



Station-Based, Monthly and Seasonal Variations in Heavy Metal Concentrations in Water from Awoye River, Ondo State, Nigeria

Emmanuel Rufus Aribio

Aribio-Haribo Environmental and Aqua Services Nig. Ltd, 103 Ogo Road Extension, Sapele, Delta State, Nigeria.

*Corresponding authors' email: ariboharibo90@gmail.com

ABSTRACT

The presence and potential toxicity of metals in surface waters represents an environmental concern. This study investigated the concentrations of metals in water samples obtained from three sampling stations (NNPC Platform, Stone Jetty and Awoye Gulf) in Awoye River, Ondo State, Nigeria, monthly between January and June 2015. The levels of nine trace metals (Fe, Zn, Mn, Cu, Ni, Cd, V, Cr and Pb) were determined by atomic absorption spectrophotometry. Significant differences in metal concentrations were reported between sampling stations for some metals. The highest mean concentrations of eight of the nine metals (Fe 9.08 ± 0.86 mg/L, Zn 5.88 ± 0.56 mg/L, Ni 3.74 ± 0.35 mg/L and V 4.11 ± 0.39 mg/L) were found at the NNPC Platform while that of Cu was highest at Awoye Gulf 1.46 ± 0.22 mg/L. For the eight metals with complete monthly records, concentrations were generally lowest numerically in March and highest in June, although statistically no significant differences were found among months according to the multiple-comparison results reported. Rainy-season concentrations were higher numerically than those of the dry season for all nine metals at the three sampling stations, while statistically significant seasonal differences were found only for Zn, V and Cr. These results characterize spatial, monthly and seasonal trends in the historical 2015 data set and constitute a baseline record against which future monitoring can be compared. The results should not be taken as representing present-day metal concentrations in Awoye River.

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INTRODUCTION

Heavy-metal contamination is also a significant environmental issue in surface-water systems because the metals can be bioaccumulated in aquatic organisms and pose harmful effects if they are present at high concentrations. Metals can not be degraded into harmless end products, but can be transported, transformed (between chemical states) or re-distributed between water, sediments and aquatic organisms. Other metals such as iron (Fe), zinc (Zn), copper (Cu) and manganese (Mn) have physiological roles at appropriate levels, but are toxic at higher levels. Metals like lead (Pb) and cadmium (Cd) on the other hand are lacking in any beneficial biological function and are linked to adverse effects at relatively low exposure levels (Ouma et al., 2022). Heavy metals are persistent, toxic and can be transferred among environmental compartments, so continued monitoring is important to gain a better understanding of the ecological health of aquatic systems and to determine if exposure is a concern (Idowu, 2022).

Heavy metals can be introduced to the surface waters naturally or anthropogenically. Geogenic inputs can be from the weathering and erosion of metal bearing geological materials and the deposition from the atmosphere; anthropogenic inputs can be from industrial and municipal effluents, agricultural runoff, waste disposal, mining and petroleum related activities (Idowu, 2022; Ouma et al., 2022). Coastal and estuarine areas could be especially vulnerable since they can receive pollutants carried from upstream catchments as well as pollutants produced by upstream settlements, industries, and other activities. In the Niger Delta area, petroleum exploitation occurs alongside other

anthropogenic activities that can introduce contaminants to riverine and coastal areas exist. Anyanwu et al. (2023) observed variations in heavy metals and petroleum hydrocarbons across the Niger Delta, with differences among seasons and sites. Similarly, Iwegbue et al. (2023) reported the occurrence of Pb, Cd, Cu, Zn, Fe and Mn in Bomadi Creek in the Niger Delta. The same applies to the coastal zones of Ondo State where petroleum-related activities, settlements, fishing and water transportation are sharing space with aquatic resources that the local communities depend on.

There can also be significant differences in heavy-metal levels between locations in the same aquatic system. These station to station variations may be due to variations in contaminant inputs, land use surrounding the station, proximity to discharge points, and local hydrodynamic processes that affect contaminant transport, mixing, and dilution. However, the results of recent studies on surface waters of Nigeria have shown that metal concentrations can differ among stations that are subjected to varying anthropogenic pressures (Jolaosho et al., 2025). Similar differences have been reported from aquatic ecosystems of the Southern part of Nigeria, and the need to consider individual sampling sites is emphasised. Nubi et al. (2022) for example, investigated 32 stations across Awoye and Abereke estuaries and adjoining coastal waters in southwestern Nigeria and reported spatial differences in heavy-metal distributions, including enrichment of Pb, Cr and Cu at some stations. The information that can be gained from a station-based assessment can thus be used to show local variation that might not be reflected in the information from observations collected from different, but environmentally similar, sites.

