ISSN: 2710-0758
URL: https://journal.ku.ac.ke/index.php/AJPAS/article/view/651

African Journal of Pure & Applied Sciences

Journal homepage: http://journal.ku.ac.ke/index.php/AJPAS

Research Article Open Access

Assessing the Effect of Anthropogenic Disturbance on Macroinvertebrates Abundance and Diversity in Selected Streams in Kirinyaga County, Kenya: A Citizen Science Approach

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Received 31st January 2025; Accepted 19th May 2025; Published online; 30th June 2025

How to Cite:
Mbaka, J. G. Assessing the Effect of Anthropogenic Disturbance on Macroinvertebrates Abundance and Diversity in Selected Streams in Kirinyaga County, Kenya: a Citizen Science Approach. *African Journal of Pure and Applied Sciences, 6(1),* 58–70. Retrieved from https://journal.ku.ac.ke/index.php/AJPAS/article/view/651

ABSTRACT

Anthropogenic disturbances have negative effects on water quality and biodiversity in riverine ecosystems. Citizen scientists have the capacity to collect data that can be used in management of riverine ecosystems impacted by human-related disturbances. The objective of this study is to evaluate the effect of anthropogenic disturbance on macroinvertebrates abundance and diversity by engaging citizen scientists (i.e., upper primary school children). The study was undertaken at seven study sites with different levels of anthropogenic disturbance in streams located in Kirinyaga County, Kenya. Physico-chemical factors such as temperature, conductivity and oxygen were determined at each study site. Additionally, macroinvertebrates abundance, taxonomic richness and diversity were determined. The low disturbance site (i.e., Nyamindi River) had the highest canopy cover intensity (44.4 %) and total dissolved solids (95.8 mg/L) values. On the other hand, high disturbance sites had the highest mean conductivity values (79-151 µs/cm) and lowest dissolved oxygen (39-72 mg/L) values. A total of 28 macroinvertebrate taxa were recorded across the study sites. The low disturbance site had the highest mean macroinvertebrate taxa richness (14.7 ± 1.5), abundance (121.4 ± 11.7 ind. m^{-2}) and Shannon-wiener diversity (2.5 ± 0.13). Additionally, the low disturbance site had the highest mean abundance (321.1 ± 35.6 ind. m^{-2}) for macroinvertebrates sensitive to pollution such as Ephemeroptera, Plecoptera and Trichoptera when compared to the high disturbance sites (e.g., Murubara and Mukengeria Rivers). Macroinvertebrates abundance and diversity differed significantly (all $p < 0.05$) across the study sites. The citizen science approach is an important strategy in macroinvertebrate data collection and provides an opportunity for public participation in scientific research, promoting data collection and scientific literacy, strengthening partnerships and informing research and policy decisions.

Keywords: Macroinvertberates, Citizen science, Water quality, Ecological status

INTRODUCTION

Water is an important resource not only for sustaining living organisms but also for promoting socio-economic activities. However, access to clean drinking water in many rural areas of Kenya is very low (Bluma, 2020; Bukachi et al., 2021; Kirira et al., 2023). This may be due to inability or unwillingness of rural residents to pay for improved domestic water supply (Collignon and Vézina, 2000; Getinet et al., 2024). Lack of access to piped water forces local residents to travel to the nearest rivers and streams to reach water that may be highly contaminated and even unsuitable for human consumption.

Rural streams and rivers are typically targeted for a wide range of human-related activities particularly during dry weather conditions in water-stressed areas where other sources of water may be inadequate or irregular (Khatri and Tyagi, 2015; Nyairo et al., 2015; Butler et al., 2021; Fekadu et al., 2022). These activities have been termed as in-stream anthropogenic activities because they mainly occur within or along the riparian zones of shallow riverine ecosystems (Yillia et al., 2007). In-stream activities occur at varying intensities during the day depending on ambient weather conditions and availability of water from alternative water sources in an area (Mathooko, 2001 a; Yillia et al., 2007).

Rivers are vital ecosystems with high ecological importance (Madhav et al., 2022) and their health is important for the humans that rely on them (Qi et al., 2024). Rivers are crucial sources of water for humans and freshwater environments and provide various goods and services such as navigation, recreation and tourism, breeding grounds, habitat provision, ground water recharge and food (e.g., fish) (Vári et al., 2021).

During the last decades, fresh water quality has deteriorated due to human impacts (Albert *et al.,* 2021). In tropical areas, especially in Sub-Saharan Africa, freshwater ecosystems are under pressure due to anthropogenic disturbances that degrade water quality, limiting water availability for various uses (Kakonge, 2002; Muringai *et al.,* 2022; Jones *et al.,* 2023). Major threats to freshwater environments include pollution, water abstraction, waste water effluents, damming, habitat degradation, invasive species and deforestation (Mwendwa *et al.,* 2019; Soesbergen *et al.,* 2019; Masindi and Foteinis, 2021).

