iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** IX **Month of publication:** September 2021

DOI: https://doi.org/10.22214/ijraset.2021.38095

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue IX Sep 2021- Available at www.ijraset.com

Spatial and Seasonal Distribution of Heavy Metal Pollution in Tropical Lagoon off the Gulf Of Guinea

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Abstract: ***The consistency of the aquatic environment at any point reflects basin lithology, anthropogenic input and climatic conditions. Spatial and seasonal distribution of heavy metal pollution in tropical Lagoon off the Gulf of Guinea was investigated between November, 2018 to October, 2019. Water samples were collected bi-monthly for heavy metal analysis and physicochemical parameters were measured in-situ every month. Results for physicochemical parameters were presumed to be ideal for marine life for both seasons as prescribed by the Federal Ministry of Environment. Salinity showed a significant negative correlation with temperature and a significant positive correlation with electrical conductivity (EC) during wet season. During the dry season, temperature showed a significant positive correlation with pH. As the temperature rises, molecular vibrations increase which results in the ability of water to ionize and form hydrogen ions and resulted into pH drop. The trend of heavy metal concentrations in the entire study area during the wet and dry season were in the order: Pb>Cu>Zn=Cr>Cd and Cu>Cr>Zn=Cd>Pb respectively. Nemerow's Pollution Index (NPI) and Contamination Index (CI) were further used to evaluate pollution status of each metal in each sample station and contamination status of the entire sample stations respectively. The CI of the study area showed a decreasing order: Apapa > Iddo > Makoko > Ibeshe > Egbin and Ibeshe > Makoko > Iddo > Apapa > Egbin for wet and dry seasons respectively.***

Keyword: tropical Lagoon, Gulf of Guinea, Physicochemical, heavy metal, Nemerow's Pollution Index, Contamination Index

I. INTRODUCTION

Estuary ecosystems play a significant role in the global economy and biodiversity of the region and function as a transitional zone between land and sea (Kaniz et al., 2014). Due to continuous variation in the physiochemical and hydrological characteristics, the brackish conditions of the Lagoon environment vary greatly from those of the freshwater environment, but generally, the consistency of the aquatic environment at any point reflects basin lithology, anthropogenic input and climatic conditions (Opadokun et al., 2015). Water quality is regarded as an important aspect in determining the health and status of the marine environment. This means that water quality is determined by natural processes such as weathering and soil disintegration, as well as human inputs such as urban and industrial wastewater discharge. Although surface overflow is a seasonal phenomenon that is heavily controlled by the atmosphere inside the basin, human effluents are a persistent polluting source. (Singh et al., 2004; Naik et al., 2020). Heavy metal pollution in the marine environment has become a global issue due to enormous quantities of dangerous chemicals being dumped into it as a result of the world's fast population expansion and intensive household activities as well as expanding industrial and agricultural production (Sin et al., 2011; Su et al., 2013; Islam et al., 2015). The abundance of heavy metals in sediment, water and marine organisms is frequently augmented by the metals mobility, solubility and persistence, as well as the medium adsorption qualities (Kumar et al., 2013; Yao et al., 2014). They either persist or bio-accumulate in food chains in such medium, causing health concerns such as renal illness, liver illness, brain tumors, and skin disorders in individuals who ingest metal contaminated water or fish. (Obasohan et al., 2010; Nyantakyi et al., 2019). During their mobility, heavy metals concede the possibility to undergo abundant changes in their speciation due to destruction, precipitation, sorption, and complexation phenomena which influence their bioavailability and behavior (Nouri et al., 2011; Islam et al., 2015). Heavy metals are generally grouped as essential and non-essential metals (Ajani et al., 2021).

Essential metals like copper, zinc, cobalt, iron, and manganese occur naturally and are good for marine plants and biota at very low concentrations, while the non-essential metals, have no positive effect, and are considered hazardous even in low quantity. However, excessive use of essential metals has been linked to cellular and systemic disorders (Ahamad et al., 2012). Coastal waters are affected by inland activities. It is used as a trap for materials carried from the inland as a result of precipitation, flocculation and sedimentation or by reckless direct dumping of waste into the Lagoon (Adokoh et al., 2011). Other processes such as re-suspension of surface sediments, desorption of metals from particles and diffusion of metals from pore water sediment to the water column, mobilization of Fe and Mn in sediment reduction, low salinity sorption and high turbidity zones will also affect the actions of trace metals in the marine environment (Beltrame et al., 2009).

In Nigeria, over 85% of all industries are located in the Lagos area. Some of these industries release their toxic waste into adjacent storm drains and coastal waterways via drainage systems. Of particular note are wastes from sewage customs, sawmills, breweries and chemical facilities. Also important are gas turbines used for power generation which release waste heat into the Lagos lagoon (Nwankwo et al., 2014). The Lagos Lagoon in Nigeria is a major repository for state-generated waste and is also especially well known for its rich fish and shellfish resources. Several studies have recorded the occurrence, biogeochemistry, origin, distribution and eco-toxicological impact of heavy metals in this natural ecosystem. (Oyewo 1998; Market and Freise 2000; Otitoloju 2000; Amaeze et al. 2012; Ajani et al., 2015; Popoola et al., 2015; Ajani et al., 2021). The objectives of this study were to evaluate the spatial and seasonal distributions of physicochemical parameters and heavy metals in Lagos Lagoon surface water. Compare their results with international quality guidelines. Pollution Index Assessment was also made from the results using Nemerow's pollution index (NPI) and Contamination index (CI).

II. MATERIALS AND METHODS

A. *Description of Study Area*

Lagos Lagoon is one of the largest Lagoon systems of the Gulf of Guinea. It is located in the eastern side of the Dahomey Basin, and is limited to the north by the Precambrian Basement Complex of southern Nigeria (Popoola et al., 2020). The Lagos Lagoon receives several important large rivers including Osun, Yewa, Ogun and Ona Rivers North of the lagoon. This lagoon empties directly into the Atlantic Ocean at Lagos Harbor. It lies between longitude 3° 10 ′ and 3° 4 ′ E and latitude 6° 5 ′ and6° 36 ′ N covering 208 km2 (Fig. 1).

B. *Sample Collection and Preservation*

A total of 60 samples of water were collected at five different sampling stations from November 2018 to October 2019. Water sample for heavy metals was taken bi-monthly and physicochemical parameters monthly. Water samples for wet season were collected from May, 2018 to October, 2018 and for dry season were collected from November, 2018 to April, 2019. Collection of water samples were done by Niskin water sampler from the surface of the Lagoon with the mouth pointing against the direction of flow of the River (Nyantakyi et al., 2019). To prevent sampling the surface micro-layer, the bottles were opened below the water's surface. The samples were then transferred into acid cleaned 1litre polypropylene bottles. Collected samples were preserved with 1 mL of ultrapure nitric acid to achieve a pH of ~1 corked, labelled, and were kept in an airtight ice chest loaded plastic (Cenci and Martin, 2004). This procedure was repeated at all five (5) sample stations. Replica samples were collected and preserved. A multi-parameter instrument (Horiba U 50) was used for in-situ measurement of temperature, salinity, DO, pH, total suspended solid (TSS), total dissolved solids (TDS), electrical conductivity (EC).