This is especially important in coastal systems where petroleum-related activities, boat operations, settlements and other possible sources of contamination are not evenly distributed.

Another useful aspect of the assessment of heavy metals concerns the temporal variability, since the concentration of heavy metals in surface waters can vary with changes in rainfall, runoff, river discharge and other hydrological conditions. A rise in precipitation could increase erosion and surface runoff, leading to greater amounts of metals being transported from land to water, and greater water volume may dilute some dissolved contaminants. On the other hand, during drier times, lower discharges can lead to lower dilution and higher levels of some metals. Therefore, the rainy season cannot be taken as having consistently higher metal concentrations as is the dry season. This variability is illustrated in the empirical studies in Nigeria. According to Anyanwu et al. (2023), there was significant site and seasonal variation in the levels of heavy metals in the Niger Delta, especially in the rainy season, while Iwegbue et al. (2023) found no clear seasonal pattern and no significant seasonal variation in the metal concentrations measured in Bomadi creek. Similarly, a recent study of Nigerian coastal waters showed that the seasonality response of individual metals varied in the same aquatic environment (Olowojuni et al., 2025). Hence month-to-month observations are useful as they help to capture intra-seasonal variations in rainfalls within the rainy and dry seasons.

Recent research studies in Nigeria also indicate that the concentration of the heavy metals and their time courses are also greatly different in aquatic environments. Idowu's (2022) review of heavy-metal research in Nigeria identified water as one of the major environmental matrices investigated and highlighted the continuing relevance of toxic-metal contamination in the country. Anyanwu et al. (2023) found significant variation between sites and seasons for the heavy metal concentrations in aquatic environment under petroleum related and other anthropogenic activities in the Niger Delta region. Similarly, Jolaosho et al. (2025) reported that there was significant spatial and seasonal variation in the physicochemical characteristics and concentrations of the heavy metals in the interconnected Nigerian coastal lagoons subjected to different anthropogenic disturbances. In southwestern Nigeria, Ololade et al. (2025) investigated Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn, among other trace metals, across six rivers and found varying distributions among the investigated river systems. Importantly, these studies do not show a single uniform seasonal pattern for all the waters of Nigeria. Instead, individual metals exhibit different behaviour depending on the local pollution sources, catchment characteristics and hydrological conditions. This heterogeneity suggests that contamination in a specific water body can only be understood by measuring the contamination at that site and not by assuming a pattern from a different water body.

The Awoye River flows through the coastal environment of Ilaje Local Government Area of Ondo State, Nigeria, where this river sustains many livelihood activities such as fishing

and transportation. The three sampling stations were chosen to reflect different local settings and potential anthropogenic influences in the river. The NNPC Platform represented an area influenced by petroleum activities, the Stone Jetty represented an area with mixed human activities, including boat operations, domestic waste disposal and agricultural and petroleum-related influences, while Awoye Gulf which is situated towards lower reach of the river, served as a reference station. Heavy metals have been studied in Awoye coastal environment previously. Nubi et al. (2022) studied the heavy metals in multiple stations within Awoye and Abereke estuaries and adjoining coastal waters while Olowojuni et al. (2025) investigated water and other environmental matrices in Awoye and Idi-ogba and reported spatial and temporal variations of the heavy metals. However, the contribution of the present study does not lie in being the first study of heavy metals in Awoye environment. The January-June 2015 data set represents a historical six months record from three contrasting stations which allows the concentrations of heavy metals to be studied at station, monthly and seasonal levels. This adds to the temporally resolved record of heavy metal variability in Awoye River which can be compared to subsequent environmental monitoring.

A combination of station-based, monthly and seasonal assessments can therefore offer a more resolved characterisation of the variability of heavy-metals in a coastal river system. Comparisons at the station level show the relative differences in concentrations among sampling sites, comparisons of consecutive monthly observations show shorter-term fluctuations, and comparisons of concentrations within the seasons show the relative fluctuations within the broader hydrologic periods. Taken together these dimensions offer a better foundation for understanding variability than a summary based on a single time or place.

