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Effects of Sand-Harvesting on River Water Quality and Riparian Soil Physico-Chemical Properties

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Abstract

The widespread distribution of river sand-harvesting activities continues to degrade river water quality and the surrounding riverine environments. This study determined practical effects of sand-harvesting on two rivers in Kakamega County Kenya. Water samples were tested for turbidity and total suspended solids (TSS). For riparian soils, nitrogen (N), phosphorus (P), pH, organic carbon (OC), moisture content and textural class were determined on composite samples obtained from the field. Two control sites not affected by sand-harvesting were also used for comparison. Results indicate TSS concentrations increased during the rainy season when sand-harvesting was occurring, with significant differences between the control and sand-harvesting sample groups. Between seasons—dry and wet—in natural circumstances, the riparian soil moisture and phosphorus contents increased significantly. The study shows that river sand-harvesting degrades the aesthetic value of riparian areas, and makes rivers prone to bank erosion, and silt. This increases river water turbidity. The study concludes that sand-harvesting does not directly affect the riparian soil moisture content, total N, P, pH, OC or textural class, but reduces productivity of riparian land and puts the riverine ecosystems at risk.

Keywords

River Ecosystem Conservation, Riparian Area, Kakamega,

River Lusumu, River Shiastala

1. Introduction

Sand is mined, using various technologies, mainly for construction industry from sources on land and under water [1], especially along the rivers on the riparian lands and the roadsides. Sand-harvesting occurs on small and large-scales, depending on the tools used [2] and the purpose for the harvesting. Small-scale harvesting normally involves simple tools like spades, wheelbarrows, and hoes, while large-scale operations involve machinery [3]. The persons harvesting the sand wade into the rivers with spades and containers, scoop the sand from the riverbeds and the banks into their containers and then carry the sand offshore in heaps ready for selling.

There is a growing demand for sand sourced from rivers [4] particularly in developing countries where rapid socio-economic development causes the construction industry to grow strongly [5]. A report from the United Nation Nations Environment Program [6] estimated that between 32 and 50 billion tons of river sand and gravel are harvested annually worldwide, making the sand mining sector a key contributor to Gross Domestic Product (GDP) [7] across the globe. Kenya, under the social pillar of its development blueprint, Vision 2030, [8] seeks to enhance the mining sector's contribution to its GDP [9]. In 2015, the mining sector's share of Kenya's GDP was 0.8%. But the Kenya government aims to increase this to 10% by the year 2030 through its guiding mining and minerals policies, [10], including [11] and [12]. The legislation and guidelines are geared towards sustainable mining, including low-value extractives like river sand [9], murram and unprocessed gravel among others.

Indiscriminate sand and gravel extraction has placed immense pressure on the environment, especially major rivers, threatening the health of riverine ecosystems [2] [13] with the greatest damage generally more pronounced in small river catchments. The widespread distribution of river sand-harvesting activities continues to degrade river water quality and the surrounding riverine environment. [14] and [5] reported damaged, contamination or drying-up of waterbodies that provide water to communities near mining activities. Sand-harvesting also modifies the physico-chemical composition of river water by influencing chemical parameters including turbidity, TSS, magnesium and iron [15], posing risks to aquatic and human life [16]. Few studies, available publicly, quantify the physical alterations that accompany sand-harvesting and how they are linked to ecological impacts [17].

In Kenya, there is limited information on sand-harvesting activities, outside the sand rich Makueni and lower eastern Counties with limited enforcement of existing policy frameworks [18]. This has resulted in widespread, unregulated, and outright illegal river sand-harvesting activities to meet the construction industry's high demands for sand. Sand-harvesting occurs extensively in Kakamega County, in the Western part of Kenya. But there is insufficient data on its effects on water quality and the surrounding environment. [19] outlines various mining activities that yield, for instance, about 278,000 tons of sand annually. Such mining is a livelihood support activity for more than 80,000 people in the region and has had negative impacts on the health of rivers like the Shiatsala, Yala and Isiukhu, the largest river network in the region.

