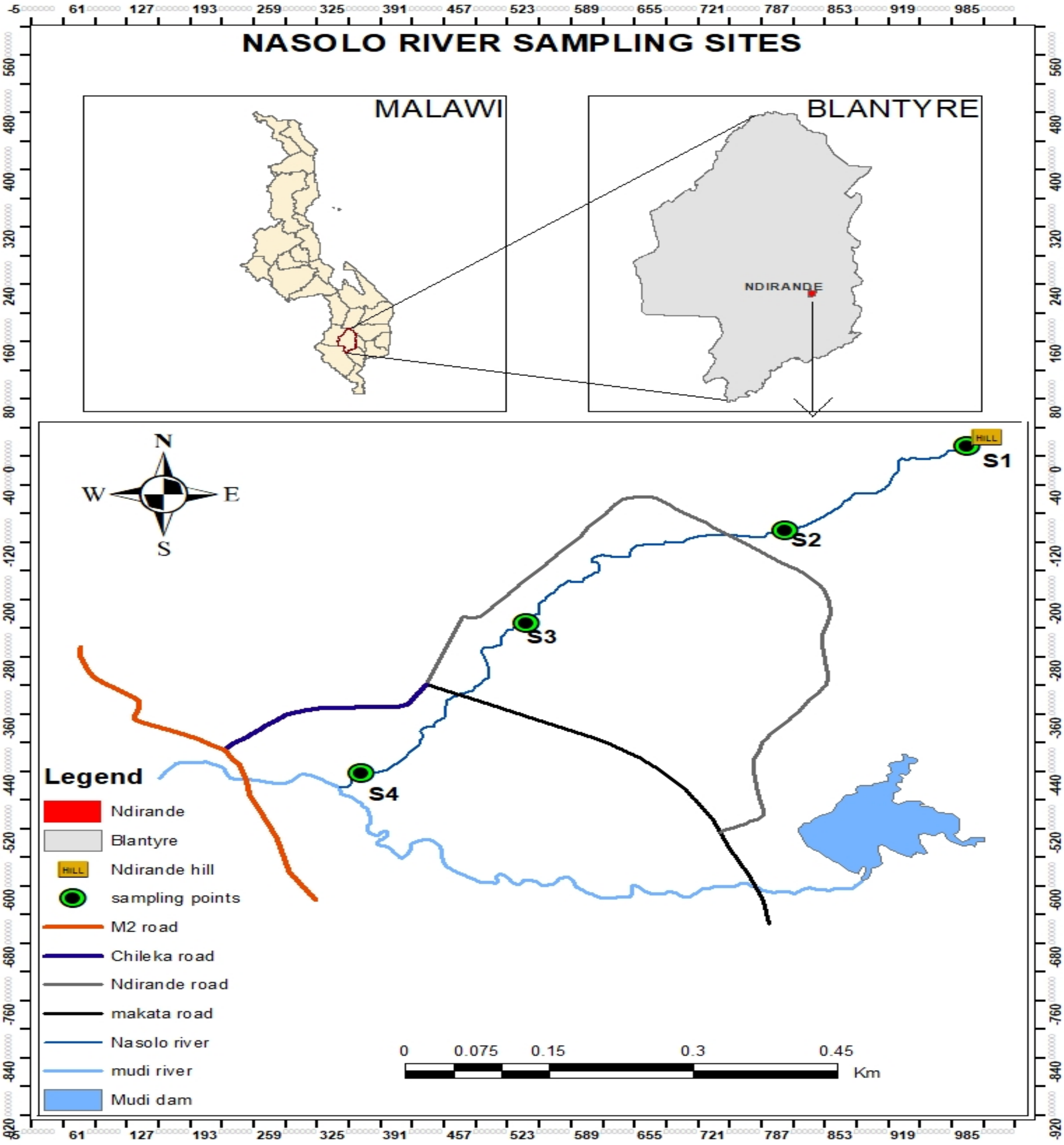

Figure 1: Map showing the study area

2.1. Sample collection

Water samples were collected from Nasolo River (15^0 45’ 18” S, 35^0 3’ 26” E) located in Blantyre district, a commercial city of Malawi from April to May 2021. Four sampling points were selected from the upstream of the river to the downstream using purposive sampling. This sampling technique was chosen for its efficiency in capturing representative samples from upstream to downstream. Sampling at each site was at random. Samples were collected in polyethylene and glass bottles and analyzed using standard analytical methods (Gupta et al., 2015) as described in the sections that follow. Coordinates of all sampling points were recorded using a GPS meter for map construction using ArcGIS 2010 software application developed by Environmental Systems Research Institute (ESRI) (Ullberg, 2015).