This study aims to characterise spatial, monthly and seasonal variations in selected trace-metal concentrations in Awoye River using water samples collected from January to June 2015.

MATERIALS AND METHODS

Description of the Study Area

This study was carried out in Awoye community of Ilaje Local Government Area of Ondo State, Nigeria. Awoye is a coastal community, and one of the major fishing terminals in Ilaje Local Government Area. It is an area of abundant surface waters, coastal forest and mangrove-swamp vegetation and fishing and water transportation are key livelihoods. The study area is in the tropical swamp-forest zone and has a rainy season for the most part from April to October, and a dry season for the most part from November to March. The annual rainfall is about 1500-2000 mm and temperature is 28.23-29.75 °C.

Sampling was conducted from January to June 2015. Accordingly, January to March constituted the dry-season sampling period represented in this study, while April to June constituted the rainy-season sampling period. The map of the study area indicating the location of Awoye River and the three sampling stations is presented in Figure 1.

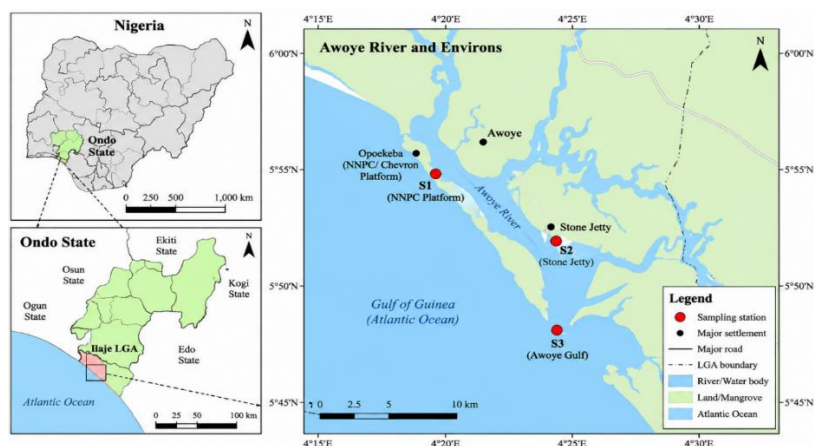


Figure 1: Map of the study area showing the sampling stations at Awoye River, Ondo State, Nigeria

Sampling Stations

Three sampling stations were selected to reflect contrasting local settings and potential anthropogenic inputs in Awoye River. Stations 1 and 2 were chosen due to their proximity to petroleum-related and other human activities, while Station 3, representing the lower reach of the river, was selected as a reference station for comparative analysis. The exact geographic coordinates could not be confirmed based on the available historical records and are, therefore, not provided as precise GPS coordinates in this study.

Station 1 (NNPC Platform) had petroleum-related industrial activities. The station was located near Chevron/NNPC Joint-venture platform at Opoekeba, where pipelines were also connected to several oil wells. Houseboats, industrial generators, helicopter landing site, oil pipelines and gas flaring were other activities and facilities in the area. Potential inputs to the aquatic environment were industrial wastes and waste oil, which were discharged directly, runoff and spilt accidentally.

Characteristics of Station 2 (Stone Jetty) included mixed agricultural, domestic and petroleum-related influences and relatively high human activity. The jetty was used as a mooring and loading and off-loading for outboard and inboard-engine boats. Potential inputs to the surrounding aquatic environment were waste oils, carbon deposits and domestic wastes.

The third station (Awoye Gulf) was at the lower end of the Awoye River where it narrows before flowing into the neighbouring Atlantic Ocean. The station was used as a reference station to compare with Station 1 and Station 2.

Water Sample Collection

Water samples were collected in triplicates from the three sampling stations for six months (January to June 2015). Samples were taken below the water level in 1-L plastic bottles and 250-mL oxygen bottles, and brought to the laboratory for further analysis. An exact numerical sampling depth and detailed preservation and storage conditions for the water samples were not available for retrospective reporting.

Determination of Heavy Metals in Water

The concentrations of iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), nickel (Ni), cadmium (Cd), vanadium (V), chromium (Cr) and lead (Pb) in the water samples were determined by atomic absorption spectrophotometry (AAS). The water samples received no further treatment or digestion before analysis and were aspirated directly into the AAS

flame. The instrument was standardised using stock standard solutions for the respective metals.

