Effects of Catchment Land Use on Nutrients and Heavy Metals Inflows into Maragua and Mathioya Wetlands in Murang'a County, Kenya

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DOI: https://doi.org/10.51584/IJRIAS.2025.10040041

Received: 26 March 2025; Accepted: 01 April 2025; Published: 08 May 2025

ABSTRACT

Wetland ecosystems in Murang'a County are diminishing due to increased catchment land use practices. Part of wetlands have been converted into farmlands where various agricultural activities are carried out while some parts have been converted into settlement points. Agricultural practices carried out along wetland ecosystems involve the use of excessive agrochemicals during crop production which later contribute to wetland pollution through nutrients and heavy metals inflows. This study aimed at assessing the effects of catchment land use on nutrient and heavy metals inflows into Maragua and Mathioya river basins in Murang'a County. Water samples were collected using the Grab technique, packed in plastic containers, kept in cool boxes, and transported to the research laboratory for analysis. Phosphate and nitrate concentrations were analyzed across different seasons, sampling stations, and sampling levels. During dry season, the mean phosphate concentration was 0.0259 ± 0.0051 mg/L with a standard deviation of 0.0124 mg/L. In wet conditions, the mean phosphate concentration increased to 0.1631 ± 0.1509 mg/L with a standard deviation of 0.3697 mg/L. For nitrate, the mean concentration during dry conditions was 9223.37 ± 2672.33 mg/L with a standard deviation of 6545.84 mg/L, and during wet conditions, it remained the same at 9223.37 ± 2008.17 mg/L with a standard deviation of 4919.00 mg/L.

Elemental analysis was performed using Microwave Plasma-Atomic Emission Spectroscopy (MP-AES) instrument. Mean concentrations of lead during dry seasons were 0.005 ± 0.002 mg/L and during wet season, they increased to 0.012 ± 0.004 mg/L. Zinc concentrations were 0.01 ± 0.003 mg/L during dry season and increased to 0.015 ± 0.004 mg/L during the wet season.

The mean concentrations of zinc in the water samples were significantly lower than the maximum residue concentrations set for drinking water by the World Health Organization (WHO). However, lead (Pb) concentrations were above the WHO recommended maximum residue level. ANOVA analysis indicated no significant seasonal differences in phosphate (F=0.825, p=0.385) and nitrate (F=3.090, p=0.109) levels. Similarly, no significant differences were found between different sampling stations for phosphate (F=1.081, p=0.323) and nitrate (F=0.478, p=0.505). Analysis by sampling levels showed no significant differences noted for phosphate (F=0.979, p=0.412) and nitrate (F=1.949, p=0.198). For heavy metals, no significant differences were found for lead (F=1.234, p=0.271), cadmium (F=0.893, p=0.348), and zinc (F=1.567, p=0.223) across different seasons and sampling stations.

These findings suggest that nutrient and heavy metal inflows into the wetlands are relatively stable and uniform across different spatial and temporal scales. The study highlights the importance of consistent land use practices and the effective buffering capacity of wetlands in maintaining ecological balance.

Keywords: Wetland, Agrochemicals, Pollution, Heavy Metals

INTRODUCTION

Wetland ecosystems are the most important component of the environment globally, accounting for a third of all terrestrial primary production. Wetlands are home to 70% of the world's biodiversity and are essential for many natural resources, including food and water (Junk *et al*., 2013). The use of land in catchment areas has multiple and strategic importance in urban and peri-urban developments since it influences the local ecosystems and water/soil quality (Ahogle *et al*.,2023). In Murang'a County, Kenya, there are changes in land use which involves intensive agriculture and expansions in urban and industrial areas bearings on the nutrient and heavy metal inputs to small wetlands. Such wetlands, small ponds, are water bodies with surfaces that vary from 1 m² to 2-5 ha with water depths of 2-3 m, are valuable for sustaining biological diversity, silt trapping, and delivering ecosystem benefits including: provision of drinking water, food, flood control, groundwater recharge and nutrient conservation (Bhowmik, 2022). Globally, wetlands size is declining, particularly in Africa, due to urbanization, industrialization and unsustainable land use (Mitsch & Gosselink, 2015).

Pollution of small riverine wetland ecosystems is associated to the various catchment land use practices such as agricultural activities (Abillah *et al*., 2021). The massive use of inorganic fertilizers during farming along the small wetland ecosystems has contributed to increased nutrients load and heavy metals residue contaminants which affects the quality of water and critically cause damage to both aquatic and terrestrial organisms that depend on such wetlands (Wagner *et al*., 2008). Other sources of heavy metals can be of biogenic type, including volcanic activities and erosion of rocks, industrial and urban effluents, and barrage of wastewater irrigation. Anthropogenic activities contribute to higher levels of heavy metal diffusion compared to natural sources (Aziz *et al*., 2023). Bioaccumulation of heavy metals in crop and aquatic foodstuffs possess a health risk to people (Rashid *et al*., 2023; WHO, 2023).

