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RESEARCH ARTICLE

Review of Spatial Variation in Physico-Chemical Properties of Rainwater in South-East and South-South Nigeria

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ABSTRACT

A review of spatial variations in physicochemical properties of rainwater in parts of Southeast and South-south, Nigeria. It was carried out using literature on similar topics. From the South-east, Imo, Enugu, and Ebonyi data were used, while Edo, Akwa-Ibom, and Delta were used for South-south. The study evaluated the spatial variations of rainwater properties mainly within wet seasons using temperature, pH, colour, turbidity, electrical conductivity, Total dissolved solids, Total suspended solids, sulphates, hardness nitrates, copper, sodium, magnesium iron, and lead as parameters used. Results showed that there was spatial variation in the physicochemical properties of rainwater in the study. The research concluded that the rainwater from both regions was acidic. South-east rainwater was more polluted than the south-south region due to higher concentrations of TSS, Sulphate, Nitrates, Turbidity, and lead. The physicochemical properties of rainwater were directly related to the prevailing air quality which determined the quality of rainwater. The study also observed that rainfall intensity, agriculture, industries, and other anthropogenic activities could have contributed to Rainwater quality variation. The study recommends that reduction in emission of greenhouse gases, use of scrubbing systems in industries, improved electricity from the national grid a well as employing the use of gas turbines by industries will go a long way in mitigating the impact of rainwater pollution.

Keywords: *Physico-chemical Properties; Separation Variation; Rainwater; South-Eastern*

Introduction

Rainfall is a major component of the hydrological cycle and contribute to freshwater deposits on Earth as well as provides good conditions for all types of ecosystems. It is essential for hydroelectric power generation and irrigation for better crop yield (Chidiebere, 2017). Rainfall is liquid water dropping from the atmosphere to the Earth's surface, ranging from 1–5mm in diameter. However, Alexander (2020), identified rainwater as one of the most important natural resources, because it is viewed as a key to prosperity and wealth. The type of rainfall produced reflects the circumstance in which it is formed. Rainfall is one of the most frequently discussed of all climatic variables in the tropics (Temitope, Ibrahim, and Alade, 2018). In many parts of the world, rainwater is considered a blessing, it saves life and is a common alternative source of water around the world that got huge attention. Although rainwater is safe, the chemical compositions at the point of collection are altered and are influenced by the local environment and atmospheric conditions; hence, different places might have different elemental concentration levels (Arif and Asiful, 2020).

Rainfall is an important driver for many hydrological processes and represents one of the main sources of uncertainty in studying hydrological response (Thorndahl, Finfalt, Williams, and Nelson, 2017). Surface water is usually naturally replenished by precipitation and is vitally important to everyday life. Surface water includes oceans, rivers, lakes, seas, reservoirs, or wetlands. Surface water collects on the surface of the earth and is maintained by rainfall or other precipitation and lost through the ground evaporation used by plants and animals (Tahmina, Leela, and Kelvin, 2018).

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The history of mankind shows that man had experienced one form of climatic variability or another. Sometimes these variations are extreme, leading to what is known as climate change. The case of Noah's flood and the famine of Joseph's days all in the Bible are a few cases of extreme climatic variability (Alexander, 2020). In a study of the Niger Delta region by Adejuwon (2018), he stated that the dry season and wet season contributed rainfall quantity of 1.34 to 4.05% and 95.5 to 98.66% respectively. Therefore, season is a determinant of the spatial variability of rainfall in a location. In another study of spatial variation of rainwater carried out in Ile –Ife and its environment from October 2012 to September 2013, the results showed that local land use activities had an influence on all the chemical parameters of rainwater in the area. The assessment of the change in rainwater chemistry and the determination of factors influencing atmospheric chemical alterations could be challenging (Aderonke, Bamikole, & Temi, 2017). The main purpose of this research is therefore, to evaluate for a better understanding of the spatial variations in physico-chemical properties of rainwater in some states in the South-east (SE) and South-south (SS) part of Nigeria.

