

Assessment of the effects of sand harvesting on river water quality: case study in Iuuma river, Kivaa ward, Machakos county

Abstract

The research was aimed at analyzing the impacts of sand-harvesting on river water quality. A case study was done in River Iuuma, Kivaa ward, Machakos Country. Two areas, sand-harvesting area and non-sand harvesting area in River Iuuma were selected for the study where sand; sediment and water samples were analyzed in triplicates. Physico-chemical water analyses were done for the parameters: pH, turbidity, electrical conductivity, hardness (total, calcium and magnesium), alkalinity, total dissolved solids (TDS), fluoride, chlorine and bromine. The metals: K, Ca, Ti, V, Mn, Fe, Ni, Cu, Zn and Sr were analyzed using the standard methods. The water from the regions A and B had the following parameter values respectively: pH(7.31, at 23.7°C; 7.45, at 21.3°C); Turbidity (392; 112NTU); EC (2402;793 μ S/cm); TDS (1601; 528mg/L); Total hardness (803; 375mg/L); Calcium hardness (381; 47mg/L); alkalinity(305; 261ppm); Fluoride(3.7; 261ppm); Chlorine(1508; 81ppm); K(56.9; 2.6ppm); Ca(126.5;10.7ppm); Ti(0.55; 0.20ppm); V(0.14; 0.02ppm); Mn(2.18; 0.18ppm); Fe(2.94; 2.02ppm); Bromine(5.41; 0.16ppm); Sr(3.14,0.15ppm); Ni(<0.002; 0.003ppm); Cu(<0.002; 0.007ppm) and Zn(<0.002; 0.018ppm). The sand and sediments were analyzed for: pH, soil total nitrogen, phosphorous (Olsen), electrical conductivity (EC), total organic carbon and the metals: K, Ca, Mg, Mn, Cu, Fe, Zn and Na.

The sand and sediment analyses revealed that the two areas had different concentrations of nutrients. For the sand-harvesting area, there were high values of magnesium and electrical conductivity in the sand. In this area the sediments had high values of calcium, magnesium, iron, sodium and electrical conductivity. In the non-sand harvesting area, the sediments revealed a high value for the iron concentration. All the other parameters analyzed for the sand and sediment samples had values within the acceptable range (WHO, Kenya Agricultural and Livestock Research Organization, KALRO). The water parameters were compared to the world health organization (WHO) and the Kenya bureau of standards (KEBS) guideline values. The water samples over the two areas samples had significant differences in the total hardness, calcium hardness, electrical conductivity, TDS, fluoride, chlorine and the turbidity where such parameters were higher in the sand harvesting area. The analyzed parameters revealed that the water from the sand harvesting area is of a different quality (more dissolved ions and high metal concentration) from that in the non-sand harvesting area and that prior water treatment for the water from the sand harvesting area is essential. Sand harvesting areas should be demarcated from the water collection points. The sand harvesting area can be alleviated through the construction of weirs and dams across the rivers. Alternative water sources to complement the river water sources. The residents should be sensitized on the impacts of sand-harvesting on river-water quality.

Keywords: water quality, physico-chemical, sand harvesting, metals, iuuma river

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Introduction

Water is the fundamental need of man to sustain life. Water is a universal solvent and picks up impurities easily and thus changes its taste, color and odour. Some contaminants are easily identified by assessing the taste, odour and turbidity of the water: pure water remains tasteless, colorless and odorless. However, most water parameters cannot be easily detected by mere observation and require chemical testing.

Drinking water should be suitable not only for human consumption but also for washing and domestic food preparation since chemical and other constituents of the water would give a rise to economic damage as well.¹

River water is marked with varying properties. Acceptable water

should have such properties within the standards and/or guidelines set by both local and international water quality regulatory bodies such as World Health Organization (WHO) and the United States Environment Protection Agency (USEPA).²⁻⁵ Byrnes & Hilandz⁶ in their research concluded that sand harvesting processes can destroy riverine vegetation, cause erosion, pollute water sources and consequently reduce the diversity of animals supported by these woodland habitats. Prospecting, extracting, concentrating, refining and transporting minerals have a great potential for disrupting the natural environment.⁷

The study area

River Iuuma is in Kivaa Ward, Masinga sub-County, Machakos County (10 31'S 370 16'E) in Kenya. The surrounding environment

that hosts river Iuuma has for a long time been exposed to hysterical commercial sand harvesting. Below is the map showing the study area, Figure 1.