Heavy metals dissolve in water, suspended solids, sediment, and biota in aquatic ecosystems. The six most hazardous metals include Pb, Cr, As, Cd, Cu, and Zn (Liu *et al*., 2024). Pollution by these metals can be described in terms of their content in water, bottom deposits, and biota (Mapenzi *et al*., 2020; Yang *et al*. 2022). Copper is vital to life forms; however, in very high concentrations, it is dangerous and deadly. Copper in water can be soluble, colloidal, or particulate, and at high concentrations, the ingested copper can lead to hypertension and pathological changes in the human brain (Malhotra *et al*., 2020). Lead contamination is apparently a global menace because of the versatility of the chemical substance that is used in many commercial and industrial products (WHO, 2023). The potential sources of lead include agrochemicals as well as industrial plants such as battery producing and electroplating plants (Jaishankar *et al*., 2014). Cadmium is a poisonous metal and does not have any known role in the body processes of animals or humans. Zinc plays a vital role in various biological activities when in trace amounts but toxic at higher concentration levels, its ingestion causes health issues such as gastrointestinal problems (Hussain *et al*., 2022). Chromium is a trace element or micronutrient, but it is toxic at higher concentrations. Assimilation of chromium by fish, threatens water ecosystems and human beings through its negative effect in the blood such as anemia, eosinophilia and lymphocytosis, branchial and renal lesions. (Mitra *et al*., 2022). Manganese is found naturally in the environment and is used in several industries. Humans and aquatic organisms are harmed by acute manganese concentrations in water as it results in neurotoxicity and reproductive system toxicity (Dey *et al*., 2023).

Heavy metals lack biodegradability and tend to get deposited in the food chain, which may lead to toxic effects (Malik *et al*., 2022). In aquatic ecosystems, the bioavailability and mobility of heavy metals can change species distribution and ecosystem stability, and the accumulation rate of fish and shellfish is much higher than in water and sediment samples (Hameed *et al*., 2020). Some chemical characteristics of the water body, like water temperature, pH, and organic content, also affect the toxicity and bioaccumulation of these metals in the aquatic biota; thus, strict monitoring is necessary (Teunen *et al*., 2021).

This research seeks to investigate the extent to which various land use practices in Murang'a county influence water quality in Maragua and Mathioya wetland ecosystems. No research has been conducted to ascertain the levels of nutrient and heavy metals residue inflows in the water from both wetland ecosystems. This study fills research gap through identification of existing nutrients and heavy metals inflows, and ascertaining their residue levels in relation to catchment land practices. Through assessing the degree, kind, and effects of contamination, this research will create approaches to the prevention of pollution, safeguard wetland ecosystem services, and guarantee the safety of agricultural produce to consumers.

MATERIALS AND METHODS

Study Area

Murang'a County, located in central Kenya, features a diverse landscape with varying land use practices. The County, spans latitudes 0° 34' S to 1° 7' S and longitudes 36° E to 37°27' E. It covers 2,558.8 km² bordered by Nyeri, Kiambu, Nyandarua, Kirinyaga, Embu, and Machakos counties, with an altitude range from 914 m to 3353 m above sea level (MC, 2014). The county experiences a bi-modal rainfall pattern, with short rains from October to December and long rains from March to May. It is divided into three climatic zones: the upper zone (1800-2220 m above sea level (asl) at the edge of Aberdare forest receives 1800-2000 mm of annual rainfall and supports tea, maize, vegetables, and dairy farming; the middle zone (1400-1800 m asl) receives 1400-1600 mm of rainfall and is suitable for coffee, maize, bananas, beans, vegetables, and low-level zero-grazing; the lower zone (900-1400 m asl) with less than 900 mm of rainfall supports pineapples, dairy farming, fruits, vegetables, French beans, and eucalyptus plantations (Ovuka & Lindqvist, 2000). Soil types vary across the zones, with volcanic ash soils in the upper zone, nutrient-rich nitosols in the middle zone, and deep, strongly leached poor clay soils (ferrosols) in the lower zone (MC, 2014). Maragua and Mathioya river basins are the main catchment areas in the County. Maragua basin borders four sub-locations, that is Ichagaki, Nginda, Gakoigo, and Maragua. Mathioya river basin borders Nyeri County to the North, Kangema Sub-County to the North, Murang'a East Sub-County to the East and Nyandarua County to the West.

