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PHYSICO-CHEMICAL EFFECTS OF SAND HARVESTING ON WATER QUALITY IN RIVER THWAKE MACHAKOS COUNTY, KENYA

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ABSTRACT- A study was conducted to assess the physico- chemical effects of sand harvesting in River Thwake, Machakos County-Kenya. A total of 8 water samples from a sand harvesting site (point A) and no-sand harvesting site (point B) were collected and analyzed for; temperature, Hydrogen Potential, turbidity, color, electrical conductivity, Lead, Copper, Zinc, Iron, Biological Oxygen Demand and Chemical Oxygen Demand. There were significant differences in the means of point A and B water samples as regards to; color (p=0.001), turbidity (p=0.001), Iron (p=0.001) Chemical Oxygen Demand (p=0.001) and Zinc (p=0.02) which was associated with sand harvesting activities at point A. However, Copper (p=0.54), conductivity (p=0.17), temperature (p=0.93), Hydrogen Potential (p=0.09), Lead (p=0.85), Biological Oxygen Demand (p=0.63) mean scores were not significantly different despite sand harvesting activities. The results were compared with WHO guidelines, 2009 and Kenya Bureau of Standards 2006 water guidelines to ascertain its suitability for domestic use.

INDEX TERMS- Environmental management plan, sand, sand harvesting, sustainable resource utilization

1. INTRODUCTION

Sand is a type of soil formed through weathering and soil erosion. It is characterized by small fragments of rocks that come in various sizes and shapes. When compared to other natural occurring minerals, sand resources have been considered as the most abundant making them easily accessible. Sand resources are important in infrastructural development as they are used for construction purposes (5). This is reaffirmed by other scholars who acknowledge the importance of sand and its aggregates for making of slabs, beams and pillars that are used for construction and as such a contributor to the growth of economies around the world through infrastructural development (11). Sand plays an important role in the environment as it maintains environmental aesthetics, helps in reducing water evaporation and enhances water purification thus improving the water quality in rivers (12).

According the (13) water quality is the evaluation of the physical, chemical and biological composition of water in relation to its uses, natural quality and human effects. Rivers are surface water sources and among the challenges associated with surface water is pollution and contamination. This may be caused by anthropogenic activities carried out in the water body or the area around the water body. Water quality is of importance as rivers provide water supply for both domestic and industrial purposes as well as provide habitats for aquatic life (1). Therefore, it is essential to ensure that the integrity of water is upheld to ensure quality water is available for domestic and industrial usage and to sustain the aquatic ecosystem.

Sand harvesting is done on large scale and small scale also called artisan sand harvesting. Artisan sand harvesting is characterized by the use of simple tools such as; shovel, hand hoes, wheelbarrows whereas large- scale sand harvesting is mechanized (8). It can be done both on land and inside water bodies where the sand occurs. Research by various scholars from different areas has shown that sand harvesting contributes to pollution in different ways (6). Pollution reduces the water quality in the river due to the introduction of microorganisms that may lead to waterborne diseases to the humans and tampers with the physico- chemical composition of water making it unsuitable for the survival of aquatic life (10).

Some of the physiographic problems associated with sand harvesting includes; the alteration of the river as a result of scooping and dredging of sand from the river, erosion and degradation of arable land adjacent to the river, oil spills resulting from the moving lorries and poor disposal of water during sand harvesting (11). Sand harvesting also modifies the physic-chemical composition of river water by influencing the pH, BOD, COD, increasing turbidity, temperatures, conductivity as well as the presence of heavy metals such as Copper and Iron (7). The alteration of these water properties and the riparian land posses risks to aquatic life and the human using the water (2).

Further, sand is a finite natural resource from the environment and if it not sustainably managed, it would be overexploited leading to its depletion since the rate at which it rejuvenates is very slow compared to the rate of extraction (5). Despite the existence of regulatory law governing sand harvesting, it continues to be done illegally and in an unregulated manner within Machakos County and the rate of extraction overweighs the rate of regeneration of the resource creating a problem (9). Communities dependent on these resources to sustain their social and economic status will suffer as a result of the dwindling sand resources thus increasing poverty in those communities (8 and 9). Therefore, this research sought to establish the impact of sand harvesting on the water quality of River Thwake in Machakos County.