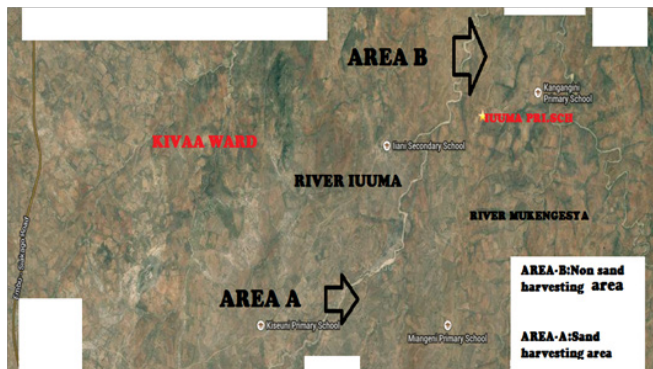


Figure 1 Map of the study area: Shows the two study areas in Iuuma River.

The map above shows the study area and features the two sampling areas. The area marked A is the sand harvesting area whereas the area B is the non-sand harvesting area.

Currently, the River is subject to intense risk of drying, bank widening and pollution by wind and water erosive forces. Such activities often result into the introduction of nutrients and potentially hazardous levels of trace metals and xenobiotic compounds into the riverine ecosystem. The resulting impact that this has on the environment can be evident from a compendium of effects on different observable variables that the foreign bodies pose on the environment.

Methodology

The water samples were obtained using standard methods according to APHA method.⁸ The water samples were collected in 500ml pre-washed and labeled polypropylene bottles: these bottles were thoroughly washed and rinsed with tap and distilled water after which they were rinsed with the river water before the actual sample collection. The bottles were filled to the top to eliminate air bubbles and then firmly corked.

Table 1 Results of sand and sediment analysis.

S/No	Parameter	Unit	Sample			
			SAND- A	SAND- B	SED'-A	SED'B
1	Soil pH	-	8.24.00%	8.82	7.07	8.08
2	Soil total nitrogen	%	0.01%	0.01	0.07	0.04
3	Total organic carbon	%	0.07	0.05	0.63	0.33
4	Phosphorous(Olsen)	ppm	3.00	2	18	6
5	Potassium	me%	0.26	0.6	0.86	0.64
6	Calcium	me%	8.50	3.3	26.5	6.9
7	Magnesium	me%	4.90	2.61	6.31	2.89
8	Manganese	me%	0.18	0.14	0.7	0.63
9	Copper	Ppm	1.68	1.19	8.35	7.18
10	Iron	Ppm	92.5	37.6	990	465

The sand and sediment samples were collected into polythene bags. All the sand, sediments and the water samples were collected over the dry season. They were labeled according to the site from which they were collected: sand harvesting area (area A) and non-sand harvesting area (area-B). Quality analysis was done for water, sand and sediments samples collected from the two areas: sand harvesting and non-sand harvesting areas. Water analyses were done for the physico-chemical properties and trace elements, as well as some selected heavy metals concentrations while the sand and sediments were analyzed for their nutrient content.

Sand and sediment analysis

The oven-dry soil samples were analyzed for Na, Ca and K using a flame photometer while P, Mg and Mn were analyzed calorimetrically following the Mehlich Double Acid Method.^{9,10} Trace elements (Fe, Zn, and Cu) were determined by Atomic Absorbance Spectrophotometer.¹¹ Total organic carbon (C) was determined by calorimetric method.¹² Total nitrogen was determined by Kjeldahl method,¹³ Soil pH was determined using a pH meter on a 1:1 (w/v) soil-water suspension.

Exchangeable Ca, Mg, K, Na were determined by AAS and Na and K by flame photometer after leaching with 1M KCl. Cation Exchange Capacity (CEC) was determined on the leachate at pH 7.0 by distillation followed by titration with 0.01 M HCl.^{14,15}

Water analysis using total reflectance X-ray fluorescence, TXRF

The TXRF water analyses were done at the University of Nairobi, Main Campus, Institute of Nuclear science and Technology laboratories using S2PICOFOX TXRF machine.

Results and discussion

Results on the sand and sediment analysis: The results of the sand and sediment analyses for the samples collected from the sand harvesting and the non-sand harvesting areas are shown below (Table 1).