The widespread distribution of river sand-harvesting activities continues to degrade river water quality and the surrounding riverine environments [6]. This paper contributes to knowledge by documenting how unsustainable sand harvesting practices pose serious environmental problems to river ecosystems. The resultant impacts from river sand harvesting are a cause for concern even by the UN [6] [17] [20] [21]. This paper also discusses the impact of sand harvesting on river water quality and riparian areas in the given region of study. No such study has ever been undertaken in this particular region. The methodology applied is also new, and will enrich such studies in future. The findings will also be useful to policy makers in water resources management.

It is against this background that this study examined the effects of river sand-harvesting on riverine ecosystems along the two rivers with extensive sand-mining activities in Kakamega County. Emphasis was placed on the effects of the sand-harvesting on water quality and the riparian soil's physico-chemical properties. The study was carried out on the Shiatsala and Lusumu rivers within Kakamega County, during the dry period December 2020 and wet period June 2020.

2. Materials and Methods

2.1. Study Area

Kakamega County is situated in the western part of Kenya and lies between latitudes 0˚07'0"N and 0˚16'30"N, and longitudes 34˚37'30"E and 34˚49'0"E, an approximate 400 km northwest of Nairobi City. It covers 3034 km^2 with Kakamega Town as its administrative headquarters, and its altitude is ranges from 1240 and 2000 m. Several large rivers traverse the county, including Yala, Isiukhu, Lusumu, and Nzoia (**Figure 1**).

Mean annual precipitation is 1280 mm and rainfall is bi-modally distributed, with the short rains occurring during October to December and long rains from March to May [20] [21]. These established seasons are slowly shifting forward in the recent decades. The short rainy season is characterized by less intense downpours and daily variability, while the long rains is characterized by heavy downpours almost daily. The average rainfall is 500 to 800 mm (short rainy season) and 1000 to 1200 mm (long rain season) [21]. Notably, Kakamega Forest plays a significant role, modulating the environment of the surrounding areas, including precipitation [22]. The dry season runs from December to February. The temperature varies annually with an average temperature range of 10.6˚C to 27.7˚C [23].

