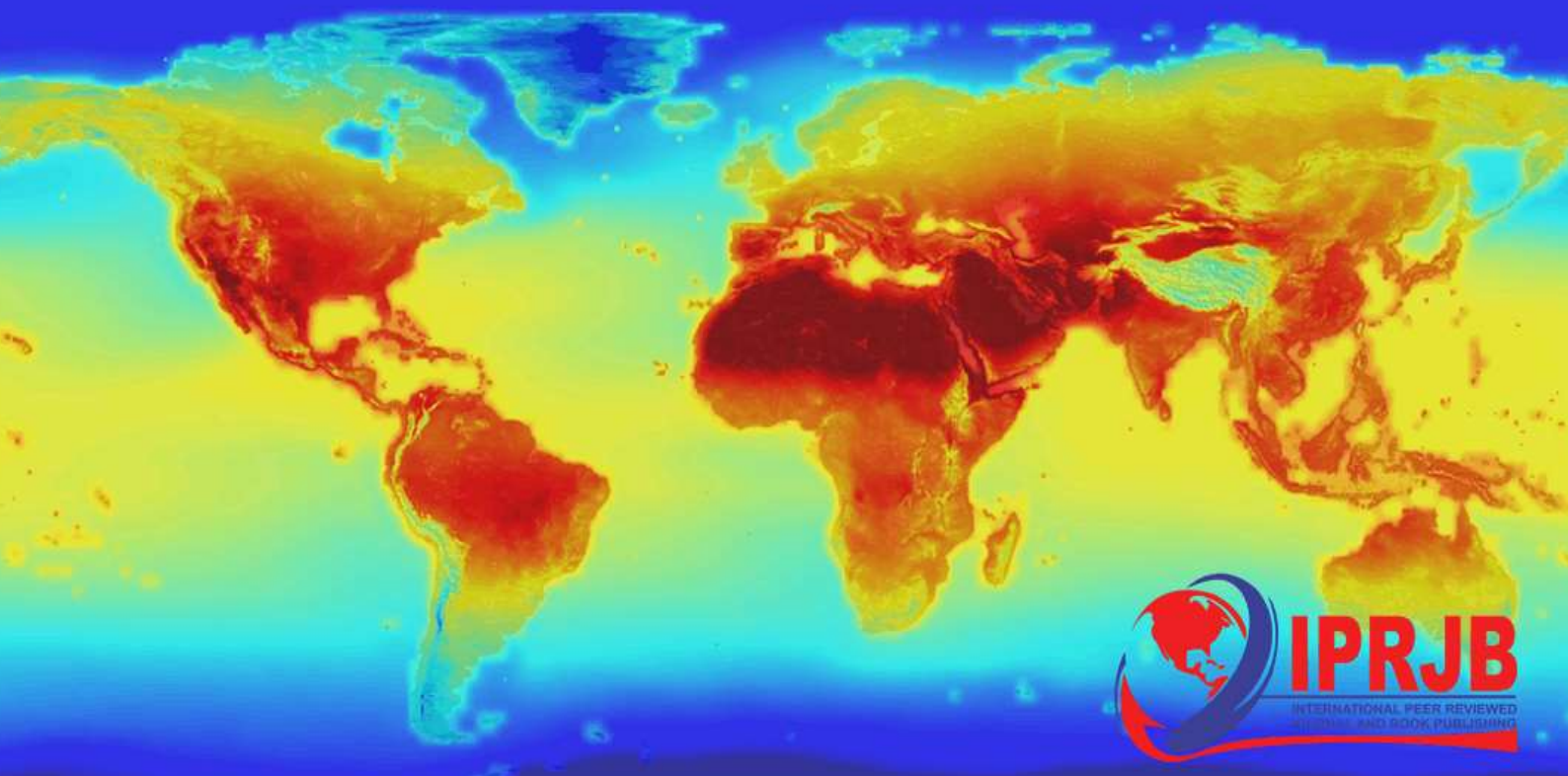
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Seasonal and Spatial Variations of Heavy Metals Levels in Water and Sediments from the Ondiri Wetland and Its Outflows

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Abstract

Purpose: The purpose of this study is to assess pollution levels, identify contamination sources, and evaluate ecological and human health risks to the community around and far from the study area.