2.2. Physico-chemical water quality variables in-situ analysis

To obtain quantitative information on the physical and chemical water quality variables of water in the Nasolo river, grab sampling was done using Malawi standards. Values of pH, electrical conductivity, total dissolved solids, oxidation-reduction potential, salinity, and temperature were recorded in situ by immersing into the river, an AP 800 multimeter (Aqua read, 2022) The readings were recorded on paper after the meter had stabilized. In situ data were required to aid the interpretation of other water quality results that were analyzed in the laboratory. Akoteyen (2013) discussed the importance of in-situ measurements for the parameters above since they are likely to change if there is a lengthy period between sample collection and analysis. American Public Health Association (APHA) standard analytical methods were used for the determination of all the parameters (Baird & Bridgewater, 2017).

2.3. Standard biomonitoring techniques

To assess macro-invertebrates in the river, the aquatic invertebrates were sampled by a South African Scoring System (SASS) net on a sandy and vegetative habitat using the kick sampling technique. When undertaking the biomonitoring technique, a wader was worn for protection. Then, a net was rested on the bottom of the stream at right angles to the water current to collect the invertebrates. The substratum was vigorously disturbed by kicking with the heel of a boot to dislodge the fauna for the organisms to be easily trapped, and then they were allocated into a water-filled tray for counting and identification using the aquatic invertebrates' booklet. The counting and identification was based on the SASS Version 5 Rapid Bio-assessment Method for Rivers (Water Research Commission, 2022) as described by Dickens & Graham, 2002 & Dickens et al., 2018. The identified macroinvertebrates at each site were marked on separate miniSASS sensitivity scoring sheets. The sensitivity scoring sheet for the macroinvertebrates consists of scores 1 to 14 based on their resistance or susceptibility to water pollution. After scoring, total scores were calculated by summing up the sensitivity scores for each group of organisms that were identified and marked, and then the total score was divided by the total number of groups present at each sampling point to calculate the average score per taxon (ASPT) values in distinctive tables (Etemi et al., 2020). Lastly, the ASPT was then compared to the ecological category table 1b to define the status of the river in terms of excellent, good, fair, poor, or very poor.

2.4. Laboratory Analysis

Water samples for analyzing nitrates, ammonia, turbidity, and total suspended solids (TSSS) were collected in polyethylene bottles that were pre-rinsed with distilled water and rinsed with the sample water several times. Triplicate samples were collected at each sampling point. Water samples for microbial analysis were collected in pre-cleaned and pre-sterilized (autoclaved at 121°C for 15 minutes) 300 mL Borosilicate glass bottles. Upon collection, microbial samples were transported and stored under ice at 4°C until sample analysis. Ex-situ samples were transported to the Environmental Quality Testing and Ecotoxicological Laboratory (EQTEcoL) for further analysis of physico-chemical water quality variables. Turbidity, TSS, nitrate, and ammonia were analyzed using an HT1000 UV-Vis Spectrophotometer (Trace$_2$O, 2022), for microbial analysis while membrane filtration technique (MFT) was used to enumerate fecal coliforms. All standard methods for sampling and sample analysis were as described in Standard Methods for the Examination of Water and Wastewater (APHA, 2017).

2.5. Data Analysis

Data were analyzed using Microsoft Excel (MS Office, 2016) to calculate means and standard deviations of water quality variables that were measured in triplicates at each sampling point. The results were then presented in a table and compared with the US Environmental Protection Agency (USEPA) water quality standards for surface waters (2019 for water protection (EPA, 2019) and MoAIWD (Ministry of Agriculture, Irrigation and Water Development) surface water quality standards (MoAIWD, 2019) under the Malawi Government, Water Quality Service Division.

The water quality data obtained was summarized using a modified water quality indexing method proposed by the National Sanitation Foundation (NSF) as described in Uddin et al. (2021) and Ravikumar et al. (2013). The NSF Water Quality Index (NSFWQI) utilizes seven water quality variables: pH, dissolved oxygen, turbidity, nitrates, total dissolved solids, temperature, and fecal coliform to determine the overall level of pollution for different sampling sites in Nasolo river as shown in Table 2. The NSFWQI approach assigns weights to the nine water quality variables based on their importance to aquatic life and human consumption (Mirzaei et al., 2016). The modified NSFWQI method allows the modification of these weights based on the specific characteristics of a water system.

The water quality index was then computed based on the formula in equation 1:

$$\text{NSFWQI} = \sum_{i=1}^{n}(Wi \; * Qi) \; \ldots\ldots\ldots \; \text{Equation 1}$$

where W_i is the weight and Q_i is the quality value (sub-index of the quality variable, i).

The index value forms dimensionless intervals between 0 and 100 which indicate different water quality status: excellent (90-100), good (70-90), moderate (50-70), bad (25-50), and very bad quality (0- 25). This index decreases with increasing pollution (Khalili et al., 2020).

