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Relationship between sediment grain sizes and macroinvertebrate distribution along the Isiukhu River, western Kenya

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The current study investigated the relationship between sediment grain sizes and macroinvertebrate distribution along the Isiukhu River, a tropical stream in western Kenya. Ten sites in total were selected from the upstream, midstream and downstream areas. Sampling of sediments and macroinvertebrates was carried out twice a month from March 2018 to March 2019. Sediment was characterised as polymodal and extremely poorly sorted at the upstream; trimodal and extremely poorly sorted in the midstream; and polymodal and extremely poorly sorted towards the downstream of the river. Upstream sediments were fine gravelly mud and very coarse gravelly mud, while downstream sediments were very coarse gravelly muddy very fine sand and very fine gravelly, clayey very fine sand, indicating sediments became finer downstream. The study identified 993 individual macroinvertebrates from 21 families. Highest mean abundance (100 ± 9.2) was recorded at Kimangeti (upstream) while least was at Mutono (11 ± 0.7) (downstream). A regression model of the relationship between mean sediment grain size and mean macroinvertebrate abundance indicated that sediment grain size accounted for 28.7% of the spatial variability of macroinvertebrate abundance. The connection between sediment size and macroinvertebrate abundance and diversity in the Isiukhu River highlights that control of soil erosion in this catchment is important for the ecology of this river.

Keywords: habitats, land use, physico-chemical, diversity, tropical streams, water quality

Introduction

Excessive sediment accumulation is a key source of stream habitat deterioration in Kenya (Wanderi et al. 2022). Sediment accumulation dynamics has a significant influence on the benthic environment including organic matter variations and macroinvertebrate community structures (Giam et al. 2017). High levels of fine sediment buildup, in particular, can drastically affect macroinvertebrate colonisation. Sediment changes can alter the appropriateness of a substrate for some taxa, increase macroinvertebrate mobility, and influence respiration and foraging behaviours (Harrison et al. 2007). Most tropical lotic systems and their adjacent natural vegetation have been seriously degraded as a result of shifts in land use, associated with agricultural growth and urbanisation (Turyahabwe et al. 2022). This has significantly contributed to sediment accumulation in water regimes that have attained a characteristic brown colour. As a result, the ecological viability, hydrologic operations, water quality and quantity, and associated biodiversity of tropical river systems have all deteriorated (Shivoga 2001; Shivoga et al. 2007; Kibichi et al. 2007).

Benthic sediments provide an essential habitat resource for faunal communities in many streams which mostly dwell within or on the surface of sediment (Shuman et al. 2020). The streambed sediments may affect aquatic macroinvertebrates directly or indirectly by altering their habitats. The landscape influences the flow properties of the river (such as magnitude and timing of flow events), as well as its associated physical, chemical and biological properties. Rivers are cumulative in nature, flowing from their headwater sources downstream through a gradient of land uses. According to Palmer et al. (2010), many stream ecosystems continue to be increasingly impacted by multiple stressors within their catchments that lead to a loss of sensitive species and an overall reduction in diversity. However, very few studies have attempted to underscore the importance of sediment on instream macroinvertebrates, particularly in tropical sub-Saharan Africa (Akamagwuna et al. 2019).

Sedimentation is a ubiquitous problem which arises because of the expansion of industry and intensification of agriculture within catchments, especially in areas not regulated through appropriate policies. Rapid human population growth and continuous cultivation and conversion of natural ecosystems into agriculture has resulted in the predominance of fine sediments. Stream water quality changes, especially due to erosion and sediment discharge, and water pollution are directly linked to land use changes within most catchments of Kenya (Baldyga et al. 2008). During torrential loads, systems become turbid due to large amounts of suspended matter and sediment within the water column, some of which may be caused by the scouring of accumulated material on the streambed and substrata movement (Shivoga 2001).

As rivers and streams flow downstream through different land uses, their physico-chemical properties change, impacting riverine macroinvertebrate communities (Mzungu et al. 2022). Sediments from erosion deposition into streams have been shown by studies elsewhere to be an important factor in determining the abundance, richness, composition and diversity of macroinvertebrates (Shivoga 2001; Jones et al. 2012). However, the relationship between macroinvertebrates and sediment grain sizes in the Isiukhu River, a tropical stream in western Kenya, is poorly understood. The Isiukhu River is a reliable source of freshwater and supports a rich floral and faunal biodiversity (Onyando et al. 2016; Oremo et al. 2020). The river is exposed to extreme flow events associated with high variability in rainfall patterns in the region. It drains an area of diverse gradient of land uses ranging from agriculture (mainly sugar-cane farming along the upper course and mixed farming along the lower course), undisturbed forested area within the Kakamega Forest, and peri-urban surroundings within the Kakamega Municipality. This results in spatial heterogeneity of ecological conditions in different parts of the river, which becomes more distinct under the influence of human-induced factors. However, little or no information on the distribution of macroinvertebrates along substrate characteristics and sediment size gradients was available for this region, and thus the ecology of Isiukhu River is not well understood. This study investigated the relationship between sediment grain sizes and macroinvertebrate distribution along the Isiukhu River.

Materials and methods

Study area

The study was carried out along the Isiukhu River in Kakamega County, western Kenya. The river originates from the Nandi Escarpment (at an altitude of 1 700 m to 2 000 m above sea level). It is a tributary of the Nzoia River, which flows into Lake Victoria. A major section of the Isiukhu River water catchment is within the Kakamega County. Kakamega lies between latitudes 0°07′ N and 0°15′ N and longitudes 34°32′ E and 34°57′ E, with altitudes ranging from 1 250 m to 2 000 m above sea level. It has two rainy seasons; the long rains are from March to June while the short rains are from July to September. The rainfall varies from 1 000 mm to 2 400 mm per annum. The study area also experiences a maximum temperature of 28 °C to 32 °C and minimum of 11 °C to 13 °C. The mean annual evaporation ranges from 1 600 mm to 2 100 mm with high humidity and low evaporation rates. The heavy rainfall makes the soil vulnerable to erosion and tends to reduce the agricultural productivity in the area. Most of the 1.9 million residents depend entirely or partly on agriculture for survival, and are reliant on the water from the Isiukhu River in the county (Wanyonyi et al. 2021).

Seventy percent of the area along the course of the river is under agriculture; mainly mixed farming of maize and peas, sugarcane plantation and small-scale tea farming. Livestock rearing is another land use activity that dominates the area. In the upper region it drains an area comprising sugarcane plantations and Kakamega tropical rainforest while the middle and lower courses are characterised by peri-urban and mixed agricultural land uses. The main crops grown in the county are sugarcane, maize, beans, cassava, finger millet, sweet potatoes, bananas, tomatoes, tea and sorghum. Maize and sugarcane are generally grown on large scales, while beans, millets and sorghum are grown on smaller scales. Many residents in the county also keep livestock such as cattle, sheep, goats, pigs, donkeys and chickens (GOK 2007; Mulinya et al. 2015).