Machaoks County has vast sand resources both on land in its rivers and streams. Among the major rivers in the County is River Thwake that supplies water to the local community and feeds into the Athi River downstream. The Unsustainable sand harvesting in River Thwake has raised concerns from both the local community and the County Government. Therefore, in addition to the National Sand Harvesting Regulation of 2007, the County Government formulated the Machakos Sand Harvesting Bill of 2014 to help regulate the sand harvesting sector.

Unfortunately, despite the existence of the two regulations, sand harvesting is still done illegally and in an unregulated manner in the county (9). The rationale of this study was therefore to establish the physico- chemical, effects of sand harvesting on the water quality of River Thwake in Machakos and how to best utilize the sand resources while ensuring minimal negative impacts to the environment and the community in order to improve the livelihoods of the locals and promote sustainability of the natural resource through conservation.

2. STUDY AREA

The research was carried out in Machakos County, which is composed of six constituencies namely; Kathiani, Kangundo, Machakos Town, Masinga, Yatta and Mwala. The River Thwake study area is confined within coordinates 1°24'46.7"S and 37°19'51.4"E (figure 3.1) and is approximately 60- 70 kilometers from Nairobi. Iveti hills in Machakos are the catchment area for River Thwake which finally flows into Athi River.

The climate of the area is hot and dry (3). Rainfall is bimodal, long rains that starts end of March and stretches to May whereas the short rains that occur between Octobers and December. The region’s annual rainfall average is between 500 mm– 1300 mm though it varies among the constituencies in the County and is affected by altitude. Therefore, reliability of rainfall in the area is quite low. The temperatures range between 18 degrees Celsius to 25 degrees Celsius. July is the coldest month while March and October are the hottest months in the County (4).