Statistical analysis was carried out using Microsoft Excel (MS Office, 2016). The Spearman Rank Coefficient (r^2) was calculated to understand the relationship between the environmental indices developed from the study, the NSFWQI, and the Biotic Index, as well as for various water quality variables. This test was selected because it is a non-parametric test that does not make assumptions about the normality of the data. Further, one way analysis of variance (ANOVA) was undertaken using Microsoft Excel to determine if the water quality was different among the four sample sites at the 5% significance level.

3. Results and discussion

This section will present the results of the study and provide a thorough discussion of the same.

3.1. Physico-chemical and microbiological analysis of water quality variable

Using all physico-chemical and microbiological water quality variables at the four different sampling sites (S1, S2, S3, and S4), a single factor ANOVA was performed, and a p-value of 0.017 was obtained. The results showed that the four sampling sites were statistically different from each other at the 5% level of significance (n = 39). Through the individual paired t-tests, the downstream sampling sites S2, S3 and S4 were significantly different from the upstream station at the $\alpha = 0.05$ level of significance (p-values = 0.01, 0.02 and 0.003 respectively, n = 39). This indicated a general deterioration of the water quality in the river as it moved downstream. Table 1 shows the mean values for water quality variables obtained in Nasolo river sampled at four points and Table 2 shows the correlation between water quality variables.

Table 1: Mean values for physio-chemical and microbiological water quality variables

	SAMPLING SITES					
Water quality variable	**Sampling site 1**	**Sampling site 2**	**Sampling site 3**	**Sampling site 4**	**EPA acceptable limit**	**MoAIWD acceptable limit**
pH	7.42±0.30	7.70±0.20	6.40±0.10	6.50±0.60	6.50±0.00	6.5-9±0.00
Temperature(°C)	19.47±0.20	21.80±0.40	23.00±0.70	23.80±0.50	20±0.00	Guideline value not stated
Dissolved Oxygen (mg/L)	5.20±0.30	3.00±0.20	2.10±0.30	2.20±0.30	4-5±0.00	5±0.00
ORP (millivolts)	6.27±2.60	-5.70±0.60	-11.60±13.20	-5.70±3.00	Guideline value not stated	Guideline value not stated
EC (µS/cm)	71.67±49.80	522.30±134.40	463.00±13.90	1896. 70±72.20	<500±0.00	Guideline value not stated
TDS (mg/L)	53.00±32.4	363.30±50.60	300.30±9.10	1234.00±43.50	<600±0.00	Guideline value not stated
Salinity (ppt)	0.03±0.00	0.30±0.00	0.20±0.00	1.00±0.10	0.50±0.00	Guideline value not stated
Turbidity (NTU)	10.00±0.30	51.00±0.60	23.00±1.20	38.00±0.60	<5±0.00	<5±0.00
TSS (mg/L)	14.00±1.10	52.00±0.60	22.00±0.60	23.00±0.60	20±0.00	30±0.00
Fecal Coliform (CFU/100mL)	10.00±5.00	1464.00±30.70	1966.00±80.20	618.00±163.10	15-20±0.00	50 ±0.00
Total Coliform (CFU/100mL)	126.00±36.20	2050.00±427.20	2313.00±300.90	1343.00±126.60	500 ±0.00	Guideline value not stated
Nitrates (mg/L)	20.00±1.00	68.90±1.30	27.20±2.90	32.90±9.20	50±0.00	Guideline value not stated
Ammonia (mg/L)	2.27±0.80	4.10±0.30	3.10±0.70	5.60±0.40	Odor threshold = 1.2 mg/L±0.00	Guideline value not stated

3.1.1. Physico-chemical water quality analysis

According to Weiner (2013), the pH of pure water at 25^0C is 7. Mostly in surface water systems, pH changes are a function of dissolved carbon dioxide (CO_2) and exposure to minerals containing carbonates, bicarbonates, hydroxides plus other such species. As shown in table 3, the pH values for sampling sites 1, 2, and 4 ranged from 6.5 to 7.7. They were within the EPA and MoAIWD water quality standards of pH range from 6.50-9±0.00 (EPA, 2015 & MoAIWD, 2019). Going along the river, the pH of the Nasolo River at S1 and S2 increased slightly from 7 to 7.70. This could be due to loss of CO_2 by diffusion to the atmosphere or by consumption during photosynthesis of algae and other plants in the water. However, for sampling sites S3 and S4, it is observed here that the pH was slightly acidic. One of the potential reasons for the significantly lower pH in this section of the river is that this section was highly impacted by unregulated discharge of domestic wastewater from residential homes along the river. As reported by Ayiti et al. (2022), nitrogen removal processes from environmental matrices including wastewater result in the production of hydrogen ions thereby inducing low pH in aquatic systems. Apart from this, these two sampling sites were also characterized as being dumpsites for various solid waste including scrap metals. Metals in aquatic systems can potentially result in the production of hydrogen ions as these metals would react with water to form metal hydroxides resulting in the release of hydrogen ions which would also depress pH in the system (Arman et al., 2021).