Three replicate samples were used to check the analytical precision. The standard deviations of less than 5% were obtained for the elements Zn, Cu and Pb, and less than 1% for Cd using the procedure described by Parker (1972). The AAS make and model, calibration-curve characteristics, method detection limits, water-sample blank results and recovery data were not available for retrospective reporting.

Experimental Design and Statistical Analysis

The water dataset was assessed based on sampling location, month and season with three replications of treatments. The sampling sites were NNPC Platform, Stone Jetty and Awoye Gulf. The sampling period was from January to June 2015, with January-March representing the dry-season sampling period and April-June being the rainy-season sampling period.

Heavy-metal concentrations were summarised as mean $\pm$ standard deviation (SD). One-way analysis of variance (ANOVA) was employed to assess the significance of the differences in the concentrations of the heavy metals between sampling stations and months. Where significant differences were detected, Duncan's Multiple Range Test was used for post-hoc mean separation. An unpaired t-test was used for comparing dry-season concentrations with rainy-season concentrations. The P value of < 0.05 was considered as the statistical significance. The 2012 SPSS for Windows version was used for data analysis.

The original statistical analysis did not explicitly account for repeated monthly measurements from the same sampling stations as repeated measures. As the original data set was unavailable for backward analysis, a repeated-measure or mixed-effect analysis could not be conducted. Temporal inference results were therefore cautiously interpreted in the current study, and numerical monthly and seasonal patterns were differentiated from statistically supported differences reported by the original analysis.

RESULTS AND DISCUSSION

Station-Based Variations in Heavy-Metal Concentrations

Station-based concentrations of heavy metals in Awoye River during the January–June 2015 sampling period were different among the three stations with statistical significance demonstrated for several of the metals (Table 1). Station 1 (NNPC Platform) recorded the highest mean concentrations of eight of the nine metals investigated: Fe (9.08 ± 0.86 mg/L), Zn (5.88 ± 0.56 mg/L), Mn (1.96 ± 0.18 mg/L), Ni

(3.74 ± 0.35 mg/L), Cd (0.87 ± 0.08 mg/L), V (4.11 ± 0.39 mg/L), Cr (1.62 ± 0.15 mg/L) and Pb (1.42 ± 0.13 mg/L). Cu was the exception, with the highest numerical concentration

recorded at Station 3 (1.46 ± 0.22 mg/L), followed by Station 2 (1.30 ± 0.18 mg/L) and Station 1 (0.89 ± 0.08 mg/L).

Table 1: Station-Based Concentrations of Heavy Metals in Water from Awoye River, January–June 2015

Metal	Station 1: NNPC Platform (mg/L)	Station 2: Stone Jetty (mg/L)	Station 3: Awoye Gulf (mg/L)
Fe	9.08 ± 0.86^a	1.78 ± 0.25^b	0.61 ± 0.09^c
Zn	5.88 ± 0.56^a	0.69 ± 0.09^b	0.77 ± 0.11^b
Mn	1.96 ± 0.18^a	0.34 ± 0.05^c	0.53 ± 0.08^b
Cu	0.89 ± 0.08^b	1.30 ± 0.18^a	1.46 ± 0.22^a
Ni	3.74 ± 0.35^a	1.95 ± 0.27^b	0.49 ± 0.07^c
Cd	0.87 ± 0.08^a	0.37 ± 0.05^b	0.11 ± 0.02^c
V	4.11 ± 0.39^a	0.29 ± 0.04^c	0.71 ± 0.11^b
Cr	1.62 ± 0.15^a	0.09 ± 0.01^b	0.19 ± 0.03^b
Pb	1.42 ± 0.13^a	1.14 ± 0.15^b	0.77 ± 0.11^c

Note: Values are mean $\pm$ SD (mg/L). Means within the same row bearing the same superscript letter are not significantly different ($P > 0.05$).

The Duncan groupings are further evidence of the spatial variation of metal concentrations. The concentrations of Fe, Mn, Ni, Cd, V and Pb were significantly different between the three stations. For Zn and Cr, Stations 2 and 3 were not significantly different from each other, but were significantly different from Station 1. Likewise, concentrations of copper were similar at Stations 2 and 3, but different from Station 1. Thus, the station-based differences were statistically supported for several metals rather than representing numerical differences alone.