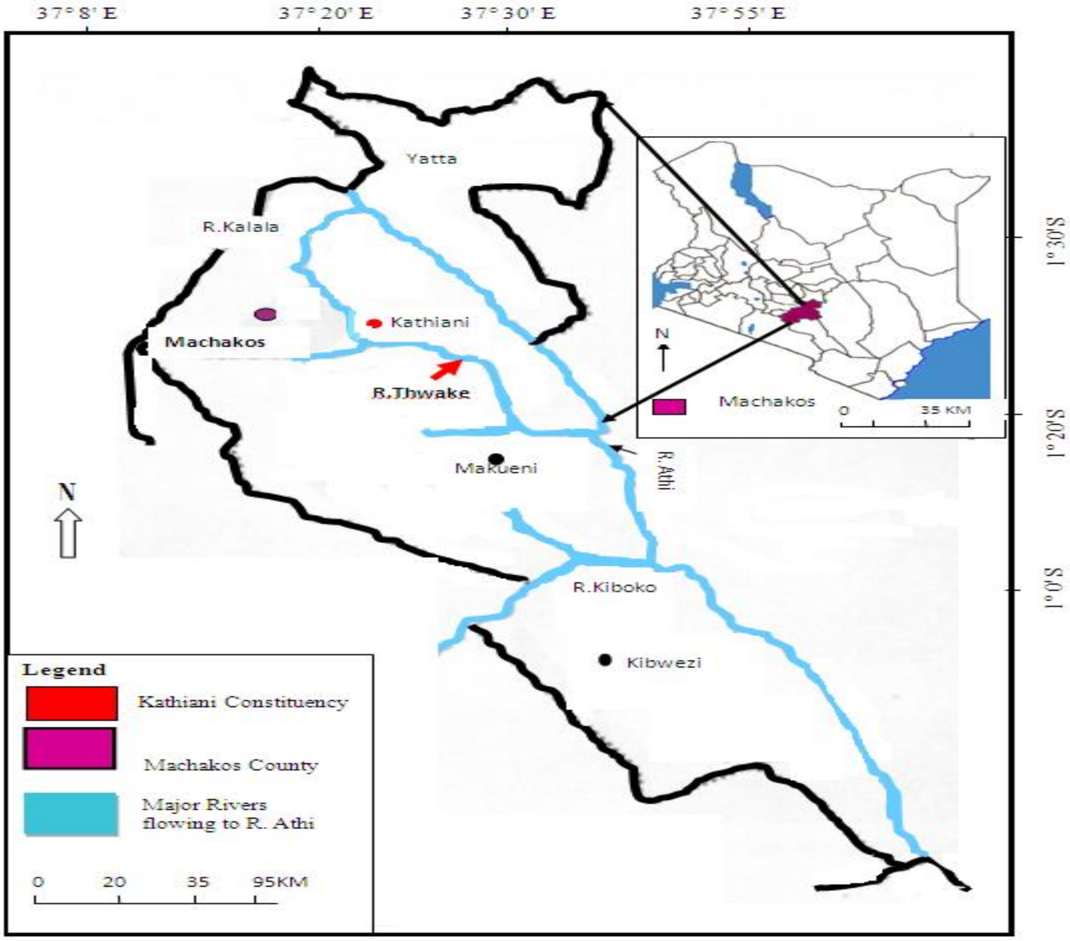

Figure 3.1: Map showing River Thwake that flows in Kathiani, Machakos County (Modified from Machakos Intertgrated Development Plan, 2015)

3. MATERIAL AND METHODS

a) Sample Area, Sample Collection and Preservation

This study sought to establish the impact of sand harvesting on the water quality of River Thwake. It was achieved through the testing of water samples from two different points (A- 1°28'17.6"S and 37°24'30.6"E) and (B-1°27'44.6"S and 37°24'36.1"E) in the river. Each sampling point was recorded by GPS (Global Positioning System).

For water sampling, a scooper was dipped inside the river to a depth of 30cm. Water was sampled from point A and directly opposite point A (across the river) at 1.5m from the shore of the river. The two samples were then mixed in a bucket to form the composite sample then transferred into 1.5 liter pre-sterilized bottles. Water sampling from the identified points A and B was done at two weeks intervals for a period of two months between June and September, 2016. The same routine was repeated for point B upstream and the results compared to those of point A.

At the sampling points, water samples were collected in 1.5 liter plastic bottles that had been washed using detergent then thoroughly rinsed with distilled water. At the sampling sites, the bottles were later rinsed again with the sample water before the actual sampling. For BOD analysis, 3 liter bottles were used for water sampling on either sides of the identified sampling points and the samples were then mixed in a bucket to form the composite sample. All samples were then labeled accordingly and stored in an icebox to avoid contamination then delivered to the Ministry of Mines and Geology and Water Resource Management Authority laboratories for further analysis. Physical parameters that were tested included; temperature pH, color, turbidity and electrical conductivity whereas the chemical parameters included; Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and heavy metals; Copper (Cu), Zinc (Zn), Lead (Pb) and Iron (Fe).

b) Physico-chemical Analysis

The temperature of the water was measured using a thermometer (Hanna H193510 model). The thermometer was immersed in water to a depth of 10cm, allowed to stabilize and temperature recorded in °C. The pH of the water was measured using a portable Winlab Dataline (PROFI-BOX SET 1) pH meter. The pH meter was dully calibrated to 25°C and immersed in the water to a depth of 10cm. The reading was allowed to stabilize. The stabilized reading was then recorded. Electrical conductivity was measured using Model Con 200 portable conductivity meter calibrated to 25°C. It was immersed to a depth of 10cm, allowed to stabilize and the reading recorded. The unit of measurement used was milliSeimens per centimeter. Turbidity was measured in Nephelometric units using Model 6035 JENWAY portable turbidity meter that measure light when scattered at 90 degrees. The water sample was shaken, allowed to settle to remove the bubbles and put inside a clean tube that was placed in a calibrated meter. The readings from the meter were afterwards recorded. To establish the level of BOD, the BOD5 test was administered and after a 5 days incubation period. Before the water samples were incubated, the amount of dissolved oxygen was determined and then compared to the results after the five days at 20 degrees Celsius. The final BOD reading was determined by subtracting the readings from of the initial first reading and the final reading after the incubation and was expressed in milligrams per liter. The COD was determined by Redox titration that involved incubating water sample with potassium dichromate as the chemical oxidant in combination with sulfuric acid. The catalyst used was silver sulfate and mercuric sulfate was added to remove the chloride. The excess dichromate was titrated with ferrous ammonium sulfate and orthophenanthroline as the indicator in the reaction. From the titration, the average COD value was recorded and expressed as milligrams per liter. The concentration of Copper, Zinc, Lead and Iron was analyzed using Atomic Absorption Spectrometry (AAS). The AAS provided accurate and fast determination of the heavy metals. It used wave lengths of light of the specific elements to determine the concentrations of the respective heavy metals in the water sample

c) Statistical Analysis

Using Statistical Package for Social Sciences version 20 and Independent Sample T test was used to test the hypothesis that sand harvesting significantly affects water quality by analyzing the physico- chemical parameters of water samples collected from point A and B of River Thwake which were compared to the set limits international limits of WHO and local limits of KEBS.

