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Geochemical Evaluation of Imo River Southeastern Nigeria, in Relation to Environmental Sustainability

Adeyi, G. O., Okeke, O. C., Onyekuru, S. O., Meribe, P. N.
Department of Geology,
Federal University of Technology,
Owerri, Imo State, Nigeria

Adeyi A. A.
[2]Department of Electrical Electronic Engineering,
Maritime Academy of Nigeria,
Oron, Akwa Ibom State, Nigeria

Abstract:- The aim of this study is to conduct geochemical evaluation of Imo River water as a management strategy for sustainable development. The objectives are to determine the physical and chemical characteristics of Imo River water; to make a comparison of the physiochemical parameter value with the WHO standard for drinking water; to ascertain the pollution index (status) of the area's water; to determine the SAR (Sodium Adsorption Ratio); and to ascertain the geochemical facies of the river. Water samples were taken from ten (10) strategic gauge stations designated WS_1-WS_{10} along the stretch of the Imo River at a distance of 100 meters apart. Land use features such as dump sites were visited and examined. A global positioning system (GPS) was later used to geo-reference the sampling points. The results of the pH values ranged from 5.45 to 6.30, the turbidity values ranged from 10.4 to 12.5 NTU, and the electrical conductivity ranged from17.0 to 33.6 micro ohms. Total dissolved solids ranged from 10.2 to 20.2 mg/l. The results of physiochemical and geochemical parameters after comparison fell within the value of the WHO (2011) standard for quality water, showing that the water samples are safe for domestic, industrial, and agricultural purposes with a few exceptions for pH, which were slightly acidic, high turbidity levels, as well as high levels of Pb^{2+} and Cd^{2+} in some of the sampling stations. Different calculations and plots were also made, ranging from numerical calculations of the chemical models such as the pollution index (PI), which is to evaluate the extent of degradation of the river water. Although the PI value between 0.6 and 0.7 is yet to attain the critical value of 1, it is necessary to monitor it because it is quickly approaching 1. The figures for sodium adsorption ratio (SAR) were deemed excellent for irrigation purposes. Graphical methods such as: Piper (all ten stations fell on the right hand side, indicating that they are $Na^+ + K^+ – Cl^-$ waters), Durov (the pH section of the plot reveals that the river's water is acidic, making it unsafe for consumption). Finally, the major sources of contamination within the study area revealed that they are mainly from agricultural practices, dumpsites, and human defecation by humans. The quality can be improved by applying appropriate treatment to the water before its use for various purposes.

Keywords:- *Geochemical Evaluation, Atomic Absorption Spectrophotometer (AAS), pH, Pollution Index (PI) and Imo River.*

I. INTRODUCTION

Water is a basic necessity for human survival and socioeconomic development in any community. Many Nigeria towns, particularly those in the Imo River Basin, rely on surface and groundwater for both domestic and agricultural water. The component of water existing at the optimum level for suitable plant and animal growth is referred to as water quality. Aquatic organisms require a healthy environment as well as sufficient nutrients for growth; productivity is determined by the water body's physicochemical qualities. Only when all of the physical and chemical parameters are at their best can you achieve optimal productivity. Human-drinking water must be free of organisms and chemical substances, as high amounts might be harmful to one's health. Water contamination is on the rise as a result of rising human populations, industrialization, fertilizer use in agriculture, and other man made activities. As many communities in Imo River Basin begin to experience population increase and industrialization, there is a need for them to reverse these trends and prevent additional damage so as to ensure a sustainable environment. This can be achieved through birth control, environmental education, industrial waste recycling as well as improved farming systems such as crop rotation, bush fallowing, cover cropping, natural manuring, etc.

Environmental sustainability, on the other hand, is the obligation to conserve natural resources and protect global eco systems in order to support current and future health and well-being. The forward-thinking character of this is crucial.The concept of environmental sustainability can be seen of as adding depth to one aspect of sustainable development, namely meeting current generation requirements without jeopardizing future generations' ability to meet their own (Morelli, 2011).