Research design

The study was conducted using a stratified randomized design. Ten sampling sites were marked out across the upstream, midstream and downstream sites based on accessibility, land use practices and landscape gradient. The main land use practices considered were forest area, sand harvesting, livestock keeping and farming, as well as urban wastewater flow into the river. Unimpacted Kakamega tropical forest (upstream), urbanization and municipal (midstream) and agriculture (downstream) are the main activities. For each reach and based on land use type, sampling sites were selected at random (Table 1): upstream (Ichina – 1, Ivakale – 2, Kimangeti – 3 and Senyende – 4); midstream (Shirere – 5, Rosterman – 6 and Mwibatsilo – 7); and downstream (Shibeye – 8, Mutono – 9 and Ekero – 10). Routine sampling of sediments and macroinvertebrates was completed twice a month in the first and last week of each month from March 2018 to March 2019. Physico-chemical variables were measured, sediments samples were collected, and macroinvertebrates were sampled at each site for each sample.

In situ measurement of physico-chemical variables

On each sampling occasion physico-chemical variables including temperature, dissolved oxygen, pH, salinity, percentage saturation oxygen, conductivity, oxygen reduction potential (ORP, a measure of the ability of a river to cleanse itself or break down waste products such as organic matter) and turbidity were measured using a Hydrolab Quanta Multi-Probe Meter (Quanta Sonde Model). Similarly, velocity was measured at random within the indicated reach using a mechanical flow meter (General Oceanics; 2030 flow meter, Miami, Florida).

Macroinvertebrate sampling

A representative stretch of around 100 metres was chosen at each sampling location that featured stream biotopes (riffles, edge waters and pools), for a section of one to several kilometres. To reduce the effects of physical disturbance and consequently macroinvertebrate drift, sampling was carried out in an upstream direction. Within 2–5 minutes, benthic macroinvertebrates samples were quantitatively collected using a 25 × 25 cm kick-net sampler (100 µm mesh net), in which substrate used by macroinvertebrates as habitats was disturbed by foot or hand and macroinvertebrates allowed to flow with current into the net. In some sampling sites that had fine sand, muddy and silty substrates, a corer sampler with an area of 20.83 cm^2 was used.

Swimming macroinvertebrates were collected using plankton sweep nets with 100 µm mesh size, which enclosed an area of 0.0284 m^2. The net was repeatedly used in sweeping the water surface. Macroinvertebrates were processed in the field by sorting and removing bigger unwanted particles such as river debris. These materials were first washed and inspected for macroinvertebrates, and the net contents transferred into a specimen bottle and preserved with 50 ml of 70% ethanol (Lubanga 2021). The bottles were sealed, labelled, and transported in a cooler box to Masinde Muliro University of Science and Technology's Zoology Laboratory for identification.

Sediment sampling

Simultaneously with physico-chemical and macroinvertebrate sampling, sediments were collected using two techniques. At each sampling episode, three replicate samples were collected from pools, riffles and running water microhabitats, ensuring that sediment samples reflected the areas where macroinvertebrates were collected.

Benthic sediments were collected using an Ekman dredge grab sampler, and a small stainless steel shovel. The grabber, made from stainless steel, had a capacity of 3.5 litres and a dimension of 152 × 152 × 152 mm. Overlapping flaps prevented any loss of samples. The dredge's drop-weight system enabled sampling at various depths. For the shovel, the procedure was carried out by wading, with least stream bed disturbance, into the surface water body and scooping the sampler along the bottom of the surface water body in an upstream direction. Excess water was drained from the shovel, avoiding loss of fine sediments. Sediments in soft sediments were collected in this way, in the midstream and parts of the downstream sites. The upstream sites were mostly of hard substrate which prevented the use of the dredge sampler, in which case only the stainless shovel was employed.

Suspended fine sediments were sampled using an open-ended polythene bag (height 70 cm; diameter 40 cm) cautiously interleaved in an undisturbed patch of stream bed to a depth of 15 cm. The water column was then disturbed vigorously for about 2 minutes using a wooden stick without touching the bed surfaces, in order to raise fine sediment on the surface of the stream bed. The suspended fine sediments were then collected from within the cylinder into a 250 ml hard polythene bag. One fine sediments sample was taken per sampling site. The samples were preserved and transported to the laboratory for size determination analysis. At each sampling site, three

Table 1: Description of sites along the Isiukhu River used for the collection of samples employed for the analysis of physico-chemical parameters, substrate characteristics and macroinvertebrates

Site	Description of the study site	Land use type	GPS position
Ichina	Found upstream. Width of about 5 m. It is more of a pool and there no vegetation cover on the surface. Mainly composed of large pebbles. Water is clear with high velocity.	Include sand harvesting, grazing, sugar cane farming, maize, cassava plantation and natural forest.	0°16′45″ N, 34°41′17″ E
Ivakale	Found upstream. Width of about 7 m. Found at upstream of the river and the water and has very high velocity. Surrounded by a wetland, with reeds and other swampy grasses.	Sugar cane and maize plantation, grazing is the main activity. Within the Kakamega forest.	0°26′35″ N, 34°53′24″ E
Kimangeti	Found upstream, Width of about 10 m. Water is clear with a high velocity, sometimes it floods and form a swampy region. Vegetation at this point is mainly a forest and some area is covered with grasses.	Human activities: water harvesting, mixed farming. Natural forest	0°28′01″ N, 34°52′31″ E
Senyende	Found upstream. Width of about 25 m. Water is clear with a high velocity Vegetation is mainly guava trees and other indigenous species within the forest.	Human activities, mainly sand harvesting, maize farming sugar cane plantation. Natural forest	0°22′04″ N, 34°52′31″ E
Shirere	Found midstream. Width of about 40 m. Water with moderate velocity. Rocky and the water flows with high turbulence.	Both natural and planted forest of eucalyptus, some parts are covered with napier grass.	0°15′17″ N, 34°44′59″ E
Rosterman	Found midstream. Water is not clear with moderate velocity Normally floods and it is more of a swamp of grass	Land uses napier and maize farming, mining of gold.	0°15′19″ N, 34°43′38″ E
Mwibatsilo	Found midstream. Water clear, moves with moderate velocity. Sometimes it floods and form pools of water. Vegetation is mainly planted forest of eucalyptus with some grasses.	Land use: maize, sugar cane and sand harvesting.	0°14′31″ N, 34°39′08″ E
Shibeye	Found downstream. Water is not clear.	Land use: sugar cane plantation, man-made forest, sand harvesting and construction	0°16′06″ N, 34°37′53″ E
Mutono	Found downstream. High turbidity, riffles and turbulence.	Land use: sugar cane plantation, maize farming, grasses	0°16′20″ N, 34°35′29″ E
Ekero	Found downstream. High turbidity, riffles and turbulence.	Land use: sugar cane, beans, maize and cassava farming, sand harvesting, grazing	0°17′05″ N, 34°30′06″ E

samples were taken using the different methods, based on the nature of the location.

