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Metal Analysis of Dissolved Sediments Discharged from Samaru Stream into Kubanni Reservoir of the Ahmadu Bello University Zaria, Nigeria

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Abstract

This study analyzes heavy metals in the dissolved sediment delivery of Samaru stream into Kubanni reservoir of Ahmadu Bello University, Zaria. Sediment samples were collected using the USDH sediment sampler between 1st of April to 10th of October, 2014 which marks the flow period of the year. The study analyzed the dissolved sediment concentration (DSC) and heavy metals from the residue sample of dissolved sediment. DSC obtained vary from a minimum value of 20 mg/L to a maximum value of 120 mg/L with a mean value of 58.87 mg/L. Total of 17 elements with varying degree of concentrations ranging from as low as 0.0 for Re to 9.50 mg/L for Ca were detected by the x-ray fluorescence (XRF) analysis. The World Health Organization (WHO) and National Standard for Drinking Water Quality (NSDQW) recommended standards were used as guideline. Eleven out of the seventeen elements identified were heavy metals with nickel (Ni) as the most toxic with a mean concentration value of 0.08 mg/L. Other elements identified to be above the recommended standards are iron (Fe) and aluminum (Al) with mean concentrations of 1.25 mg/L and 0.38 mg/L, respectively. Comparing the result of the XRF analysis with the recommended standards, it was observed that most of the heavy metals identified are below the permissible limits for drinking purpose, domestic use and discharges into stream which implies that the Samaru stream is still well oxygenated from the anthropogenic activities upstream.

Keywords: Dissolved sediment, heavy metals, Samaru stream, Kubanni reservoir, Ahmadu Bello University

1. Introduction

Water is a natural substance which covers 71% of the earth's surface and vital for all known forms of life on earth. 96.5% of the planet's water is found in seas and oceans, 1.7% in groundwater, 1.7% in glaciers and the ice caps of Antarctica and Greenland, a small fraction in other large water bodies, and 0.001% in the air as vapor, clouds (formed of solid and liquid water particles suspended in air) and precipitation. Only 2.5% of the earth's water is freshwater, and 98.8% of that water is in ice and groundwater. Less than 0.3% of all freshwater is in rivers, lakes, and the atmosphere, and an even smaller amount of the earth's freshwater (0.003%) is contained within biological bodies and manufactured products [1]. It was estimated in Nigeria that more than half of the population have no access to clean water, and less than half of the population had access to improved sanitation facilities therefore millions of Nigerians depend on dirty and contaminated water for domestic use. Hundreds die every year from water borne diseases [2]. Sediments are naturally occurring materials that have

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been broken down by the processes of weathering and erosion, and are transported by the action of wind, water, or ice, and/or by the force of gravity acting on the particle itself. Sediments are most often transported by water (fluvial processes), wind (aeolian) and glaciers. The total amount of sediments that are generated within the catchment area of a river and moved to a drainage basin to be deposited into flood plains, storage reservoirs, or carried to the seas is referred to as sediment yield, which is a function of many variables including nature of the geology and soil, relief characteristics, vegetation cover, drainage characteristic, climate, time, and land use pattern within the drainage basin [3]. Others are human activities such as mining, construction, agriculture etc. and rock solubility which are chemical process involving hard water in carbonate terrain and also erodibility of material in the drainage basin. Relief and slope also affect the Potential Energy (PE) of flow [4]. There are three kinds of sediments which include bed load; this is the portion of sediment load that is transported along the bed by sliding, rolling or hopping. Suspended load moves at the same velocity as the flow with small particle (e.g. clay and fine silt). The greater part of sediment yield obtained is the suspended sediment load [5], and lastly is dissolved load which consist of organic and inorganic particulate materials that are chemically carried in the water or solution by a river and capable of passing through a 0.45-µm filter membrane. Ayoade [6] states that dissolved load is the most important sediment in the assessment of water quality.