2.2. Sampling Site Selection

Eight experimental and two control sites were sampled purposively. The

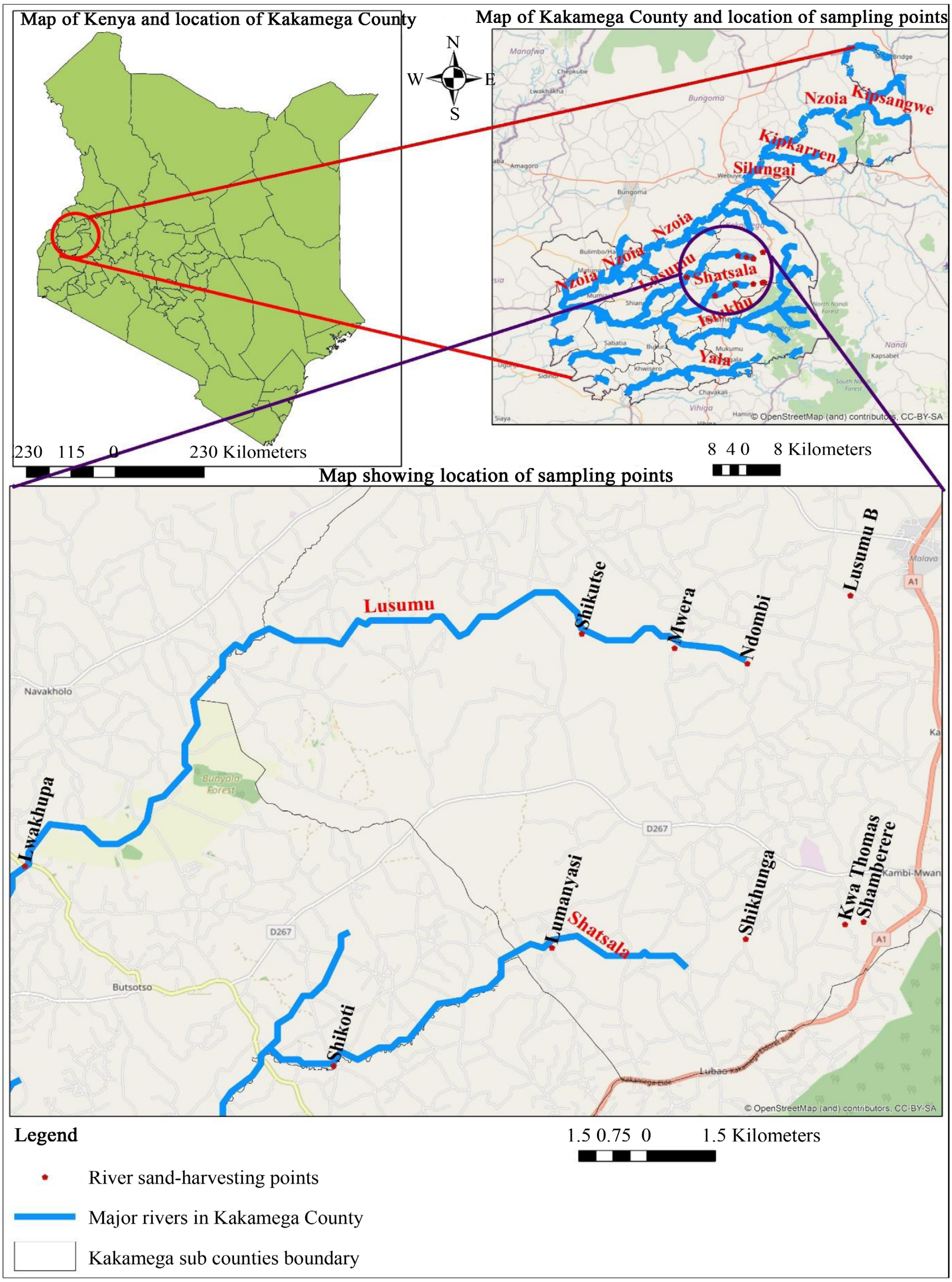

Figure 1. Sampling points on rivers traversing Kakamega County. Major rivers are named in red, sampling points labelled in black.

sand-harvesting sites were chosen using reconnaissance data that identified sand-harvesting hotspots along the two rivers. Four sand-harvesting sampling sites were established on each river, between 2 and 15 km apart as shown in Figure 1. The four sites on the Shiatsala River were at Kwa Thomas, Shikunga, Lumanyasi and Shikoti, while those on the Lusumu River were at Mwera, Ndombi, Shikutse and Lwakhupa. The control sites were at Shamberere on the Shiatsala River and Lusumu B on the Lusumu River, where there was no evidence of sand-harvesting.

2.3. Data Collection

Data on eight parameters was collected as shown in Table 1.

2.4. Laboratory Analysis

The parameters were analyzed as tabulated in Table 2.

Table 1. Data collection matrix.

Parameter	Methodology
Turbidity	Turbidity was determined on-site with an MRC turbidimeter using duplicate sampling at all sampling points in line with [24].
TSS	TSS was measured by collecting three 500 ml samples from each sampling point. Each sample set was mixed, and 500 ml taken from the composite. The composites were transported in a cool box for analysis in the Water Resources Authority (WRA) Regional laboratory in Kakamega.
Soil Physico-Chemical Properties	Soil samples from each site were determined for moisture content, total N, P, pH, OC and soil textural class. A duplicate 5 m × 5 m quadrat was established at each site 5 m from the riverbank. The 500 g composite soil samples were collected from each point on the quadrat using an auger at 0 to 15 cm and 15 cm to 30 cm depths (Figure 2). They were then mixed and transported in a cool box for determination at Kenya Agricultural and livestock Research Organization (KALRO) Laboratory, Kakamega.

Table 2. Methods used during laboratory analysis.