Laboratory sample processing

In the laboratory, the preserved benthic macroinvertebrate samples were washed through 100 μm and 250 μm mesh-size sieves. Together with the swimming macroinvertebrates, they were then sorted in a petri dish and counted under a Leica Stereo Microscope (Model SZ61-TR). Identification to family and subfamily was completed according to Stals and de Moor (2007) and Merritt et al. (2008). The macroinvertebrates were then preserved in 70% alcohol.

Sediment grain size was determined according to Dickens and Graham (2002). Sediment samples were wet sieved for 15 minutes using a Retsch Sieve Shaker machine (Model GmbH AS200) with sieves ranging from 0.063 μm to 5 mm mesh sizes. The weight of each fraction was measured after oven drying (Model Mika MST50PUAGSL) at 80 °C.

Analysis of data

Descriptive statistics (means ± standard deviation) were used to present spatial variation of physico-chemical parameters at the ten sampling sites, distributed in the upstream, midstream and downstream of the Isiukhu River. The Statistical Package for the Social Sciences (SPSS) version 23 was used. Data were verified for normality using the Kolmogrov–Smirnov normality test prior to analyses.

Significant variations in water quality parameters among sampling sites were tested using one-way analysis of variance (ANOVA) followed by Tukey multiple post hoc comparisons of the means where there were significant differences.

The sediment grain size distribution was analysed using GRADISTAT version 9.1. The software was able to categorize the sediments in each sampling site into the different classes ranging from gravel to fine silt sand.

The mean abundance (individuals dm^{-2} and relative abundance of macroinvertebrate were calculated for each site. Taxon richness was calculated using Margalef's index (d) which provides a measure of the number of taxa for a given number of individuals present and reduces the dependency of the number of taxa on sample size. The index was computed using the following equation:

$$d = (s - 1)\log_{10} N$$

where d is the Margalef's index, s the total number of taxa and N the total number of individuals (Clarke and Warwick 2001).

Diversity was determined, using the Shannon diversity index (H'), calculated as:

$$H' = -\sum p_i \, \mathrm{Ln} p_i$$

where p_i = the proportion of the i^{th} taxon; and $\sum$ = the summation of all values from the first to the i^{th} taxon encountered (Omayio and Mzungu 2019).

Diversity was computed using the Simpson's diversity index (D), calculated as:

$$D = 1/\sum \pi^2$$

where π is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N) and $\sum$ the sum of the calculations (Lubanga et al. 2021).

The Pielou Evenness index, was calculated as:

$$E = H'/H_{max}$$

where H' is the Shannon diversity index for the sample, and H_{max} the maximum possible diversity for a collection of N individuals in a sample. H_{max} was calculated as $H_{max} = \log S$; where S is the number of species identified (Lubanga et al. 2021).

Dominance (J') was calculated on the basis of evenness as:

$$J' = 1 - E$$

and was estimated for each sample at each site (Lubanga et al. 2021). Fisher's alpha (Lubanga et al. 2021) was used as an additional index to determine macroinvertebrate diversity.

The mean similarities of macroinvertebrates families between the sampling sites in the upstream, midstream and downstream were compared using two-way nested Analysis of Similarities (ANOSIM), with replicate land uses nested spatially. The ANOSIM statistic contrasts the average of ranked differences within groups with the average of ranked differences between groups. An R^2 value close to zero denotes a uniform distribution of high and low ranks both within and between groups, whereas an R^2 value close to one denotes a dissimilarity between groups.

To determine the main macroinvertebrate families responsible for variations amongst the ten sampling sites, attributed to changes in land uses, physico-chemical parameters and sediment accumulation, Similarity Percentage Analysis (SIMPER) was employed. The percentage contribution of each family to the general dissimilarity between site categories was quantified. SIMPER is a strictly pairwise analysis between two-factor levels (Clarke and Warwick, 2001), and in this case, comparisons were made between undisturbed upstream, disturbed municipality and mining midstream and agricultural disturbed downstream. All analyses were performed using PAST software (Version 3.21).

One-way ANOVA was also used to determine differences in mean sediment, mean abundance and taxon richness in the Isiukhu River. Mean sediment grain size was the dependent variable, and mean abundance and taxon richness were the independent variables.

Pearson correlation and linear regression analysis were used to determine the importance of sediment grain size in structuring river macroinvertebrates in terms of abundance and taxon richness in the Isiukhu River.

Results

Spatial variation in physico-chemical water quality

The mean variation in physico-chemical parameters along the Isiukhu River from its headwaters to downstream during the study is shown in Table 2. There was a general increase in temperature, conductivity, turbidity, salinity, pH and ORP from the upstream to downstream. Conversely, there was a slight reduction in dissolved oxygen, percentage oxygen saturation and velocity downstream as the river traversed the land uses in the Isiukhu River catchment. However, there was no statistically significant difference in physico-chemical water quality parameters among the sampling sites along the river (ANOVA, $p \leq 0.05$) indicating that there was no significant spatial variation of pH, temperature, turbidity, conductivity, oxygen and ORP from Ichina to Ekero.

There was a general increase in water temperature with downstream distance (Table 2). The highest temperature (22.86 ± 1.8 °C) was observed at Ekero, while the lowest mean temperature (19.94 ± 0.30 °C) was recorded at Ichina.

There was a general increase in conductivity from upstream to downstream. However, the highest mean conductivity (96.86 ± 56.50 µS cm^{-1}) was recorded at Shirere sampling site while the lowest (54.14 ± 24.73) was observed at Ivakale (Table 2). Shibeye, Mutono and Ekero recorded conductivity values of above 90 µS cm^{-1} indicating the river has low conductivity throughout its course. However, there was no significant difference in conductivity between the sampling sites (ANOVA, $p \leq 0.05$).

Salinity and turbidity followed the same trend as conductivity, increasing from upstream to downstream. The highest mean salinity was recorded at Mutono (0.049 ± 0.012 pss) and Ekero (0.049 ± 0.016 pss) while the lowest was at Ivakale (0.032 ± 0.005 pss) (Table 2). The highest turbidity was measured at Ekero (624.62 ± 548.46 NTU) and the lowest (96.08 ± 59.53 NTU) at Ichina.

The pH showed a slight increase from upstream to downstream (Table 2). The highest pH range was recorded at Mwibatsilo (7.33–9.70) and the lowest at Ichina (6.72–9.50).