Biological monitoring is valuable in determination of natural and anthropogenic disturbances in aquatic environments because organisms respond to stressors from multiple spatio-temporal scales (Comín *et al.,* 2004; Verberk *et al.,* 2005; Wolter *et al.,* 2016). Additionally, utilization of organisms in monitoring of aquatic environments has proven more effective than solely utilizing physico-chemical variables because aquatic organisms integrates functional and structural characteristics and portrays the ecological status of the studied aquatic ecosystems (Zhou *et al.,* 2008; Li *et al.,* 2010; Parmar *et al.,* 2016). Among aquatic organisms, aquatic macroinvertebrates are among the most commonly used bioindicators in aquatic ecosystems (Hodkinson and Jackson, 2005; Mezgebu, 2022; Lukhabi *et al.,* 2024).

Macroinvertebrates are routinely utilized in biological monitoring because of various desirable characteristics, such as varied levels of tolerance to environmental disturbances, ubiquity, wide distribution, limited mobility and cost effectiveness during samples collection and processing (Chen *et al.,* 2019; Kwakye *et al.,* 2021; Lukhabi *et al.,* 2024). Aquatic macroinvertebrates differ in their response to stressors and their diversity and composition are utilized to make inferences on status of aquatic environments (Mabidi *et al.,* 2017; Raphahlelo *et al.,* 2022; Chaib *et al.,* 2023). The responses of aquatic macroinvertebrates to variability in habitat conditions is recognized globally and their responses are utilized in biological indices to assess freshwater ecosystems ecological status, aiding in decision making by aquatic ecosystem managers (Dickens and Graham, 2002; Edegbene *et al.,* 2021; Eriksen *et al.,* 2021; Bendary *et al.,* 2023; Omary *et al.,* 2023). Despite the development and utilization of various macroinvertebrate-based biotic indices in assessment of anthropogenic disturbances in aquatic environments, there is still limited information on application of biotic indices in aquatic assessments in areas of Sub-saharan Africa such as Kenya (Musonge *et al.,* 2020; Dallas, 2021).

Citizen science entails general public, or non-professional volunteers, actively engaging in scientific research (Fraisl *et al.,* 2022; Finger *et al.,* 2023). Benefits of citizen science include increased awareness about environmental matters and scientific literacy, generation of large amounts of data at a low cost, active community involvement and generation of large-scale data on organisms composition and distribution (Lee *et al.,* 2020; Walker *et al.,* 2021; Pocock *et al.,* 2023).

Citizen science has largely been applied in areas such as meteorological monitoring while relatively few studies have focused on aquatic biomonitoring (Eden, 2009; Zheng *et al.,* 2018; Njue *et al.,* 2019). Additionally, in many regions of Africa, information on the potential role of citizen scientists in aquatic biomonitoring is limited. Such areas of the world can benefit from the citizen science approach of data collection to extend their biomonitoring networks. Additionally, providing evidence that citizen scientists can collect reliable datasets in different regions of the world can address a critical barrier when incorporating citizen-based assessments in monitoring programs.

The citizen science approach used in this study illustrates a collaborative and inclusive methodology involving primary schoolchildren and experienced aquatic ecologists (Zoellick *et al.,* 2012; Pinto *et al.,* 2020). This approach not only facilitates rapid monitoring of macroinvertebrates assemblage but also promotes the engagement of volunteers in scientific research (Moffett and Neale, 2015; Peeters *et al.,* 2022). Citizen-based macroinvertebrates assessments actively involve volunteer scientists and public in research activities and raise awareness about the importance of healthy environment and the effect of anthropogenic disturbances on aquatic environments (Moolna *et al.,* 2020). As Kenyan riverine ecosystems faces increasing anthropogenic disturbances, such a citizen driven approach is crucial in collecting important data on macroinvertberates abundance and diversity.

The objective of the current study is to determine if there are significant differences in physico-chemical parameters and macroinvertebrate abundance and diversity across study sites.

MATERIALS AND METHODS

Study area and sites

The study was conducted in three constituencies (i.e., Mwea, Gichugu and Kirinyaga central) of Kirinyaga County between July 2023 and April 2024. Seven rivers located within the Mount Kenya drainage basin in Kirinyaga County were selected for study. They were Murubara, Mburi, Nyamindi, Thiba, Mukengeria, Kandakame and Rutui Rivers. The Mount Kenya is one of the most important water catchments in Kenya and is a biodiversity hot-spot (MEWNR, 2015). However, the catchment has experienced an increase in human-related disturbances in the last decades, negatively affecting natural habitats and biodiversity (Bussmann, 1996).