Parameter	Method
TSS	APHA 2540 D [25]
Soil pH	Electrochemical [26]
P	Mehlich double-acid extraction [27]
TN	Colorimetric [28]
OC	Walkley Black [29]
Soil textural class	Bouyoucos/Hydrometer [30]

2.5. Sampling Site Selection

The water quality and soil physico-chemical parameters for the sampling sites were compared between periods/seasons. Significant differences between periods/seasons were determined using the paired-sample T-test at 5% confidence level. Significant differences between the control and sand-harvesting sites were investigated using the independent sample T-test at 5% confidence level. One Way ANOVA was used to test for differences between the control and sand-harvesting sampling sites, and significant differences between the sampling sites were investigated with Tukey's Honestly Significant Difference (HSD) post-hoc tests at 5% confidence level. Statistical analysis was done using Statistical Package for the Social Sciences (SPSS) Version 22.

3. Results and Discussions

3.1. Effects of Sand Harvesting on Turbidity

Turbidity was high and fluctuated during the rainy season compared to the dry season. Figure 3 shows the analysed results. Notably, the sites where sand-harvesting was extensive—Lumanyasi and Shikoti on Shiastala river, and Lwakhupa on the Lusumu river—reported the highest turbidity levels during the rainy season. Turbidity levels increased significantly at all sampled sites during the rainy season ($t_{(9)} = -2.679$, $p = 0.025$). This agrees with reports by [31] that rivers tend to have higher turbidity during the rainy season and sand-harvesting influences turbidity among other properties. Similarly, [32] in a study in India on River Periyar, concluded that relatively larger amounts of sand were harvested in the middle parts, raising riverine turbidity levels. Also, [33] attributed high turbidity levels in the reservoir he was studying to settling and resuspension of solids. Hence, this agrees with findings of this study that river sand-harvesting impacts water quality through re-suspension of sediments in the river resulting in temporary increases in turbidity.

However, at sampling sites 1 (Mwera), 2 (Ndombi bridge) and 3 (Shikutse) of Lusumu river, the turbidity levels were almost similar both during the rainy and dry season. This could be because the three sites had ongoing sand harvesting

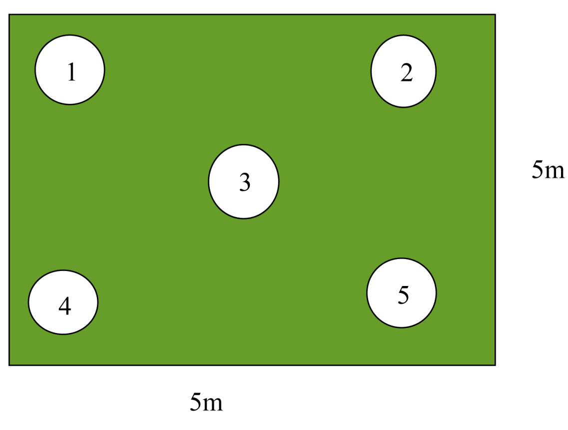

Figure 2. 5 m × 5 m zig zag soil sampling quadrat.

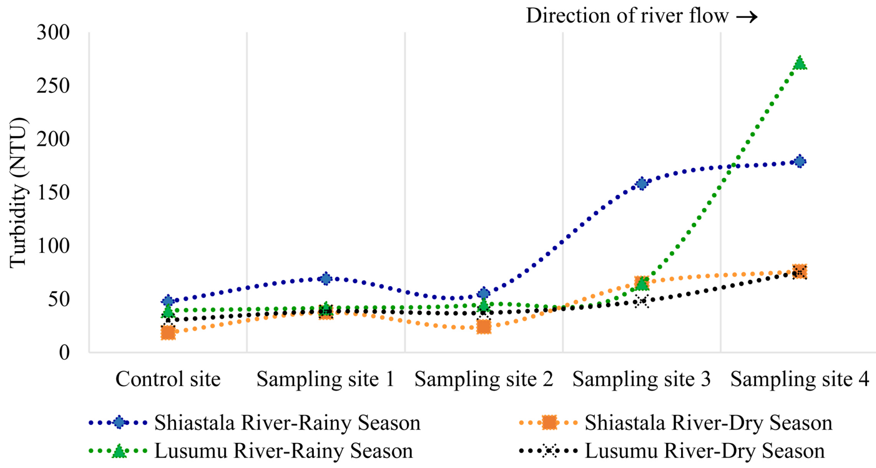

Figure 3. Turbidity in the rainy and dry seasons.

activities during the reconnaissance study period of December 2019, but the sites had been abandoned during the data collection period of 2020. Hence, sand harvesting was not taking place at the time of field visit, both in the rainy and dry season. In addition, it was observed that sampling sites 1 (Mwera), and 2 (Ndombi bridge) were being rehabilitated through planting of trees by members of the Lusumu Water Resources Users Association (WRUA).