However, the low pH of between 6.40 and 6.50 observed at these sites is considered harmless to some other aquatic species (GJU, 2015). Further characterization of the chemical composition and emerging pollutants in Nasolo River would be useful to understand better the risks associated with the increasing demand and use of chemicals and emerging pollutants as reported by Scheringer (2017). At station S4, after the river passed through the Makata industrial area, the observed pH of 6.5 was slightly lower than the one previously obtained by Kuyeli et al. (2009) of 7.7 for the same site. This indicated increased discharge of acidic wastewater effluents from industries such as metal solutions and organic acids into the river.

Higher values for EC (1896.70 µS/cm), TDS (1234 mg/L), and Salinity (1.00 ppt) were obtained at sampling site 4. S4 is the station after the Makata industrial area. The high salt content in the river after the industrial area is indicative of the deposition of chemical species from the various industrial activities in the area which increases salts in the system. However, the results obtained in this study were significantly lower than the ones obtained by Kuyeli et al. (2009) who found EC values higher than 3600 µS/ cm.

Higher values for TSS were obtained at sampling sites 2, 3, and 4 but are within the MoAIWD standards of < 30 mg/ L. These sites were dominated by human settlements, a market, industrial activities, sand mining, bricklaying, laundry, and agricultural activities which are happening within the catchments of these sites. According Butler & Ford (2018), TSS in water systems may include sand, silt, clay, mineral precipitates, and biological matter and its formation primarily via hydrology-driven physical processes.

Biological matter is a very important source of TSS in water systems. The TSS values from this study correlate well with the observed fecal coliform counts in the river which may help explain the TSS profile observed along the stretch of the river under investigation. Suspended solid materials provide adsorption sites for chemical water constituents including nitrates and phosphates, and biological agents such as pathogenic micro-organisms. Nitrate levels were high at all sites, especially site 2 only beyond the acceptable limit of EPA of 50 mg/L (note: MoAIWD guideline value for nitrate not available). Wastewater contains elevated concentrations of nutrients, such as different forms of nitrogen which include nitrates and ammonia (Obarska-pempkowiak et al., 2015). The catchment area for S2 is heavily under the influence of human settlements as well as agriculture which could be the source of the observed high nitrate levels.

Higher values for turbidity and ammonia were obtained at all four sampling sites. Turbidity ranged from 10 to 51 NTU. The typical turbidity values for rivers during low-flow conditions are usually below 10 NTU (EPA, 2019). According to Syah & Purnaweni (2018), land use change and sand or gravel mining activities in the river can cause river degradation by sedimentation and erosion, as well as affect the ecosystem health of the river water. The Nasolo River has a heavily modified catchment as well as river channel, due to deforestation and sand mining respectively.

Consequently, the observed turbidity values can be attributed to deforestation and sand mining. Release of household and industrial wastes such as soaps and detergents can also potentially contribute to high turbid water leading to undesirable odors as well as providing adsorption sites for chemical and biological agents which facilitates altering in the chemistry of the water. Ammonia, a product of decaying nitrogenous organic wastes ranged from 2.27 to 5.6 mg/L which was above the odor threshold value of 1.5 mg/l. Ammonia concentrations were high at sampling site 4 possibly because of industrial discharge from the organics-based industries including dairy, opaque beer, and others in the industrial area draining into S4. These high levels of ammonia can be toxic to aquatic life and impair the ecological integrity of the stream (Manahan, 2017).

At sampling site 1, the DO levels obtained were above 4mg/L and ORP value measured was positive (+6.27 mV). Further downstream, at sampling sites 2,3, and 4, the DO levels decreased below 4mg/L and ORP values were negative. DO decreases as a result of the degradation of biomass coming from dead algae, plant leaves and other organic matter and ORP decreases as a result of sewage and industrial wastes (UN-Water, 2016). According to Manahan (2017), DO values that range from 4.5 – 6.5 define the river as moderately polluted while DO values below 4.0 state the river as severely polluted. In this case, sampling site 1 had a DO level of 5.2 mg/L which means that its water quality was moderately polluted while the other sites 2, 3, and 4 had values that ranged from 2.1 to 3 mg/L which means that the water quality at these sites was severely polluted by human activities. ORP values of between 300 – 500 mV are indicative of healthy, functional rivers capable of supporting aquatic life. The less positive ORP values, therefore, show that the river has a limited ability to self-purify which is in line with the observed DO values that show insufficient oxygen levels for the degradation of organic matter in the river.