Surface water is usually naturally replenished by precipitation and is vitally important to everyday life. The example is oceans, seas, lakes, rivers, reservoirs or wetlands. Surface water collects on the surface of the earth and is maintained by rainfall or other precipitation, and lost through the ground, evaporation, or used by plants and animals

Statement of the Problem

The type of rainfall produced reflects the circumstance in which it is formed. (Romeo, *et al.*, 2011). Assessment of the chemical composition of rainwater is highly dependent on the concentration of air pollutants and particulate matter in the atmosphere. This type of assessment helps in understanding the relative contribution of different sources of atmospheric pollutants (Bodor *et al*., 2020; Boga *et al*., 2019; Keresztesi *et al*., 2019b). Thus, the chemical composition of rainwater can serve as a tracer for air pollution (Zheng *et al*, 2020).

Aerosols particles have been identified as critical factors in ecosystem biogeochemistry and nutrient cycling, as well as cloud development processes. The chemical composition of rainwater shows that the local characteristics can be diminished or enhanced by the dominant air masses, loaded with various pollutants (Keresztesi *et al*., 2019). The assessment of precipitation chemistry is important to define the chemical composition and physical characteristics of the atmosphere. The concentrations of chemical species in rainwater are influenced by multiple factors, such as the type and distribution of aerosol sources, the transport of chemical species, and the scavenging processes (*Roy et al*., 2016).

The area of study has a high population, industrial activities, oil exploration, and refining as well as the commercial nerve centre of Nigeria. As a result, there is a need to evaluate atmospheric phenomena with a view to understanding the impacts of variations in physicochemical properties of rainwater in the southern part of Nigeria and to provide a solution to the pollution problem.

Aim and Objectives

The aim of this work is to evaluate the spatial variation in physico-chemical properties of rainwater in south-south and south-east of Nigeria. The objectives of the study are:

i. To identify the physico-chemical parameters of rainwater in the study area
ii. To determine the spatial variations in physico-chemical quality of rainwater in the study area
iii. To identify factors responsible for the variations in the physico-chemical qualities of rainwater in the area.

Hypotheses of the Study

The following hypotheses were identified to enable us to achieve the aim of the study:

1. Nitrates, Sulphates, Carbonates and methane are not some of the physico-chemical parameters in rainwater in the South-east and South-south part of Nigeria.
2. There is no spatial variations in the physico-chemical parameters of rainwater in the area

Review of Related Literature

Conceptual Review

In studying chemical properties of rainwater, the composition of rainwater reflects the composition of the atmosphere through which it falls. Menget *et al*, (2019), explained that rainwater has been confirmed to be polluted in most regions of the world due to numerous pollutants loads in the atmosphere. The characteristic or properties of rainwater depends on the atmospheric particulate or gaseous constituents produced locally or transported from distant sources by natural or anthropogenic sources. Owing to the effect of local sources, the chemical composition of rainwater varies by geographical locations (Rao, *et al*, 2016). The rainwater chemistry is influenced by a mixture of weather-controlled-sea sprays, agricultural activities, and industrial activities around the area (Mojeed *et al*, 2018). This was further explained by (Bodor *et al* and Keresztesi *et al*, 2019b), that the assessment of the chemical composition of rainwater is highly dependent by the concentration of air pollutants and particulate matter from the atmosphere, being an indicator of the air quality and helping to understand the relative contribution of different sources of atmospheric pollutants). Research in the chemical composition of rainwater is important to enable investigation on the atmospheric condition of a region and the concentration of the soluble components that contribute the rainwater chemistry (Siti *et al*, 2022).

In his contribution to spatial variation in physico-chemical properties of rainwater in Benin city, Godwin *et al.* (2019) stated that, there was spatial variation in rainwater quality in Benin City due to distant decay effect as one move from the core of the city to the periphery. This assertion also agrees with Onah *et al.* (2019), when he was studied different location in Enugu metropolis. In East Malaysia for instance, Siti, *et al*. (2022), stated that rainwater acidity was associated with the Mg^{+}, Na^{+}, and Cl^{-}, which signifies that these ions mostly originated from marine aerosols. However, SO_4^{2-}, NO^{3-} and NH_4^{+} are the secondary aerosols formed via the atmosphere's chemical reaction and mainly originated from anthropogenic activities. The alkaline ions such as Mg^{+}, Na^{+}, NH_4^{+} suggested, neutralized the acidity of rainwater.