C. *Heavy Metals Determination*

Ajani et al., (2021) procedure was used for sample digestion. The water samples were first digested with concentrated HNO_3 before analysis of the heavy metals using Atomic Absorption Spectrophotometry (AAS). 25ml of water sample was measured into a 250 cm^3 beaker and 10 ml of concentrated HNO_3 was added. The solution was evaporated to near dryness in a beaker on a hot plate whose temperature was allowed to rise gradually until it reached a maximum temperature of 160ºC in a fume cupboard. The beaker with the content was allowed to cool at room temperature. The samples were then filtered through Whatman filter paper # 42 into a 50ml volumetric flask and made to the mark with distilled water. The solution was then transferred into another 60ml standard polythene flask before AAS analysis. Reagent blanks were prepared similarly. All solutions were analyzed for five heavy metals (Pb, Zn, Cu, Cr, Cd). All chemicals used were analytical grade reagents. Standard solutions of the studied metals were prepared from their respective salts and used for the calibration curve.

D. Pollution Index Assessment

A pollution index is a powerful tool for assessing water quality (Sudhakar et al., 2015). Nemerow's pollution index (NPI) and contamination index (CI) has been used by many researchers (Adamu et al., 2014: Yingran et al., 2017: Ramadan and Haruna, 2018, Ajani et al., 2015; Popoola et al., 2015) to evaluate pollution status of each metal in each sample station and contamination status of the entire sample stations respectively for surface water. In this research, pollution levels, specifically NPI for a single pollutant and CI have been used to evaluate different contamination levels across the study area.

To determine the magnitude contribution of each metal to the toxicity of the area, the Nemerow pollution index for a single pollutant (NPI) was applied. This single-factor pollution index can evaluate the pollution of single contamination and is used to establish water quality parameters.

$$NPI = \frac{Ci}{Si} \quad (1)$$

Ci (mg/l) is the measured concentration of heavy metals, and Si (mg/l) is the standard value of the pollutants.

The contamination index (CI) here has been used to identify the enrichment of heavy metals for the maximum admissible limit (MAL) standards (WHO, 2008).

$$CI = \frac{Pb/0.01 + Zn/3 + Cu/1 + Cr/0.05 + Cd/0.003}{5} \quad (2)$$

The numerator is the determined concentration of Pb, Zn, Cu, Cr and Cd at each sample station divided by the WHO (2008) for each metal; all summed up and then divided by the number of elements analyzed. Contamination index (CI) and NPI are categorized in Table 2.

E. Statistical Analysis

The information obtained from analytical methods was evaluated statistically using SPSS software version 20.0. Descriptive data analysis was performed including the calculation of mean, standard deviation, minimum and maximum. Pearson correlation matrix was carried out to identify relationships between heavy metals and physical parameters.

III. RESULTS AND DISCUSSIONS

The distribution of the physicochemical parameters along the study area is shown in figure 2. The mean temperature varied from 28.68 ± 0.44 ℃ (Apapa) to 30.36 ± 0.62 ℃ (Egbin) in the wet season and from 30.73 ± 0.53 °C (Apapa and Ibeshe) to 35.26 ± 1.94 °C (Egbin). The high-temperature value recorded at Egbin in both seasons could be due to heat energy from the power generating plant around this station. The temperatures of the study area are similar to other tropical regions following the Federal ministry of environment (FEPA, 1991; FMENV, 2001) effluent permissible limit of <40°C. In the dry season, solar radiation and clear sky enhance the atmospheric temperature whereas, in the wet season, rainfall and cloudy sky reduced the atmospheric temperature and consequently the water temperature fall to the minimum (Kaniz et al., 2014). This study corroborates with Alagoa and Aleleye-Wokoma (2012) who recorded high-temperature value during the dry season (29.4℃ – 30.22℃) to wet season (27.63℃ – 28.20℃) unlike Mansor *et al*,.(2012) who observed an increase in temperature during the wet season and the reverse in the dry season. The average pH of the study area ranged from 6.85 ± 0.30 (Egbin) to 7.37 ± 0.08 (Iddo) and from 5.91 ± 0.45 (Egbin) to 6.58 ± 0.57 (Iddo and Ibeshe) during wet and dry seasons respectively. Generally in this study, the pH varied from slightly acidic to slightly alkaline. The slightly acidic nature at Egbin station could be traced to the emission of carbon dioxide from the Egbin power plant which lowers the pH of the surrounding surface water (Sankpal et al., 2015) and also the decomposition of organic matter in the presence of dissolved oxygen increases the carbon dioxide content of water and lowers the pH. A lower pH value was also recorded by Oyeleke et al., (2019) from the same station (Egbin) among the stations studied. The change from acidic (dry season) to alkaline (wet season) in the study area could be due to the mixture of colloidal particles with seawater and become coagulated in the presence of dissolved oxygen which increases the carbon dioxide content of water and lowers the pH (Anila Kumary *et al.*, 2007). Contrary to our findings, higher pH values were recorded during the dry season than the wet season in Merbok Estuary, Kedah, Malaysia (Kaniz *et al.*, 2014). Water with a pH ranging from 6.0 to 9.0 is generally regarded as suitable for organism's growth and aquatic animals (FMENV, 2001). The result showed that pH values were within the permissible limit. The acid and alkaline death points are approximately pH 4 and pH 11 (Huq, 2002). Dissolved oxygen (DO) varied from 6.00 ± 0.44 mg/L (Ibeshe) to 8.19 ± 1.21 mg/L (Iddo) in wet season while in dry season it varied from 2.18 ± 0.52 mg/L (Makoko) to 3.87 ± 0.78 mg/L (Iddo). Higher values of DO were recorded in the wet season than in the dry season. This could be attributed to the influx of fresh water from the surrounding rivers, run-off from precipitation and wind-assisted surface mixing. Also, the relative lower level of DO in the dry season could be due to an increase in temperature of the study area and increase organic load during the season. Organic load encourages aerobic biodegradation, resulting in oxygen depletion (Akther *et al.*, 2012).