3.1.2. Microbiological analysis of water quality variables

The fecal coliforms level that was obtained at sampling site 1 was 10 CFU/100mL. According to Weiner (2013), natural surface waters always contain some background level of fecal coliforms, usually less than 15–20 CFU/100mL. However, at sampling sites 2, 3, and 4, the levels of fecal coliforms ranged from 618-1966 CFU/100mL. On the other hand, total coliform counts at sampling site 1 was 126 CFU/100mL which was less than the EPA guideline value of 500CFU/100mL (note: no guideline value available from the MoAIWD). Total coliform bacteria occur naturally in plant material and soil (Sperling, 2007). At sampling sites 2, 3, and 4, the total coliform count was high. The levels ranged from 1343-2050CFU/100mL. However, their presence does not necessarily indicate fecal contamination (Baird & Bridgewater, 2017). Apart from S1, the rest of the sampling sites had a fecal coliform: total coliform ratio of > 50%. This indicated that the river is heavily polluted by fecal contamination owing to the presence of pit latrines that have discharge pipes into the river. Given that the water from the river is used for various domestic uses including bathing and dishwashing by communities along the river, there is a potential risk of waterborne diseases due to the increased levels of fecal contamination.

3.1.3. Correlation analysis

Table 2 illustrates correlation analysis for physico-chemical and microbiological water quality variables to determine the relationship between the variables whereby values greater than 0.5 show a strong positive relationship and values less than -0.5 show a strong negative relationship.

Table 2: Correlation analysis for physico-chemical and microbiological water quality variables

	pH	***Temp***	***DO***	***ORP***	***EC***	***TDS***	***Sal***	***NTU***	***TSS***	***FC***	***TC***	***NO3***	***NH3***
pH	1												
Temp	-0.732	1											
DO	0.660	-0.971	1										
ORP	0.581	-0.855	0.952	1									
EC	-0.542	0.784	-0.622	-0.354	1								
TDS	-0.526	0.782	-0.622	-0.353	0.999	1							
Sal	-0.485	0.761	-0.600	-0.327	0.998	0.999	1						
NTU	0.186	0.533	-0.576	-0.501	0.469	0.485	0.506	1					
TSS	0.522	0.166	-0.295	-0.348	0.000	0.019	0.045	0.883	1				
FC	-0.282	0.546	-0.731	-0.900	-0.071	-0.069	-0.091	0.423	0.485	1			
TC	-0.314	0.704	-0.854	-0.954	0.167	0.172	0.155	0.615	0.579	0.964	1		
NO3	0.543	0.158	-0.270	-0.301	0.046	0.065	0.094	0.899	0.996	0.418	0.527	1	
NH3	-0.325	0.783	-0.672	-0.434	0.943	0.949	0.957	0.735	0.332	0.078	0.336	0.375	1

Note: DO = dissolved oxygen; ORP = oxidation – reduction potential; EC = electrical conductance; TDS = total dissolved solids; NTU = turbidity; TSS = total suspended solids; FC = fecal coliform; TC = total coliform; NO_3 = nitrate; and NH_3 = ammonia.

The correlation matrix shown in Table 2 shows that temperature is highly correlated to variables that are driven by ions in the river including TDS, EC as well as nutrient-related variables of TC and NH3. Negative correlations show that an increase in the temperature of the water was connected to a reduction in the water quality variable. Temperature is one of the factors that would affect rates of chemical and/ or biochemical reactions in water systems such that increased temperatures will favor reactions that result in the mobilization of ions in water systems. This implies that higher temperatures would induce higher values in the ion-driven variables such as EC and TDS. High temperatures also favor increased microbial growth which would explain the higher correlation between temperature and total coliforms (Chigo et al., 2013). A very strong positive correlation was observed between suspended solids and nitrates (r^2 value of 0.996). According to Weiner (2013), suspended solids act as a medium that continually carries nutrients and enables nutrients to remain in the water for long periods. As such, the higher the TSS, the more the concentrations of nutrients in an aquatic system. Turbidity and ammonia also show a strong positive relationship of 0.7 meaning that as turbidity is high, it provides adsorption sites for chemicals such as ammonia that result in undesirable odor. The relationship between DO and temperature showed a strong negative correlation meaning that the DO level decreases as the temperature rises (Saha et al., 2016). Another very strong correlation is observed for ORP and TC ($r^2 = -0.954$) and FC ($r^2 = -0.900$) which can be explained by the fact that ORP measures the ability of an aquatic system to cleanse itself. Thus, a more positive ORP value will imply more cleansing abilities of the river and favor a reduction in the microbial communities as the river is cleaner and reflective in decreased TC/ FC counts. This significant correlation between ORP and TC suggests the potential of ORP as a proxy indicator for TC in water quality assessments. Turbidity is also strongly correlated to the nutrient variables NO_3 ($r^2 = 0.899$) and NH_3 ($r^2 = 0.735$). Turbidity is a proxy indicator for microbial growth in water systems. On the other hand, the growth of these microbial species would be encouraged by the availability of nutrients in the river. Therefore, increased nutrient levels in the river would be connected to higher turbidity levels as shown here.