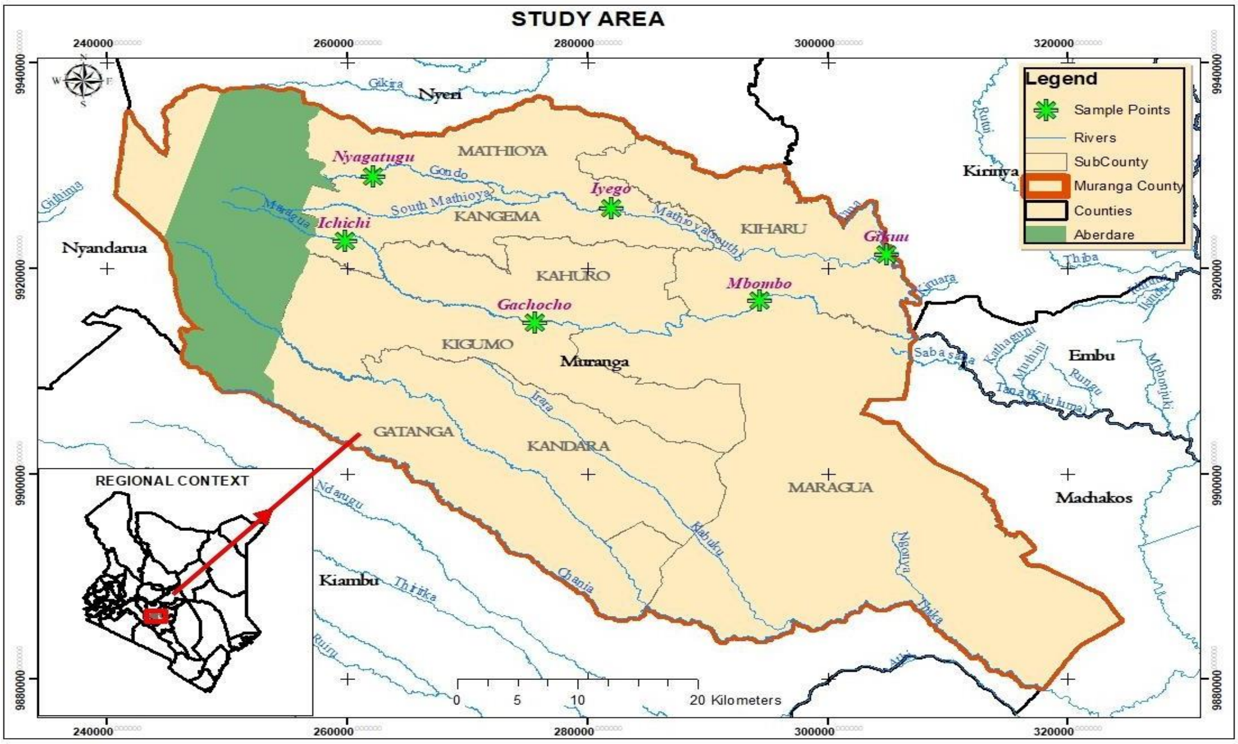

Fig. 2.1 Study Area Map

Data Collection

Standard procedures were employed for the collection and preservation of water samples. A total of 48 water samples were analysed during the study. Distribution of samples was done in three sampling levels, that is, the upstream, mid-stream and downstream. The distance between the sampling points/levels was twelve-kilometer stretches in both Maragua and Mathioya river basins. Sampling started from the source and proceeded downstream. The samples were packed in containers, labeled, stored in air-tight plastic bags, kept in ice boxes, and transported to the laboratory, where they were stored at 0-4°C before analysis.

Sampling points: Upstream, Mid-stream and downstream chosen with consideration of the intensity of local land use/catchment land use practices. Upstream considered to be a region closer to the origin of the two riverine wetlands; where human encroachment into the catchment is minimal and less catchment land practices are carried out; thus, minimal level of pollution is expected. However, progressing downstream, encroachment intensify and more catchment resource is converted into farmland with intensive agricultural practices which would contribute to wetland pollution and subsequently affect the wetland water quality.

Data Analysis Techniques

Nutrients were analyzed using standard methods (APHA/AWWA/WEF, 2005), including ammonia-nitrogen (NH_3-N), nitrate-nitrogen, and phosphates. Nitrate-nitrogen was measured using the cadmium reduction method, ammonia-nitrogen by the colorimetric method with Nessler's reagent, and phosphates by the ascorbic acid method (Bahobail *et al*., 2016).

Metal ions were analyzed by digestion of samples and measuring with agilent 4210 MP-AES instrument (Ranjbar *et al*., 2012). Data were pre-processed, coded, and entered into a spreadsheet for analysis using descriptive (error bars, frequency tables, percentages) and inferential statistics (Pearson correlations, regression, ANOVA) with SPSS software (Garth, 2008). Seasonal means were compared using Least Significance Differences (LSD).

Quality Control and calibration details

Quality protocols were observed through continuous calibration verification and servicing of the equipment as per maintenance schedule. Also, through proper sample preparation and handling to avoid TDS.