On factors that cause rainwater variations in properties, increasing population and industrial growth is said to have impacts on air quality. As in West Kalimantan-India, besides the industrialization factor, the condition of peatlands is a contributor to air pollution due to fires in the dry season. Under highly polluted air conditions, the quality of rainwater normally gets affected, for example, increase in the heavy metal content, such as lead (Adi *et al,* 2019).

Theoritical Framework

Firstly, the theory of Precipitation proposed by Bergeron Findeisen around 1935, states that "Ice crystals high in the atmosphere grow by collecting water vapour molecules, which are sometimes supplied by microscopic evaporating cloud droplets." It provides a mechanism for growth of raindrops in ice/water cloud. Precipitation is the natural process of conversion of atmospheric vapour into water. The presence of dissolved ions also provides information on both local and long-range transported pollutants (Akpo, et al., 2015), and quantitative assessment of wet deposition enables identification of the various natural and anthropogenic source strengths, and their temporal and spatial variabilities (Tiwari, et al., 2015).

Secondly, the theory of solubility proposed by Charles Augustine Columbus in 1784. The theory states that "the force of attraction/repulsion between two charged bodies is directly proportional to the product of their charges and inversely proportional to the square of the distance between them". The factors that control the solubility or ions can be complex, for instance, the charges on the ions also affect the strength of the interaction with the water molecules. To explain further, Oduber et al. (2020), opined that in atmosphere, water droplets eventually coalesce causing it to become bigger and eventually drops a rain to the earth surface. In an ideal model, as a raindrop is falling, it could collide with all the particles contained in the swept volume constituted by a cylinder of radius equal to the raindrop radius and length equal to the distance travelled by the raindrop. They concluded that the RW amount and intensity of precipitation influence the composition of rainwater. The RW composition is also linked to the physical properties of raindrops. However, the theory backing this study is the first theoretical framework. This is due to some variables in the topic of the seminar

Methodology

The research design employed was review research method. The main purpose of this method was to collect data from previous literatures to gain information and insight in to the topic. The population of the study area was derived from six states, three each from South-East and South-South they are; Imo, Ebonyi, Enugu, Akwa-Ibom, Delta and Edo states. Sources of data were from secondary sources. The sources of such data included commentaries, articles, magazines, newspapers, academic journals, textbooks, text books, Internet and unpublished research work. International and National publications.

Using Taro Yamene equation (1968).