Methodology: The study was carried out in Ondiri wetland, which is located 200m South of Kikuyu town in Kikuyu ward, Kikuyu Sub-County in Kiambu County and 20km West of Nairobi City. Strategically sampling points were chosen across spatial gradients representing the swamp interior/source, active agricultural fringes, and major outflow points downstream. Aliquots of 500ml Water samples were collected approximately 20cm below the surface. Portions of 5 drops of preservative (HNO_3) were added to each sampled water were sealed. The sediments were collected from all study areas; SP1, SP2, SP3, SP4, SP5, and SP6. Two samples of sediments were taken from each sampoling point. Sediments were scooped into a zipable polythen bags with lebles, using a trowel from the same points where the water was sampled. All collected samples were stored in a cooler box and transported to the laboratory where they were refrigerated at 4 ^{0}C until analysis time. An atomic absorption spectrophotometer (AAS) was used to analyze heavy metals (Lead, Cadmium, Copper, and Zinc) in sediments and water samples.

Findings: The study found that in both seasons, the sediments contained high levels of the heavy metals compared to the water samples. Metal concentrations in the sediments were marginally greater than those in the water. This indicates that even when water tests appear to be safer, sediments serve as a significant trap for contaminants, posing a long-term threat to the local ecology and human health.

Unique Contribution to Theory, Practice and Policy: The study recommends reducing chemical input into the environment, focusing on improving monitoring, creating vegetated buffer zones, and managing land better to reduce sediment runoff around the Ondiri wetland.

Keywords: *Heavy Metals, Ondiri Wetland, Spatial Variation, Seasonal Analysis, Sediment Pollution, Water Quality*

JEL Codes: *Q53, Q25, Q57*

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INTRODUCTION

Wetlands are areas of land that are saturated or flooded with water, either permanently or seasonally (Geze & Desta, 2025). Wetlands play a crucial role to human society, as well as sustainability of both surface and ground water resources on Earth (Sharma & Naik, 2024). A wetland is an important subsystem of overall ecosystem and plays a major role in both biotic and abiotic factors (Wang *et al*., 2025). Flood control, groundwater replenishment, biodiversity preservation, water purification, water conservation, and other vital ecological services are all made possible by these ecosystems (Dawoud & Al Hassan, 2025). Wetlands offer society a variety of social and economic benefits in addition to their ecological roles (Sharma & Naik, 2024). Wetlands are crucial for recreational pursuits such as hunting, fishing, and bird watching, for instance, which have a major positive economic impact on nearby communities (Abata *et al*., 2025). Additionally, wetlands offer significant cultural and spiritual benefits to local and indigenous communities, who depend on them for cultural practices, medicine, and subsistence (Wood, 2025). Wetlands can be classified as either natural or man-made, with artificial wetlands going through comparable processes in controlled settings (Bassi *et al*., 2025). Natural wetlands are formed by natural processes such as geological and hydrological over time, while artificial wetlands are constructed or significantly altered by human activities (Innocent *et al*., 2025).

The rise in agricultural activity, urbanization, and industrialization coupled with poorly managed landfills lead to contamination of wetlands. They release contaminants inform of industrial effluents, vehicle emissions, fertilizers in agricultural runoff, pesticides and herbicides, sewage, and leachates from municipal wastes (Izah & Ogwu, 2026). A combination of all these factors plays a role in the buildup of contaminants within the wetland ecosystems. Heavy metals are among the most harmful environmental pollutants even when in low concentrations (Du et al., 2025). They are therefore categorized as toxic pollutants with significance pollution impact since they persist in the environment for a long time leading to continuous emission source (Durães et al., 2026).

These metal pollutants directly impact quality of water and pose a serious threat to the health of organisms when they enter the food chain (Izah & Ogwu, 2026). Consequently, they accumulate in aquatic ecosystems and in the tissue of organisms like bivalve mollusks and a variety of fish species and are passed on to fish-eating animals, birds, and ultimately humans via the food chain (Oros, 2025). Humans and aquatic organisms' bodies do not metabolize metals and are not from the body (Jomova *et al*., 2025). Instead, they are deposited and accumulated in bodily tissues like fat, muscles, and joints, leading to numerous health issues and illness (Suresh, 2025). Present-day research indicates that heavy metals like arsenic (As), copper (Cu), lead (Pb), mercury (Hg), cobalt (Co), and cadmium (Cd) are among the harmful substances that contaminate both surface and groundwater (Sward, 2025).