Study sites were selected based on observable physical anthropogenic disturbances on the rivers by humans and livestock. Retardation of riparian vegetation due to anthropogenic disturbances was evident at the study sites and canopy cover intensity ranged between 5 % and 44 %. Seven river reaches were selected for study and categorized as low, medium and high disturbance sites based on the intensity of human and livestock-related activities (Table 1). High disturbance sites are expected to support a higher abundance and diversity of macroinvertebrates while low disturbance sites are anticipated to harbour sensitive species, higher macroinvertebrate diversity and richness (Lakew, 2015; Raphahlelo et al., 2022).

Activities of humans and livestock (i.e., anthropogenic disturbances) on the study sites were assessed through head counts on eight separate occasions as described by Yillia *et al.* (2008). All the counts were undertaken on an hourly basis between 6 a.m. and 7 p.m. There were no other observable disturbances, such as mining or sewage disposal, at the study sites. Details of the geographical positions and environmental factors of the study sites are provided in Table 2.

Table 1: The type of activities recorded during the sampling period at the low, medium and high disturbance study sites in the studied rivers. The means (± SE) represent the number of people or livestock recorded during the time of sampling.

Activity	Murubara	Mburi	Nyamindi	Thiba	Mukengeria	Kandakame	Rutui
Fetching water (personal use)	16 (3)	7 (0.9)	1 (0.6)	8 (0.8)	18 (1.9)	11 (2)	11 (2)
Livestock watering	7 (1)	-	-	1 (0.4)	6 (1.4)	7 (1)	8 (0.8)
Bathing	2 (1)	-	-	-	2 (0.6)	1 (0.4)	1 (0.3)
Laundry	6 (1)	3 (0.6)	-	2 (0.6)	5 (1.3)	2 (0.9)	-
Grazing	3 (1)	1 (0.4)	1 (0.5)	1 (0.3)	3 (0.6)	4 (0.7)	6 (1.3)
Trampling (people)	3 (1)	-	-	-	3 (0.8)	2 (0.6)	2 (0.6)
Swimming	-	-	-	-	1 (0.2)	-	-
Car washing	-	-	-	-	-	3 (0.5)	2 (0.4)
Disturbance level	High	Medium	Low	Medium	High	High	High

- Activity was not recorded at the study sites;

Citizen scientists engagement and training

Permission to conduct research in the study area was obtained from the County Director of Education and County Commissioner while a research license was issued by the National Commission for Science, Technology and Innovation. Upper primary schoolchildren (grades: 4-6) were involved in the research project as citizen scientists. After obtaining research authorization, teachers from six local primary schools, a university lecturer and two research assistants were engaged in development of a training programme for the schoolchildren. Other stakeholders such as water resource users associations were also engaged. The training programme consisted of background information about the study area, procedures for measuring physico-chemical factors, application of macroinvertebrates in biological monitoring, sampling and processing of macroinvertebrates and recording of data. To develop a sustainable citizen-science biomonitoring programme, it is vital that citizen scientists have grasped the fundamental scientific concepts through training programmes and background literature (Pinto *et al.*, 2020).

From each constituency, two schools were randomly selected for involvement in the study. The selected schools include Rwambiti, St. Thomas Mburi, Kianjiru, Gatunguru, Kutus and Kiabarikiri primary schools. Before starting field work, the selected schools were contacted and prior arrangements made with teachers to facilitate training of students and collection of data in the field. Classroom training presentations were conducted at the selected schools. During training, educational materials such as pamphlets explaining the effects of anthropogenic disturbances on the environment and aquatic life were distributed to the children. In addition to classroom training, schoolchildren received additional training on sampling and processing of macroinvertebrates and measurement of physico-chemical parameters during a preliminary sampling session dedicated on training. The sampling protocols were supported with illustrations such as pictures of macroinvertebrates and sampling equipment. During subsequent sampling occasions, two teachers, a university lecturer and two research assistants were involved in field assessments. Additionally, primary schoolchildren, comprising 5-10 individuals in a group, actively participated in sampling and processing of macroinvertebrate samples. A total of 189 students were involved in collection of macroinvertebrate samples.

The educational materials and training were tied to the primary school science curriculum where schoolchildren are supposed to learn about animals, plants and the environment. In particular, the Competency Based Curriculum which is currently being implemented in Kenya promotes hands on learning and integrated acquisition of new knowledge through observation, experiential learning and practical experiments (Amutabi, 2019).

The citizen science approach is an important method for monitoring riverine macroinvertebrates which are vital biological indicators of water quality and lotic ecosystems ecological conditions. Previous studies have demonstrated citizen science as a valuable approach for collecting reliable macroinvertebrate data sets, promoting community engagement and environmental awareness (Moffett and Neale, 2015; Moolna *et al.*, 2020; Gönner *et al.*, 2024).