DO values (> 5 mg/L) in the wet season in all the sample stations support the proper survival of aquatic life and the use of water for domestic purposes (FMENV, 2001). Salinity ranges from 1.25±1.07 PSU (Egbin) to 14.17±1.88 PSU (Apapa) during the wet season and from 14.42±1.87 PSU (Egbin) to 31.13±3.83 PSU (Iddo) during the dry season. EC of the study area varied from 3.79 ± 1.71 mS/cm (ST5) to 25.78 ± 2.95 mS/cm (Apapa) during the wet season and from 23.15±2.97 mS/cm (Egbin) to 53.32 ± 7.99 mS/cm (Egbin). In this study, it was observed that the salinity and EC of the study area are inversely proportional to the distance from the sea. The sample stations closer to the sea recorded high salinity and EC value decreases as it moves farther away from the sea this is due to multiple inflows of the freshwater from tributaries. The higher value of salinity recorded in the dry season could be due to high temperature which led to evaporation and reduction of influx of freshwater most especially from rainfall. A high value of salinity and EC recorded at station 1 for both wet and dry season could be due to influx from the sea. TDS values varied from 3.65±1.89 mg/l (Egbin) to 7.49±3.22 mg/l (Apapa) and from 13.10 ± 5.96 mg/l (Apapa) to 19.70 ± 7.33 mg/l (Ibeshe) during the wet and dry season respectively. Water with total dissolved solids concentrations ranging from 0.1 to 20 mg/l is presumed to be ideal for marine life (Akther *et al*., 2018). TDS values were below the permissible limit for marine organisms in all the sample stations. Many species of marine organisms are harmed as TDS levels increase due to dissolved salts. The salts dehydrate the marine animals' skin/tissue which can be fatal. Higher TDS concentrations recorded during the dry season to wet season could be attributed to higher temperature experienced during this season, which aided the dissolution, ion exchange capability, desorption, and weathering processes. Furthermore, during the dry season, the water evaporated and ion concentrations increased. Islam *et al*., (2018) also recorded high TDS concentration during the dry season to wet season at coastal waters of Cox's Bazar, Bangladesh. The TDS result recorded in the study area were lower compared to surface water of Ayetoro community, Ilaje, South West Nigeria which recorded a range of 299 to 3056 mg/L (Nubi et al., 2019). TSS concentrations ranged between 14.90±3.40 mg/l (Egbin) and 83.14±20.00 mg/l (Ibeshe) also between 7.57±2.88 mg/l (Egbin) and 30.69±13.68 mg/l (Ibeshe) for wet and dry season respectively. TSS may enter the water body through surface runoff that is erosion by rainwater, upland soil erosion, and land sliding could be responsible for higher concentrations recorded in the wet season. Dan et al., 2014 also recorded a higher value of TSS during the wet season (17010 ± 580 ppm) to dry season (1208 ± 628 ppm) in Qua Iboe river estuary and adjoining creeks South-South Nigeria which corroborate with our findings.

A. Heavy Metals

The concentrations of heavy metals in the water sample concerning seasonality and special distribution is shown in figure 4. Pb contributed approximately 29% and 10% to the total heavy metals analyzed (fig. 5 & 6) and varied from 0.34 mg/l (Makoko) to 2.51 mg/l (Apapa) and from 0.03 mg/l (Makoko & Ibeshe) to 0.15 µg/l (Iddo) with an average of 0.87 ± 1.17 mg/l and 0.07 ± 0.06 mg/l for wet and dry season respectively. Zn contributed 16% and 15% to the total analyzed metal and ranged from 0.36 mg/l (Makoko) to 0.62 mg/l (Iddo) with a mean of 0.48 ± 0.22 mg/l during wet season and from 0.05 mg/l (Egbin) to 0.15 mg/l (Apapa & Iddo) and a mean of 0.11 ± 0.06 mg/l. Cu averaged 0.87 ± 0.74 mg/l, ranged from 0.35 mg/l (Egbin) to 1.84 µg/l (Ibeshe) during the wet season and in the dry season, it ranged from 0.04 mg/l (Egbin) to 0.63 µg/l (Ibeshe) with an average value of 0.30 ± 034 µg/l. Cu put up 29% and 42% to the total metal analyzed during wet and dry season respectively. Cr has a minimum concentration (0.28 mg/l & 0.10 mg/l) at Egbin and the maximum concentration (0.77 mg/l & 0.27 mg/l) with an average of 0.47 ± 0.37 mg/l and 0.13 ± 0.19 mg/l for wet and dry season respectively. Cd has a minimum concentration of 0.10 mg/l and 0.08 mg/l at Egbin for wet and dry season respectively. The maximum concentration of 0.27 mg/l and 0.13 mg/l was recorded at Makoko during the wet and dry season with their respective mean of 0.30 ± 0.27 mg/l and 0.10 ± 0.09 mg/l. The concentration of Pb, Cr and Cd in all the sample stations were above the maximum permissible limit (mg/l) of 0.01, 0.05, 0.003 respectively stipulated by WHO (2008). The values recorded in all sample stations for Zn and Cu were within the maximum admissible limit quoted by WHO (2008) except at Iddo (1.36 mg/l) and Ibeshe (1.84 mg/l), during the wet season. Similar observations were made at Ilaje coastal water, Ondo Nigeria where Cr (0.31-0.34 mg/l) Cd (0.08-0.21 mg/l) and Pb (0.57-0.79 mg/l) were higher than the permissible recommended limits (Olusola and Festus, 2015). High value of Pb (0.17 ± 0.23 mg/l), Cr (0.18 ± 0.02 mg/l), Cu (7.08 ± 0.40 mg/l) and Cd (0.26 ± 0.23 mg/l) were also recorded in Lagoon of Boughrara, Tunisia (Mensi et al., 2008). Higher concentrations of analyzed metals were observed in the study area during the wet season than the dry season. This finding corroborates with Abdul et al., (2019), Abiodun and Oyeleke (2016) who also recorded a higher concentration of the analyzed metal in the wet season than the dry season in the Lekki lagoon and Lagos lagoon respectively. The trend of heavy metals concentration in the entire study area during the wet season was in the order: Pb>Cu>Zn=Cr>Cd. In the dry season a dissimilar and relatively lower concentration was observed in the study area for the heavy metals Cu>Cr>Zn=Cd>Pb.

B. Pearson's Correlation Coefficient

The Pearson's correlation matrix of heavy metals and physicochemical parameters in surface water for wet and dry seasons are shown in Table 3 and 4 respectively. It was carried out to assess possible similar sources of the metals. Similar to Abdul et al (2019) study, none of the analyzed metals showed a significant correlation with other metals during both seasons. The insignificant correlations between the metals in the study area showed the diverse source of input. For physicochemical parameters during wet season salinity showed a significant negative correlation with temperature ($R= -0.971$, $p < 0.01$) and a significant positive correlation with EC ($R= 0.932$, $p<0.05$) and Cd ($R= 0.978$, $p< 0.01$). EC showed a significant positive correlation with Cd ($R=0.955$, $p<0.05$). TSS showed a significant positive correlation with Zn and Cr. During the dry season, Temperature showed a significant positive correlation with pH ($R= -0.952$, $p<0.05$). Temperature plays a significant role in pH measurements. As the temperature rises, molecular vibrations increase which results in the ability of water to ionize and form hydrogen ions and resulted into pH drop. Salinity showed a significant positive correlation EC ($R= 0.965$, $p < 0.01$) and Zn ($R= 0.951$, $p < 0.05$). EC showed a significant positive correlation Zn ($R= 0.998$, $p < 0.01$).