Heavy metals are naturally occurring elements of the earth's crust that are toxic in small amounts (Jomova et al., 2025). High soil concentrations of soluble heavy metal components can be absorbed by plants, which can slow down plant growth and occasionally cause plant death (Zhang & Li, 2025). Additionally, research indicates that human exposure to high concentrations of heavy metals (Jomova et al., 2025), causes spontaneous abortions, kidney damage, severe neurological symptoms, seizures, mental disturbance, slow growth and development, central nervous system cognitive impairment, and irregular heartbeats (Ram & Vadhera, 2024). People are exposed to heavy metals through the food they eat, the water they

drink, and the air they breathe (Jomova et al., 2025). However, metal pollution remains a significant major issue largely because environmental lobby groups have historically paid less attention to metal pollution, focusing more on other types of environmental pollution (Rathod et al., 2024)

The largest peat bog in Kenya, Ondiri Wetland, forms the headwaters of the Nairobi River in the Athi drainage basin. Both the city of Nairobi and Kiambu County rely heavily on it for household, agricultural, and industrial water. The Ondiri Wetland is renowned for its incredibly rich and varied biodiversity, which includes bird species such as the uncommon Marabou storks and the endangered Gray Crowned Cranes. Additionally, it is home to a variety of aquatic and semi-aquatic plants, including grasses like Eriochloa meyerana, Leersia hexandra, and Eragrostis exasperate, as well as native and foreign trees. The greatest quaking bog in the nation is created when these plants grow on accumulated semi-decomposed organic matter that forms a thick layer of peat (about 0.5 m thick) on top of the water.

Problem statement

Ondiri Wetland is a vital hydrological resource experiencing escalating anthropogenic pressures (agricultural runoff, Industrial effluent, sewage and municipal waste), yet there is a critical knowledge gap regarding how seasonal hydrological shifts (wet verses dry seasons) modulate the spatial distribution and bioaccumulation potential of heavy metals (Lead, Copper, Cadmium, and Zinc) in its waters and sediments.

Objective

To determine the levels of Lead, Copper, Cadmium and Zinc in sediments and water from Ondiri wetland and its outflows during dry and wet seasons