3.1.4. Water Quality Index

This section shows the results obtained from the NSFWQI. Table 3a shows the NSFWQI calculations for Nasolo River and Table 3b shows the interpretation of the results in different water quality status categories:

Table 3a: NSFWQI Calculations for Nasolo River in 4 sampling sites

Sampling Sites		**S1**			**S2**			**S3**			**S4**		
Water Quality variables (i)	**Weight (W_i) for each variable (i)**	**Mean value**	**Q_i**	**W_i*Q_i**	**Mean value**	**Q_i**	**Wi*Qi**	**Mean value**	**Qi**	**Wi*Qi**	**Mean value**	**Qi**	**Wi*Qi**
pH	0.11	7.42	93	10.23	7.70	91	10.01	6.40	68	7.48	6.50	72	7.92
DO sat	0.17	62.94	62	10.54	36.31	25	4.25	25.42	16	2.72	26.63	16	2.72
Temp (^{0}C)	0.10	19.24	23	2.30	21.80	21	2.10	23.00	17	1.70	23.80	17	1.70
TDS	0.07	53.00	87	6.09	363.30	52	3.64	300.00	60	4.20	1234.00	20	1.40
Turbidity	0.08	16.00	76	6.08	51.00	38	3.04	23.00	59	4.72	38.00	47	3.76
Fecal Coliform	0.16	10.00	72	11.52	1464.00	20	3.20	1966.00	18	2.88	618.00	27	4.32
Nitrates	0.10	20.40	37	3.70	68.13	5	0.50	27.20	30	3.00	32.90	24	2.40
Overall WQI (%) = $\sum_{i=1}^{n}(Wi * Qi)$				**50.46**			**26.74**			**26.70**			**24.22**

Note: W_i is weight, Q_i is sub- water quality index of the variables in percentages and W_i*Q_i is the overall water quality index

Table 3b: Showing the interpretation of the overall Water Quality Index at all sampling sites for Nasolo River based on NSFWQI calculations in Table 3a

Sampling Sites	**Overall WQI**	**Water Quality Status**
S1	50.46	Moderate
S2	26.74	Poor
S3	26.7	Poor
S4	24.22	Very poor

Based on Table 3a, the overall water quality index at sampling site 1 was 50.46. This revealed that the water quality status at upstream of Nasolo River was moderate as per Table 3b. This meant that this site was moderately polluted by deforestation. Most water quality variables at this site were at acceptable levels and below the EPA water quality standards for freshwater. Practically, only two water quality variables; nitrates and temperature obtained Q-values less than 50. The water quality status at sampling sites 2 and 3 was poor. Q-values for DO, temperature, fecal coliform, turbidity, and nitrates at sampling site 2 were below 50 due to laundry, sand mining, and agricultural activities. At sampling site 3, DO, temperature, nitrates, and fecal coliform obtained Q-values less than 50 due to domestic wastewater from human settlements along the river. Lastly, the water quality status at sampling site 4 at the downstream was very poor because DO, temperature, TDS, turbidity, nitrates, and fecal coliforms obtained Q-values that were less than 50. In other studies, Pullanikkatil et al. (2015), used five parameters to develop a water quality index for the Likangala River and recommended that indices could be applied by authorities in Malawi to determine the health of water bodies and results revealed the downstream of the river had the poorest water quality than the upstream.

4.2.Biomonitoring analysis for Nasolo river

This section presents and discusses the results for macro-invertebrates collected at each sampling site and their sensitivity scores. Each invertebrate group has a different sensitivity score. Groups with less scores are highly tolerant to pollution meaning that the water is of poor quality while those with high scores are less tolerant to pollution, therefore, the water is unpolluted and not highly impacted by human activities and other natural conditions. Table 4 depicts the miniSASS sensitivity scoring sheet that was employed.