C. Nemerow's Pollution Index (NPI)

The level of metal pollution in water samples was assessed through the metal pollution index. NPI of the study area is shown in table 3. NPI values for Pb, Cr and Cd were greater than one in all the sample stations which implicated that the study area was polluted with these metals. Seaport activities with various effluents as well as ship discharge from the passing vessel and paints from homes around this station could be responsible for the high NPI value of Pb that was observed at Apapa during both seasons. Higher values recorded in the wet season could be aided by erosion from precipitation. NPI values recorded for Cu and Zn showed that study area were not polluted ($NPI < 1$) except for Cu at Iddo and Ibeshe during wet season. Ibeshe is one of the important coastal communities around the Ikorodu waterfront characterized by several years of sand wining using manual or mechanical dredging operations; artisanal fisheries and transportation (Adekunbi et al., 2018). The excavation of this sand among other activities in Ibeshe distribute the accumulated metals within the sediment into the water column during the process of dredging could have been attributed to high concentrations of Cu, Cr and Cd in this station. Discharge of sewage is another important source of coastal pollution worldwide. About 67 % of sewage from urban areas is discharged untreated into lakes, rivers and coastal waters, and yearly 5.9 trillion gallons of sewage is discharged into coastal waters by the sewage treatment facilities (Sharifuzzaman et al., 2016). Sewage discharge from various sources like textiles, livestock operations, soap and detergents, and from households are the major source of pollution in Iddo and could be responsible for the pollution status of the analyzed metals recorded in this station. CI of the study area is shown in figure 7 and it varied from 16.89 at Egbin to 87.67 at Apapa and from 6.74 at Egbin to 10.48 at Ibeshe during wet and dry season respectively. CI showed that the study area was contaminated in the wet and dry season in all the sample stations. Higher contamination was recorded in the wet season than in the dry season. The contamination status of the study area was not unconnected to the anthropogenic activities associated with each sample station along the study area such as sewage, cement bags washing, domestic and industrial wastes that took place within and around the Lagoon aided with precipitation. The contamination status of the study area would have a negative impact on water quality because heavy metals from water can be poisonous to marine organisms and can lead to a decrease in productivity of marine fisheries, marine culture, and biodiversity (Drira et al., 2017). The CI of the study area was observed in the decreasing order: Apapa > Iddo > Makoko > Ibeshe > Egbin and Ibeshe > Makoko > Iddo > Apapa > Egbin for wet and dry seasons respectively.

IV. CONCLUSION

Spatial and seasonal distributions of physicochemical parameters and heavy metals in the surface water of Lagos lagoon have been carried out. Among the parameters analyzed, higher value of temperature, salinity, EC and TDS were recorded during the dry season. Temperature and pH were within the permissible limit of FMENV except for DO which was above the permissible limit of FMENV during dry season across the sample stations. The results obtained for heavy metals showed high contents of Pb, Zn, Cu, Cr and Cd in the water column compared to the standard of WHO (2008) for the surface waters in the wet and dry seasons except for Zn in Ibeshe and Egbin during the dry season. The heavy metal levels recorded in this study, which exceeded the permissible limits (Pb, Cr and Cd), could alter the marine structure and functioning of this marine ecosystem. Moreover, this has resulted in the contamination ($CI > 5$) status of the study area during both seasons. The high contamination index of the study area could lead to serious human health risks caused by their potential bioaccumulation in some seafood especially during the wet season due to the enriched contamination index during the wet season compared to the dry season.

This study showed the need for an effective treatment and management measures for industrial effluents and other anthropogenic discharges into the study area to reduce the impact of heavy metal pollution.

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CAPTIONS

Figure 1: Map of the study area showing the sampling stations.
Figure 2a. Physicochemical parameters distribution along the study area during wet season.
Figure 2b. Physicochemical parameters distribution along the study area during wet season.
Figure 3a. Physicochemical parameters distribution along the study area during dry season.
Figure 3b. Physicochemical parameters distribution along the study area during dry season.
Figure 4. Heavy metal distribution along the study area.
Figure 5. Metals percentage contribution in dry season.
Figure 6. Metals percentage contribution in dry season.
Figure 7. Nemerow's Pollution Index and Contamination index along the study area.

Table 1. The GPS locations of the study area.
Table 2. Standard ratio of CI and NPI
Table 3. Nemerow's Pollution Index along the study area.
Table 4. Pearson correlation matrix for physicochemical parameters and heavy metals concentration during wet seasons
Table 5. Pearson correlation matrix for physicochemical parameters and heavy metals concentration during dry seasons.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
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Figure 1. Map of the study area.