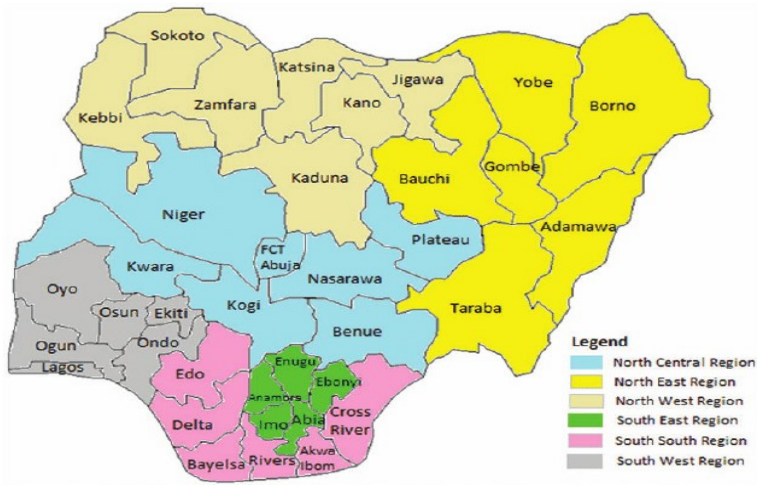
$n= N/1+N^{(e)2}$,

The population of South-East and South-South, totalling 48million people

by substitution, $n = 48,000,000/1+48,000,000*(0.05)^2$; 48,000,000/121,000

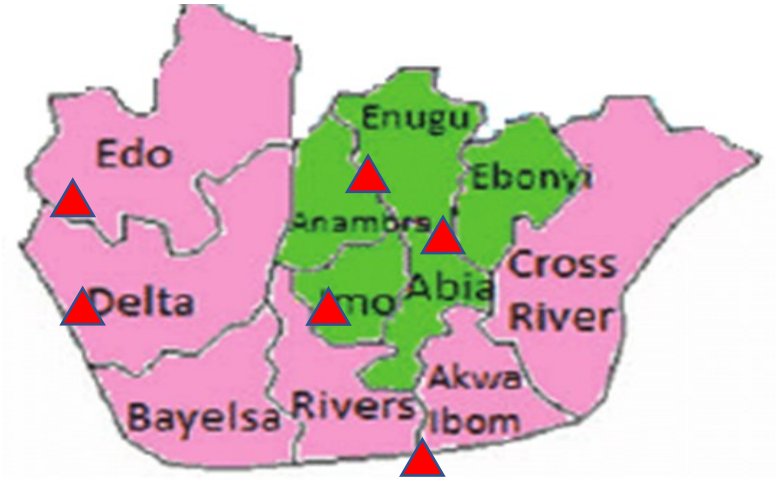
n=399.996, estimated population was 400 people

Figure 1: Map of Nigeria showing the six political zones



Source: NIMC (2015)

Figure 2: Map of South-east and South-south of Nigeria showing six selected study areas



Source: NIMC (2015)

Data Analysis

The data analyses technique used for this study is statistical, which involved use of tables, percentages, mean, range, variance, correlation, frequency, and graphs. Median was used to assess a possible linear association between two continuous variables, while bar charts provided a visual summary of the clustering process.

Data Presentation and Analyses

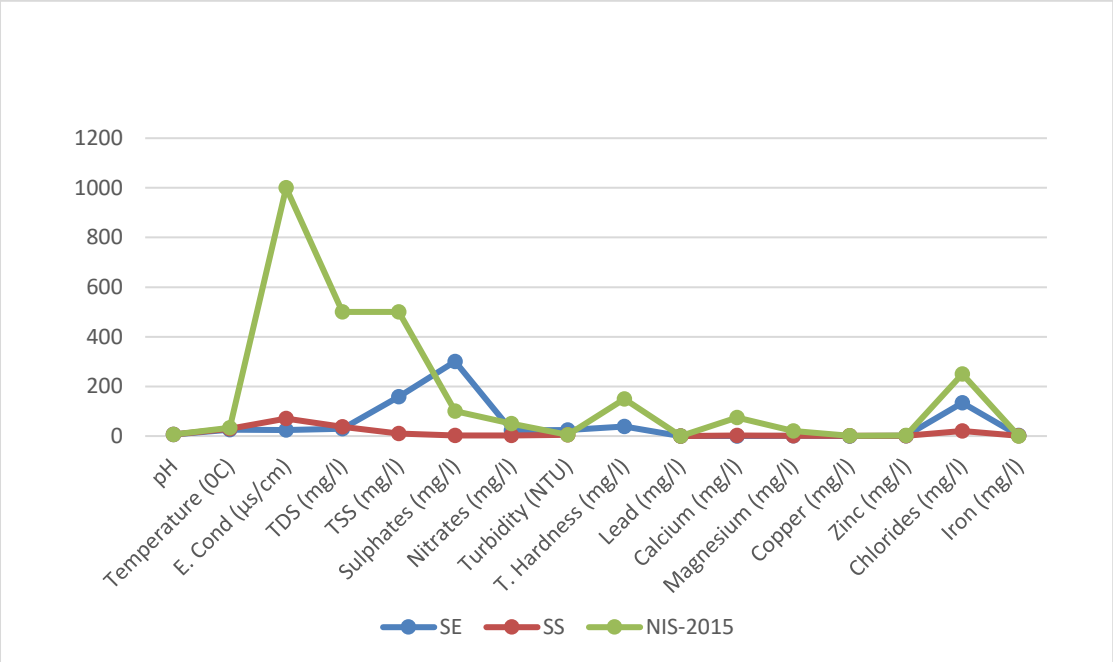
Data Presentation

Table 1: Showing Data from SE and SS regions on Physico-chemical Properties of Rainwater