The highest mean dissolved oxygen (9.76 ± 6.03 mg l^{-1}) was recorded at Mutono and the lowest at Ichina (7.0 ± 3.06 mg l^{-1}) (Table 2). Similarly, the highest oxygen saturation was recorded at Ekero (85.33 ± 44.33 %) followed by Mutono (85.33 ± 44.33 %) and the lowest at Ivakale (58.73 ± 38.64 %). The shallow, bedrock nature at Mutono and Ekero, with high velocities (0.248 ± 0.23 m s^{-1} and 0.208 ± 0.19 m s^{-1} respectively) created riffles to increase dissolution of oxygen in the river water.

The ORP increased from upstream to downstream (Table 2). The highest ORP was recorded at Ekero (340.9 ± 32.28 mV) and the lowest at Senyende (277.24 ± 43.77 mV).

Sediment grain size characteristics

Percentage sediment grain size composition, mean grain size, sorting coefficient, skewness/kurtosis, textural groups and sediment types along the river during the study period are recorded in Table 3. Generally, sediment grain sizes at sampling sites within the same reach were similar. Rosterman recorded the highest percentage of gravel (18.2%), followed by Ivakale (14.2%). The midstream and downstream sites recorded higher percentages of sand compared to upstream sites. Shirere recorded the highest percentage of sand (69.2%), followed by Rosterman (54.4%) and Ekero (50%). Senyende recorded the highest percentage of very fine sand (44.0%), followed by Ekero (35.4%); and the downstream sampling sites also recorded

Table 2: Spatial variation of mean physiochemical parameters (mean ± standard deviation) along the Isiukhu River during the study period

Sites/Parameters	Ichina	Ivakale	Kimangeti	Senyende	Shirere	Rosterman	Mwibatsilo	Shibeye	Mutono	Ekero
Temperature (°C)	19.94 ± 0.30	20.20 ± 0.35	20.72 ± 0.75	20.55 ± 0.61	20.74 ± 18.84	20.78 ± 1.85	21.24 ± 2.16	21.6 ± 2.29	22.15 ± 1.85	22.86 ± 1.8
Conductivity (µS cm^{-1})	71.66 ± 4	54.14 ± 24.73	57.86 ± 22.95	83.71 ± 24.05	96.86 ± 56.50	67.57 ± 30.29	90.05 ± 27.11	92.43 ± 30.06	90.71 ± 31.04	91.71 ± 31.84
Salinity (pss)	0.044 ± 0.008	0.032 ± 0.005	0.039 ± 0.011	0.045 ± 0.013	0.043 ± 0.01	0.043 ± 0.014	0.046 ± 0.011	0.039 ± 0.016	0.049 ± 0.012	0.049 ± 0.016
Turbidity (NTU)	96.08 ± 59.53	147.79 ± 111.84	132.5 ± 56.61	251.68 ± 280.17	472.86 ± 581.05	463.87 ± 540.43	351.13 ± 364.76	502.74 ± 69	529.85 ± 637.90	624.62 ± 548.46
pH range	6.72 - 9.5	6.65 - 9.81	6.96 - 9.54	7.18 - 9.66	7.02 - 9.54	7.16 - 9.71	7.33 - 9.7	6.67 - 9.73	6.63 - 9.5	6.68 -9.48
Dissolved oxygen (mg l^{-1})	7.0 ± 3.06	8.21 ± 5.04	9.13 ± 5.5	8.53 ± 5.3	7.42 ± 4.7	9.38 ± 5.4	7.05 ± 4.33	7.65 ± 4.11	9.76 ± 6.03	7.93 ±4.85
Oxygen saturation (%)	75.0 ± 31.97	58.73 ± 38.64	73.78 ± 37.51	75.73 ± 38.95	77.31 ± 39.64	80.84 ± 36.31	79.42 ± 37.3	80.29 ± 34.4	83.88 ± 42.45	85.33 ± 44.33
ORP (mV)	306.81 ± 43.57	296 ± 115.80	309.24 ± 27.19	277.24 ± 43.77	322.81 ± 55.15	327.81 ± 38	327.19 ± 37.35	334.57 ± 38.56	337.69 ± 32.85	340.9 ± 32.28
Velocity (m s^{-1})	0.41 ± 0.39	0.303 ± 0.322	0.165 ± 0.16	0.166 ± 0.20	0.291 ± 0.28	0.17 ± 0.2	0.31± 0.3	0.29 ± 0.27	0.248 ± 0.23	0.208 ± 0.19
Depth (m)	0.03 ± 0.02	0.042 ± 0.02	0.11 ± 0.2	0.051 ± 0.03	0.0409 ± 0.026	0.063 ± 0.037	0.076 ± 0.039	0.066 ± 0.04	0.161 ± 0.22	0.154 ± 0.115

Table 3: Percentage sediment grain size composition, mean grain size, sorting coefficient, skewness, kurtosis, textural groups and sediment types along the Isiukhu River during the study period

Sediments/Site	Ichina	Ivakale	Kimangeti	Senyende	Shirere	Rosterman	Mwibatsilo	Shibeye	Mutono	Ekero
Gravel	28.7	27.9	28.1	5.3	12.3	34.7	36.6	12.9	22.0	27.4
Sand	32.0	31.9	46.9	53.7	69.2	54.4	43.5	46.4	39.0	50.0
Mud	39.3	40.2	25.0	40.9	18.5	10.9	19.9	20.7	38.9	22.7
V. Coarse Gravel	3.9	14.3	0.4	0.1	2.5	18.2	4.7	3.2	7.3	5.5
Coarse Gravel	9.9	3.8	0.3	1.0	3.1	7.0	7.4	7.1	5.1	3.0
Medium Gravel	1.3	2.2	0.2	0.2	2.0	0.9	7.0	3.8	0.8	1.2
Fine Gravel	11.1	5.0	26.2	1.6	2.4	4.1	9.5	10.0	6.1	2.0
V. Fine Gravel	2.5	2.6	1.0	2.4	2.4	4.4	8.0	8.7	2.6	15.6
V. Coarse Sand	7.2	7.6	11.2	0.9	1.8	2.2	8.7	8.4	4.9	1.5
Coarse Sand	1.2	4.6	1.9	2.0	2.0	10.9	5.3	6.2	2.1	6.7
Medium Sand	7.2	0.8	1.3	2.4	9.4	1.8	7.0	7.1	4.7	4.7
Fine Sand	2.6	2.2	19.1	4.4	26.1	19.2	11.7	11.6	2.2	1.7
Very Fine Sand	13.9	16.8	13.3	44.0	29.9	20.3	10.8	13.1	25.1	35.4
V. Coarse Silt	3.4	3.3	2.0	3.5	1.6	0.9	1.7	1.6	3.3	0.0
Coarse Silt	3.4	3.3	2.0	3.5	1.6	0.9	1.7	1.6	3.3	0.0
Medium Silt	3.4	3.3	2.0	3.5	1.6	0.9	1.7	1.6	3.3	0.0
Fine Silt	3.4	3.3	2.0	3.5	1.6	0.9	1.7	1.6	3.3	0.0
Very Fine Silt	1.4	3.3	2.0	3.5	1.6	0.9	1.7	1.6	3.3	3.6
Clay	22.3	12.8	14.8	23.5	10.7	6.4	11.4	23.8	22.6	22.6
Mean Grain Size) (mm)	4.93	7.69	2.02	0.56	2.34	9.97	5.51	4.46	4.91	3.83
Sorting Coefficient (φ)	11.55	18.32	3.97	2.97	9.33	20.27	12.03	10.53	14.01	12.29
Skewness	3.60	2.66	8.34	10.60	6.13	2.16	3.68	4.20	3.66	4.60
Kurtosis	18.45	9.10	125.60	158.10	44.83	6.59	18.73	24.35	16.55	24.85
Sample Type	Polymodal, Extremely Poorly Sorted	Polymodal, Extremely Poorly Sorted	Trimodal, Extremely Poorly Sorted	Unimodal, Very Poorly Sorted	Trimodal, Very Poorly Sorted	Polymodal, Extremely Poorly Sorted	Polymodal, Extremely Poorly Sorted	Polymodal, Extremely Poorly Sorted	Polymodal, Extremely Poorly Sorted	Trimodal, Extremely Poorly Sorted
Sediment Textural Groups	Gravelly Mud	Gravelly Mud	Gravelly Muddy Sand	Gravelly Muddy Sand	Gravelly Muddy Sand	Muddy Sandy Gravel	Muddy Sandy Gravel	Muddy Sandy Gravel	Gravelly Muddy Sand	Gravelly Muddy Sand
Sediment Type	Fine Gravelly Mud	Very Coarse Gravelly Mud	Fine Gravelly Muddy Fine Sand	Very Fine Gravelly Muddy Very Fine Sand	Coarse Gravelly Muddy Very Fine Sand	Muddy Sandy Very Coarse Gravel	Muddy Sandy Fine Gravel	Muddy Sandy Fine Gravel	Very Coarse Gravelly Muddy Very Fine Sand	Very Fine Gravelly Clayey Very Fine Sand