Measurement of physico-chemical factors

Depth and width of the river were assessed using a graduated rod and tape measure, respectively. Water temperature, pH, dissolved oxygen, conductivity and total dissolved solids were measured using portable sensors. Riparian vegetation canopy cover and river substrates were evaluated visually as described by Bain and Stevenson (1999) and Paletto and Tosi (2009).

Macroinvertebrates sampling and processing

The sampling strategy used in this study involved nine sampling occasions at each study site with a focus on benthic macroinvertebrates. During each sampling occasion, three benthic samples were randomly collected from each of the study sites using a surber sampler. Macroinvertebrates were picked from a sorting tray using forceps and placed in trays for taxonomic identification and counting. The macroinvertebrates were identified to order and family levels.

Taxonomic identification and verification processes of macroinvertebrates were done by schoolchildren under supervision by a university lecturer, primary schoolchildren and research assistants, guided by identification guides (Gerber and Gabriel, 2002; Fry, 2003). The collaborative effort between a university lecturer, primary schoolchildren and research assistants aimed at compilation of comprehensive data on invertebrate assemblages.

Hand lenses were utilized during sorting and picking of macroinvertebrates from the debris. Unidentified macroinvertebrates were preserved in 70% ethanol and transported to the laboratory for further identification. In the laboratory, a stereo microscope was utilized to facilitate identification of macroinvertebrate samples. Macroinvertebrates abundance was expressed per unit area (individuals m^{-2}). Macroinvertebrates taxa richness and Ephemeroptera, Plecoptera, Trichoptera (EPT) taxa richness were determined by enumerating the number of overall taxa and EPT taxa present, respectively. The Shannon-Wiener diversity index (H') was determined using the following equation:

$$H' = -\sum\left[\frac{ni}{N} * \ln\left(\frac{ni}{N}\right)\right]$$

where ni is the number of individuals affiliated to species I and N is the total number of individuals (Shannon and Wiener, 1949).

Data analysis

Differences in physico-chemical variables and macroinvertebrates abundance and diversity among the study sites were analyzed using one-way analysis of variance. Tukey contrasts were used for pairwise comparisons of statistically significant models (Hothorn *et al.,* 2008). Model residuals were assessed for normality and homogeneity of variances as described by Zuur *et al.* (2009). Data was analyzed using the R statistical package (R Development Core Team, 2018).

RESULTS

Anthropogenic disturbances

Water abstraction (i.e., fetching water) for domestic utilization by local residents was recorded across all study sites. However, the average number of people fetching water at the study site with low disturbance was relatively low (1 ± 1 people). Fetching water was the major activity at the highly disturbed sites, with an average of more than 10 people being recorded at each study site (Table 1). Grazing of animals was also recorded across all study sites, although the average density of animals recorded at the study sites with low and medium disturbance was comparatively low (1 ± 1 animals) when compared to the highly disturbed sites (3 - 6 animals). Livestock watering was also a major activity at the highly disturbed sites and an average of 6 – 8 animals were recorded at the study sites. Human activities such as swimming, trampling of stream bed, bathing and car washing were only observed at the highly disturbed sites (Table 1).

Physico-chemical variables

Mean water temperature ranged from 10.5^{o}C at the Murubara River study site to 15.8^{o}C at the Thiba River study site. The Nyamindi River study site had the highest mean canopy cover intensity (44.4%) while the Mukengeria River study site had the lowest (5.1%) mean canopy cover intensity (Table 2). The highest mean dissolved oxygen content was recorded at the Thiba River study site (12.8 mg/L) while the lowest mean dissolved oxygen content was recorded at the Murubara River study site (7.9 mg/L). Mean water pH ranged from 7.5 (Murubara) to 8.3 (Thiba). Mean river width varied from 1.6 m (Murubara) to 17.1 m (Thiba). The highest mean conductivity was recorded at the Mukengeria River study site (151 µs/cm) while the lowest mean value was recorded at the Nyamindi River study site (78.1 µs/cm). With regard to total dissolved solids, the Murubara River study site had the lowest mean value (39.4 mg/L) while the Nyamindi River study site had the highest (95.8 mg/L) mean value (Table 2). The physico-chemical variables differed significantly among the study sites (all p <0.05 in ANOVA) (Table 2).