Parameters	*South-East*	*South-South*	*WHO (mpl)*	*NIS-2015 (mpl)*
pH	5.98*	5.84*	6.5-8.5	6.5-8.5
Temperature (^{0}C)	25.95	29.26	Ambient	Ambient
E. Cond (µs/cm)	23.80	70.35	NS	1000
TDS (mg/l)	29.58	36.75	600	500
TSS (mg/l)	157.88	9.97	NS	500
Sulphates (mg/l)	300.40*	2.71	250.0	100.0
Nitrates (mg/l)	22.67	2.57	50.0	50.0
Turbidity (NTU)	23.92*	5.48*	5.0	5.0
T. Hardness (mg/l)	39.0		250.0	150.0
Lead (mg/l)	0.40*	0.04*	0.01	0.01
Calcium (mg/l)	0.23	2.58	100	75.0
Magnesium (mg/l)	0.60	0.86	50.0	20.0
Copper (mg/l)	0.12	0.54	2.0	1.0
Zinc (mg/l)	0.81	1.65	NS	3.0
Chlorides (mg/l)	134.20	20.63	250.0	250.0
Iron (mg/l)	2.20*	0.49*	0.30	0.30

(*) – Above WHO or NIS Standards
NS – Not Specified; Ambient – Temperature of the environment
Source; Field work, (2022)

Figure 3: Physico-chemical Properties of Rainwater in South-East and South-South



Source: Field survey (2022)

Data Analysis

The data in table 1 shows that the rainwater samples from these regions were acidic, with mean value of 5.91, then 5.98 for South-East and 5.84 for South-south when judged from the pH scale where, a pH of 7 is neutral while a pH above 7 is alkaline and below 7 is acidic. The acidic rainwater in these regions could be attributed to the industrial activities within the regions.

Nitrates-Emissions of sulphate and nitrates are attributed to be the main sources of rainwater acidity. High level of nitrates, 22.67mg/l for South-East and 2.57mg/l for South-south are observed (as shown in table 1 figure 3). Nitrates or oxides of nitrogen concentration level is attributed to industrial activities, fertilizer, agro-allied industries, other industries that generate power by burning fossil fuels and over population. Although the South-East had higher values of oxides of nitrogen, other pH neutralising ions could be responsible for this effect. For instance, Calcium, a pH stabiliser, has a neutralising effect on rainwater. The reason for lower NOx could be due frequent intensity of rainfall in South-south than in the South-East region. This could have caused dilution effect in the rainwater. The oxides of nitrogen (NOx) could be released from the gas flares, industrial power sources, burning of biomass and vehicular transportation. These sources of emission of oxides of nitrogen are in abundant in both South-East and South-south. To show the effect of wind effect on transportation of chemical substances through rainwater, Ayeki, *et al*, (2018), said that there was spatial variation in rainwater quality in Benin City due to distant decay effect as one move from the core of the city to the periphery. He concluded that wind trajectory could carry suspended particles far away from the source with higher concentration to other locations with lower concentrations of chemical pollutants. South-South had calcium value of 2.58mg/l, while South-East had 0.23mg/l, all below WHO and NIS Maximum Permissible limit (MPL) of 75.0mg/l.