The higher concentrations observed at Station 1 coincided with an area characterised by petroleum-related and other human activities around the NNPC Platform. Oil infrastructure, pipelines, boat-related activities, waste oil, accidental petroleum discharges and industrial generators were among the area's characteristics. These activities are possible routes for metals entering the aquatic environment. In this case, the observed spatial association does not imply source-specific causation, however, as source-apportionment analysis was not performed.

Similar spatial heterogeneity has been found elsewhere in the Niger Delta and Nigerian coastal environment. Anyanwu et al. (2023) identified heavy metals and petroleum hydrocarbons in the aquatic environment of the Niger Delta region and reported their spatial and temporal variations and correlations with the environmental site parameters and the seasons. Likewise, Jolaosho et al. (2025) found spatial variations in the abundance of the heavy metals in interconnected Nigerian coastal lagoons under different anthropogenic pressures. The results indicate that local environmental conditions and anthropogenic activities play an important role in metal distribution in aquatic systems.

The study by Olowojuni et al. (2025) on assessment of pollution levels of selected heavy metals (Pb, Cd, Cr, Fe, Zn, Cu, Ni and Co) in water and other environmental matrices of Awoye and Idi-Ogba in the coastal environment of Odo State is important. They reported spatial and seasonal variability in

the concentrations of these metals. These later results establish contemporary evidence that occurrence of heavy metals is still an environmental monitoring concern in the broader coastal environment of Awoye. An increase or decrease in the concentrations observed in the 2015 sampling campaign as compared to those reported by Olowojuni et al. (2025) cannot be concluded directly as the sampling periods are not directly comparable, with the same being true for the sampling locations and the analytical methods used. The overall study designs are also different.

The distribution of Cu was significantly different from the overall spatial distribution. The lowest concentration was at Station 1 and Station 3 had the highest numerical concentration. There was no difference between stations 2 and 3. This suggests that Cu distribution was influenced by other factors than the distribution of Fe, Zn, Mn, Ni, Cd, V, Cr and Pb. Differences in their sources, aqueous chemistry, particle affinity and interactions with local environmental conditions cause individual metals to exhibit different spatial behaviour. Similarly, spatial variations in metals have been reported in the Nigerian coastal waters, reflecting the sensitivity of individual metals to environmental conditions and anthropogenic activities (Jolaosho et al., 2025).

Monthly Variations in Heavy-Metal Concentrations

The monthly concentrations had a general temporal consistency for the eight metals with complete and internally consistent monthly records (Table 2). The numerical monthly means for Fe, Zn, Cu, Ni, Cd, V, Cr and Pb were the lowest during the month of March and the highest during the month of June. For example, Fe increased from 3.35 ± 4.15 mg/L in March to 4.29 ± 5.07 mg/L in June, while Pb increased from 0.93 ± 0.33 mg/L to 1.27 ± 0.35 mg/L over the same period. These differences are numerical temporal trends, and should not be interpreted as automatically statistically significant monthly differences.

Table 2: Monthly Concentrations of Selected Heavy Metals in Water from Awoye River, January–June 2015

Metal	January	February	March	April	May	June
Fe	3.54 ± 4.26 ^a	3.54 ± 4.26 ^a	3.35 ± 4.15 ^a	4.05 ± 4.84 ^a	4.18 ± 4.94 ^a	4.29 ± 5.07 ^a
Zn	2.26 ± 2.76 ^a	2.26 ± 2.76 ^a	2.14 ± 2.69 ^a	2.59 ± 3.13 ^a	2.61 ± 3.20 ^a	2.74 ± 3.28 ^a
Cu	1.11 ± 0.26 ^a	1.11 ± 0.26 ^a	1.01 ± 0.18 ^a	1.30 ± 0.33 ^a	1.36 ± 0.35 ^a	1.39 ± 0.36 ^a
Ni	1.89 ± 1.52 ^a	1.89 ± 1.52 ^a	1.78 ± 1.48 ^a	2.18 ± 1.71 ^a	2.27 ± 1.75 ^a	2.33 ± 1.80 ^a
Cd	0.42 ± 0.36 ^a	0.41 ± 0.36 ^a	0.39 ± 0.35 ^a	0.47 ± 0.41 ^a	0.49 ± 0.42 ^a	0.51 ± 0.43 ^a
V	1.57 ± 1.95 ^a	1.57 ± 1.95 ^a	1.49 ± 1.89 ^a	1.81 ± 2.20 ^a	1.86 ± 2.26 ^a	1.91 ± 2.32 ^a
Cr	0.58 ± 0.79 ^a	0.58 ± 0.79 ^a	0.56 ± 0.77 ^a	0.67 ± 0.91 ^a	0.69 ± 0.93 ^a	0.70 ± 0.95 ^a
Pb	1.02 ± 0.31 ^a	1.02 ± 0.31 ^a	0.93 ± 0.33 ^a	1.18 ± 0.33 ^a	1.23 ± 0.34 ^a	1.27 ± 0.35 ^a