Deposition of sediment load into a water body can have a number of effects on the environment which includes, upsetting the dynamic balance in the biota and ecology of water body; disrupting the aquatic chemistry or natural buffer balance (cationic, anionic, acidic and alkalinity) of a water body; continuous deposition of sediments resulting to siltation into a water body leads to decrease of the depth or bank of a water; and lastly, the form and structure of a water channel (i.e. channel morphology) can change greatly as a result of sediment deposition [4]. Another factor that can affect the environment as a result of sediment load is pollution. This is the contamination of a substance or a body that makes it unfit for desire or intended uses. Sediments carry a lot of debris containing harmful materials into water bodies which pollutes the water and makes it unfit for the intended use. Inputs of sediment into water channels may often be associated with dangerous agricultural chemicals from fertilizers such as nitrogen and phosphorus, and also herbicides and pesticides which are washed down into water bodies by sediments [4].

Heavy metals are among the most dangerous natural substances that man has concentrated in its immediate environment. This is because they can neither be degraded nor metabolized, which means they persist in the environment for a very long period [7]. Metals enter into the environment or living organism either as inorganic salt or organic metallic derivatives. They get accumulated in time, in soil, water, and plants which could have negative influence on the physiological activities of their host. For example, in plants, they influence photosynthesis, gaseous exchange, nutrient absorption, and in determining the reduction in plant growth, dry matter accumulation and yield. In small concentration, the traces of heavy metals in plants, or animals are not toxic however in excess amount they are detrimental to health. Lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As) are an exception, because they are toxic even in very low concentration [8]. Monitoring the endangerment heavy metals is of interest due to their influence on groundwater and surface water and also on plants, animals and humans. It is in view of the importance of water to man that dams are constructed across rivers to retain water for various purposes which includes hydro electricity generation, irrigation, purification and cooling of nuclear reactors etc.

The Ahmadu Bello University (ABU) dam was constructed in 1974 with a storage capacity of 2.6 x 10^6 m^3, depth of about 8.5m, a catchment area of 57km^2, and a lake surface area of 83.4 ha and supply capacity of 13.64 million litres per day to cater for about 50,000 people [9]. However, the utilization of the dam is being threatened by pollution and siltation. Researches carried out on the siltation of the ABU dam with specific interest on suspended sediment load showed a decrease in depth of the dam over the years [10, 11, 12]. A study on the dissolved sediment concentration (DSC) of Samaru stream was conducted, the relationship amongst discharge, suspended sediment discharge (SSD) and dissolved sediment discharge (DSD) of Samaru stream in which the DSDs was derived from the DSC was examined [5]. Results showed that there is a direct relationship between DSC and discharge with a straight line scatter curve which however did not start from the origin, indicating a weak relationship while the summary statistics result varied from 0.69 mg/s to 25.74 mg/s and a mean value of 11.58 mg/s. Part of the recommendations by the researchers is more enforcement and monitoring on the banned human activities at the basin catchment area particularly sand mining for construction which contributes to the increase in DSD through erodiblity of soil materials.

The objectives of this study are to analyze the dissolved sediment delivery of Samaru stream into the ABU reservoir, to be achieved by determining the DSCs, and to investigate the heavy metal contents in the sediments load flowing into the reservoir.

2. Materials and Methods

In order to achieve the aim of the study, data on DSC and stream discharge were collected from the gauging station indicated in Figure 1 during the study period from April, 2014 to October, 2014 covering 7 months and marking the flow period of the study area.

2.1. The Study Area

The study area is Samaru in Zaria, Kaduna State, Nigeria. The study site is a minor tributary of the Kubanni River located within the Kubanni drainage basin, lying about $11^0$08'32"- $11^0$09'38"N and $7^0$38'36"- $7^0$38'48"E. The Kubanni River has its source from the Kampagi Hill, in Shika, near Zaria. It flows in southeast direction through Ahmadu Bello University. The Kubanni River which forms one of the main drainage systems in Zaria carries water almost throughout the year. The geology of Samaru is fundamentally crystalline metamorphic and igneous rocks. The type of soil is alluvial which composed of fine grey-brown sands, clay, red sand and gravel. The upper parts of the soil are a mixture of quartz, mica and windblown particles from the savannah harmattan.