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Conceptual Framework

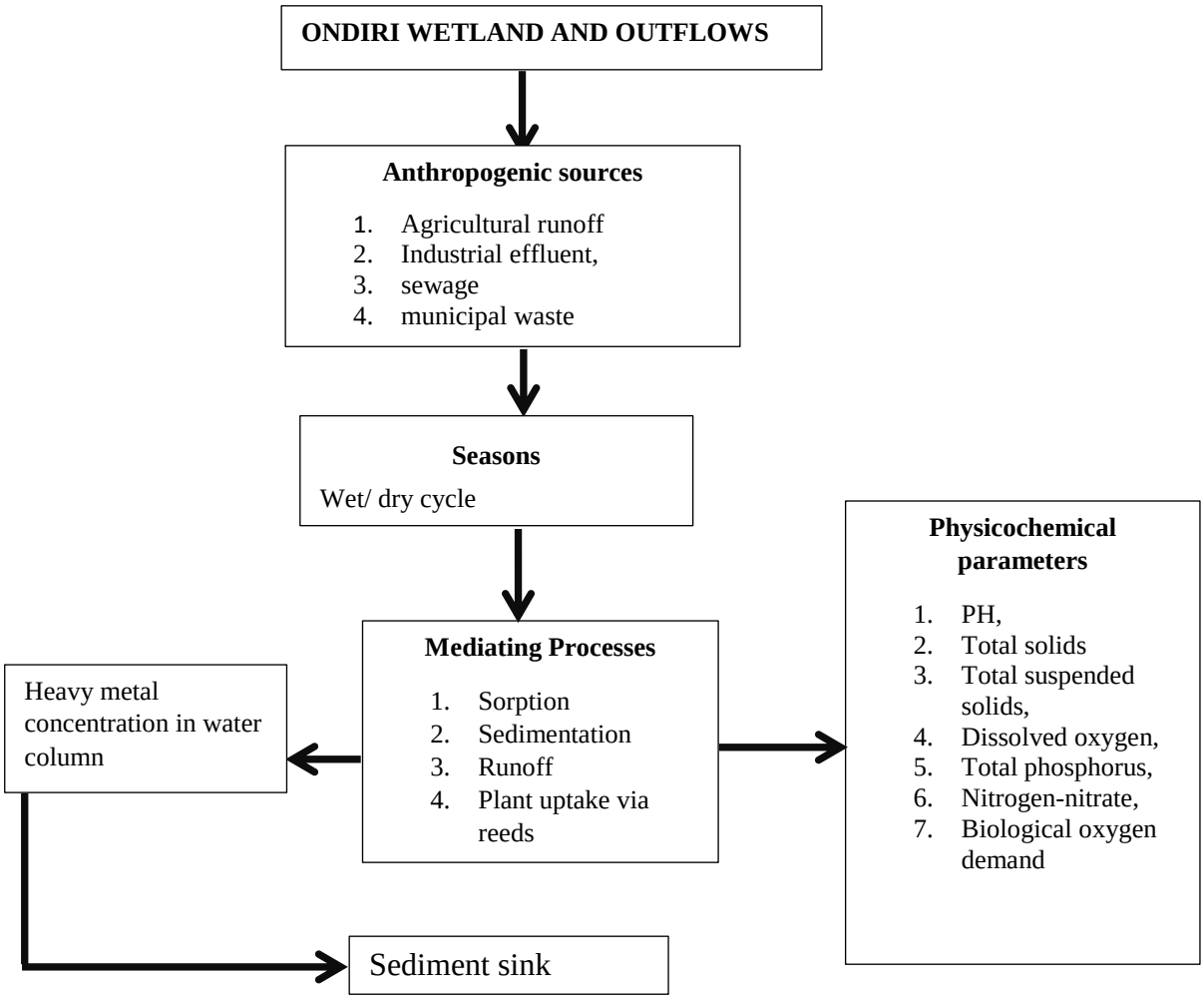


Figure 1: Conceptual Framework

METHODOLOGY

This study adopted experimental research design, which aimed to accurately and systematically observe, record, and describe situation in Ondiri wetland and its outflow without manipulating any variables. The sampling sites were selected to ensure samples reflected anthropogenic activities. Replicate sampling was adopted for this research, where two samples of water and sediments were collected from the same location one after the other in quick succession. Replicate samples were collected independently but under identical conditions. They were stored in separate plastic containers and polythen bags, and replicate samples were subjected to the same handling, preservation, and transportation procedures.

Aliquots of water samples were collected in 500mL HDPE bottles for heavy metal analysis. The bottles were pretreated by keeping them in 10% v/v HNO_3 for 24hours then washed and rinsed with deionized water and finally rinsed three times with the sample water to be collected. Bottles were labeled appropriately with waterproof stickers. Water samples were collected approximately 20cm below the surface. 5 drops of preservative (HNO_3) were added to each sampled water sealed and then packed in pre-chilled cooler boxes to maintain at least 4^{o}C while

being transported to the Laboratory freezer awaiting further analyses. The location of each sampling point was recorded using a GPS and then recorded in notebook. Samples were collected from 6 sampling points in duplicates, namely: SP1, SP2, SP3, SP4, SP5, and SP6.

The sediments were collected from all study areas; SP1 to SP6. Two samples of sediments were taken from each sampling point. Sediments were scooped into a zipable polythen bags with lebles, using a trowel. Sediments were collected to a depth of 15 cm from the same locations where the water was sampled (Wazne *et al*., 2025). The samples were then stored in a cooler box and transported to the laboratory where they were refrigerated at 4 ^{0}C until analysis time (Webster *et al*., 2025).

Analysis

An atomic absorption spectrophotometer (AAS) machine was used for analysis of Lead, Copper, Cadmium, and Zinc metals in soil sediments and water (Simon *et al*., 2025). The samples were drawn into a flame; the flame vaporized the metal atoms, which was then excited by a light source (Akash & Rehman, 2025). The absorbance of the light was measured and compared to the standards to determine the concentration of the metals in the sample (Wei *et al*., 2025). The absorbance of each sample was read three times and an average was calculated for each standard solution and then a graph of absorbance against standard concentrations of solution was plot and the concentration of the unknown obtained through extrapolation (Wilcox *et al*., 2025). The concentrations of heavy metals in various matrices were presented as arithmetic mean with standard deviation (mean ± standard deviation) (Msellek *et al*., 2025). Statistical analysis was done at p = 0.05 and the results were presented in tables (Chen *et al*., 2025).