Note: Values are mean ± SD (mg/L). Means within the same row bearing the same superscript letter are not significantly different ($P > 0.05$).

The common superscript letters across the eight complete series of data are because no statistical differences were reported in the multiple-comparison results for the numerical variations observed. Fe is a good example as it was lowest in March and highest in June, but no significant difference was reported between the months. The general trend towards June, therefore, should be viewed as a numerical trend and not as a pattern of statistically significant progressive accumulation towards June.

The verified Mn monthly results indicated that March had the lowest concentration (0.82 ± 0.81 mg/L) while June had the highest concentration (1.06 ± 0.97 mg/L). The observed increases in numbers with sampling months later in the year coincide with a shift from dry-season sampling months to rainy-season sampling months. Increased rainfall associated with the rainy season could contribute to increased metal transport via runoff to receiving waters, though increased volumes of water could also dilute dissolved contaminants. These factors were not measured in this study and hence cannot be identified as causes of the observed monthly pattern.

Temporal complexity is exemplified in recent Nigerian studies. Use of a water reserve to detect spatial and temporal variation in heavy metal concentrations was reported by Ayodeji et al. (2026) and some metals were found to be higher

in their concentration in the wet season samples in Esa-Odo Reservoir. Importantly, seasonal differences were metal-specific and were not statistically significant for all metals. In the same way, Anyanwu et al. (2023) showed significant spatio-temporal variations of heavy metals and petroleum hydrocarbons concentrations in Niger Delta aquatic ecosystems with metal variations being more significant in wet season.

The monthly pattern seen in Awoye River should thus not be considered as merely linear accumulation over time. Instead, it suggests that there were variations in time within the January to June 2015 sampling period, and that in most cases the numerical concentrations of the metals were lower in the earlier months of the sampling period and were higher towards the end months.

Seasonal Variations in Heavy-Metal Concentrations

At all three sampling stations, the mean concentrations of all nine metals were higher in the rainy-season samples than the dry-season samples (Table 3). Although this trend reflects a seasonal pattern in the descriptive data, it does not necessarily indicate that all nine metals show statistically significant seasonal differences. Statistically significant dry–rainy seasonal differences were reported for only three metals: Zn, V and Cr.

Table 3: Dry and Rainy-Season Concentrations of Heavy Metals in Water at the Three Sampling Stations of Awoye River, January–June 2015

Metal	Station 1 Dry	Station 1 Rainy	Station 2 Dry	Station 2 Rainy	Station 3 Dry	Station 3 Rainy
Fe	8.32 ± 0.18	9.84 ± 0.26	1.57 ± 0.10	1.99 ± 0.10	0.54 ± 0.04	0.69 ± 0.02
Zn	5.38 ± 0.12	6.37 ± 0.17	0.62 ± 0.04	0.78 ± 0.04	0.67 ± 0.05	0.86 ± 0.03
Mn	1.80 ± 0.04	2.12 ± 0.06	0.30 ± 0.02	0.38 ± 0.02	0.46 ± 0.03	0.59 ± 0.02
Cu	0.82 ± 0.02	0.97 ± 0.03	1.14 ± 0.07	1.45 ± 0.07	1.27 ± 0.10	1.65 ± 0.04
Ni	3.43 ± 0.08	4.05 ± 0.11	1.72 ± 0.10	2.18 ± 0.11	0.42 ± 0.03	0.55 ± 0.01
Cd	0.80 ± 0.02	0.95 ± 0.03	0.33 ± 0.02	0.41 ± 0.02	0.10 ± 0.01	0.12 ± 0.01
V	3.76 ± 0.08	4.46 ± 0.12	0.26 ± 0.02	0.33 ± 0.02	0.61 ± 0.05	0.80 ± 0.02
Cr	1.48 ± 0.03	1.76 ± 0.05	0.08 ± 0.01	0.09 ± 0.01	0.16 ± 0.01	0.21 ± 0.01
Pb	1.30 ± 0.03	1.54 ± 0.04	1.00 ± 0.06	1.27 ± 0.07	0.67 ± 0.05	0.87 ± 0.02