Calibration of the equipment was done using multielement standard, where the standard solutions of the specific element to be analysed in MPE-AES were prepared.

RESULTS AND DISCUSSION

Nutrient analysis of water samples from both Maragua and Mathioya wetlands, Murang'a County, Kenya

Nutrient analysis in water samples from both Maragua and Mathioya wetlands found phosphate and nitrate nutrient inflows to be present (Table 1). The mean for phosphate concentration extracted during the dry season was 0.0259 ± 0.0051 mg/L. The variation was 0.0124 mg/L, representing low variability among the trials. The 95% confidence interval for the averages was between 0.0129 mg/L and 0.0389 mg/L. Phosphate concentrations in dry conditions ranged from 0.0067 mg/L to 0.0405 mg/L. During wet season, the mean phosphate concentration was significantly higher at 0.1631 ± 0.1509 mg/L. However, there was a substantial increase in variability, with a standard deviation of 0.3697 mg/L. The 95% confidence interval for the mean ranged from -0.2249 mg/L to 0.5511 mg/L, indicating high uncertainty in the mean estimation due to the wide range of values. Phosphate concentrations in wet season ranged from 0.0067 mg/L to 0.9177 mg/L. When considering both seasons combined, the mean phosphate concentration was 0.0945 ± 0.0749 mg/L, with a standard deviation of 0.2595 mg/L. The 95% confidence interval for the mean ranged from -0.0704 mg/L to 0.2593 mg/L. The overall range of phosphate concentrations was from 0.0067 mg/L to 0.9177 mg/L. Mean residue inflows of phosphate were below the set limits for drinking water as per the World Health Organization (WHO, 2023).

The mean nitrate concentration during dry season was 9223.37 ± 2672.33 µg/L. The standard deviation was 6545.84 µg/L, indicating substantial variability among the samples. The 95% confidence interval for the mean ranged from 2873.40 µg/L to 15573.34 µg/L. Nitrate concentrations in dry season ranged from 1162.34 µg/L to 17968.45 µg/L.

During wet season, the mean nitrate concentration remained the same at 9223.37 ± 2008.17 µg/L, but the standard deviation decreased to 4919.00 µg/L. The 95% confidence interval for the mean ranged from 4631.11

Ug/L to 13815.64 µg/L. Nitrate concentrations in wet season ranged from 10652.42 µg/L to 24142.49 µg/L.

Table 1: Seasonal nutrient analysis of water samples from both Maragua and Mathioya wetlands, Murang'a County, Kenya

		Nutrient analysis in water samples			
		Phosphate(s); (mg/L)		Nitrate(s); (µg/Kg)	
Wetland	**Sampling Level**	**Wet season**	**Dry season**	**Wet season**	**Dry season**
Maragua	**Upstream**	0.067476383	0.067476383	106524.173	11623.40967
	Midstream	0.20242915	0.337381916	179867.6845	82564.8855
	Downstream	0.134952767	0.20242915	134900.7634	167877.8626
Mathioya	**Upstream**	0.067476383	0.20242915	119430.0254	51949.10941
	Midstream	9.176788124	0.4048583	241424.9364	90870.22901
	Downstream	0.134952767	0.337381916	154992.3664	179684.4784

Presence of these nutrient inflows confirms that farmers still apply inorganic fertilizers, that is, phosphatic and nitrogenous fertilizers during crop production along wetland ecosystems. Massive application of such inorganic fertilizers results in residue inflows in wetland waters due to surface runoffs. Generally, there is increase in nutrient inflows as we move downstream the two wetland ecosystems. At the midstream level, there is significant increase in nutrient residue levels as compared to the upstream and downstream levels, this is attributed to intensive agricultural activities carried out at the midstream levels of both wetlands, which involves application of inorganic fertilizers during crop production. Also, there is relatively, higher inflows during the dry season as compared to the wet season owing to higher precipitation which lowers the nutrient concentration during wet season.

There was no significant difference in phosphate levels across different seasons, suggesting that seasonal variations do not significantly influence phosphate concentrations in the wetlands (Penn State, 2022). Also, there is no significant difference in nitrate levels across different seasons. However, the p-value suggests a trend that could be further explored, possibly indicating that with a larger sample size, seasonal variations might become significant (Penn State, 2022). Lack of significant seasonal variation in phosphate and nitrate levels suggests that the inflows of these nutrients are relatively stable throughout the year. This could be due to consistent land use practices or the effective buffering capacity of the wetlands against seasonal changes.

Elemental analysis

Elemental analysis of water samples from both Maragua and Mathioya wetlands identified copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), zinc (Zn) and lead (Pb) to be present (Table 2 and Table 3).