Table Continued...

S/No	Parameter	Unit	Sample			
			SAND- A	SAND- B	SED'-A	SED'B
11	Zinc	Ppm	1.14	1.02	3.9	2.89
12	Sodium	me%	1.41	0.56	5.98	0.76
13	Electrical conductivity	µS/cm	2300	290	8660	380

Keywords: SAND- A, river sand from sand harvesting area; SAND- B, river sand from non-sand harvesting area; SED'- A: river sediments from sand harvesting area; SED'- B, river sediments from non-sand harvesting area.

The parameters over which significant differences were noted are highlighted in **bold**.

Source: laboratory data

Calculation of the hydrogen ion concentrations from the pH

Sand –A

$$\text{pH} = 8.24$$

$$[\text{H}^+] = \text{antilog}(-\text{pH}) = \text{antilog}(-8.24) = 5.75 \times 10^{-9} \text{M}$$

Sand –B

$$\text{pH} = 8.82$$

$$[\text{H}^+] = \text{antilog}(-\text{pH}) = \text{antilog}(-8.82) = 1.51 \times 10^{-9} \text{M}$$

Sediment-A

$$\text{pH} = 7.07$$

$$[\text{H}^+] = \text{antilog}(-\text{pH}) = \text{antilog}(-7.07) = 8.511 \times 10^{-8} \text{M}$$

Sediment-B

$$\text{pH} = 8.08$$

$$[\text{H}^+] = \text{antilog}(-\text{pH}) = \text{antilog}(-8.08) = 8.32 \times 10^{-9} \text{M}$$

Results of the water analysis

The results obtained for the water analysis are shown below. The values highlighted in bold are the parameter values where huge differences were detected over the two areas: sand harvesting and non-sand harvesting areas, area A and B respectively (Table 2-4).

Calculations: Hydrogen ion concentration in the water samples

Water–A

$$\text{pH} = 7.31$$

$$[\text{H}^+] = \text{antilog}(-\text{pH}) = \text{antilog}(-7.31) = 4.90 \times 10^{-8} \text{M}$$

Water-B

$$\text{pH} = 7.45$$

$$[\text{H}^+] = \text{antilog}(-\text{pH}) = \text{antilog}(-7.45) = 3.55 \times 10^{-8} \text{M}$$

Table 2 Results for the water quality analysis

S/No	Parameter	Water-A	Water-B	Who Value	Kebs Value	Units
1	Total hardness, CaCO ₃	803	375	<500	500	mg/L
2	Calcium hardness	381	47	50	-	mg/L
3	Magnesium hardness	102	79	-	-	mg/L
4	pH	7.31 at 23.7°C	7.45 at 21.3°C	6.5-8.5	6.5-8.5	-
5	Turbidity	392	112	<5	5	NTU
6	Total Dissolved Solids	1601	528	<500	1500	mg/L
7	Temperature	23.7	21.3	25	25	°C
8	Conductivity	2402	793	<800	NG	µS/cm
9	Fluoride	3.7	1.43	1.5	1.5-3	ppm
10	Alkalinity	305	261	250	NG	ppm

Table 3 Results for the TXRF water analysis

Parameter	Water-A	SD-A(±)	Water-B	SD-B(±)	Who value	Kebs value	Units
Chlorine, Cl	1508.5	18.521	81.4	0.3175	5	NG	mg/L
Potassium, K	56.911	0.9715	2.645	0.034	NG	NG	mg/L
Calcium, Ca	126.544	1.7685	10.729	0.058	200	NG	mg/L
Titanium, Ti	0.552	0.0445	0.198	0.0065	NG	NG	mg/L

Table Continued....

Parameter	Water-A	SD-A(±)	Water-B	SD-B(±)	Who value	Kebs value	Units
Vanadium, V	0.141	0.0295	0.016	0.003	NG	NG	mg/L
Manganese, Mn	2.0855	0.0555	0.181	0.004	0.1	0.1	mg/L
Iron, Fe	2.936	0.0645	2.0245	0.0115	0.3	0.3	mg/L
Nickel, Ni	BL		0.003	0.001	0.02	NG	mg/L
Copper, Cu	BL		0.007	0.001	1	0.05	mg/L
Zinc, Zn	BL		0.0185	0.001	5	1.5	mg/L
Bromine, Br	5.417	0.0815	0.164	0.0015	NG	NG	mg/L
Strontium, Sr	3.136	0.0515	0.15	0.0015	1.5	NG	mg/L