Note: Values are mean ± SD (mg/L). Station 1 = NNPC Platform; Station 2 = Stone Jetty; Station 3 = Awoye Gulf. Dry season period = January–March; rainy season period = April–June. Pairwise statistical superscripts are not presented because they were not available for these seasonal comparisons.

Seasonal increases were observed to be different for each metal at each station. At Station 1, Fe increased from 8.32 ± 0.18 mg/L during the dry season to 9.84 ± 0.26 mg/L during the rainy season, while V increased from 3.76 ± 0.08 to 4.46

± 0.12 mg/L. At Station 3, Cu increased from 1.27 ± 0.10 to 1.65 ± 0.04 mg/L. The examples cited illustrate the general enrichment during the rainy season but do not provide statistical significance for all metals.

The original statistical analysis reported a significant dry-rainy season difference for Zn with increased concentrations during the rainy-season sampling period. Significant seasonal differences were also reported for V and Cr. With Fe, Mn, Cu, Ni, Cd and Pb, there were numerically higher concentrations during the rainy season than in the dry season, but statistically significant seasonal differences were not reported. Due to limitations in the original statistical design described in the Materials and Methods, the above seasonal inferential results are treated with caution.

The seasonal pattern of the present study is comparable to reports in other Nigerian aquatic systems, although the statistical significance of seasonal variation varied among individual metals. Nda Amlabu et al. (2026), in a study in River Gwagwalada, Nigeria, reported significant seasonal differences for Co, Cr, Fe, Mn and Ni, whereas Cd and Zn did not differ significantly between the rainy and dry seasons. Likewise, Ayodeji et al. (2026) reported seasonal variation in heavy-metal concentrations in Esa-Odo Reservoir, with the significance of seasonality varying among metals. Anyanwu et al. (2023) also reported spatio-temporal variation in heavy metals and other contaminants in Niger Delta aquatic environments. These reports support the interpretation that seasonal variation in aquatic metal concentrations can be metal-specific rather than statistically uniform for all metals. Seasonal variations in metals in coastal waters have been shown by Olowojuni et al. (2025) at Awoye and Idi-Ogba. While these latter measurements should not be compared directly with the 2015 data, they confirm the overall conclusion that seasonality is a key factor in the behaviour of metals in the coastal environment of Ondo.

One possible explanation for this rainy season effect in the present study is rainfall associated runoff. Metals that are attached to soil particles, domestic wastes, agricultural materials and petroleum wastes can be carried into receiving waters by surface runoff. Higher flow and hydrodynamic disturbance can also resuspend particle-associated metals from the deposited material. On the other hand, higher water volumes can help to dilute dissolved contaminants. The concentrations observed are thus likely to be a result of interactions between contaminant inputs, runoff, hydrological transport, dilution and the environmental behaviour of contaminants. The relative contribution of these processes cannot be inferred from the present data as none of the sources were investigated by source apportionment analysis.

Environmental Implications of Heavy-Metal Distribution

Overall, the spatial, monthly and seasonal results show the occurrence of heavy-metals in Awoye River in 2015 was unevenly distributed. The main concentration hotspot was located at Station 1 with the exception of Cu which showed a different spatial distribution. In terms of monthly means, most metals with complete monthly data had their lowest numerical concentrations in March and highest numerical concentrations in June, although the reported multiple-comparison results indicated no statistically significant monthly differences in these eight complete series. All nine metals were numerically higher during the rainy-season sampling period than during the dry-season sampling period at all three stations, but statistically significant seasonal differences were reported for only Zn, V and Cr.

When compared to water quality benchmarks, the concentrations are also not insignificant to the environment, but the use of each water quality benchmark needs to be understood. The Guidelines for Drinking-water Quality by the World Health Organization (WHO) offer guidance on the management of drinking-water quality for protecting public

health, and should not be used as ecological classification criteria. The current guidelines are the fourth edition with first, second and third addenda (WHO 2026).