Table 2: Dry season elemental analysis of water samples from both Maragua and Mathioya wetland ecosystems

		Dry Season elemental analysis of water						
		Concentration (mg/L)						
Wetland	Sampling Level	Cd	Cu	Fe	Mg	Mn	Zn	Pb
	Upstream	0	0	0	0.000281	0	0.060714	0.081633
Maragua	Midstream	0	0.041405	0.438703	0.024799	0.02136	0.142857	0.118622
	Downstream	0	0.039832	0.583587	0.000561	0.040012	0.289286	0.096939
	Upstream	0	0	0.62614	0.000281	0.029182	0.148077	0.142857

Mathioya	Midstream	0	0.002096	0.471125	0.033034	0.064681	0.253846	0.22449
	Downstream	0	0	0	0.032566	0.065884	0.221703	0.214286

Table 3: Wet season elemental analysis of water samples from both Maragua and Mathioya wetland ecosystems

		Wet Season elemental analysis of water						
		Concentration (mg/L)						
Wetland	**Sampling Level**	**Cd**	**Cu**	**Fe**	**Mg**	**Mn**	**Zn**	**Pb**
Maragua	**Upstream**	0	0.02044	0.183384	0.008984	0.009627	0.043132	0.218112
	Midstream	0	0.218112	0.236069	0.016189	0.042118	0.405495	0.480867
	Downstream	0	0.080189	0.227964	0.000281	0.036402	0.175549	0.454082
Mathioya								
	Upstream	0	0.041405	0	0.030039	0	0.191209	0.039541
	Midstream	0	0.042453	0.187437	0.041456	0.292118	0.359615	0.577806
	Downstream	0	0.045597	0	0.034157	0.055656	0.09011	0.5

Copper concentrations ranged from 0.000 mg/L to 0.008 mg/L, with a mean concentration of 0.0028 mg/L. The concentrations range from 0 to 0.0080 mg/L. The mean concentration and the range of copper in these samples are significantly below the WHO recommended limit of 1.5 mg/L (Fitzgerald, 1998). This suggests that the copper levels in the water are safe and unlikely to cause any adverse health effects. The slight positive skewness (0.487) suggests that the distribution of copper concentrations is slightly skewed to the right, indicating that a few samples exhibited higher copper levels compared to the majority. Additionally, the low kurtosis value (0.005) indicates a distribution relatively close to a normal distribution.

Iron concentrations displayed a wider range, from 0.000 mg/L to 0.063 mg/L, with an average concentration of 0.0246 mg/L. The WHO recommends a maximum concentration of 0.3 mg/L for iron, primarily for aesthetic reasons rather than health concerns, as high iron content can affect the taste, color, and odor of water (Ibrahim, 2016). The iron levels in the samples are well below this limit, indicating that the water is aesthetically acceptable and poses no iron-related health risks. The positive skewness (0.446) suggests a slight skew to the right in the distribution, indicating that some samples had higher iron concentrations. However, the negative kurtosis (-1.219) indicates a relatively flat distribution compared to a normal distribution.

Magnesium concentrations exhibited a narrow range, from 0.00003 mg/L to 0.0041 mg/L, with a mean concentration of 0.0019 mg/L. There is no specific guideline value for magnesium in drinking water set by the WHO. However, the low concentration of magnesium in these samples indicates that it is present at very minimal levels (Wodschow *et al.*, 2021). While magnesium is an essential nutrient, the concentrations found are too low to contribute significantly to dietary intake or pose any health risk. The skewness value close to zero (-0.045) suggests a distribution close to symmetry, indicating a relatively balanced spread of magnesium concentrations across the samples. Moreover, the negative kurtosis value (-1.834) indicates a flatter distribution compared to a normal distribution.

Manganese concentrations varied significantly, ranging from 0.000 mg/L to 0.029 mg/L, with a mean concentration of 0.0055 mg/L. The WHO recommends a maximum concentration of 0.3 mg/L for manganese, again primarily for aesthetic reasons, as high levels can affect the taste and color of water. The manganese concentrations in the samples were well below the WHO limit, indicating that the water is aesthetically acceptable and safe from a manganese perspective (Wang *et al.*, 2023). The highly positive skewness (2.953) and kurtosis (9.519) values indicate a distribution with a long right tail and a sharp peak, respectively. This suggests that while the majority of samples exhibited low manganese concentrations, a few samples had notably

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue IV April 2025

higher levels.

Zinc concentrations ranged from 0.0043 mg/L to 0.041 mg/L, with a mean concentration of 0.0198 mg/L. The WHO guideline for zinc in drinking water is 5 mg/L, set mainly to prevent taste issues. The zinc levels in these samples were also within the permissible limit, suggesting that the water is safe and free from any adverse taste effects due to zinc (Khan *et al*., 2023). The slight positive skewness (0.451) indicates a mild right skewness in the distribution, implying that some samples had slightly higher zinc concentrations. The negative kurtosis value (-0.536) suggests a flatter distribution compared to a normal distribution (Table 5).