3.2. Effects on Total Suspended Solids

The results for TSS rainy during dry season are shown in **Table 3** and **Figure 4**. Sampling sites 3 (Lumanyasi) and 4 (Shikoti) on Shiastala River, and sampling site 4 (Lwakhupa) on Lusumu River reported the highest TSS values that averaged 125 $mg \cdot L^{-1}$ that agrees with [31] and [34] [35] observation that high TSS levels are associated with activities of sand-harvesting. In addition, high demand for sand with the presence of reliable access road was noted to increase the frequency of sand-harvesting, thus increasing the level of TSS.

Logging activities upstream [34], natural runoff which allow more silt and clay to flow into the river [36] [37] and reduced river channel water levels [33] [35] can also contribute to high TSS level.

3.3. Effect on Soil Moisture Content

The rainy and dry season soil moisture content results are shown in **Figure 5**. Soil moisture content decreased at the sand-harvesting sampling sites from 22.71% ± 3.61% during the rainy season to 17.56% ± 7.10% during the dry season. A comparison of soil moisture content for the rainy and dry season using paired sample T-test analysis revealed a significant increase in moisture content at all sampling sites during the rainy season ($t_{(9)} = -2.566$, $p = 0.030$) from 18.14 ± 6.66 m to 22.3% ± 3.44%; an increase of 4.21% ± 5.18%. Results of the independent sample T-test revealed a statistically insignificant difference in soil moisture content between the control sites and the sand-harvesting sampling sites during the rainy ($t_{(8)} = -0.642$, $p = 0.539$) and dry seasons ($t_{(8)} = 0.526$, $p = 0.613$). [38]

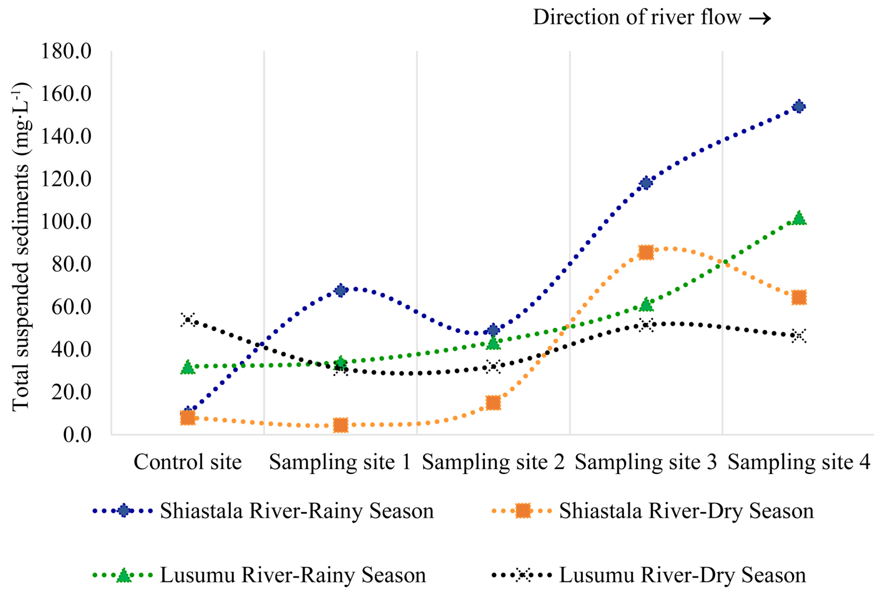

Figure 4. Rainy and dry season TSS concentrations.