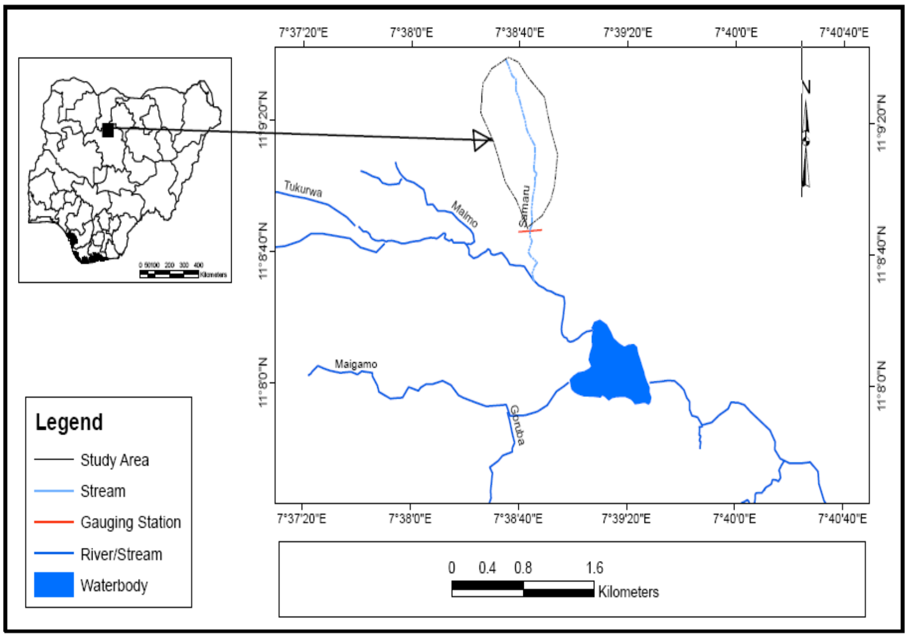

Figure 1. Location of the Study Area on the Kubanni River Basin

(Source: Zaria SHEET 102 South-West)

The study area belongs to the tropical continental type of climate corresponding to Koppen`s wet and dry climate zone [13], the geology is that of the developed crystalline metamorphic rocks of the basement complex overlain by wind and drifts sediments [14], while the soil is highly leached ferrugenous tropical soils, developed on weathered regolith overlain by thin deposit of windblown silt from Sahara desert. Furthermore, the natural vegetation of the study area is northern guinea savannah characterized by scanty deciduous trees, herbs, shrubs and grasses [15], the landforms falls within the Galma basin situated on an extensive peneplain developed on crystalline basement rock [16], the land use pattern prior to year 2000, was agriculture, grazing and fishing which forms the dominate human activities in the basin before they were stopped in an attempt to reduce the rate of siltation of the ABU dam [10, 11]. Trees plantation have since taken over the basin and lastly the drainage characteristic of Samaru stream linking the Malmo stream is a 1^{st} order basin with a stream length of 1.05km, a basin area of 2.28km^2, drainage density of 0.4605m/km^2 and a relative relief of 30.48m which finally empties into the Kubanni river [5].

2.2. Dissolved Sediment Concentration

Samples were collected at the gauging station using the USDH 48 sediment sampler designed by the US Federal Inter-Agency Sedimentation Project after rainfalls events and during discharge measurement taking. The samples were stored in clean plastic bottles, labeled and taken to the laboratory for analyses following the procedure of Matthes *et al*. [17].

2.3. Heavy Metals

Based on the sample size for a mobile matrix, 33 samples were calculated and applying systematic random sampling gave a total of 3 groups of sediment samples that were analyzed across the year. Samples collected were filtered by an automated filtering pump using the Whatman cellulose nitrate membrane 0.45µm filter paper and evaporated to dryness. The dry residue sample was carefully scrapped out of the crucible and analyzed by an x-ray fluorescence (XRF) machine for heavy metals in the sediment.

2.4. Statistical Analyses

Result of the dissolved sediment samples were analysed and interpretated using the descriptive statistical test. The discriptive statistical test used is the mean, stanadard deviation, variance etc. All analyses were carried out by the use of SPSS statistical package.

3. Results and Discussions

3.1. Dissolved Sediment Concentration

The result obtained from the summary statistics shows that the DSC range is 100 mg/L and the mean value is 58.87 mg/L, with minimum and maximum values of 20 mg/L and 120 mg/L, respectively. These minimum and maximum DSC values were spread across the year with April marking the commencement of the rainfall season having more of 120 mg/L DSC values while October has value of 20 mg/L.