higher percentages of very fine silt. Sand harvesting was noted at Senyende, and mining at Rosterman. Shibeye (23.8%), Mutono (22.6%) and Ekero (22.6%) had the highest percentages of clay. Generally, however, upstream sites had more gravel, while downstream sites had higher percentages of silt and sand.

Sediments in Isiukhu River are characterised as polymodal and extremely poorly sorted upstream; trimodal and extremely poorly sorted in the midstream; and polymodal, extremely poorly sorted towards the downstream of the river (Table 3). The river from upstream to downstream has poorly sorted sediments with varying grain sizes indicating that the sediments have been deposited fairly close to the source area, i.e. had not undergone much transport.

Upstream sediments (Ichina, Ivakale and Kimangeti) were fine gravelly mud and very coarse gravelly mud, and downstream sediments (Shibeye, Mutono and Ekero) were very coarse gravelly muddy, very fine gravelly clayey and very fine sand. Rosterman had the highest mean sediment grain size (9.97 mm), followed by Ivakale (7.69 mm); the least grain size of 0.56 mm was recorded at Senyende. The sorting coefficients for the river ranged from 2.97 φ at Senyende to 20.27 φ at Rosterman. Skewness range from 2.16 at Rosterman to 10.60 at Senyende. The kurtosis values ranged between 6.59 at Rosterman to 158.10 at Senyende.

Spatial variation of macroinvertebrates taxa

A total of 993 individual macroinvertebrates from 21 families were identified in the 10 sampling sites (Table 4). The macroinvertebrate families were dominated by Veliidae (water striders), Gerridae (water striders), Notonectidae (backswimmers) and Heptageniidae (mayflies). The families were not evenly distributed across all sampling sites. Upstream sites were dominated by Vellidae, Gyrinidae, Gerridae and Notonectidae; midstream sites were dominated by Vellidae, Gerridae, Notonectidae, Cybaeidae, Heptageniidae and Belostomatidae; and downstream sites were dominated by Vellidae, Gerridae, Notonectidae, Cybaeidae, Heptageniidae and Dictynidae.

Spatial variation in macroinvertebrate taxon richness and diversity

The spatial variation in mean abundance (mean ± standard deviation), diversity and taxon richness of macroinvertebrates in the sampling sites is shown in Table 5. A general decrease in macroinvertebrates mean abundance, number of taxa, taxon richness and diversity from upstream to downstream sampling sites occurred. The highest mean abundance of macroinvertebrates (100 ± 9.2 individuals) was recorded at Kimangeti, Senyende (91 ± 8.4) and Ivakale (90 ± 6.3), while the least was at Mutono (11 ± 0.7). Similarly, the highest taxon richness was observed at Senyende (11.4) and Kimangeti (9.1), and the least at Mutono (1.4). A similar observation was evident with the number of macroinvertebrates (Table 5).

The diversity indices varied significantly, with high diversity at the undisturbed upstream sites and lower at the disturbed midstream and downstream sites. The Shannon diversity index was greatest at Kimangeti (2.217) and lowest at Ekero (1.201) (Table 5). Using the Simpson's diversity index (*D*′), similar tendencies were observed, with higher values at Kimangeti (7.630) and lowest at Ekero (2.627). The midstream sites of Rosterman and Mwibatsilo had moderate Simpson's diversity index values (5.051 and 3.914, respectively), while the lowest value was Shirere (2.929). The highest value for the Shannon evenness (*J*′) was at Kimangeti (0.865) and the lowest value (0.632) were

Table 4: Spatial variation in the number of individuals of macroinvertebrate families identified at sampling sites along the Isiukhu River

Families	Macroinvertebrate									
	Ichina	Ivakale	Kimangeti	Senyende	Shirere	Rosterman	Mwibatsilo	Shibeye	Mutono	Ekero
Veliidae	29	12	29	31	49	23	24	14	0	10
Gyrinidae	4	13	0	0	0	5	6	0	9	0
Gerridae	12	12	0	1	0	3	15	0	18	65
Notonectidae	40	17	34	21	5	15	9	14	0	10
Cybaeidae	1	0	0	1	3	15	3	33	9	5
Heptageniidae	1	28	17	27	27	15	6	10	18	0
Chironomidae	3	0	0	0	0	0	0	0	0	0
Aeshnidae	3	0	7	0	0	0	0	0	0	0
Belostomatidae	7	3	1	15	11	18	21	0	0	0
Psepheridae	0	0	0	0	0	0	0	0	9	0
Neritidae	0	3	0	0	0	0	9	0	9	0
Perlidea	0	1	0	2	0	0	0	0	0	0
Naucoridae	0	1	0	0	0	0	0	5	0	0
Reduviidae	0	1	1	0	0	0	0	0	0	0
Oligoneuriidae	0	3	3	1	3	5	0	10	0	0
Calopterigidae	0	3	2	0	0	0	0	0	0	0
Coenagrionidae	0	1	3	0	0	0	0	0	0	0
Hydrophilidae	0	0	1	0	0	0	3	0	0	0
Dictynidae	0	0	2	0	3	0	0	10	18	10
Elmidae	0	0	0	0	0	0	0	5	0	0
Gomphidae	0	0	0	0	0	0	0	0	9	0

at Shirere. However, the highest dominance (1 − *J*′) was at Ekero (0.330), while the lowest was at Rosterman (0.135). Fisher's alpha diversity index had the highest values at Ivakale (4.001) and the lowest at Ekero (1.980).