Elemental residue inflows showed varied concentrations downstream during both the wet and dry seasons. Cadmium was also tested but its concentration was at zero in all the samples. Concentrations along the wetlands is that, there was increase in elemental inflows as we moved from upstream to downstream of the two wetland ecosystems. At the midstream level, there was significant increase in elemental residue levels as compared to the upstream and downstream sampling points. This is attributed to intensive agricultural practices along the midstream regions of the wetlands which subsequently contribute to inflow build up via surface runoffs. Trace amounts of some metal ions, such as zinc (Zn), copper (Cu), iron (Fe), magnesium (Mg) and manganese (Mn) are essential for metabolic processes in living organisms. However, excessive bioaccumulation in tissues may reach toxic levels posing health hazards to living organisms. All elemental inflows detected were below the recommended/permissible limits for drinking water, except for lead whose concentration across the seasons, surpassed the permissible residue limits of 0.05 mg/L and 0.015mg/L set by WHO and US EPA, respectively. Presence of copper (II) ions residues is associated to the application of copper-based fungicides used by farmers for crop protection where inflows get into wetland ecosystems through surface run-offs.

Cadmium concentrations in the wetland samples were consistently recorded at zero across all measurements. This constant value indicates either the absence of cadmium or that its concentration falls below the detection limit of the measurement method. Consequently, no variability in cadmium levels was observed within the sampled area.

Table 4: Summary statistics for elemental/heavy metals analysis

Descriptive Statistics

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Cd	12	0	0	0	.00	.000	.000	.000	.	.	.	.
Cu	12	.0080188679	.0000000000	.0080188679	.0028214535	.0007192830	.0024916693	.000	.487	.637	.005	1.232
Fe	12	.0626139818	.0000000000	.0626139818	.0246200608	.0067201895	.0232794192	.001	.446	.637	-1.219	1.232
Mg	12	.0041175370	.0000280741	.0041456111	.0018552311	.0004578867	.0015861662	.000	-.045	.637	-1.834	1.232
Mn	12	.0292117930	.0000000000	.0292117930	.0054753309	.0022542929	.0078090998	.000	2.953	.637	9.519	1.232
Zn	12	.0362362637	.0043131868	.0405494505	.0198466117	.0032768656	.0113513953	.000	.451	.637	-.536	1.232
Valid N (listwise)	12											

The descriptive statistics underscore the variability in elemental concentrations within the wetland ecosystem. While cadmium was consistently absent or below detection limits, copper, iron, magnesium, manganese, and zinc displayed varying degrees of concentration and distribution patterns (Table 4). These variations highlight the complex interplay of environmental factors and varied catchment land use practices influencing the presence and distribution of heavy metals in the wetland samples.

Assumptions and ANOVA analysis

Before interpreting the ANOVA results in this study, the following statistical assumptions were taken into account, Independence of observations where the sampling approach ensured that observations were independent, with data collected from distinct seasons, stations, and sampling levels without overlap or duplication. Normality of residuals, while this study did not explicitly assess the normality of residuals, the assumption of approximate normality is considered reasonable given the small sample sizes. However, for future research, it is recommended that normality be tested using the Shapiro-Wilk test or evaluated visually through Q-Q plots to enhance statistical rigor. Homogeneity of variances, the assumption of equal variances across groups

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue IV April 2025

was maintained throughout the analysis. Although Levene's Test was not conducted in this case, future studies should apply it to verify the assumption of homoscedasticity for more robust conclusions.

Table 5: ANOVA analysis for metals concentration by seasons

ANOVA						
		Sum of Squares	Df	Mean Square	F	Sig.
Cd	Between Groups	.000	1	.000	.	.
	Within Groups	.000	10	.000		
	Total	.000	11			
Cu	Between Groups	.000	1	.000	5.640	.039
	Within Groups	.000	10	.000		
	Total	.000	11			
Fe	Between Groups	.001	1	.001	2.999	.114
	Within Groups	.005	10	.000		
	Total	.006	11			
Mg	Between Groups	.000	1	.000	.495	.498
	Within Groups	.000	10	.000		
	Total	.000	11			
Mn	Between Groups	.000	1	.000	.608	.454
	Within Groups	.001	10	.000		
	Total	.001	11			
Zn	Between Groups	.000	1	.000	.132	.724
	Within Groups	.001	10	.000		
	Total	.001	11			

An ANOVA was conducted to examine whether metal concentrations (Cd, Cu, Fe, Mg, Mn, Zn) varied significantly across different seasons. Cadmium (Cd) analysis could not be performed due to insufficient data (Sum of Squares = 0). Copper (Cu) showd significant seasonal variation was observed ($F = 5.640$, $p = 0.039$), indicating that Cu concentrations differ significantly across seasons, possibly due to seasonal inflows or runoff. Iron (Fe), Magnesium (Mg), Manganese (Mn), and Zinc (Zn): No significant seasonal variation ($p > 0.05$), suggesting consistent levels across the seasons. In conclusion, only Cu showed significant seasonal variation. This suggests that seasonal factors (e.g., rainfall, agricultural runoff) may influence Cu concentrations.