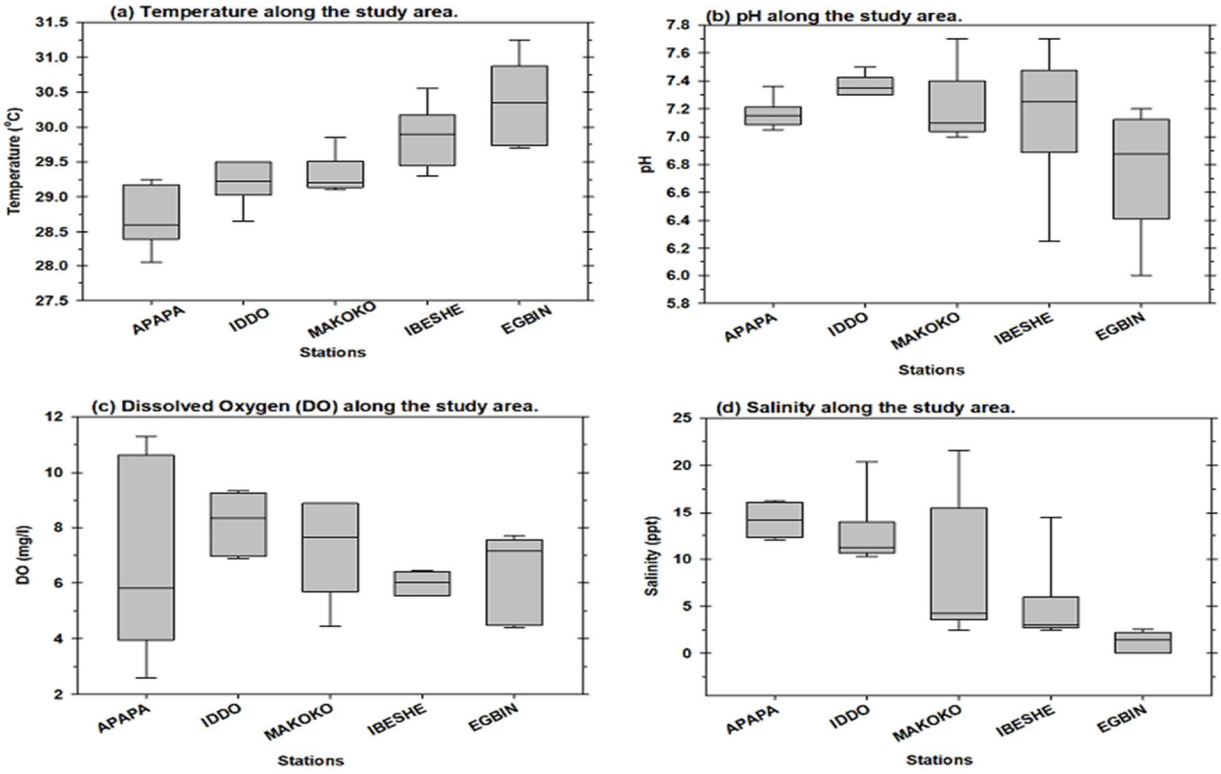

Figure 2a. Physicochemical parameters distribution along the study area during wet season.

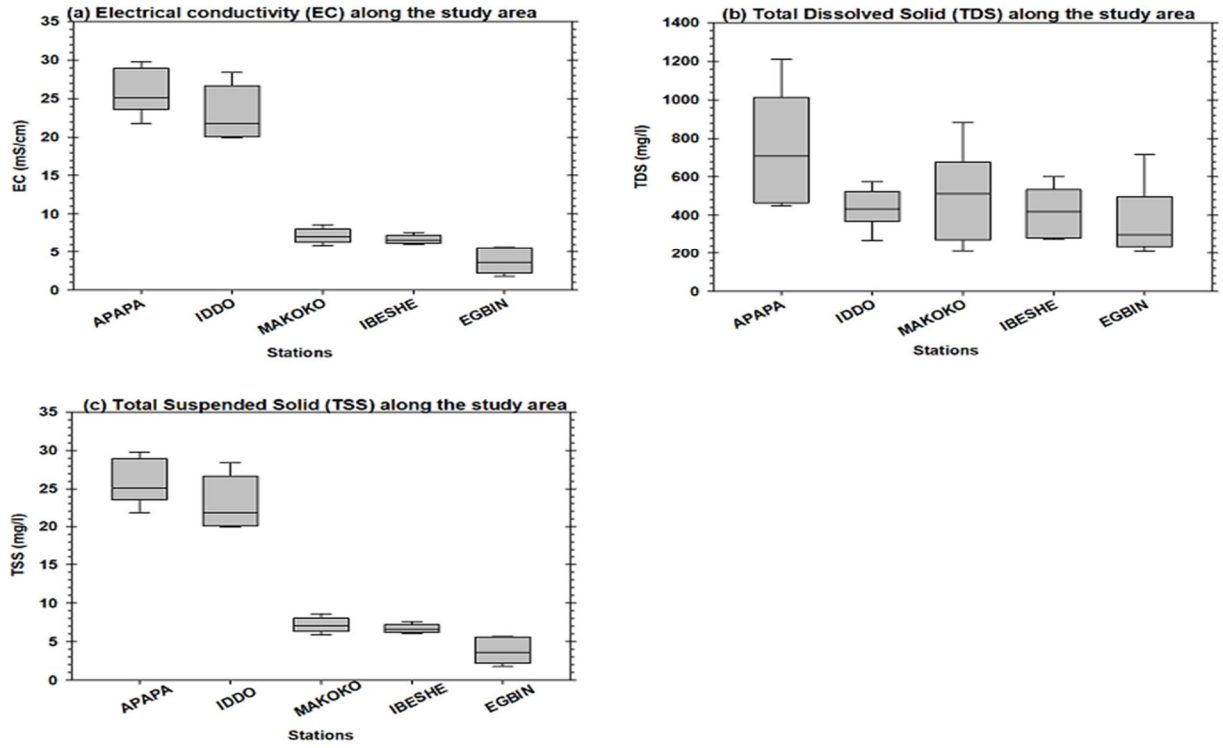

Figure 2b. Physicochemical parameters distribution along the study area during wet season.

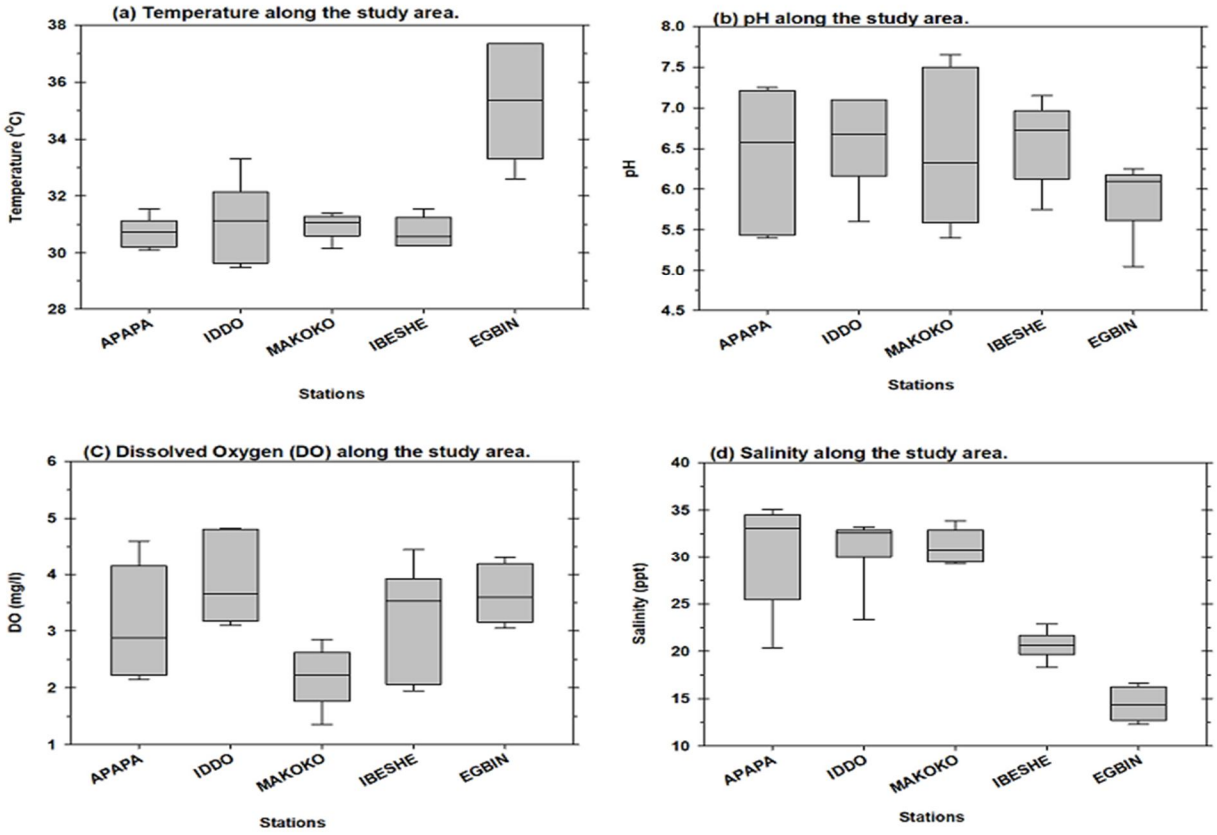

Figure 3a. Physicochemical parameters distribution along the study area during dry season.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue IX Sep 2021- Available at www.ijraset.com