Macroinvertebrate family patterns across sites

ANOSIM indicated significant differences in distribution and composition of macroinvertebrates for unprocessed abundance data among sampling sites in the upstream, midstream and downstream (R = 0.883, p < 0.0001).

Top-ranked SIMPER results in the composition of macroinvertebrate families' cumulative percentage and mean abundances are shown in Table 6. Veliidae (21.88%), Gyrinidae (16.41%), Notonectidae (15.87%) Heptageniidae (8.50%) and Gerridae (6.53%) contributed the greatest dissimilarity between the sampling sites, with higher abundances in Ichina, Ivakale, Kimangeti and Senyende. Elmidae (0.23%), Psepheridae (0.25%), Chironomidae (0.25%) and Naucoridae (0.35%) were identified as the lowest dissimilarity between sites at Ekero, Mutono and Shibeye.

Relationship between sediment grain size and macroinvertebrate distribution

Pearson correlation (r) and regression analyses (R^2) of the mean sediment grain size against mean abundance and taxon richness in the Isiukhu River is shown in Table 7. There was a negative correlation of (−0.191) and (−0.396) for the mean abundance and taxon richness, although not significant. Therefore, the mean sediment grain size accounted for 28.7% spatial variability of macroinvertebrates abundance along the Isiukhu River.

The impact of sediment grain size on the number of taxa, taxon richness, Shannon diversity index (*H*′) and Simpson's diversity index (*D*′) were determined using regression analysis (R^2; Table 8) The taxon richness (R^2 = 0.201, p = 0.193) was highly influenced by sediment grain size

Table 5: Spatial variation in mean abundance (mean ± standard deviation, n = 21), diversity indices and taxon richness of macroinvertebrates in the Isiukhu River

Sites	Ichina	Ivakale	Kimangeti	Senyende	Shirere	Rosterman	Mwibatsilo	Shibeye	Mutono	Ekero
Individuals	180	166	158	133	100	81	67	39	30	39
No. of taxa	10	14	11	8	7	8	10	8	8	5
Mean abundance	75 ± 7.4	90 ± 6.3	100 ± 9.2	91 ± 8.4	37 ± 4.1	39 ± 2.8	34 ± 2.3	21 ± 1.7	11 ± 0.7	20 ± 2.7
Taxon richness	7.5	6.4	9.1	11.4	5.3	4.9	3.4	2.6	1.4	4.0
Shannon diversity index (*H*′)	1.652	2.026	2.218	1.718	1.389	1.825	1.774	1.755	1.728	1.201
Shannon evenness (*J*′)	0.717	0.748	0.865	0.746	0.632	0.831	0.740	0.762	0.786	0.670
Simpson's diversity index (*D*′)	4.143	5.401	7.630	4.539	2.929	5.051	3.914	4.100	4.167	2.627
Dominance (1 − *J*′)	0.283	0.252	0.135	0.254	0.368	0.169	0.260	0.238	0.214	0.330
Fisher alpha	2.283	4.001	3.357	2.506	2.397	2.591	3.742	4.349	4.359	1.98

Table 6: Top-ranked SIMPER results of macroinvertebrate families between ten sampling sites in the upstream, midstream and downstream of the Isiukhu River

Taxon	Av. dissim	Contrib. %	Cumulative %	Mean Ichina	Mean Ivakale	Mean Kimangeti	Mean Senyende	Mean Shirere	Mean Rosterman	Mean Mwibatsilo	Mean Shibeye	Mean Mutono	Mean Ekero
Vellidae	13.85	21.88	21.88	28.0	27.0	14.5	24.0	14.0	10.0	15.0	7.5	0	1.0
Gyrindae	10.38	16.41	38.29	12.5	18.0	10.0	10.0	25.0	6.0	6.0	0	5.0	0
Notonectidae	10.04	15.87	54.16	30.0	7.5	17.0	9.5	1.0	3.0	1.5	1.5	0	10.0
Heptageniidae	5.38	8.50	62.67	0.5	10.0	8.5	12.5	5.0	3.0	1.0	1.0	1.0	0
Cybaeidae	5.23	8.27	70.94	0.5	0	0	0.5	0.5	12.5	0.5	5.5	5.0	0.5
Gerridae	4.13	6.53	77.47	9.0	5.0	0	0.5	0	0.5	2.5	0	1.0	6.5
Belostomatidae	3.12	4.93	82.39	2.5	1.5	0.5	8.5	2.0	3.5	3.5	0	0	0
Dictynidae	2.22	3.51	85.90	0	0	8.5	0	1.0	0	0	0.5	1.0	1.5
Halobatinae	1.72	2.71	88.61	5.0	2.5	2.5	1.0	1.0	1.0	0.5	0.5	0.5	0.5
Coenagrionidae	1.01	1.59	90.21	0	5.0	1.5	0	0	0	0	0	0	0
Reduviidae	1.00	1.57	91.78	0	0.5	5.0	0	0	0	0	0	0	0
Oligonueriidae	0.91	1.44	93.22	0	1.5	1.5	0.5	0.5	1.0	0	1.0	0	0
Hydrophilidae	0.89	1.40	94.62	0	0	5.0	0	0	0	0.5	0	0	0
Neritidae a	0.69	1.10	95.72	0	1.5	0	0	0	0	1.5	0	0.5	0
Aeshnidae	0.69	1.09	96.81	1.0	0	3.5	0	0	0	0	0	0	0
Gomphidae	0.43	0.68	97.49	0	0	0	0	0	0	0	1.0	0.5	0
Calopterigidae	0.37	0.58	98.07	0	1.5	1.0	0	0	0	0	0	0	0
Perlidea	0.24	0.38	98.45	0	0.5	0	1.0	0	0	0	0	0	0
Avenae	0.23	0.36	98.81	0	0	0	0	0	0	1.0	0	0	0
Naucoridae	0.22	0.33	99.15	0	0.5	0	0	0	0	0	0.5	0	0
Chiromidae	0.16	0.25	99.40	1.0	0	0	0	0	0	0	0	0	0
Psepheridae	0.16	0.25	99.65	0	0	0	0	0	0	0	0	0.5	0
Elmidae	0.15	0.23	99.88	0	0	0	0	0	0	0	0.5	0	0

distribution, as was the Shannon diversity index (R^2 = 0.039, p = 0.584). The Simpson's diversity index (R^2 = 0.003, p = 0.886) is the least impacted by sediment grain size.