WHO drinking water guideline values for relevant contaminants are 0.003 mg/L for Cd, 0.05 mg/L for total Cr, 0.07 mg/L for Ni, 0.01 mg/L for Pb and 2 mg/L for Cu. At all three sampling stations, Cd, Cr, Ni and Pb were above their respective drinking-water guideline values when compared to these drinking-water benchmarks, while Cu was below its drinking-water guideline value at all stations.

This comparison is not a human health risk comparison and does not imply that untreated water from Awoye River was supplied or consumed as drinking water. It only reflects the relative concentrations measured to chemical benchmarks that are set for drinking-water purposes. Information on the pathways of exposure, rates of consumption, duration and frequency of exposure and other risk-assessment parameters that would be necessary to determine actual health risk was beyond the scope of the study.

Care should be taken when conducting direct comparison to aquatic-life criteria. The United States Environmental Protection Agency (USEPA) has established national recommended aquatic-life criteria for a few metals. However, several aquatic-life criteria are based on dissolved metal and some freshwater criteria are based on water hardness or other water-chemistry properties. These criteria are thus not directly applicable to the Awoye River measurements without evidence of analytical comparability and environmental comparability (USEPA, 2026). Furthermore, no metal-speciation analysis was performed, so it is recommended that Cr be reported as Cr and not as a specific oxidation state.

The spatial enrichment that is evident at Station 1 is environmentally significant as it suggests that aquatic organisms in different reaches of the river can be exposed to very different levels of the metals. The results of these studies by Olowojuni et al. (2025) which reported the presence of several metals in water from Awoye and Idi-Ogba further underscores the need for the ongoing monitoring of the Ondo coastal environment. Likewise, Jolaosho et al. (2025) showed that the levels of heavy metals were significantly different in interconnected coastal lagoons of Nigeria with varying anthropogenic disturbances. The combined findings of these studies provide a clear indication of the need to assess the contamination at the site instead of taking it for granted that all water sources in Nigeria are contaminated.

The results presented here are therefore only applicable to Awoye River during the sampling period (January-June 2015) and are not a reflection of its present state. The fact that heavy metals have been identified in the broader Awoye/Ondo coastal area means that environmental monitoring remains pertinent and relevant but does not necessarily suggest any rise or fall in concentration compared to 2015. To determine temporal change would need a modern monitoring programme with the same sampling sites, sampling times and testing methods.

CONCLUSION

The study found spatial differences in heavy-metal concentrations in Awoye River during the January-June 2015 sampling campaign. For eight of the nine metals analyzed, numerical concentrations were highest at Station 1 (NNPC Platform); for Cu, a contrasting spatial pattern was seen, with numerical concentrations highest at Station 3 (Awoye Gulf). Statistically significant differences among all three stations were reported for Fe, Mn, Ni, Cd, V and Pb. For Zn and Cr, Station 1 differed significantly from Stations 2 and 3, but Stations 2 and 3 were not significantly different from each

other. For Cu, Station 1 differed significantly from Stations 2 and 3, but Stations 2 and 3 were statistically similar. The relatively high concentrations of several metals at Station 1 coincided with an area subject to petroleum-related and other human activities, but the study did not identify the sources of the measured metals; the observed spatial pattern should not be interpreted as evidence of source-specific causation.

Temporal patterns were also observed during the six-month sampling period. For the eight metals for which complete monthly data were available, numerical concentrations were generally seen to be lowest in March and highest in June; however, the multiple-comparison results reported in the study did not show statistically significant differences among months. At all three stations, the concentrations of all nine metals were numerically higher during the rainy-season sampling period than during the dry-season sampling period. The original statistical analysis reported significant seasonal differences only for Zn, V and Cr. Thus, the higher rainy-season concentrations seen for the other metals should be interpreted as numerical, rather than statistically significant, seasonal differences.

These findings represent conditions seen during the January-June 2015 sampling campaign, and should not be taken as representing the present condition of Awoye River. Contemporary monitoring is therefore recommended to assess current heavy-metal concentrations and determine whether the spatial and seasonal patterns seen in 2015 have persisted or changed; future monitoring should preferably encompass a complete annual cycle and use comparable sampling locations and well-documented sample preservation, analytical quality-control procedures and detection limits to allow reliable long-term comparisons.

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