4. RESULTS AND DISCUSSION

The temperature recorded in point B (table 4.2) ranged between 22°C and 23 °C as well as those from point A that also ranged between 22°C and 23°C recorded similar mean results of 22.5°C (table 4.1). An independent sample *t* test showed a non- significant difference between the mean temperatures from water samples in point A and B t (6) = -0.09, p =0.93 (table 4.1). The above results imply that sand harvesting did not necessarily affect the water temperature of the water since point A and B recorded similar temperature results.

Turbidity in point A ranged between 299.00 NTU and 400.00 NTU and recorded a mean of 358.75 NTU (table 4.1) as compared to point B whose turbidity ranged between 48.50 NTU and 65.70 NTU and recorded a mean of 55.95 NTU (table 4.2). The turbidity results of an independent sample *t* test analysis (table 4.1) between the means of water samples of point A and B found a significant difference of t (6) = 13.568, p = 0.001. The increased turbidity in point A could be because of the presence of increased suspended particles arising from sand harvesting. It could also be due to other sand harvesting associated activities such as the movement of the lorries carrying the sand and people that increases dust and other solid particles in the air and river water.

TABLE 4.1: Descriptive Statistics of Water from a site with Sand Harvesting

	N	Range	Min	Max	Mean	Std. Dev
Physical Parameters						
pH (1-14 scale)	4	1.29	7.52	8.81	8.2725	.60813
Color (mgPt/l)	4	25.00	100.00	125.00	112.5000	14.43376
Turbidity (NTU	4	101.00	299.00	400.00	358.7500	43.89666
Conductivity ((µS/cm)	4	229.00	1120.00	1349.00	1269.7500	102.08289
Temp (°C)	4	.90	22.10	23.00	22.4500	.38730
Chemical Parameters						
Pb (mg/l)	4	.04	.00	.04	.0250	.01915
Cu(mg/l)	4	.02	.00	.02	.0100	.01155
Zn (mg/l)	4	.02	.00	.02	.0150	.01000
Fe(mg/l)	4	16.90	30.05	46.95	40.0875	7.30107
BOD (mg/l)	4	72.00	18.00	90.00	53.5000	29.94996
COD (mg/l)	4	65.00	124.00	189.00	151.0000	27.96426

The pH of the water in point A (table 4.1) ranged between 7.52 and 8.81 with a mean of 8.27 whereas point B ranged between of 7.37 and 7.99 with a mean of 7.61 (table 4.2). The pH mean levels varied from the two sites with point B recording the lowest mean (table 4.2). An independent sample *t* test (table 4.3) indicated that there was no significant difference between the pH mean levels of point A and point B t (6) = -1.980, p =0.095 (table 4.3). The slight increase in alkalinity in point A could have been caused by the method of sand harvesting used in the area that usually involves digging and scooping of sand hence causing friction and abrasion of the alkaline parent rock which mixed with water making the water more alkaline. The alkalinity in the water could also be due to the presence of Magnesium Carbonate rocks and Calcium in the water, when the rocks weather and react with water, the water naturally becomes alkaline [7].

The results showed varied color concentrations in the two water samples (table 4.2). Water samples from point A (table 4.1) ranged between 100mgPt/l to 125mgPt/l and recorded a mean of 112.5mgPt/l whereas water samples from point B ranged between 40mgPt/l and 50mgPt/l and a mean of 47.5mgPt/l (table 4.2). An independent sample *t* test was done and showed a significant difference in the scores of color from point A and point B, t (6) = 8.510, p = 0.001 (table 4.3). These results imply that sand harvesting affects water color by increasing its concentrations. The increased color intensity results from the particulates in the water brought about by sand harvesting and related activities.