Macroinvertebrates composition, abundance, richness and diversity

The macroinvertebrate taxa collected from the seven rivers are summarized in Table 3. Benthic macroinvertebrate taxa with the highest mean abundances include Baetidae (68.9 – 674.3 ind. m^{-2}), Chironomidae (218.4 – 689.7 ind. m^{-2}), Oligochaeta (65.1 – 731.8 ind. m^{-2}), Caenidae (45.9 – 459.8 ind. m^{-2}), Heptageniidae (38.3 – 375.5 ind. m^{-2}). Oligochaeta were the most abundant macroinvertebrate taxa and had the highest mean abundance (731.8 ± 47.6 ind. m^{-2}) at the Kandakame River (Table 3). Chironomidae also had relatively high mean abundance, particularly at the Thiba (689.7 ± 49.7 ind. m^{-2}), Nyamindi (609.2 ± 85.6 ind. m^{-2}) and Rutui (605.4 ± 37.7 ind. m^{-2}) Rivers (Table 3). Trichopterans such as Hydropsychidae, Glossosomatidae and Pisuliidae had relatively high mean abundances at the Nyamindi River study site while they were not recorded at the Thiba, Mukengeria and Rutui Rivers. Odonates were also primarily recorded at the Nyamindi River study site.

Table 2: Geographical coordinates, major substratum and mean (±) values for physico-chemical variables in the sampled rivers

Parameters	Murubara	Mburi	Nyamindi	Thiba	Mukengeria	Kandakame	Rutui	$F_{6,56}$	*p-value*
Geographical Coordinates	00^{O}31’52.9”S 37^{O}21’24.5”E	00^{O}30’45.3”S 37^{O}21’27.0”E	00^{O}33’5.4”S 37^{O}23’3.2”E	00^{O}33’58.9”S 37^{O}19’19.5”E	00^{O}29’56.5”S 37^{O}18’15.8”E	00^{O}29’33.5”S 37^{O}16’32.3”E	00^{O}29’33.5”S 37^{O}16’50.4”E		
Major substratum (%)	Clay, sand and silt - (70%)	Cobbles and gravel – (55%)	Boulders and bedrock – (50%)	Cobbles and gravel – (60%)	Clay, sand and silt – (60%)	Clay, sand and silt – (75%)	Clay, sand and silt – (45%)		
Width (cm)	157.8 (11.6)	201.1 (12.3)	1468.8 (56.2)	1706.7 (30.3)	741.1 (36.6)	446.7 (40.3)	592.2 (24.3)	324.1	0.001
Depth (cm)	33.3 (1.9)	57.2 (6.7)	87.1 (1.9)	125.8 (2.7)	147.9 (3.5)	118.4 (2.2)	87.2 (2.6)	133.2	0.001
pH	7.5 (0.02)	7.7 (0.04)	8.0 (0.04)	8.3 (0.01)	7.8 (0.06)	7.2 (0.1)	7.2 (0.04)	66.3	0.001
Dissolved oxygen (mg/L)	7.9 (0.01)	8.8 (0.06)	12.3 (0.1)	12.8 (0.02)	11.5 (0.3)	11.7 (0.2)	10.5 (0.2)	101.2	0.003
Conductivity (µs/cm)	79.8 (0.2)	86.8 (0.9)	78.1 (1.4)	115.7 (2.1)	151 (2.7)	134.7 (2)	148.3 (2.2)	93.1	0.01
Total dissolved solids (mg/L)	39.4 (0.4)	44.3 (0.8)	95.8 (0.7)	73.6 (3.5)	68.4 (1.5)	72.9 (0.9)	64.1 (0.9)	378.8	0.003
Temperature (^{O}C)	10.5 (0.06)	13.9 (0.1)	14.9 (0.2)	15.8 (0.05)	12.5 (0.3)	11.5 (0.3)	10.8 (0.2)	99.5	0.006
Canopy cover (%)	23.3 (2.4)	26.1 (1.8)	44.4 (1.5)	13.8 (1.4)	5.1 (0.5)	6.2 (0.7)	6.0 (0.8)	100.3	0.004

Table 3: Mean (±) abundance (ind. m^{-2}) of macroinvertebrate taxa recorded in the sampled rivers.