Table 4: MiniSASS Sensitivity Scoring Sheet (Graham et al., 2012)

AQUATIC INVERTEBRATE GROUPINGS	SENSITIVITY SCORES
Flatworms	3
Worms	2
Leeches	2
Crabs or shrimps	7
Stoneflies	14
Minnow mayflies	6
Other mayflies	13
Damselflies	4
Dragonflies	7
Bugs or beetles	6
Caddisflies	9
True Flies	2
Snails	4
TOTAL SCORE = $\sum(Sensitivity\ \text{score})$	
NUMBER OF GROUPS	
AVERAGE SCORE = $\frac{\sum(Sensitivity\ \text{score})}{\text{Number of groups}}$	
WATER QUALITY STATUS	

After the collection and identification of macroinvertebrates, the results in Tables 5a, 5b, 5c, and 5d show the average score per taxon value for each sampling site. The values were compared to table 6 to define the status of the river in terms of excellent, good, fair, poor, or very poor.

Table 5a: Sampling site 1

NUMBER *OF GROUPS*	**ORDER**	**FAMILY**	**COMMON NAME**	**COUNT**	**SENSITIVITY SCORE**
1	Ephemeroptera	Baetidae	Small minnow mayflies	3	5
2	Ephemeroptera	Leptophlibidae	Prongills (Other Mayflies)	2	11
3	Diptera	Chironomidae	Midges (True flies)	13	2
4	Diptera	Psychodidae	Moth flies	4	2
5	Diptera	Dixidae	Meniscus midges (flies)	3	2
6	Diptera	Tipulidae	Crane flies	2	2
7	Trichoptera	Psychomyiidae	Caseless caddisflies	2	9
8	Trichoptera	Ecnomidae	Caseless caddisflies	3	9
9	Annelida	Oligochaeta	Aquatic earthworms	4	2
	TOTAL SCORE = $\sum(Sensitivity \text{ score})$				44
	NUMBER OF GROUPS				9
	AVERAGE SCORE = $\frac{\sum(Sensitivity \text{ score})}{\text{Number of groups}}$				4.9

Table 5b: Sampling site 2

NUMBER OF GROUPS	**ORDER**	**FAMILY (Groups)**	**COMMON NAME**	**COUNT**	**SENSITIVITY SCORE**
1	Diptera	Chironomidae	True flies	100	2
2	Diptera	Dixidae	Meniscus midges (flies)	12	2
3	Diptera	Muscidae	House flies	10	2
4	Annelida	Oligochaeta	Aquatic earthworms	20	2
5	Coleoptera	Dytiscidae larvae	Predacious diving beetle	2	5
TOTAL SCORE= $\sum(Sensitivity \text{ score})$					13
NUMBER OF GROUPS					5
AVERAGE SCORE= $\frac{\sum(Sensitivity \text{ score})}{\text{Number of groups}}$					2.6

Table 5c: Sampling site 3

NUMBER OF GROUPS	**ORDER**	**FAMILY**	**COMMON NAME**	**COUNT**	**SENSITIVITY SCORE**
1	Diptera	Chironomidae	True flies	1000	2
2	Diptera	Psychodidae	Moth flies	6	2
3	Diptera	Athericidae	Snipe flies	10	2
4	Diptera	Culicidae	Mosquitos (flies)	500	2
5	Diptera	Muscidae	House flies	100	2
6	Annelida	Oligochaeta	Aquatic earthworms	20	2
7	Coleoptera	Dytiscidae larvae	Predacious diving beetles	5	5
8	Coleoptera	Elmidae Larvae	Riffle beetles	4	5
9	Turbellaria	Planaria	Flatworms	12	3
TOTAL SCORE $=\sum(Sensitivity\ \text{score})$					25
NUMBER OF GROUPS					9
AVERAGE SCORE $=\frac{\sum(Sensitivity\ \text{score})}{\text{Number of groups}}$					2.8

Table 5d: Sampling site 4

NUMBER OF GROUPS	**ORDER**	**FAMILY (Groups)**	**COMMON NAME**	**TOTAL NUMBER**	**SENSITIVITY SCORE**
1	Diptera	Chironomidae	True flies	500	2
2	Diptera	Dixidae	Meniscus midges (flies)	10	2
3	Diptera	Muscidae	House flies	100	2
4	Annelida	Oligochaeta	Aquatic earthworms	15	2
5	Annelida	Hirudinae	leeches	3	2
6	Turbellaria	Planaria	Flatworms	2	3
7	Coleoptera	Dytiscidae larvae	Predacious diving beetle	2	5
TOTAL SCORE $=\sum(Sensitivity\ \text{score})$					18
NUMBER OF GROUPS					7
AVERAGE SCORE $=\frac{\sum(Sensitivity\ \text{score})}{\text{Number of groups}}$					2.57

Table 6: Ecological category of a river (Grahamet al., 2012)

Ecological category (Condition)	**River Category** (**Sandy Type**)
Unmodified (**NATURAL** condition)	>6.9
Largely natural/few modifications (**GOOD** condition)	5.8 to 6.
Moderately modified (**FAIR** condition)	4.9 to 5.7
Largely modified (**POOR** condition)	4.3 to 4.8
Seriously/critical modified (**VERY POOR** condition)	<4.3