TABLE 4.2: Descriptive Statistics of Water from a site Without Sand Harvesting

	N	Range	Min	Max	Mean	Std. Dev
Physical Parameters						
pH (1-14 scale)	4	.62	7.37	7.99	7.6075	.28547
Color (mgPt/l)	4	10.00	40.00	50.00	47.5000	5.00000
Turbidity (NTU	4	17.20	48.50	65.70	55.9500	8.07321
Conductivity ((µS/cm)	4	296.00	1028.00	1324.00	1144.2500	126.29694
Temp (°C)	4	.90	22.10	23.00	22.4750	.38622

Chemical Parameters	0					
Pb (mg/l)	4	.04	.00	.04	.0275	.01893
Cu(mg/l)	4	.02	.00	.02	.0050	.01000
Zn (mg/l)	4	.02	.00	.02	.0050	.01000
Fe(mg/l)	4	2.20	5.20	7.40	6.2250	.91059
BOD (mg/l)	4	30.80	34.00	64.80	45.0500	13.55224
COD (mg/l)	4	30.00	2.00	32.00	22.2500	13.81726

The Electrical Conductivity recorded in point A ranged between 1120µS/cm and 1349µS/cm and a mean of 1269.8µS/cm (table 4.1) whereas those recorded in point B ranged between 1028µS/cm and 1324µS/cm and a mean of 1144.3µS/cm (table 4.2). Compared to the WHO and KEBS limits, the Electrical conductivity of both samples was above the acceptable limits meaning that the water had a high content of dissolved ions thus raising the electrical conductivity. Further, an independent sample *t* test (Table 4.3) showed a non-significant difference of mean between water samples of point A and point B t (6) = 1.546, p = 0.17.

From the results (table 4.1), the COD in the water at point A ranged between 124 mg/l and 189mg/l with a mean of 151mg/l as compared to the water from point B that ranged between 2mg/l and 32mg/l with a mean of 22.3mg/l (table 4.2). These limits are high than the WHO and KEBS acceptable limits (table 4.5). The COD scores after an independent sample *t* test showed significant differences in the scores in the means of water samples from point A and point B t (6) = 8.255, p = 0.001 (table 4.4). These results suggest an increase in COD concentrations in point A which can be associated with the sand harvesting activities in that section of the river. It could also be caused by the anthropogenic activities within and outside the river that lead to decay of organic matter and the pollution in the river.

The BOD levels in both sites (point A and B) were both high than WHO and KEBS limits of 0.00 mg/l. Point B (table 4.1), BOD concentrations ranged between 34mg/l and 64.80mg/l and recorded a mean of 45.1mg/l whereas that of point A (table 4.2) ranged between 18 and 90 and recorded a mean of 53.5mg/l. An independent sample *t* test was done and recorded non- significant score of t (6) = 0.5, p = 0.63 in the means of point A and B (table 4.4). Although the BOD levels of both sites was high, it is evident from the results that site A had a higher level which can be because of the sand harvesting in that section of the River. These high levels of BOD in the water imply that the water was contaminated hence the high content of bio-degradable matter. Contamination could have been due to the anthropogenic activities inside and outside the

The levels of Lead metal in point A and B was shared and ranged between 0.00 mg/l and 0.04mg/l. The recorded mean in both points A and point B (table 4.1 and 4.2) were 0.02mg/l which is within the acceptable limits of WHO of 0.05 but outside the KEBS limits of 0.01 (table 4.5). An independent sample *t* test showed a non- significant difference in the mean scores of Lead (Pb) in point A (M = 0.025, SD = 0.0192) and point B (M = 0.027, SD = 0.0189), t (6) = -0.186, p= 0.859 (table 4.4). These trace concentrations of Lead could be as a result of indiscriminative disposal of wastes with Lead contents into the water body thereby releasing Lead into the river or the parent rock that may contain some trace amounts of Lead.