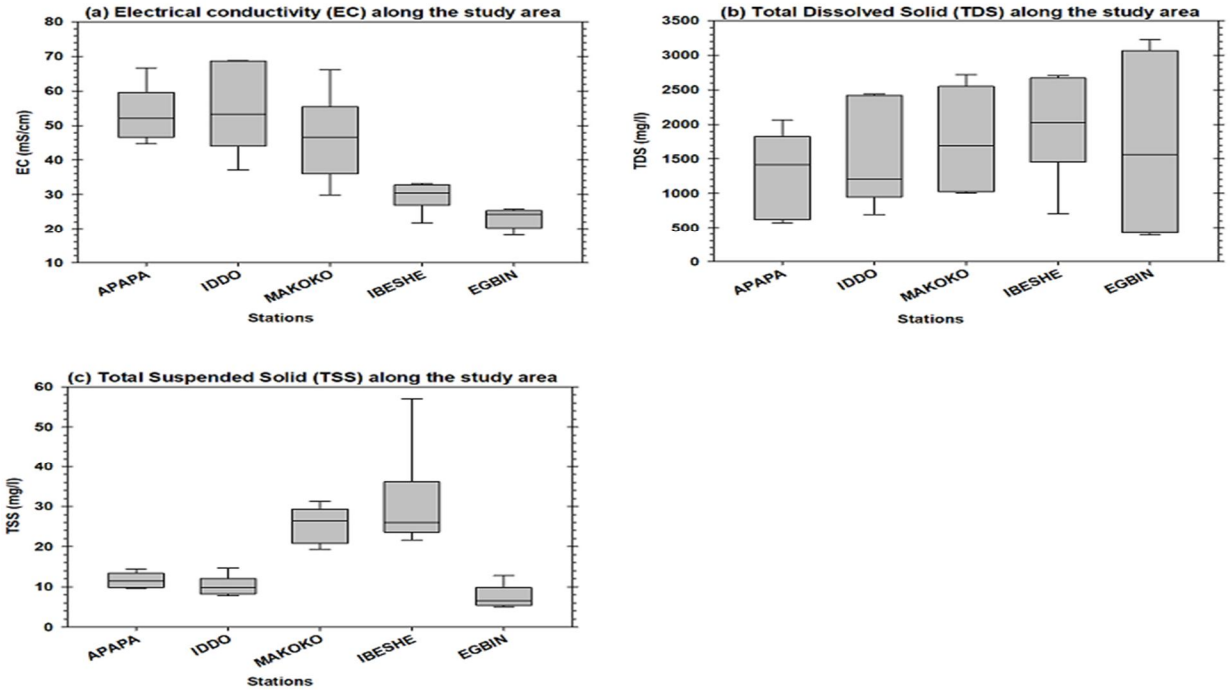

Figure 3b. Physicochemical parameters distribution along the study area during dry season.

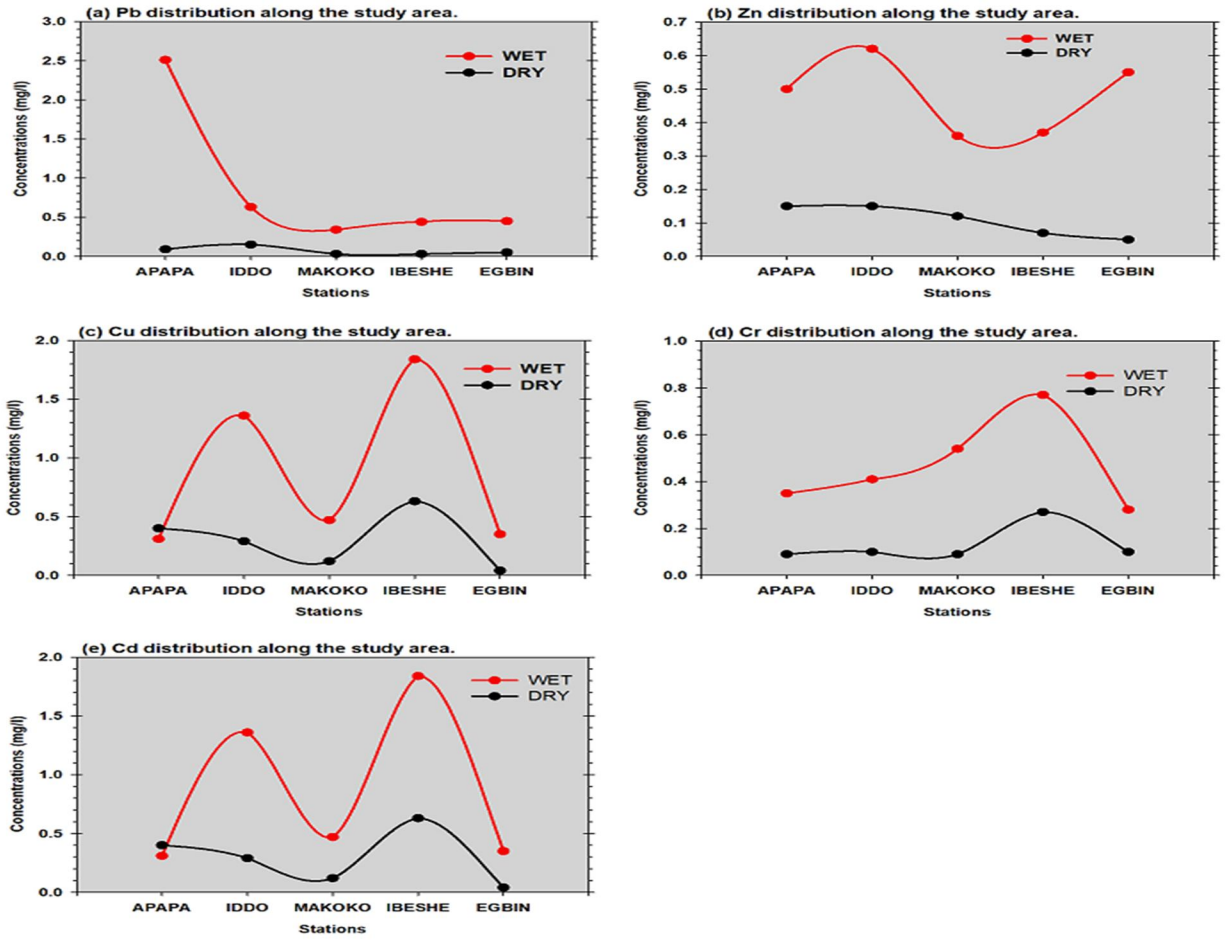

Figure 4. Heavy metal distribution along the study area.