Table 4 Calculations: Hydrogen ion concentration in the water samples

Parameter	Water-A	Sd-A(±)	Water-B	Sd-B(±)	Who value	Kebs value	Units
Chlorine, Cl	1508.5	18.521	81.4	0.3175	5	NG	mg/L
Potassium, K	56.911	0.9715	2.645	0.034	NG	NG	mg/L
Calcium, Ca	126.544	1.7685	10.729	0.058	200	NG	mg/L
Titanium, Ti	0.552	0.0445	0.198	0.0065	NG	NG	mg/L
Vanadium, V	0.141	0.0295	0.016	0.003	NG	NG	mg/L
Manganese, Mn	2.0855	0.0555	0.181	0.004	0.1	0.1	mg/L
Iron, Fe	2.936	0.0645	2.0245	0.0115	0.3	0.3	mg/L
Nickel, Ni	BL		0.003	0.001	0.02	NG	mg/L
Copper, Cu	BL		0.007	0.001	1	0.05	mg/L
Zinc, Zn	BL		0.0185	0.001	5	1.5	mg/L
Bromine, Br	5.417	0.0815	0.164	0.0015	NG	NG	mg/L
Strontium, Sr	3.136	0.0515	0.15	0.0015	1.5	NG	mg/L

Key

- a. **Water A:** river water from sand harvesting area in the river.
- b. **Water B:** river water from non-sand harvesting area in the river.
- c. **BL:** value below the instrument detection limit.
- d. **NG:**WHO and KEBS guideline value not available.
- e. **Bold values:** values with major concentration differences.
- f. **SD:** standard deviation.

The results obtained for the sand and sediments are further discussed below. Results of the sand analysis are shown in Figure 2.

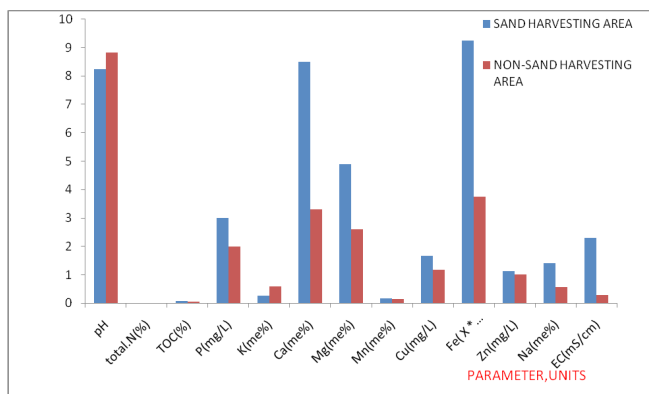


Figure 2 A comparative chart representing the results of the sand analysis.

The pH values for the two sand samples were slightly different. This implies that the hydrogen ion concentrations over the sand harvesting area (S.H.A) and the non-sand harvesting area (N.S.H.A) were almost the same.

Trace values of total nitrogen and total organic carbon were detected in the sand samples over the two areas. Very low concentrations of potassium and manganese metals were noted over the S.H.A and the N.S.H.A. Considerable differences were noted in parameters: phosphorous, calcium, magnesium, copper, iron, zinc, sodium and electrical conductivity. These parameters were more concentrated in the S.H.A than in the N.S.H.A.

During sand harvesting, there is induced agitation of the system which results into more nutrient elements content in the sand. The increased nutrient concentration poses a high pollution potential to the river water. The results for the sediment analysis are further discussed in Figure 3.

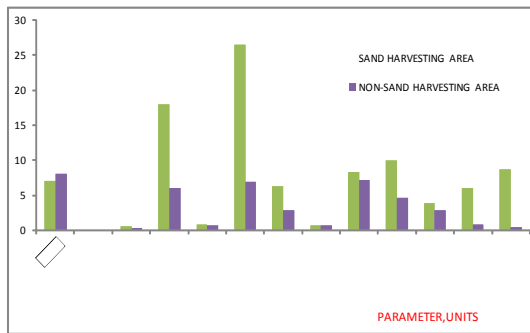


Figure 3 A comparative chart representing the results of the sediment analysis.

The pH values for the two sediment samples were slightly different. This implies that the hydrogen ion concentrations over the sand harvesting area (S.H.A) and the non-sand harvesting area (N.S.H.A) were almost the same.