Copper metal levels in point A and B were shared and ranged between 0.00 mg/l and 0.02 mg/l and recorded a mean of 0.01 mg/l (table 4.1 and 4.2). After and independent sample *t* test (table 4.4), Copper showed non- significant difference in the mean scores of point A (M = 0.010, SD = 0.012) and point B (M =0 .005, SD = 0.010), t (6) = 0.655, p = 0.537. Both levels from the two sites are within the KEBS and WHO limits 1.000 mg/l (table 4.5). However, it should be noted that the sand harvesting site had a slightly higher recording when compared to the site with no sand harvesting activities. Implying the sand harvesting activities made Copper easily available probably due to water and rock disturbance as a result of scooping of sand from the river.

The Zinc levels in point A and B were also shared and ranged between 0.00mg/l and 0.02 mg/l with the mean of 0.01 mg/l (table 4.1 and 4.2). An independent sample t test showed the mean scores of Zinc in point A and B were not significantly different t (6) 1.414, p = 0.207 (table 4.4). These results suggest that sand harvesting had no impact on the level and availability of Zinc in the River. This could be because the parent rocks did not contain high levels Zinc in their composition hence the trace amounts of the metal.

TABLE 4.3: A comparison of the Physical parameters of sand harvesting and no sand harvesting site along River Thwake

Physical Parameters	Sand harvesting site		No sand harvesting		T-Test
	Mean	Std. Dev	Mean	Std. Dev	
pH (1-14 scale)	8.3	.6	7.6	.3	0.09
Color (mgPt/l)	112.5	14.4	47.5	5.0	0.001
Turbidity (NTU	358.8	43.9	55.9	8.0	0.001
Conductivity (µS/cm)	1269.8	102.1	1144.3	126.3	0.17
Temp (°C)	22.5	.4	22.5	.4	0.93

TABLE 4.4: A comparison of the Chemical parameters of sand harvesting and no sand harvesting site along River Thwake

Chemical Parameters	Sand harvesting site		No sand harvesting		T-Test
	Mean	Std. Dev	Mean	Std. Dev	
Pb (mg/l)	.03	.02	.03	.02	0.85
Cu(mg/l)	.01	.01	.01	.01	0.54
Zn (mg/l)	.02	.01	.01	.01	0.20
Fe(mg/l)	40.1	7.3	6.3	.91	0.001
BOD (mg/l)	53.5	29.9	45.1	13.6	0.63
COD (mg/l)	151.0	27.9	22.3	13.8	0.001

The concentration of Iron metal in point A was higher than the recommended limits by WHO and KEBS of 0.10mg/l and 0.30mg/l respectively. Point A Fe levels ranged between 30.05mg/l and 46.95mg/l with a mean of 40.09mg/l (table 4.1) whereas those of point B ranged between 5.2mg/l and 7.4mg/l and the mean was 6.23mg/l (table 4.2) indicating that sand harvesting increased the concentration of Iron in the water sampled. After an independent sample *t* test, Fe mean scores were significantly different between point A (M = 40.0875, SD = 7.30107) and point B (M = 6.2250, SD = 0.91059), t (6) = 9.205, p = 0.001 (table 4.4). The high levels of Fe could be due to the geology of the area and the tools (hand hoes and shovels) used in the sand harvesting activities that could have been made out of Iron thus contributing to the high levels of Iron in the water.

TABLE 4.5: WHO and KEBS guidelines for drinking water quality

Parameters	SI Units	KEBS	WHO
Turbidity	NTU	5	5

Conductivity	µS/cm	-	300
pH	pH scale	6.5-8.5	6.5-9.2
Color	mgPt/l	15	15
Temperature	°C	-	-
BOD	Mg/L	0.00	0.00
COD	Mg/L	0.00	0.00
Lead	Mg/L	0.01	0.05
Iron	Mg/L	0.30	0.10
Zinc	Mg/L	5.00	5.00
Copper	Mg/L	1.00	1.00

5) CONCLUSION

The study established that sand harvesting along River Thwake in Machakos County was influenced by many socio- economic benefits associated to the activity which included; the provision of employment, generation of income and infrastructural development. These factors have led to the increased, unsustainable and indiscriminative sand harvesting in the area leading to the associated negative effects on the community, the environmental status of riparian land and on water quality. Indiscriminative and harvesting activities overlooked the associated benefits resulting from sand resources which included; water purification, aesthetics and the maintenance of aquatic ecosystem by compromising water quality in the river by interfering with the physico-chemical properties of the river.

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