According to Table 5a, the average score per taxon (ASTP) calculated was 4.9. This revealed that the upstream of Nasolo river was moderately impacted based on Table 7. Hence, depicting that the water quality status was fair. The presence of mayflies and caddisflies indicated that the water was not severely polluted. Secondly, table 5b showed that the ASPT was 2.6, signifying that the ecological condition as well as the water quality at S2 was very poor. The analysis proved that this sampling site was critically and seriously modified by human activities such as sand mining, bricklaying, and agricultural activities. Thus, posing a health risk to people and the ecosystem. Table 5c shows that the average score for sampling site 3 was 2.8. This means that the ecological condition, as well as the water quality, was very poor because this site has been seriously modified by human activities such as commercial businesses in the market and human settlements along the Nasolo river. Table 5d showed that the average score for sampling site 4 was 2.57. This means that the ecological condition as well as the water quality was very poor because this site was possibly critically impacted by industrial activities that discharge their effluent into the river. Sampling sites 2,3, and 4 were heavily polluted and the presence of highly tolerant species such as Chironomidae and Oligochaeta were dominant. Therefore, the presence of low dissolved oxygen, high turbidity, elevated levels of total suspended solids and total dissolved solids in the river as well as high concentrations of nitrates and ammonia might have been caused by these human activities such as construction activities, industrial and sewage discharge, sand mining, commercial activities in markets, agricultural activities and fertilizer applications on the fields along Nasolo River (Taban et al., 2020). Therefore, this created a very critical and harsh environment for aquatic organisms. Hence, the absence of highly sensitive macroinvertebrates such as stoneflies, caddisflies, dragonflies, mayflies, and crabs was low (Damanik-Ambarita et al., 2016). All the above macroinvertebrates that were collected are good indicators of disturbances from anthropogenic activities (Huang et al., 2022). Masese et al. (2011) stated that highly tolerant species such as Chironomidae, possess high glycogen content that allows them to withstand organic pollution. Except for South Africa which has developed a miniSASS biotic index, the development and application of macroinvertebrates in biomonitoring are far behind in tropical African countries, and more studies have been recommended to be done across the tropics to improve knowledge of stream macroinvertebrates (Jacobsen et al., 2008). Therefore, the findings obtained on macroinvertebrates in this study have revealed the ecological health of the catchment of Nasolo River and greatly contributed to the scientific community on the stream macroinvertebrates.

4.3. Correlation analysis between the National Sanitation Foundation Water Quality Index (NSFWQI) and Average Score Per Taxon (ASPT)/ Biotic Index score

A strong positive relationship between the NSFWQI and the SASS average score per taxon (biotic index) as the correlation coefficient was found to be 0.997. A paired t-test two-tailed also showed that the NSFWQI and ASPT are statistically significant, whereby the p-value was 0.01 ($p<0.05$). These results are in tandem with a study by Mnisi (2004). Using the two indices together, the water quality of Lusushwana river, Swaziland produced almost similar classifications. The indices have shown that the water quality of the river is poor and heavily polluted due to the surrounding human activities. The biotic index results reveal that there has been a negative impact on macroinvertebrates that were present and some species that are highly sensitive to pollution have even become scarce like mayflies. This is a clear indication that pollution levels are very high in a river and there is a need to start conducting regular water quality monitoring studies which will help to keep in check the water quality status of the river. As it has been demonstrated in this study that water quality indices in conjunction with biomonitoring techniques can effectively be used in assessing the water quality in rivers and give insights on whether toxic pollutants have less or more catastrophic effects on people and other living organisms that live in such environments.

5. Conclusion

The overall objective of this study was to assess the water quality in the Nasolo river. The water quality status of the river at different sampling sites was defined by the application of the National Sanitation Foundation Water Quality Index and South African Scoring System biotic index scores. Both indices revealed similar results. At sampling site 1, the water quality was fair while at sampling sites 2, 3, and 4, the water quality was very poor. The results revealed that the river is not appropriate for usages such as drinking, fishing, and washing but can support a limited number of aquatic animals. As such, necessary measures to improve the water quality of Nasolo River must be taken up to ensure the health of the river together with its users. As the study was conducted only during the rainy season with a limited number of sampling points, it is recommended that future studies include more sampling sessions and sampling points, covering both the rainy and dry seasons. In addition, this study recommends the establishment of national water quality guidelines for freshwater ecosystems and a Malawian-based macroinvertebrate scoring system as a national environmental education tool to encourage water quality management in Malawi.

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Conflict of interest

The authors declare no conflict of interest.

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