Elect Cond -The electrical conductivity in the South-East was 23.80µs/cm and, in the South-South it was 70.35µs/cm. This water property depends on dissolved ions. For instance, there were high iron content in both regions; having 2.20mg/l for South-East and 0.49mg/l for South-south. However, the Total Dissolved Solids in South-East were 29.58mg/l as against 36.75mg/l in the South-south. The results showed that there was no correlation between Total Dissolved Solids and electrical conductivity in these regions. What could have been the reason? The answer could be attributed to dilution effects of rainfall which is more frequent and more intense in the South-south than in South-East. In addition, there are more cottage and medium industries as well as more cities in the South-East than in the South-south.

TSS -Total Suspended Solids, is directly proportional to particulate matter concentrations. South-East had the value of 157.88mg/l, while South-south had 9.97mg/l. High Total Suspended Solids could be an indication of higher commercial, industrial and construction activities. From the data, South-East had more of these activities. This also agrees with the assertion of Ebong *et al*, (2016), that particulate matters concentration in atmosphere influences the quality of harvested rainwater (HRW), which also agrees with Emerole (2015), who emphasized the impacts of population density on quality of rainwater in Orji community in Imo state. That high population goes with increase in commercial activities, vehicular movement and burning of fossil fuels for electricity generation.

Turbidity -The value for turbidity in South-East was 23.92NTU, while 5.48NTU was for South-south. The two regions had their turbidity above WHO and NIS MPL of 5.0NTU. This was an indication of high industrial, agricultural and construction activities. High iron (Fe^{3+}) content as reported could have affected the rainwater clarity. Sulphates- The values were 300.40mg/l in South-East and 2.71mg/l from South-south regions. The sulphate is emitted from biomass, coal and petroleum products combustion. The value for South-East was above both WHO and NIS MPL. It could be attributed to heavy industrial activities within the region, and less rainfall intensity. Lead is a major component of antiknock ingredients in petrol, usually added to improve quality (petrol pump price). South-East and South-south had the values of 0.40mg/l and 0.04mg/l respectively. These values were all above WHO and NIS MPL of 0.01mg/l. This could be attributed to flaring, transportation and combustion of petroleum products. These activities were common in the two regions due to industrial presence as well as activities of oil companies and refineries.

For the heavy metals, calcium from South-East and South-south were 0.23mg/l and 2.58mg/l respectively, which were within WHO and NIS MPL. For Magnesium ions, 0.6mg/l for South-East and 0.86mg/l for South-south. Calcium and magnesium ions are both soluble in rainwater and they constitute hardness of rainwater. However, the result indicated the water from South-East and South-south are soft. Iron levels were higher than WHO and NIS MPL in both regions. South-East and South-south were having 2.20mg/l and 0.49mg/l respectively. Sources of iron in

rainwater could have been through crustal source, marine rain, quarrying and construction activities. It impacts colour, smell and taste. These characteristics are noticed in plumbing pipe build-ups. Generally, Iron, Nitrates, sulphates, lead impacts on rainwater, are through anthropogenic activities. Emerole (2015), also emphasized the impacts of population density on quality of rainwater in Orji community in Imo state. He said that population goes with commercial activities, vehicular movement and burning of fossil fuels for electricity generation. The sources of higher values in iron, lead, turbidity in the two regions is attributed to their commercial and industrial activities coupled with high population. In addition, South-east has its additional problem of high concentration of sulphate, which is mainly due to burning of coal and petroleum products.

Test of Hypotheses

i. Rainwater physicochemical properties is determined by its chemical components.
ii. Rainwater physico-chemical properties are a function of location.
iii. The physicochemical properties of Rainwater is directly proportional to anthropogenic activities of that location

Discussion of findings

Pearson Chi-square analysis was adopted. It is used to compare observed result and expected results. The main purpose of the test was to determine if a difference between observed data and expected data is due to chance or due to a relationship between the variables studied. Asymptotic significance or p-value determines the statistical significance of the relationship between South-east and South-south regions. The p-value in our chi-square output is $p = 0.07$.

This means that the relationship between physico-chemical properties of South-east and South-south regions are significant. It has statistically significant, not due to chance. The skewness test shows the measure of how much the probability distribution of random variable deviates from the normal distribution. It explains the direction of outliers. The result of the skew test shows that the outliers for South-East and South-south with respect to standard error are small (0.580).