	Murubara	Mburi	Nyamindi	Thiba	Mukengeria	Kandakame	Rutui
EPHEMEROPTERA							
Baetidae	68.9 (14.1)	149.4 (25.1)	674.3 (37.2)	226.1 (64.7)	164.8 (49.4)	168.6 (42.7)	383.1 (46.8)
Caenidae	95.8 (39.7)	45.9 (20.7)	459.8 (75.8)	222.2 (45.7)	95.7 (34.8)	53.6 (31.5)	-
Heptageniidae	-	-	375.5 (64.6)	226.1 (34.5)	-	38.3 (21.0)	-
ODONATA							
Coenagrionidae	76.6 (9.6)	-	-	-	-	-	-
Aeshnidae	-	76.6 (23.5)	34.5 (20.7)	-	-	-	-
Calopterygidae	-	-	183.9 (53.9)	-	-	-	-
Lestidae	-	-	45.9 (9.9)	-	-	-	-
TRICHOPTERA							
Hydropsychidae	88.1 (11.7)	199.2 (58.3)	283.5 (52.6)	-	-	26.8 (7.8)	-
Glossosomatidae	-	-	76.6 (46.6)	-	-	-	-
Pisuliidae	-	-	57.5 (20.7)	-	-	-	-
DIPTERA							
Chironomidae	260.5 (95.5)	360.2 (66.3)	609.2 (85.6)	689.7 (49.7)	218.4 (73.4)	555.6 (38.3)	605.4 (37.7)
Culicidae	103. 4 (47.0)	-	-	-	38.3 (24.0)	95.7 (64.9)	-
Limoniidae	7.7 (3.6)	-	-	-	-	-	-
Athericidae	3.8 (1.8)	-	-	-	-	-	-
Ceratopogonidae	57.5 (32.5)	26.8 (13.8)	53.6 (38.2)	325.7 (34.5)	-	-	65.1 (43.9)
Simuliidae	-	68.9 (30.4)	84.3 (31.0)	206.9 (60.8)	-	141.7 (75.6)	-
Tipulidae	-	38.3 (19.4)	210.7 (54.9)	-	-	-	-
COLEOPTERA							
Elmidae	-	130.3 (13.8)	210.7 (33.2)	329.5 (44.6)	-	7.7 (4.2)	-
Helodidae	-	130.3 (24.9)	65.1 (24.0)	268.2 (49.0)	-	-	-
Dysticidae	-	157.1 (26.4)	168.6 (21.1)	-	-	3.8 (1.4)	57.5 (40.6)
HEMIPTERA							
Gerridae	-	153.3 (21.6)	-	-	-	-	-
Notonectidae	-	99.6 (35.6)	-	-	-	-	-
Nepidae	-	-	65.1 (36.9)	-	-	-	-
MEGALOPTERA	68.9 (23.7)	-	-	-	-	-	-
OLIGOCHAETA	-	65.1 (40.0)	486.6 (68.8)	478.9 (47.8)	306.5 (89.8)	731.8 (47.6)	383.1 (127.8)
TURBELLARIA	-	-	49.8 (24.5)	114.9 (51.1)	-	-	134.1 (65.1)
HIRUDINAE	-	-	22.9 (12.8)	-	-	-	26.8 (19.7)
BIVALVIA							
Sphaeriidae	-	-	30.7 (19.4)	-	-	-	-

he highest mean macroinvertebrate abundance was recorded at the Nyamindi River study site (121.4 ± 11.7 ind. m^{-2}) while the lowest mean macroinvertebrate abundance was recorded at the Mukengeria River study site (23.5 ± 5.2 ind. m^{-2}) (Figure 1). Macroinvertebrate abundance differed statistically significantly among the study sites ($F6,56 = 32.7$, $p = 0.003$).

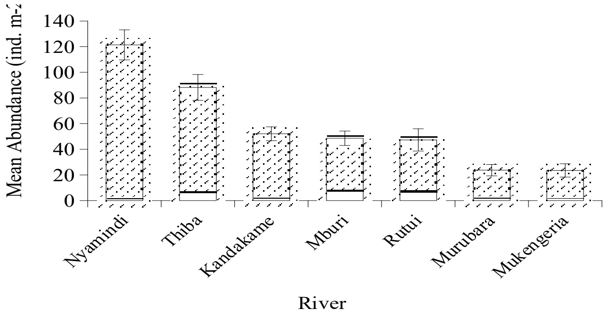

Figure 1: Mean abundance (ind. m^{-2}) of macroinvertebrates in the sampled rivers.

Ephemeroptera, Plecoptera and Trichoptera (EPT) mean abundance was highest at the Nyamindi River study site (321.1 ± 35.6 ind. m^{-2}) and lowest at the Murubara (42.1 ± 19.2 ind. m^{-2}) and Mukengeria (43.4 ± 28.8 ind. m^{-2}) River study sites (Figure 2). Similarly, the Nyamindi River study site had the highest (6) EPT richness while the Mukengeria (2) and Rutui (1) River study sites had the lowest EPT richness. EPT abundance differed significantly among the study sites ($F6,56 = 37.1$, $p = 0.001$).

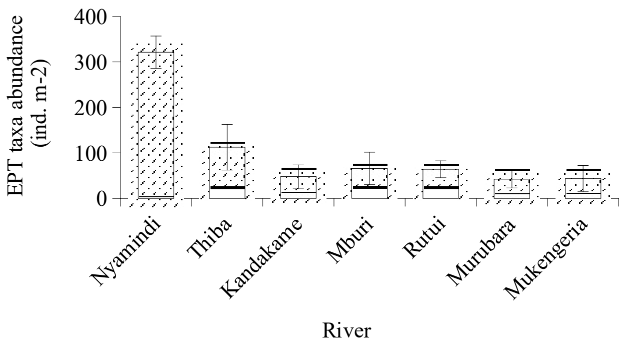

Figure 2: Mean (±) abundance of Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa in the sampled rivers.