3.2. Heavy Metals

The results of the analyses are presented in Table 1. Altogether, a total of 17 elements were identified for three samples. They are; Al, Si, S, Cl, K, Ca, Ti, V, Mn, Fe, Ni, Zn, Y, Ba, Eu, Yb and Re. Out of the 16 elements studied, 11 are heavy metals. They include; Al, Ti, V, Mn, Fe, Ni, Zn, Y, Eu, Yb and Re. Although aluminum and titanium are light metals but sometimes referred to as heavy metals in view of their toxicity to health. They are toxic at low concentrations, and able to pass to humans through food chain [18, 19].

Table 1. XRF Analysis of Residue Samples

Element	Concentration (mg/L)			Mean	±SD
	Sediment 1	**Sediment 2**	**Sediment 3**		
Al	0.60	0.16	0.38	0.38	0.1796
Si	1.24	0.64	0.6	0.83	0.2927
S	1.40	0.91	0.74	1.02	0.2790
Cl	6.80	6.21	6.00	6.34	0.3386
K	2.01	3.16	2.14	2.44	0.5142
Ca	10.5	9.40	8.70	9.53	0.7408
Ti	0.03	0.02	0.02	0.02	0.0047
V	0.0016	0.00135	0.0013	0.0013	0.0001
Mn	0.31	0.21	0.24	0.250	0.0418
Fe	1.21	1.34	1.20	1.250	0.0637
Ni	0.10	0.077	0.063	0.080	0.0152
Zn	0.04	0.06	0.09	0.063	0.0205
Y	0.30	0.21	0.14	0.210	0.0654
Ba	0.05	0.04	0.04	0.043	0.00471
Eu	0.024	0.04	0.021	0.028	0.00834
Re	0.051	0.041	0.09	0.060	0.02114
Yb	0.04	0.05	0.042	0.044	0.00432
Total	**24.7066**	**22.5693**	**20.5073**	**22.595**	

Table 1 identified Ca as the most abundant element found with a mean concentration value of 9.53 mg/L and the least is V with 0.0013 mg/L while a total mean concentration value of 22.595 mg/L was calculated for all the elements identified from the XRF analysis of the residue sample. The mean concentration value of Ca when compare with a recent study of the stream using a V2000 multi analyte photometer gave a mean concentration value of Ca as 10.02 mg/L indicating a close similarities in abundance and that the concentration of Ca has reduced with about 0.49 mg/L [20].

3.3. Comparison of Analysis with NSDQW and WHO standard

In order to achieve an adequate environmental protection measure with consideration to countries socio-economic and climatic differences, standards are therefore set based on internationally environmental baseline data [21]. For this study, two standards were adopted for water quality which comprises recommended standards for drinking water, domestic use and discharges into the stream [21, 22]. Table 2 therefore gives the average values of heavy metals identified in the three sediment groups with their recommended limits for drinking purposes and water discharge into the stream by WHO and NSDWQ [21, 22]. The result of the analysis in Table 2 shows that the level of Al, Mn, Fe, and Ni are above the recommended standards for both drinking and water discharges into stream [21, 22, 23], except for Zn and Ti which were found to be below the limits. However, the remaining metals V, Y, Eu, Yb and Re are not specified for comparison.

Table 2. Concentration of Heavy Metals and their Acceptable Limits for Drinking Water and Discharge into Streams

Heavy Metals	Concentration (mg/L)	Acceptable Limits for Drinking Water		Acceptable Limits for Discharge into Streams	
		NSDQW Standard (mg/L)	WHO Standard (mg/L)	NSDQW Standard (mg/L)	WHO Standard (mg/L)
Al	0.380	Below 0.2	Below 0.2	Not Specified	Not specified
Ti	0.020	Not specified	Not specified	Below 10	Not specified
V	0.0013	Not specified	Not specified	Not specified	Not specified
Mn	0.250	Below 0.2	Below 0.1	Below 5	Not specified
Fe	1.250	Below 0.3	Below 0.3	Below 20	Not specified
Ni	0.080	Below 0.02	Below 0.07	Below 1	Not specified
Zn	0.063	Below 3	Below 3	Below 1	Not specified
Y	0.200	Not specified	Not specified	Not specified	Not specified
Eu	0.028	Not specified	Not specified	Not specified	Not specified
Re	0.060	Not specified	Not specified	Not specified	Not specified