RESULTS

Table 1: Zn, Cd, Pb, and Cu Metal Concentration in ppm in Water and Sediment Samples during the Dry Season Reported in Mean ± SD (Standard Deviation)

Sampling Point	Sample Type	Cd Conc.	Cu Conc.	Pb Conc.	Zn Conc.
SP 1	Water	0.09±0.03	0.30± 0.06	0.14± 0.12	0.15±0.03
	Sediment	0.07±0.01	1.66± 0.04	1.18± 0.12	1.74±0.06
SP 2	Water	0.12±0.02	0.28± 0.01	0.43± 0.04	0.56±0.02
	Sediment	0.06±0.00	0.72± 0.04	0.32± 0.06	1.47±0.15
SP 3	Water	0.11±0.03	0.08± 0.02	-	0.04±0.00
	Sediment	0.05±0.01	0.91± 0.03	0.69± 0.02	1.59±0.12
SP 4	Water	0.13±0.02	0.23± 0.02	0.21± 0.05	0.02±0.01
	Sediment	0.01±0.01	1.42± 0.02	0.85± 0.07	0.71±0.04
SP 5	Water	0.11±0.00	0.16± 0.04	-	0.06±0.01
	Sediment	0.22±0.03	31.17± 2.43	1.18± 0.12	3.90±0.07
SP 6	Water	0.09±0.00	0.09± 0.03	-	0.10±0.03
	Sediment	-	0.76± 0.12	0.34± 0.01	0.85±0.06
	Average (±SEM)	**0.09±0.02**	**3.15±2.55**	**0.44±0.13**	**0.93±0.33**

Table 2: Zn, Cd, Pb, and Cu Metal Concentration (ppm) in Water and Sediment Samples during the Wet Season Reported in Mean ± SD (Standard Deviation)

Sampling Point	Sample Type	Cd Conc.	Cu Conc.	Pb Conc.	Zn Conc.
SP 1	Water	-	-	0.15±0.00	-
	Sediment	-	1.88±0.13	0.46±0.04	1.91±0.15
SP 2	Water	-	0.07±0.07	-	-
	Sediment	-	0.77±0.40	0.27±0.03	1.00±0.02
SP 3	Water	-	-	-	0.06±0.04
	Sediment	-	1.30±0.17	0.13±0.01	2.34±0.29
SP 4	Water	-	-	0.09±0.00	-
	Sediment	-	0.84±0.07	0.53±0.06	2.61±0.16
SP 5	Water	-	-	-	-
	Sediment	-	0.98±0.03	-	1.44±0.18
SP 6	Water	-	-	-	-
	Sediment	-	0.43±0.10	0.26±0.00	1.15±0.13
	Average (±SEM)	-	0.52±0.18	0.16±0.05	0.88±0.29

Discussion

According to the average data analysis, the total heavy metal accumulation in waters and sediments follows the order (ppm) during the dry season: Cu > Zn > Pb > Cd, and during the wet season: Zn > Cu > Pb > Cd. In almost all the samples studied in both seasons, the sediments contained high levels of the HMs compared to the water samples. Seasonal variations in the features of the distribution and sources of heavy metals are caused by variations in variables including temperature, precipitation, and humidity. Metal concentrations in the sediments were marginally greater than those in the water. This is because surface sediments include contaminants that have accumulated over many years, and there may be discrepancies in the distribution of some elements between the sediment and the water (Bat *et al*., 2025). According to a related study by (Liang *et al*., 2025), sediment samples contain significant concentrations of heavy metals.

Anthropogenic activities increase the amount of Cd, which raises the level of contamination in the water. The results demonstrated that Cd concentrations during the dry season in Ondiri Swamp and its outflows were above the permissible limits of WHO, which is 0.01 mg/l (Ekemube *et al*., 2025), except for the Sampling point 6 (SP 6) sediments. Similarly, Cd concentration in all sample locations was below the WHO permissive limit during the wet season. This is consistent with the findings, which indicate that the water quality is seriously threatened by the presence of chemical contaminants from various anthropogenic sources (Shanmugasundaram *et al*., 2025). The primary causes of cadmium pollution during the dry season may be mining and industrial activities (Xie *et al*., 2025). Increased metal concentrations reflected long-term pollution caused by human activities. Along the wetland is situated a construction activity, farming, a dumping site, and domestic waste due to increased built-up areas. Cd is primarily found in phosphate fertilizers as an impurity of phosphate rocks, according to a study by (Hamed *et al*., 2025). Thus, it is possible to explain the elevated metal concentrations in the sediment and water samples, which are indicators of contamination. Additionally, the most significant sources of heavy metals in the research area may be the local farmers' poor agricultural methods and the discharge of municipal waste (Li *et al*., 2025).