There were trace values of total nitrogen and total organic carbon (TOC) in the sediment samples over the two areas. Very low concentrations of potassium, zinc and manganese metals were noted over the S.H.A and the N.S.H.A. Considerable differences were noted in parameters: phosphorous, calcium, magnesium, copper, iron, sodium and electrical conductivity. These parameters were more concentrated in the S.H.A than in the N.S.H.A.

During sand harvesting, there is induced agitation of the system, which results in more nutrient elements being contained in the sediments. The increased nutrient concentration can result into increased nutrient concentrations in the river water.

Similar nutrient concentration trends were noted over the sand, sediments and the water over the S.H.A and the N.S.H.A. Below are the charts for the TXRF water analyses. TXRF spectra for the water from the sand harvesting regions are shown in Figures 4 & 5.

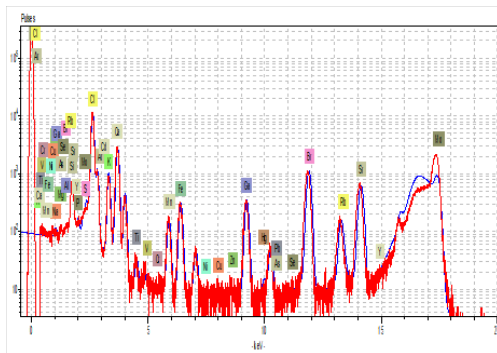


Figure 4 TXRF spectrum for water from the sand harvesting area.

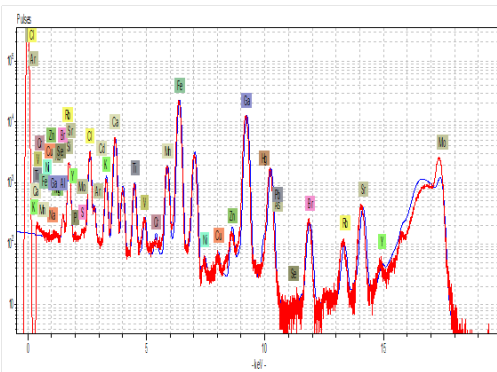


Figure 5 TXRF spectrum for water from the non-sand harvesting area.

Conclusion

The physico-chemical parameters of water from the two regions were found to be remarkably different.

Comparing the two water samples, major differences were noted for the values of the Turbidity, Total hardness, Calcium hardness, Magnesium hardness, Electrical conductivity, Fluoride, Total dissolved solids (TDS), chlorine and Calcium. These parameter values were higher for the water collected from the sand harvesting area.

For the water from the sand harvesting area, the following parameters were above the WHO and the KEBS recommended values: Turbidity, Total dissolved solids, Total hardness, Calcium hardness, and Electrical conductivity, Fluoride, Manganese, Iron and Strontium. The pH, Calcium and Potassium values were within the acceptable range. Trace values of nickel, copper, zinc, titanium and vanadium were detected. With such a high deviation from the guideline value, such water is not suitable for domestic use without proper prior treatment.

For the water collected from the non-sand harvesting area, the values for the Turbidity, TDS, Manganese and Iron were above the WHO and KEBS guideline values. The values for pH, Electric conductivity, Total hardness, Calcium, Fluoride, Strontium and Potassium were within the acceptable range. Trace amounts of Nickel, Copper, Zinc, Titanium and Vanadium were detected. Few aesthetic values fall off the recommended values and this water is therefore suitable for domestic use.

The sand and sediment chemical analyses revealed that the two regions had different concentration of nutrients.

The sand and sediment in the two areas showed low concentrations of the soil total nitrogen, total organic carbon, phosphorous (Olsen) and zinc. Trace values for zinc were also detected.

Major concentration differences for the soil samples over the two regions were seen for the parameters: calcium, magnesium, sodium and electrical conductivity where such parameter values were higher in the sand harvesting area.

Thus the water in the sand harvesting areas is of a different quality from that in the non-sand harvesting area. Most noteworthy differences are in water hardness, turbidity, dissolved and suspended solids, electric conductivity, fluoride, chloride and iron concentration values.

Thus sand harvesting affects the river water quality by contributing to an increase in the particulate matter, organic matter, total dissolved solids, total suspended solids and coloring organic matter into the river water.

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Conflict of interest

The author declares no conflict of interest.

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