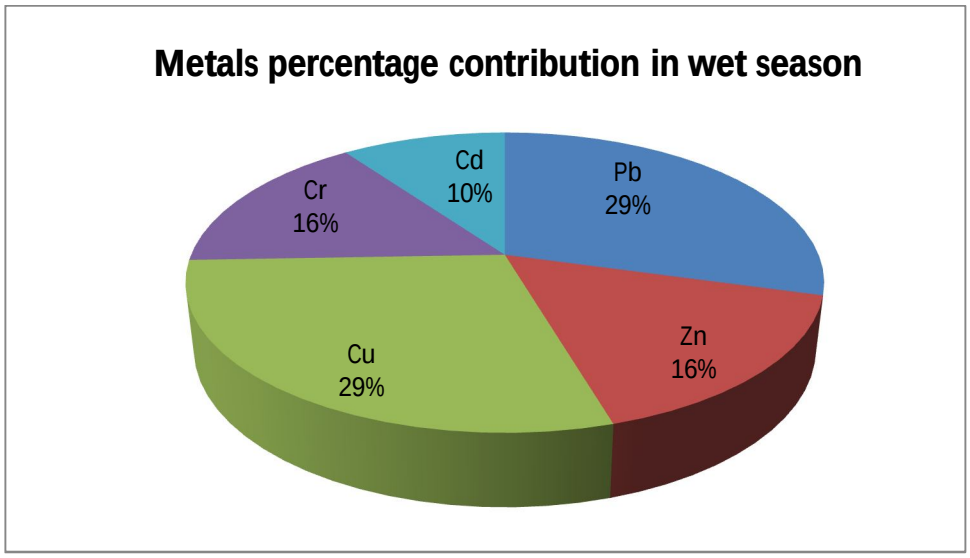

Figure 5. Metals percentage contribution in dry season.

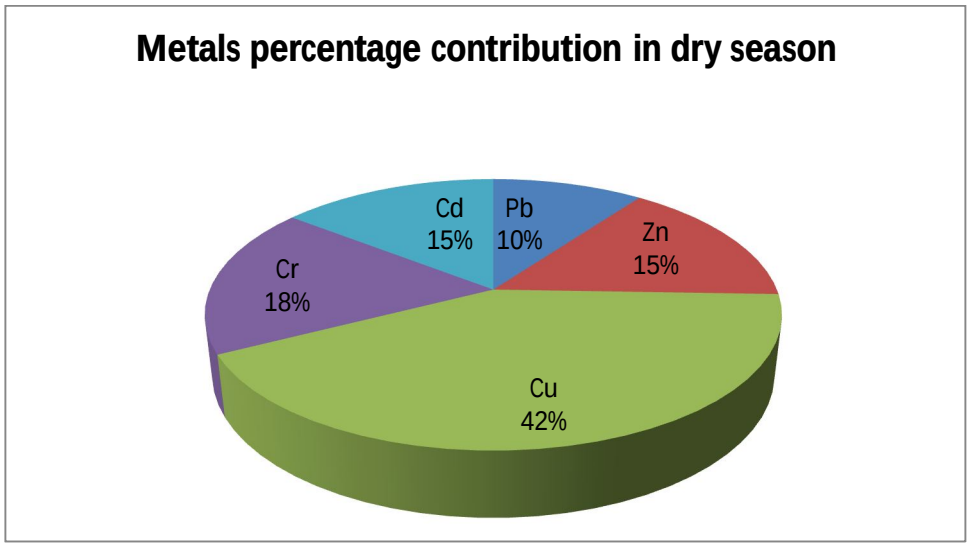

Figure 6. Metals percentage contribution in dry season.

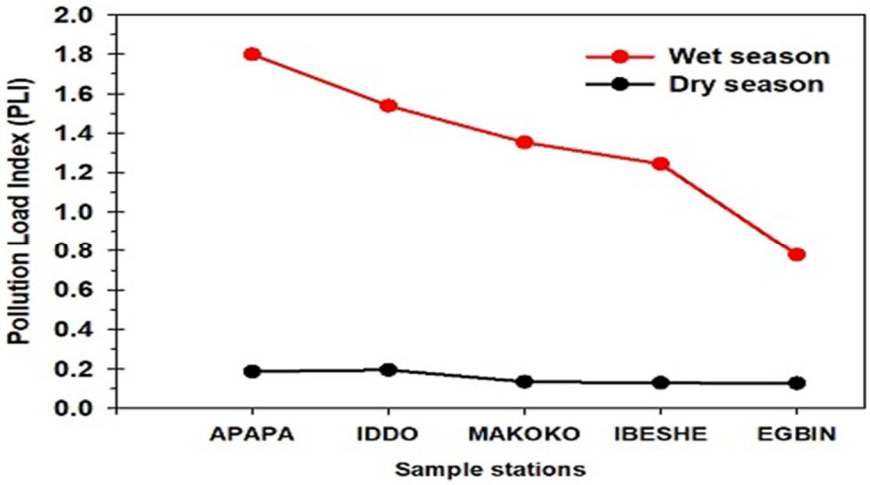

Figure 7. Contamination Index along the study area.

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Table 1. The GPS locations of the study area.

Stations	Name	Coordinates	Associated anthropogenic activities
1	Apapa	N06^0 27' 02.3" E003^0 23' 07.7"	Dredging, oil spillages.
2	Iddo	N06^0 28' 00.3" E003^0 23' 01.6"	Domestic sewage Discharges.
3	Makoko	N06^0 28' 54.0" E003^0 23' 06.4"	Sewage dump, Biodegradable organic matter.
4	Ibese	N06^0 34' 59.9" E003^0 28' 30.1"	Local dredging.
5	Egbin	N06^0 33' 24.9" E003^0 35' 51.3"	Thermal pollution.

Table 2. Standard ratio of CI and NPI (Ramadan and Haruna, 2018).

Contamination Index		Nemerow's Pollution Index	
CI < 1	Not contaminated	NPI < 1	Not polluted
1 ≤ CI ≤ 5	Slightly contaminated	NPI > 1	Polluted
CI > 5	Contaminated		

Table 3. Nemerow's Pollution Index along the study area.