Table 6: ANOVA analysis for Metal Concentrations by Sampling Stations

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
Cd	Between Groups	.000	1	.000	.	.
	Within Groups	.000	10	.000		
	Total	.000	11			
Cu	Between Groups	.000	1	.000	.747	.408
	Within Groups	.000	10	.000		
	Total	.000	11			
Fe	Between Groups	.000	1	.000	.212	.655
	Within Groups	.006	10	.001		
	Total	.006	11			
Mg	Between Groups	.000	1	.000	7.755	.019
	Within Groups	.000	10	.000		
	Total	.000	11			
Mn	Between Groups	.000	1	.000	1.894	.199
	Within Groups	.001	10	.000		
	Total	.001	11			
Zn	Between Groups	.000	1	.000	.130	.726
	Within Groups	.001	10	.000		
	Total	.001	11			

The same analysis was extended to sampling stations. Mg was significant variation was found across stations (F

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue IV April 2025

= 7.755, p = 0.019), indicating location-specific differences in Mg concentrations. All other metals (Cd, Cu, Fe, Mn, Zn) showed no significant variation (p > 0.05), with Cd analysis again not viable due to zero variability (table 6). In conclusion, Mg concentrations varied significantly by location, potentially due to differing geological or anthropogenic influences at sampling sites.

Table 7: ANOVA analysis for Metal Concentrations by Sampling Levels (Upstream, Midstream, Downstream)

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Cd	Between Groups	.000	2	.000	.	.
	Within Groups	.000	9	.000		
	Total	.000	11			
Cu	Between Groups	.000	2	.000	.045	.956
	Within Groups	.000	9	.000		
	Total	.000	11			
Fe	Between Groups	.000	2	.000	.372	.699
	Within Groups	.006	9	.001		
	Total	.006	11			
Mg	Between Groups	.000	2	.000	.180	.838
	Within Groups	.000	9	.000		
	Total	.000	11			
Mn	Between Groups	.000	2	.000	.709	.518
	Within Groups	.001	9	.000		
	Total	.001	11			
Zn	Between Groups	.000	2	.000	2.111	.177
	Within Groups	.001	9	.000		
	Total	.001	11			

ANOVA results revealed no significant differences in concentrations of all metals (Cu, Fe, Mg, Mn, Zn) across the different sampling levels. Cd could not be analyzed due to lack of data variability (table 7). In conclusion, metal concentrations are uniform across stream levels, indicating no strong gradient effect (e.g., from pollution sources or sedimentation).

Table 8: LSD Post-Hoc Tests for Sampling Levels

Multiple Comparisons

LSD

Dependent Variable	(I) Sampling level	(J) Sampling level	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Cu	Down-Stream	Mid-stream	.0004061845	.0019381604	.839	-.003978239	.0047906078
		Up-Stream	.0005634172	.0019381604	.778	-.003821006	.0049478405
	Mid-stream	Down-Stream	-.000406184	.0019381604	.839	-.004790608	.0039782389
		Up-Stream	.0001572327	.0019381604	.937	-.004227191	.0045416561
	Up-Stream	Down-Stream	-.000563417	.0019381604	.778	-.004947841	.0038210062
		Mid-stream	-.000157233	.0019381604	.937	-.004541656	.0042271906
Fe	Down-Stream	Mid-stream	-.013044580	.0174892238	.475	-.052607952	.0265187933
		Up-Stream	.0000506586	.0174892238	.998	-.039512714	.0396140314
	Mid-stream	Down-Stream	.0130445795	.0174892238	.475	-.026518793	.0526079524
		Up-Stream	.0130952381	.0174892238	.473	-.026468135	.0526586110
	Up-Stream	Down-Stream	-.000050659	.0174892238	.998	-.039614031	.0395127143
		Mid-stream	-.013095238	.0174892238	.473	-.052658611	.0264681348
Mg	Down-Stream	Mid-stream	-.000584877	.0012158204	.642	-.003335254	.0021654995
		Up-Stream	.0000865619	.0012158204	.945	-.002663815	.0028369388
	Mid-stream	Down-Stream	.0005848774	.0012158204	.642	-.002165500	.0033352543
		Up-Stream	.0006714393	.0012158204	.594	-.002078938	.0034218162
	Up-Stream	Down-Stream	-.000086562	.0012158204	.945	-.002836939	.0026638151
		Mid-stream	-.000671439	.0012158204	.594	-.003421816	.0020789377
Mn	Down-Stream	Mid-stream	-.004136582	.0056741471	.485	-.016972395	.0086992300
		Up-Stream	.0025571600	.0056741471	.663	-.010278652	.0153929725
	Mid-stream	Down-Stream	.0041365824	.0056741471	.485	-.008699230	.0169723948
		Up-Stream	.0066937425	.0056741471	.268	-.006142070	.0195295549
	Up-Stream	Down-Stream	-.002557160	.0056741471	.663	-.015392972	.0102786524
		Mid-stream	-.006693742	.0056741471	.268	-.019529555	.0061420699
Zn	Down-Stream	Mid-stream	-.010666209	.0073213291	.179	-.027228206	.0058957882
		Up-Stream	.0038530220	.0073213291	.611	-.012708975	.0204150190
	Mid-stream	Down-Stream	.0106662088	.0073213291	.179	-.005895788	.0272282058
		Up-Stream	.0145192308	.0073213291	.079	-.002042766	.0310812278
	Up-Stream	Down-Stream	-.003853022	.0073213291	.611	-.020415019	.0127089750
		Mid-stream	-.014519231	.0073213291	.079	-.031081228	.0020427662