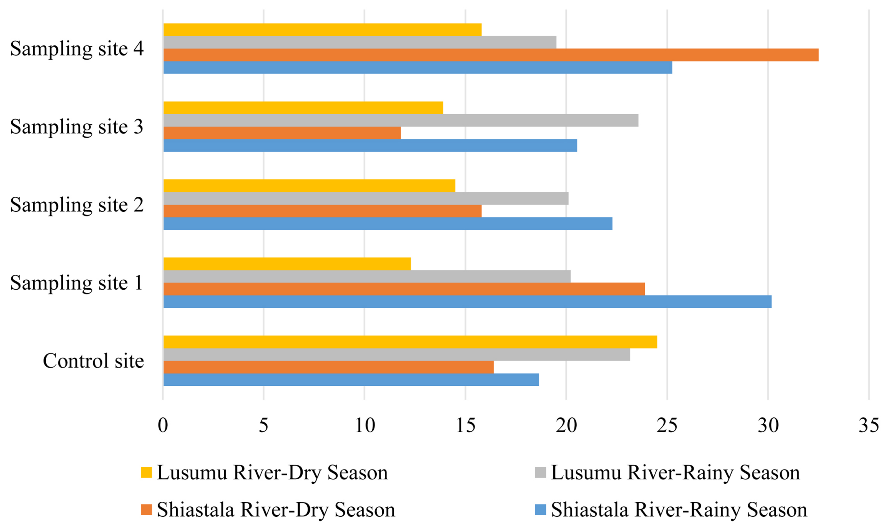

Figure 5. Site soil moisture content in %.

Table 3. Wet and dry season TSS results.

Shiastala River			Lusumu River		
Sampling Site Name	**Wet season (TSS L^{-1})**	**Dry season (TSS L^{-1})**	**Sampling Site Name**	**Wet season (TSS L^{-1})**	**Dry season (TSS L^{-1})**
Shamberere (Control)	10.0 mg	8.0 mg	**Lusumu B (Control)**	32.0 mg	54.0 mg
1-Kwa Thomas	67.5 mg	4.5 mg	**1-Mwera**	34.0 mg	31.0 mg
2-Shikhunga	49.0 mg	15.0 mg	**2-Ndombi**	43.5 mg	32.0 mg
3-Lumanyasi	118.0 mg	85.5 mg	**3-Shikutse**	61.5 mg	51.5 mg
4-Shikoti	154.0 mg	64.5 mg	**4-Lwakhupa**	102.0 mg	46.5 mg

reports that soil disturbance can affect soil moisture content. Also, although [38] found that the number of soil particles that are water-stable correlates negatively with sand content in the soil, this study did not find direct relationship between sand harvesting and soil moisture content.

3.4. Effects on Total Nitrogen

The rainy and dry season soil Total Nitrogen results are shown in **Table 4** and **Table 5**. At the two control sites, the soil total nitrogen content decreased from

Table 4. Mean values for the soil physico-chemical parameters between dry and rainy season.

	Sand-Harvesting Sites		Control Sites	
Parameter	**Rainy Season**	**Dry Season**	**Rainy Season**	**Dry Season**
TN ($mg \cdot L^{-1}$)	0.381 ± 0.83	0.246 ± 0.03	0.4 ± 0.00	0.205 ± 0.007
P ($mg \cdot L^{-1}$)	42.56 ± 13.44	381.65 ± 43.29	30.59 ± 12.05	256.78 ± 14.66
pH	6.04 ± 0.34	6.03 ± 0.21	5.96 ± 0.14	6.02 ± 0.04
OC (%)	1.28 ± 0.29	0.81 ± 0.11	1.54 ± 0.15	1.16 ± 0.05

Table 5. Physico-chemical soil parameter values during the dry and rainy seasons.