The amount of Zn in the river rises due to the presence of anthropogenic activities, raising the water's level of contamination. The experimental findings demonstrated that Zn concentrations in Ondiri Swamp and its outflows are below the permissible limits of WHO, which is 5 mg/l (Ekemube *et al*., 2025), during the wet and dry seasons. However, a sample of sediment collected at the Sampling point 5 (SP 5), was higher (3.9035±0.0739 mg/L) during the dry season. The anthropogenic activities associated with the water must have been the human actions on effluents and scrap metals that led to substances leaking onto the surface water at Sampling point 5 (SP 5), which is a densely populated area. Although heavy metals (HMs) are naturally found in river sediments in comparatively small amounts, the majority of HMs comes from pyrogenic and petrogenic sources (Zhong *et al*., 2025). Furthermore, (Malik *et al*., 2025) found that the Old Brahmaputra River's water and sediment quality were polluted by human-caused industrial, residential, and agricultural discharges.

Copper (Cu) concentrations in Ondiri Swamp and its outflows were below the permissible limits of WHO, which is 3.0 mg/l (Ekemube *et al*., 2025), only sediment sample collected at Sampling point 5 (SP 5) were above the permissible limits of WHO which was 31.17. According to the direction of the water flow, HMs increased from upstream to downstream. These high amounts are probably caused by untreated garbage discharges coming straight from industrial and residential effluents (Thiagarajan & Devarajan, 2025). In the same disposition, Cu contents in all samples from all the sampling points were below the WHO permissive limit during the wet season. High levels of HMs have been found in sediments all around the world in numerous earlier investigations (Aljahdali *et al*., 2025). Certain metals, like copper and zinc, are necessary in trace amounts, but extremely high concentrations of these elements can be harmful to living things (Popoola, 2025). It is known that sediments serve as a reservoir and sink for the build-up of HMs (Kumari *et al*., 2025). Mining, the use of sewage sludge, waste emissions, and the heavy use of fertilizers and fungicides in agricultural areas are examples of anthropogenic sources of copper. Dilution and settling processes, which transfer metals into the sediments, explain this. By enabling a considerable volume of uncontaminated water to mix with contaminated water, greater precipitation during the rainy season also decreased the total metal concentrations in the swamp and its outflows (Akhtar *et al*., 2025). The results demonstrated that Pb concentrations in Ondiri Swamp and its outflows were above the permissible limits of WHO, which is 0.01 mg/l (Ekemube *et al*., 2025), during the wet and dry seasons. In exception, during the wet season, water sampled at sampling points 6, 5, 3, and 2, and sediments sampled at the Sampling point 5, had lower permissive limits. In contrast, during the dry season, at the Sampling points 6, 5, and 3, water had lower permissive limits. Among the man-made activities linked to water contamination were production companies, illicit refineries, petroleum product bunkers, and pipeline vandalism, which caused crude oil to spill onto the lake's surface (Adebangbe, 2025).

CONCLUSION AND RECOMMENDATIONS

Conclusion

The study focused on heavy metal levels and the extent of pollution of sediments and water in Ondiri wetland and its outflows. The result showed increased amounts of Cd, Cu, Pb, and Zn in certain areas, particularly during the dry season which cause major concerns, even though many physical and chemical criteria meet World Health Organization (WHO) guidelines. Furthermore, according to the water quality indicator (geo-accumulation index), the metal levels in the water made it unsafe to drink. When compared to the water samples, the metal

concentrations in the sediments were comparatively greater. Significant anthropogenic contributions to HMs contamination were indicated by the multivariate analysis, underscoring the need for more research to evaluate the ecological effects. The ecological balance of the Ondiri Swamp and its outflow and the health of the communities that depend on it are seriously threatened when heavy metal concentrations exceed allowable levels. Long-term irrigation with tainted water can cause heavy metals to bio accumulate in crops, endangering human health and food safety.

Recommendations

The management to move the community around the bog to a different area and enforcing stringent buffer zones to reduce wet-season sediment transport and dry-season concentration surges in order to save Ondiri Wetland and its outflows from heavy metal accumulation. Discourage the overuse of synthetic fertilizers and pesticides in nearby farms and greenhouses that flow direct into the wetland. Frequent spatiotemporal sampling of the water column and bottom sediments is essential, with special attention to dry, low-flow times when contaminants concentrate.

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