The mean sediment grain size was not statistically significantly correlated to the mean abundance and taxon richness of the Isiukhu River (Table 9; p = 0.306).

Discussion

Changes in physico-chemical water quality and sediment grain size amongst river reaches are influenced by land use practices. This study shows that both the structural and functional organisation of macroinvertebrates exhibit spatial variability in taxon richness, diversity and relative abundance of the various taxa. When the physico-chemical parameters' readings at the undisturbed upstream sites were compared with the disturbed midstream and downstream sampling sites, there was an increase in the following parameters: conductivity, water temperature, specific conductivity, ORP and turbidity. The abundance and diversity of macroinvertebrates varied across the gradient of disturbance, with the maximum number of taxa found in the undisturbed areas with large sediments. In places with higher disturbance and fine sediment accumulation (downstream) there was low abundance and diversity of macroinvertebrates.

Table 7: Pearson correlation (r) and regression analyses (R^2) of the mean sediment grain size versus mean abundance and taxon richness in the Isiukhu River (*p < 0.05)

Parameters		Mean Abundance	Taxon Richness
Mean sediments	Pearson correlation	-0.191*	-0.396*
	Sig. (2-tailed)	0.597	0.257
	Coefficients	0.076	-1.16
	Regression analyses (R^2)	0.287	
	N	10	

Table 8: Results of regression analysis (R^2) of sediment grain size against number of taxa, taxon richness, Shannon diversity index and Simpson's Diversity Index of the Isiukhu River (p < 0.05)

	Sediment grain size	
Parameters	R^2	p-values
No. of Taxa	0.083	0.419
Taxon Richness	0.201	0.193
Shannon Diversity Index (H')	0.039	0.584
Simpson's Diversity Index (D')	0.003	0.886

Spatial variation in physico-chemical water quality

The physico-chemical results reveal a general increase in water temperature from upstream to downstream of the Isiukhu River during the study. This trend is in line with Vannote et al. (1980) in the River Continuum Concept, where the gradient of physical parameters from the headwaters to a river mouth presents a continuous gradient of physical conditions. In the present study, the elevation of temperature from upstream to downstream is attributed to the vegetation cover along the stream regime since it's determined by solar radiation and latent heat transfer. The changes in temperature along the regime could be responsible for the variation of macroinvertebrates, as per Burgmer et al. (2007) who determined that vegetation cover brings about stability in environmental temperatures, maintaining high macroinvertebrate abundance.

The river water became more alkaline from upstream (7.84) to downstream (8.29) during the study, possibly influenced by instream organic matter decomposition and some anthropogenic activities such as the mining of gold (concurring with a study by Cole and Caraco (2001) who observed that high organic decomposition and mining activities can lead to saturation of carbon beyond the aquatic photosynthetic need, which leads to a rise in water pH). The downstream also receive sediments from the upstream, which undergo weathering processes and increasing alkalinity. This has a direct impact on pH-sensitive macroinvertebrate colonisation (Jones et al. 2012; Karrouch et al. 2017).

The turbulent high velocity flow at Mutono may be a factor causing the increased mean dissolved oxygen and oxygen saturation at the downstream sampling sites (Venkiteswaran et al. 2007). The shallower, bedrock-lines stream enhances the dissolution of oxygen in the river waters. The low dissolved oxygen in the upstream reaches of the river could be attributed to the river's narrow channel and low flow rate (Spellman and Drinan 2012). Moreover, higher water temperatures cause low oxygen dissolution (Sinokrot and Gulliver 2000).

Turbidity, conductivity and ORP also increased from upstream to downstream in the Isiukhu River. Conversely, salinity decreases downstream, possibly attributed to riparian cover, since the upstream was forested compared to the lower reaches (Sheldon et al. 2021). The changes in salinity and turbidity could also be attributed to higher run-off and groundwater discharge downstream (Oremo et al. 2020). Hart et al. (1990) observed in Victoria, Australia, streams, that run-off and groundwater discharge are the main drivers of salinity in lotic systems. The Isiukhu River had low conductivity throughout its course, probably

Table 9: F-value and its statistical significance for one-way ANOVA of the mean sediment grain size and mean abundance and Taxon Richness in the Isiukhu River (p < 0.05)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	20.119	2	10.060	1.409	0.306[b]
	Residual	49.981	7	7.140		
	Total	70.100	9			

[a] Dependent Variable: Mean sediments
[b] Predictors: (Constant), Mean Abundance, Taxon Richness

explained by the granite bedrock with its inert materials (Wieczorek and LaMotte 2010; EPA 2011).

In summary this study observed a general trend of increase in temperature, conductivity, turbidity, salinity, pH and ORP from the upstream to downstream in Isiukhu River. Conversely, there was a slight reduction in dissolved oxygen, percentage oxygen saturation and velocity downstream as the river traversed the land uses in the Isiukhu River catchment. Therefore, we can conclude that physico-chemical parameters are largely influenced by land use practices. The physico-chemical factors are likely to contribute to the variation of macroinvertebrates along the river regime. These factors have been reported to influence macroinvertebrates abundance, diversity and taxon richness in many stream ecological studies (Aazami et al. 2015, Alexiades et al. 2019)

Sediment grain size characteristics

The upstream sediments were observed to be fine gravelly mud and very coarse gravelly mud, and downstream sediments are very coarse gravelly muddy with very fine clayey sand indicating that the sediments get finer from the upstream to downstream reaches of the Isiukhu River. The scenario could be attributed to the various anthropogenic activities that were taking place along the river, resulting in unevenly deposition and accumulation of fine sediments downstream, as per other studies (Shivoga et al. 2007, Brinkmeyer et al. 2015). The upstream also had higher gravel compared to the midstream and downstream, possibly due to upstream stability (Shivoga 2001). The midstream and upstream sites had higher mean grain size while the downstream had higher skewness, possibly due to the Isiukhu River having a higher portion of fine particles transported downstream (Harrison et al. 2007, Jones et al. 2012, Bravard et al. 2014). The calculated high kurtosis indicates that a greater proportion of the variance is due to infrequent extreme deviations in sediment grain size distribution in the Isiukhu River. The kurtosis is much greater than 1, meaning that the frequency curves of particle size are narrower and sharper than the normal distribution, and the size distributions are more concentrated (Akamagwuna et al. 2019, Mathers et al. 2022).

Spatial trends in macroinvertebrate communities

The abundance, diversity, evenness and richness at the upstream, midstream and downstream sampling sites during the 12 months of sampling appeared to respond to the sediment grain size distribution and land use practices. The high species diversity and abundance at the upstream sampling sites was associated with unimpacted conditions, while a lower species diversity at the midstream and downstream sampling sites was associated with environmental stress and fine sediments due to land use practices.