Name	River	Season	pH	P ($mg \cdot L^{-1}$)	TN ($mg \cdot L^{-1}$)	OC (%)
Shamberere (control)	Shiastala	Rainy	5.95	39.11	0.4	1.43
		Dry	5.99	269.15	0.21	0.8
1-Kwa Thomas	Shiastala	Rainy	5.38	51.71	0.28	1.91
		Dry	5.59	297.74	0.25	0.7
2-Shikhunga	Shiastala	Rainy	6.06	49.80	0.45	1.25
		Dry	6.0	268.84	0.28	0.62
3-Lumanyasi	Shiastala	Rainy	6.13	39.12	0.4	1.37
		Dry	6.19	268.83	0.24	0.82
4-Shikoti	Shiastala	Rainy	6.62	47.99	0.23	1.31
		Dry	6.28	349.56	0.28	0.84
Lusumu B (control)	Lusumu	Rainy	5.97	22.08	0.4	1.64
		Dry	6.05	246.42	0.2	1.51
1-Mwera	Lusumu	Rainy	5.88	42.08	0.44	1.24
		Dry	5.98	576.98	0.21	0.85
2-Ndombi	Lusumu	Rainy	6.11	24.38	0.45	1.16
		Dry	6.09	348.42	0.23	0.99
3-Shikutse	Lusumu	Rainy	6.07	62.16	0.45	1.2
		Dry	6.12	493.32	0.22	0.84
4-Lwakhupa	Lusumu	Rainy	6.09	23.27	0.25	0.84
		Dry	6.03	449.46	0.26	0.85

0.400 ± 0.000 mg·L^{-1} during the rainy season to 0.205 ± 0.007 mg·L^{-1} during the dry season. At sampling sites 4 (Shikoti and Lwakhupa) where sand harvesting was reportedly very intense, the total nitrogen content increased from 0.23 mg·L^{-1} during the rainy season to 0.28 mg·L^{-1} during the dry season and 0.25 mg·L^{-1} during the rainy season to 0.26 mg·L^{-1} during the dry season respectively, while it decreased in the other sand harvesting sites. However, despite the above difference, results of the independent sample T-test revealed no statistically significant difference in total nitrogen content between the control and sand-harvesting sites during either the rainy ($t_{(8)} = 0.306$, $p = 0.767$) or dry seasons ($t_{(8)} = -2.122$, $p = 0.067$).

The primary impacts of river sand harvesting are the direct removal of vegetation, which alters the rates of nitrogen cycling hence the productivity of the ecosystem [17]. However, though [38] found out that soil disturbance can affect soil physico-chemical properties, this study did not find direct relationship between sand harvesting activities and soil TN.

3.5. Effects on Phosphorus, pH and Organic Carbon

The rainy and dry season soil phosphorus, pH and OC content results are shown in **Table 4** and **Table 5**. Results of the independent sample T-test revealed a statistically insignificant difference in phosphorus content between the control sites and the sand-harvesting sites during both the rainy ($t_{(8)} = -1.140$, $p = 0.287$) and dry seasons ($t_{(8)} = -1.489$, $p = 0.175$); no statistically significant difference was found between the soil pH of the control and sand-harvesting sampling sites, in either the rainy or dry seasons; and a statistically insignificant difference of soil organic carbon content between the control sites and the sand-harvesting sites during the rainy ($t_{(8)} = 1.114$, $p = 0.298$) and dry seasons ($t_{(8)} = 0.955$, $p = 0.511$). This is an indication that sand-harvesting does not affect riparian soil P content, pH, OC levels and textural class.

4. Conclusion

River sand-harvesting impacts water quality through re-suspension of sediments in the river resulting in temporary increases in turbidity. This study finds a significant relationship between sand harvesting activities, and river water turbidity and level of TSS. Though other studies found out that soil disturbance can affect soil physico-chemical properties, this study did not find a direct relationship between sand harvesting activities and soil moisture content, TN, P, pH, OC and textural class. Also, the intensely harvested sites showed an increase in soil total N during the dry season, but it decreased at all other sites. The study, therefore, concludes that sand-harvesting does not directly affect the riparian soil moisture content, TN, P, pH, OC or textural class, but reduces productivity of riparian land and puts the riverine ecosystems at risk. Ultimately, there is a need for proper sand mining practices, upscaling of conservation efforts and creation of awareness on the need to sustainably carry out sand harvesting activities.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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