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue IV April 2025

Post-hoc Least Significant Difference (LSD) tests were conducted for metals across sampling levels. The LSD results showed no significant differences for Cu, Fe, Mg, Mn, and Zn (table 8). This corroborates ANOVA findings, confirming the consistency in metal concentrations across upstream, midstream, and downstream levels.

The study identified statistically significant differences at the 0.05 level for: Cu concentrations across seasons, and Mg concentrations across sampling stations. For all other metals and factors, no significant differences were observed ($p > 0.05$), indicating a relatively uniform distribution across most temporal and spatial scales assessed. These findings partially support the hypothesis that inflows of nutrients and heavy metals vary due to environmental and land use differences, with Cu and Mg serving as sensitive indicators in this context. Further investigations with larger datasets and more robust statistical validations are recommended to capture subtle spatial-temporal variations.

The hypothesis tested was that there are significant differences in heavy metal concentrations based on season, sampling station, and sampling level, influenced by environmental and land use factor. The findings shows that Cu concentrations significantly varied across seasons ($p = 0.039$), indicating seasonal influences on metal inflows (e.g., rainfall-driven runoff). Mg concentrations significantly varied across sampling stations ($p = 0.019$), reflecting spatial heterogeneity likely influenced by land use or geological factors. Other metals (Fe, Mn, Zn) showed no significant differences across seasons, stations, or levels. Cd could not be reliably analyzed due to lack of variation in data.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

As for phosphate, the result indicated that the concentration was relatively higher during the wet season as compared to the dry season. It is hypothesized that the rates of phosphates imported from the agricultural regions to the wetlands are higher during the wet season because of the runoff. Differences within and between wetlands and at different sampling points revealed that land use practices such as the use of inorganic fertilizers impact the amounts of phosphates incoming. The nitrate figures remained high depicting a substantial contribution from the agricultural initiatives and also from other sources such as sewage and industrial releases. Thus, it can be concluded that there are numerous and continuous sources of nitrate pollution in the catchment area and, therefore, there were no considerable variations in nitrate concentrations by seasons or by sampling points.

Cadmium levels were generally below detection in all the samples, and this indicated few sources of cadmium pollution in the study area. Copper concentration was slightly higher during post-rainy season as compared to the rainy season and slightly different at different sampling points which may be due to localized sources such as agricultural use and probably slight industrial effluent discharge. Increased lead concentrations during the wet season imply that there is a direct inflow of lead via run-off from the urban areas and roads into the wetlands. Concentration of Manganese was higher during the wet season as compared to the dry season. Some high and low zinc concentration was observed with respect to some particular seasons as well as some particular geographical locations. This implies that the pollution of zinc may be due to run-off from agricultural/urban areas.

Generally, nutrient and elemental concentrations in Maragua and Mathioya wetlands showed no significant differences between the groups with regard to all the parameters measured. Such patterns imply that the major input of nutrients and heavy metals in the wetland ecosystems is farmland use, urban drainages, and probably industrial effluents.

Additionally, the future research should increase sample size and ensure variability in data to allow for more robust analysis (especially for Cd). Also conduct assumption checks and consider non-parametric tests (e.g., Kruskal-Wallis) if assumptions are violated. Lastly, investigate land use patterns or hydrological processes to understand the sources of Cu and Mg variations.

Conflict of interest

The authors of this study wish to confirm that they have no conflict of interest. The funding sponsors had no intervention in the study design and the choice to publish the results.

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ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue IV April 2025

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