The upstream sampling sites with the more conserved headwaters and Kakamega Forest had the highest taxon richness, while the lower reaches with human settlement and mixed agriculture had the lowest taxon richness. This trend could be attributed to the variation in sediment grain sizes throughout the river regime. The upstream is composed of gravel and pebbles, providing more habitats for macroinvertebrates colonisation, and likely why the upper reaches had higher diversity, richness and composition of macroinvertebrates than the other reaches. A similar finding was observed in a tropical rainforest stream in Cameroon by Menbohan et al. (2019). The change in land uses along the river also bring disturbance and changes in riverine conditions (Taylor and Warren 2001, Muotka and Laasonen 2002, Heino et al. 2004). In this study the upstream is covered by the Kakamega tropical rainforest, providing a cool environment and food materials for macroinvertebrates.

The classification of the lower streams as a fine sediment reinforced low species diversity and abundance downstream (Harrison et al. 2007) reports that tropical streams generally have large, stable sediments at the upstream and less stable and finer sediment grain sizes at the downstream due to run off. For the purpose of conserving and maintaining the Isiukhu River, the human communities along the river must be informed as to best land use practices. This will foster a collective commitment towards preserving and maintaining the health of the river ecosystem. A possible solution is to encourage forested riparian land so as to minimise disturbance and sedimentation (Haapala et al. 2003).

This has enforced our ecological point of view that land uses influence sediment grain size distribution, which directly determine diversity and abundance of macroinvertebrates in the Isiukhu River. The magnitude to which land use practices and sediment accumulation influence the distribution of macroinvertebrate abundance and diversity at specific locations is very important. Knowledge of the effects of land uses gives the locals, county authorities and national government agencies a fundamental base for the conservation and maintenance of the river's integrity. The downstream of the Isiukhu River experiences excessive fine sediment accumulation from erosion and run off from the preceding reaches. Consequently, the high runoff forms a central point upon which governing establishments could implement and impose suitable approaches to monitor, regulate and safeguard this zone of the water course.

Relationship between sediment grain size and macroinvertebrate distribution

In the current study, the ability of macroinvertebrates to respond to sediment grain size stress were determined using the mean sediment grain size to mean abundance and taxon richness. The mean sediment grain size was found to correlate negatively with the mean abundance (−0.191) and taxon richness (−0.396). Therefore, an increase in mean sediment grain size will lead to decrease in macroinvertebrates abundance and taxon richness. The mean sediment grain size is predominantly fine sediments and influences the spatial variability of macroinvertebrates with respect to mean abundance and taxon richness. This is prominent from the upstream to the downstream reaches of the river. From the regression analysis, sediments determined the distribution of macroinvertebrates by 28.7% (Table 7). At times, variables may not be significant when their contribution is compared to others and in the present study, macroinvertebrates were influenced by physico-chemical, sediment grain size and other biotic factors (Griffiths 1999).

The sediment grain sizes along the river were not evenly distributed indicating that the sediments have been deposited fairly close to the source area, undergoing little transport. Furthermore, changing land use, vegetation cover and water use along the river influence the distribution of sediments within the water regime. The upstream sediments (at Ichina, Ivakale and Kimangeti sampling sites) were classified as fine gravelly mud and very coarse gravelly mud. The downstream sediments (at Shibeye, Mutono and Ekero) were very coarse gravelly mud with very fine clayey sand. The domination of the lower reach by fine sand could be useful in identifying the influence of human activities on the river ecosystem. The higher abundance and diversity of macroinvertebrates were observed in the upstream sampling sites at the unimpacted Kakamega forest (Ivakale, Kimangeti and Senyende), while lower abundance and diversity data were observed at the downstream sampling sites (Shibeye, Mutono and Ekero) that were excessively disturbed. This suggests that sediment distribution acts as a parameter of selection on which families survive (Buendia et al. 2013, Graça et al. 2015, Akamagwuna et al. 2019). De Castro et al. (2018) reported that many macroinvertebrate families cannot survive in highly fine sediment accumulated in reaches simply because of a lack of oxygen, and slow colonisation from fewer habitats, clogging, and lower food availability (Harrison et al. 2007). Decrease of habitat in term of interstitial spaces and attachment places from upstream to downstream concur with findings from a similar study by Wilkes et al. (2017). The majority of the macroinvertebrate families from the downstream in this study were captured through sweeping plankton nets (they resided on the water surface). These results coincide with those of Buendia et al. (2013), Murphy et al. (2017), Wilkes et al. (2017). and Mathers et al. (2017). Ibemenuga et al. (2006) investigated macroinvertebrates feeding habitats in Nigeria, and showed that filter feeding was less frequent in high fine sediment stream reaches.

From our present study, the fine sediment accumulation observed in the downstream was suspected to be the major cause of the low macroinvertebrate abundance and diversity. Earlier researchers revealed that fine sediments lower food availability for filter feeders, thereby leading to low abundance in the total macroinvertebrate population (Harrison et al. 2007). This is supported by the finding that macroinvertebrates that feed through shredding, like the Heptageniidae, are reported as highly sensitive to fine sediments accumulation (e.g. Buendia et al. 2013). Spatial heterogeneity of rivers can play a crucial role in determining the sediments composition (Monk et al. 2008). The present study shows that sediment distribution among reaches was influenced by gradient, land use and riparian vegetation. The downstream reaches had fine sediments and lower macroinvertebrate diversity and abundance. A similar scenario was observed by Hoy (2001) in rural and urban streams. However, macroinvertebrate distribution and colonisation is not entirely influenced by sediment grain sizes, but may be influenced by other factors such as the physico-chemical characteristics, hydrological factors and biotic factors.

Conclusion and recommendation

Our study's findings provide a good understanding of how land use practices in the Isiukhu River contribute to fine sediment accumulation, which ultimately determines the abundance, richness and diversity of macroinvertebrates. We suggest that the degree of survival of macroinvertebrates from sediment stress should be included in the development of biomonitoring tools. This will give a comprehensive indicator of the impacts of land use practices within riparian zones.

Many macroinvertebrate families are intolerable to fine sediments, which is why the downstream areas have low abundance and diversity. The fine sediments impact food availability, oxygen circulation, and reproduction spaces. All these factors caused the less impacted sites in the upstream to harbor many macroinvertebrate families, suggesting that it's a good indicator of sediment stability and less human influence in the riparian zone. These findings of the study provide a practical basis for macroinvertebrate distribution based on sediment grain size in Africa. This can be expanded and used as a tool for monitoring, conservation, and maintenance of healthy rivers by the concerned authorities. The study therefore recommends that control of soil erosion in the River Isiukhu catchment is important for the management and conservation of the stream.

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Data availability statement — The data that support the findings of this study are accessible from the corresponding author upon reasonable request.

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