With regard to overall taxa richness, the highest (14.7 ± 1.5) mean taxa richness was recorded at the Nyamindi River study site while the lowest (3.1 ± 0.05) mean taxa richness was recorded at the Mukengeria River study site (Figure 3). The highest mean diversity (*H'*) values were recorded at the Nyamindi (2.5 ± 0.13), Mburi (2.2 ± 0.11) and Thiba (2.2 ± 0.002) River study sites while the lowest mean diversity value was recorded at the Mukengeria (1.0 ± 0.15) River study site (Figure 4). Shannon's diversity differed statistically significantly among the study sites ($F6,56 = 21.9$, $p = 0.04$).

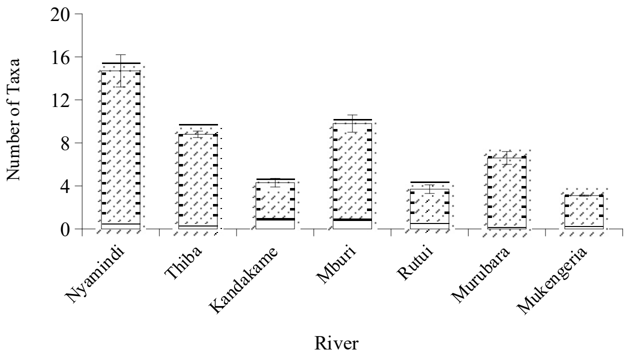

Figure 3: Mean (±) macroinvertebrate taxa richness (n) recorded in the sampled rivers.

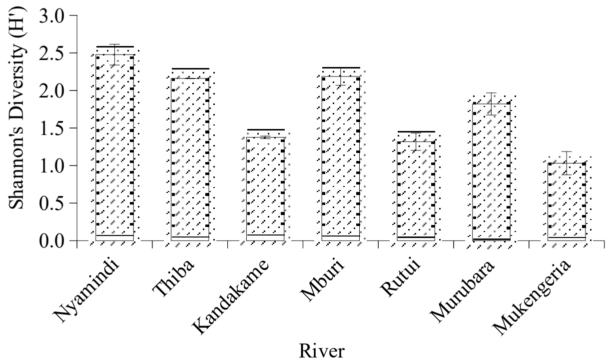

Figure 4: Mean (±) macroinvertebrates Shannon-wiener diversity (*H'*) in the sampled rivers.

DISCUSSION

Anthropogenic disturbances

Fetching water for domestic use was the most common anthropogenic activity observed at the study sites. Other common anthropogenic activities include livestock watering, laundry and grazing. Other studies conducted in other regions of sub-Saharan Africa have also reported fetching water and livestock watering to be common human activities in riverine ecosystems (Mathooko, 2001 b; Nevondo and Cloete, 1999). For example, Mathooko *et al.* (2001 b) evaluated the effect of different anthropogenic disturbances on coarse particulate organic matter distribution in a tropical Rift Valley stream and found that fetching water for domestic utilization was among the major anthropogenic activities at the study sites. Other major in-stream activities included trampling, laundry and livestock watering. Anthropogenic disturbances had a negative effect on the amount of benthic coarse particulate organic matter, an important energy resource in head-water streams. In a different study, Yillia *et al.* (2008 b) assessed the effect of in-stream activities on stream flow and chemical water quality in the Njoro River, Kenya, and found that water abstraction (i.e., fetching water) was a major anthropogenic activity. Other activities included bathing, washing clothes and vehicles. Anthropogenic activities resulted in a significant increase in total suspended solids, turbidity and biological oxygen demand.

Differences among study sites in terms of number of anthropogenic activities probably indicates that people living in high disturbance sites did not have other sources of water, resulting in increased visits to riverine ecosystems. Lack of alternative water sources, such as piped water, may result in many area residents and socio-economic enterprises depending on the services of water vendors. Some of the people observed fetching water in the current study may have been water vendors abstracting water for sale. Water vending has been linked with lack of reliable water supplies in other areas of sub-Saharan Africa (Thompson *et al.,* 2000; Gulyani *et al.,* 2005).

Physico-chemical variables

The relatively low mean canopy cover intensities at the high disturbance sites could have been caused by the negative effects of anthropogenic disturbances such as fetching water, livestock watering, trampling and grazing on riparian vegetation. For example, Ren *et al.* (2019) investigated the impacts of human disturbances on riparian plant communities in a Chinese river and found that human disturbances resulted in reduction in species richness, fragmentation of riparian habitats and species extinction. Another study investigated the effects of land use on the riparian vegetation in Kenya and found that disturbances such as grazing resulted in negative effects on grass, herbs and tree seedlings (Ruto *et al.,* 2023). The study highlighted the threats on riparian plants by anthropogenic disturbances and the need for riparian conservation and management.