Adopted from World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDQW) water quality guidelines

Moreover, the table shows that most of the elements with the exception of those not specified are above the threshold limits. Nickel (Ni) which has been identified as one of the most toxic heavy metal was found to be 0.08 mg/L while its acceptable limit is 0.02 and 0.07 mg/L by WHO [21] and NSDWQ [22], respectively. Others are iron (Fe) with a concentration of 1.25 mg/L and a recommended limits of 0.3mg/ L. However, Zinc (Zn) which has a concentration of 0.063 mg/ L and a recommended limit of 3mg/ L was found to be within the limits recommended. It can be inferred from Table 2 that all the heavy metals analyzed are below the recommended limits for water discharge into the stream. Titanium (Ti), Manganese (Mn), Iron (Fe), Nickel (Ni) and Zinc (Ni) have a concentrations of 0.02 mg/L, 0.250 mg/L, 1.25 mg/L, 0.08 mg/L and 0.63 mg/L, while the recommended limits are 10 mg/L, 5 mg/L, 20 mg/L, 1 mg/L and 1 mg/L, respectively. It is important to note that there are some heavy metals in the table whose acceptable limits have not being specified; this is because they are categorized as elements with no practical significance to sanitation or health. For instance the US Environmental Protection Agency [23].

Comparing the results of the analysis with that of a research carried out on Samaru stream [20], there is a decreasing concentration of metal pollutants particularly Zn and Fe which they analyzed using a V2000 multi analyte photometer to be 0.31 mg/L and 1.51 mg/L, respectively against the 0.063 mg/L and 1.25 mg/L analysed using the XRF analysis. Other heavy metals investigated include, lead (Pb), Cadmium (Cd) and Mercury (Hg) which were however, not identified using the XRF analysis because they are below the detection limits [20].

4. Conclusions

The result of this study is important and will be applied in monitoring variations of dissolved sediments and heavy metal pollutants in the Samaru stream and to the Kubanni reservoir in Ahmadu Bello University, Zaria. Especially that difficulty is being encountered in purification of the water for human consumption. The identification of nickel in the dissolved sediment of the stream has confirmed earlier studies on the soil type of the study area which was classified as highly leached ferruginous tropical soils which developed on weathered regolith overlain by a thin deposit of windblown silt from the Sahara desert [14, 24]. In its natural form, nickel is usually found in association with Iron. About 20% of nickel is found in this association while the remaining is believe to be derived as a result of human activities, mostly from their released into the atmosphere by power plants and trash incinerators which then settle to the ground or fall down after reactions with raindrop, while the larger part of all nickel compounds released to the environment are been absorbed by sediment and soil particles and become immobile as a result, but are washed down to streams during precipitation. In acidic ground, however, nickel is bound to become more mobile and often rinse out to the groundwater [25]. Furthermore, heavy metals show no dramatic difference in concentrations at sampling stations and depth in Aar reservoir central Germany [26]. Also distribution and sources of Pb within the three Gorges Reservoir, China showed Pb concentration roughly 1.6 times higher than the geochemical background concentration [27].

The human factor that may be responsible for the identification of nickel in Samaru stream can be associated to the growing number of small scale animal feeds production industries along Samaru-Sokoto road where the main drainage that carries water into Kubanni reservoir from Samaru stream passes. These industries operate on huge powered generators and incinerators to release smoke and dusts generated during production. Based on the findings of this research the following recommendations are made:

- The operations of these industries be monitored because the Kubanni reservoir where the Samaru stream empties is the primary means of water supply to the ABU community, checking the operation of these industries will therefore, ease the treatment of the water in the ABU reservoir for human consumption.

- Effort to restore the stream embankment from erosion in areas where it has developed over the years should commence in order to reduce erodiblity, leaching and solubility of earth materials that contributes immensely to dissolved sediment generation in the stream.
- The ABU authority should construct a sewage treatment plant and rehabilitate existing sewage channels in the campus that have collapsed and disintegrated.

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