	Wet season					Dry season				
	Pb	Zn	Cu	Cr	Cd	Pb	Zn	Cu	Cr	Cd
APAPA	251.00	0.17	0.31	7.00	180.00	9.00	0.05	0.40	1.80	30.00
IDDO	63.00	0.21	1.36	8.20	136.67	15.00	0.05	0.29	2.00	26.67
MAKOKO	34.00	0.12	0.47	10.80	90.00	3.00	0.04	0.12	1.80	43.33
IBESHE	44.00	0.12	1.84	15.40	53.33	3.00	0.02	0.63	5.40	43.33
EGBIN	45.00	0.18	0.35	5.60	33.33	5.00	0.02	0.04	2.00	26.67
Mean	87.40	0.16	0.87	9.40	98.67	7.00	0.04	0.30	2.60	34.00
SD	92.05	0.04	0.69	3.86	60.12	5.10	0.02	0.23	1.57	8.63

Table 4. Pearson correlation matrix for physicochemical parameters and heavy metals concentration during wet seasons

	Temp	**pH**	**DO**	**Sal**	**EC**	**TDS**	**TSS**	**Pb**	**Zn**	**Cu**	**Cr**	**Cd**
Temp	1	-0.726	-0.487	-.971**	-0.851	-0.851	0.146	-0.71	-0.064	0.164	0.113	-.960**
pH		1	0.643	0.775	0.606	0.3	0.208	0.119	-0.043	0.46	0.374	0.629
DO			1	0.615	0.536	0.03	-0.332	-0.063	0.521	-0.014	-0.307	0.513
Sal				1	.932*	0.748	-0.284	0.662	0.26	-0.062	-0.176	.978**
EC					1	0.693	-0.554	0.747	0.518	-0.043	-0.35	.955*
TDS						1	-0.192	.927*	-0.058	-0.433	-0.232	0.836
TSS							1	-0.458	-.935*	0.406	.895*	-0.406
Pb								1	0.199	-0.4	-0.398	0.794
Zn									1	-0.148	-0.762	0.318
Cu										1	0.75	-0.201
Cr											1	-0.313
Cd												1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

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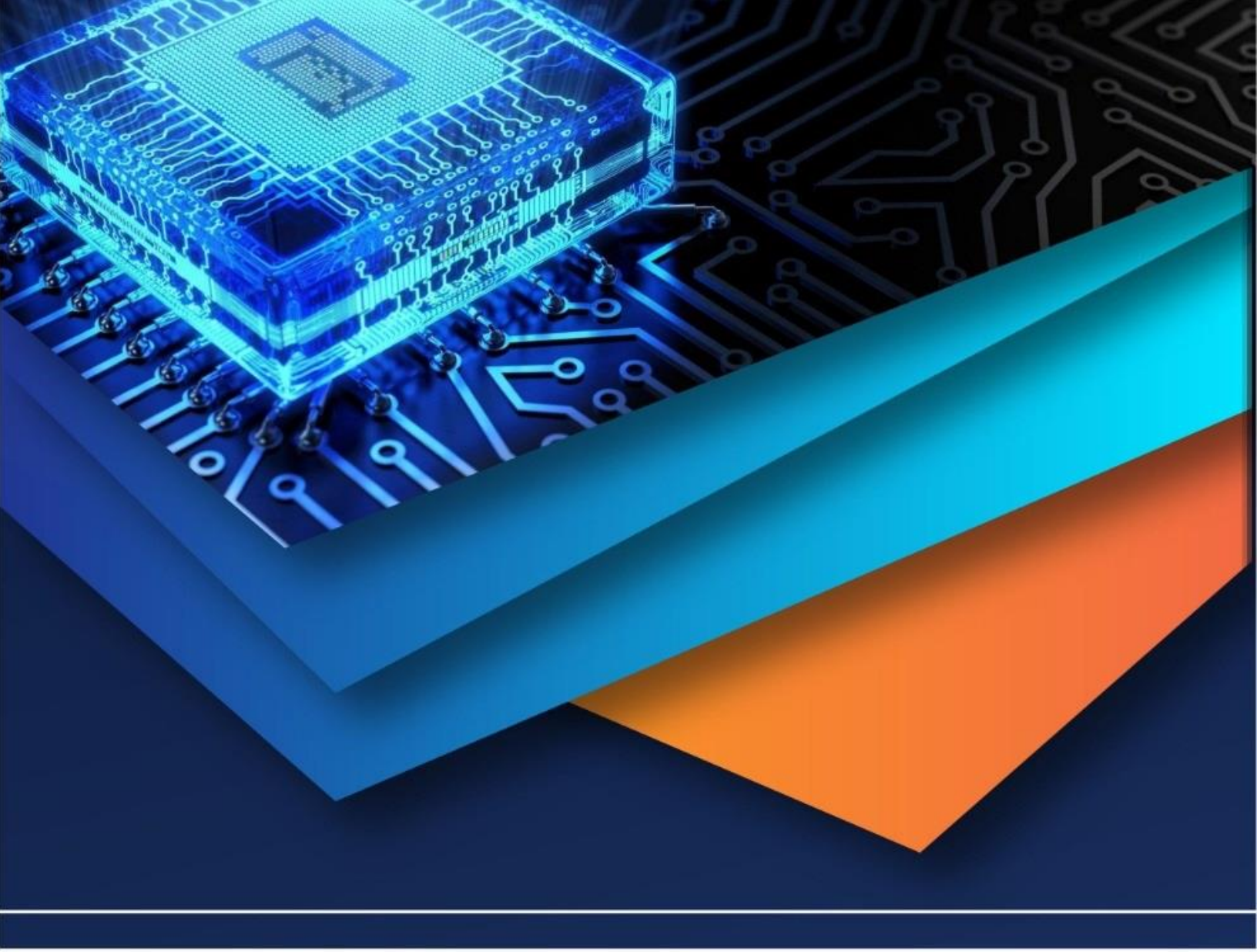
Table 5. Pearson correlation matrix for physicochemical parameters and heavy metals concentration during dry seasons.

	Temp	**pH**	**DO**	**Sal**	**EC**	**TDS**	**TSS**	**Pb**	**Zn**	**Cu**	**Cr**	**Cd**
Temp	1	-.952*	0.391	-0.784	-0.684	0.093	-0.543	-0.177	-0.676	-0.668	-0.252	-0.497
pH		1	-0.224	0.701	0.604	0.048	0.561	0.257	0.59	0.687	0.364	0.472
DO			1	-0.371	-0.153	-0.264	-0.629	0.627	-0.116	0.097	0.061	-0.769
Sal				1	.965**	-0.503	0.069	0.474	.951*	0.121	-0.392	0.103
EC					1	-0.692	-0.168	0.661	.998**	0.094	-0.49	-0.149
TDS						1	0.749	-0.723	-0.726	0.153	0.71	0.714
TSS							1	-0.641	-0.199	0.512	0.704	.979**
Pb								1	0.681	0.029	-0.413	-0.72
Zn									1	0.118	-0.485	-0.185
Cu										1	0.774	0.365
Cr											1	0.567
Cd												1

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).



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