Electrical conductivity is a measure of the ionic content in a solution in terms of its ability to conduct current (Carr and Neary, 2008). It estimates the quantity of solids dissolved in water and a sharp increase in mean values could be a sign of pollution (Zhu *et al.,* 2022). The high mean electrical conductivity values at the high disturbance sites could be due to introduction of pollutants into river water by anthropogenic disturbances such as laundry and grazing.

The mean total dissolved solids in the current study ranged between 39.4 mg/L and 95.8 mg/L. These values are less than the total dissolved solids content (600 mg/L) deemed to be good by the World Health Organization (WHO, 2011). However, there was a significant difference in mean total dissolved solids among the study sites. The difference may have been influenced by variability in intensity of human-related disturbances such as agriculture, industries and mining activities in upstream areas of the study sites.

The pH of aquatic ecosystems is one of the most vital water quality parameters and is an estimate of the concentration of hydrogen ions in water. It influences the solubility and bioavailability of chemical constituents such as heavy metals and nutrients in aquatic ecosystems (Duncan *et al.,* 2018). The pH values recorded for this study (7.2-8.3) are within the recommended range of 6.5-8.5 for the proper functioning of organisms in the aquatic environment (Carr and Neary, 2008). Additionally, the values are within the range that can cause reduced solubility of toxicants, such as heavy metals, in water hence making them less toxic in aquatic environments (Alabaster and Lloyd, 2013).

Water temperature affects water quality and environmental parameters because it controls chemical and biological reactions (Bonacina *et al.,* 2023). Differences in water temperature among study sites could have been caused by differences in canopy intensity or human-related disturbances which can cause temperature differences. These disturbances can also result in erosion of stream banks and increased deposition of fine substrates (e.g., clay, sand and silt) into rivers as observed in high disturbance sites in the current study.

Macroinvertebrates composition, abundance, richness and diversity

The relatively high mean macroinvertebrate abundance and diversity recorded at the low disturbance site (i.e., Nyamindi River) have also been reported by other studies that found low disturbance sites to have high mean macroinvertebrates abundance and diversity (Camacho and Taniegra, 2019; Wondmagegn and Mengistou, 2019). For example, Camacho and Taniegra (2019) assessed the impacts of anthropogenic disturbances on macroinvertebrate communities in streams in Philippines and found that macroinvertebrate abundance and richness in relatively undisturbed sites were significantly higher than those recorded in disturbed riverine ecosystems. A different study investigated the effects of anthropogenic activities on macroinvertebrates assemblage in Ethiopia and found that the highest macroinvertebrate family richness and abundance, Shannon-wiener diversity index, Ephemeroptera and Trichoptera richness were recorded at the least disturbed sites, compared to the disturbed sites (Wondmagegn and Mengistou, 2019).

High mean abundance of Ephemeropterans, Trichopterans and Colepterans at the low disturbance site can be due to the fact that these species are sensitive to anthropogenic disturbances and are typically found in clean waters (Edokpayi *et al.,* 2000; Edema *et al.*, 2002; Odume *et al.,* 2012). On the other hand, macroinvertebrates such as Oligochaeta and Chironomidae are more tolerant to pollution and are commonly found in disturbed sites (Gerber and Gabriel, 2002; Azis and Abas, 2021). Other than water quality, the distribution and abundance of macroinvertebrates in rivers are influenced by factors such as food availability, current velocity, substrate type and availability of microhabitats (Jun *et al.,* 2016; Min and Kong, 2020; Azis and Abas, 2021). Differences in the aforementioned factors among study sites could have resulted in variability in the abundance, diversity and distribution of macroinvertebrates.

CONCLUSION

High disturbance sites had significantly low macroinverterate abundance, richness and diversity. On the other hand, low disturbance site had significantly higher mean macroinvertebrate taxa richness, abundance and diversity. The physico-chemical factors differed significantly across the study sites. This indicates that anthropogenic disturbance has a negative effect on river habitat conditions, macroinvertebrate abundance and diversity. Management strategies should be put into place to mitigate anthropogenic impacts along affected riverine ecosystems.

The data collected by the citizen scientists (i.e., schoolchildren) is valuable in monitoring of anthropogenic disturbance in running water ecosystems. Application of the citizen science approach in macroinvertebrate-based studies can also promote collaboration among citizen scientists, scientists, natural resource managers, and stimulate public awareness and involvement in management of riverine ecosystems. In future, more comprehensive biomonitoring studies involving different types of citizen scientists (e.g., high school students and local community) should be conducted. Future studies should evaluate the effects of the citizen science approach on citizen scientists knowledge, attitudes and behaviour towards aquatic environments. There is need for a policy framework to enhance use of citizen science approach in biomonitoring programmes.

CONFLICT OF INTEREST

The author have no conflict of interest to declare.

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