Summary of Findings

From the data discussion, 15 parameters were studied. The summary of the result without temperatures showed that 8 properties were higher in South-East than in South-South, while 6 in South-south. Properties from the South-east region were; pH, Total Suspended Solids, Sulphates, Nitrates, Turbidity, lead, chlorides and iron, with concentration levels of 5.98, 157.88mg/l, 300.40mg/l, 22.67mg/l, 23.92NTU, 0.40mg/l, 134.20mg/l and 2.20mg/l respectively. Among these properties from South-East, Oxides of nitrogen, lead, turbidity, Sulphates and Iron have concentration above WHO and NIS maximum permissible levels of 50mg/l, 0.01mgl, 5.0NTU, 250mg/l and 0.01mg/l respectively. Sulphates, oxides of nitrogen and lead are three important components of coal and fossil oil combustion. Their presence in rainwater is usually attributed to industrial, commercial, transportation, high population, biomass burning and other municipal activities. The Total Suspended Solids and turbidity are correlated. Their presence indicates presence of dusts, aerosols, smoke and other suspended particles which are bye-products of anthropogenic activities.

The six rainwater physico-chemical properties that were higher in South-South than in South-East region were; Copper, Electrical Conductivity (EC), Calcium, Magnesium, Zinc and Total Dissolved Solids with concentrations levels of 0.54mg/l, 70.35mg/l, 2.58mg/l, 0.86mg/l, 1.65mg/l and 36.25mg/l respectively. However, the parameters were within (WHO/NIS) maximum permissible limit. Calcium, Magnesium, and Zinc are ions, which releases electrical charges, read as conductivity. In most analyses EC and TDA are correlated. However, they are not in these studies. This could be attributed to rainfall frequency in these regions. Wind trajectory action, lithogenic effects coupled with rainfall intensity could have played a major role in these studies.

Turbidity and iron content were above WHO and NIS Specifications of 5.0NTU and 0.30mg/l respectively. It was also observeed that rainwater contaminant levels are a function of the frequency and intensity of the rainfall; the concentration levels of rainwater components reduced with an increased rainwater intensity, and vary from one location to the other. The statistical analysis has shown that the variation in rainwater quality between South-east and South-south is significant.

The rainwater samples from study area showed that they are acidic, and the temperatures were within range (25.95 and 29.26^{0}C). This also agrees with WHO's MPL of 20-30^{0}C as reported by Azuonwu *et al* (2017).

Conclusion

South-East region was more polluted than South-South due to higher concentrations of SO_4, Nitrates, lead, iron and in turbidity. These chemical components are found in coal and fossil fuel used by industries and power generation sources, while SS region had these parameters within MPL of WHO and NSDWQ; TDS, EC, Cu, Ca, Mg, and Zn. However, both regions had iron and turbidity above WHO and NIS MPL. Closer observation shows that, spatially, SE RW was more polluted than SS. The reason could be that South-East is the current industrial hub of Nigeria. Although, SS is the hub for oil and gas industry in Nigeria, rainfall intensity and wind action could have been supported by sea breeze and transported the rainwater inwards, towards SE Nigeria. Therefore, every effort should be put in place to find alternative source of fuels (coal and fuel oils) by industries, this will reduce atmospheric pollution and rainwater contamination in the area.

Recommendation

To reduce the emissions of chemical substances, new technology in powering our industries and automobiles should be encouraged and used as part of mitigation measures. Reduction of emissions at source using clean energy or more efficient combustion processes in industries, homes, and transportation systems. For examples, the use of electricity, gas, wind or solar energy instead of fossil fuels will reduce the emission of pollutants, and also the use of scrubbers in industries in order to remove some of the harmful substances that would otherwise pollute the atmosphere.

Legislation against air pollution (gas flaring, quarrying, road construction) with stiffer penalty should be in place to control emissions of particulate matters to the atmosphere. Illegal fossil oil refining should be discouraged, rather they should be organised and modernised into modular refineries to enhance local technology, generate employment and increase government revenue.

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