The ability of the earth's biosphere and human civilization to coexist is referred to as sustainability. Lawrence (1997) defines it as "meeting the ecological, social, and aspirations of human and other species in such a way that: I the future is not sacrificed for the present; (ii) certain geographic area(s) are/are not sacrificed for other geographic area(s); (iii) human needs and aspirations are not limited by biological limits, and natural capital is preserved and enhanced; (iv) a proactive effort is made to maintain the sustainable and eliminate the unsustainable;(v) Sustainability is understood to be a fluid concept that will take many shapes and will be influenced by and adjusted to contextual conditions. Temperature, turbidity, nutrition, hardness, alkalinity, dissolved oxygen, and other key elements affecting the proliferation of living organisms in a

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water body include: (Smitha, 2013). As a result, water quality assessment entails examining physicochemical, biological, and microbiological characteristics that indicate the ecosystem's abiotic and biotic condition (Verma et al., 2012).

The impact of the Njoku sawmill landfill on water quality near the Otamiri river was evaluated by Ahiarakwem (2013). His investigation was limited to pollution sources from landfills. Onuoha et al. (2018) looked at the effects of anthropogenic activities on the Onuimo stretch of the Imo River's water quality. A section of the Imo River was considered in their investigation, making it localized. Amadi et al. (2016) assessed the Imo River's pollution status in terms of heavy metal enrichment. Their analysis was limited to heavy metal sources of pollution. In 2010, Amadi et al. examined the water quality index of the Otamiri and Oramiriukwa Rivers. Their assessment was based on weekly samples taken from four different locations only, thereby making the samples localized. Rivers serve as septic pools for most of the wastes that result from anthropogenic activities, which are agricultural practices, human domestic activities, and dredging. Water's importance to human and other biological systems cannot be overstated, and there are countless scientific and economic data that show that water scarcity or pollution can result in severe productivity losses and the extinction of living species (Garba et al., 2010).

However, due to urbanization, most people living in the Imo River basin use water mostly for domestic activities (drinking, washing, bathing, cooking, etc.). Some are engaged in agricultural practice (poultry droppings, chemical fertilizers, dredging, or other activities). Furthermore, the more people who use water, the more sewage is released into the river; the more farmlands, the more agricultural runoff; and the more people who remove sand (dredging) upstream, the more waste is thrown into the water, either intentionally or unintentionally, and the greater the tendency to pollute the water.This, in turn, has an impact on the river's physical and chemical characteristics, as well as the environment's long-term sustainability. Accurate and timely information on water quality is required to develop sound public policy and implement water quality so that activities upstream do not negatively impact activities downstream. Therefore, to maintain the sustainable and eliminate the unsustainable, geochemical evaluation of the Imo River is conducted so as to uncover other critical areas of contamination in the research area.

The aim of the research is to conduct a geochemical evaluation of Imo River water as a management strategy for sustainable development. This can be achieved through the following objectives:

- To determine the physical and chemical characteristics of the Imo River water using standard methods.
- To make a comparison of the physicochemical parameter values with recognised standards such as the World Health Organization (WHO) standard for drinking water in order to ascertain portability.
- To ascertain the pollution index and status of the area's water using some geo statistical parameters
- To determine the SAR to ascertain its usefulness for irrigation,
- To ascertain the geochemical facies of the river using some geochemical models (Piper, Durov, Schoeller, and Stiff Diagrams) in order to trace the chemical relationships and origin.

II. DESCRIPTION OF THE STUDY AREA

A. Location and physiography

The Imo River at Arondizuogu Village, which runs from Ndianiche in the Onuimo Local Government Area of Imo State, is located between latitudes 05° 49'N - 05° 47'N and longitudes 07° 16'E - 07° 15'E and covers an area of roughly 9100 km2 as indicated in the research area's location/topographic map (Figure 1). The Oramirukwa—Otamiri sub-basin and the Aba River sub-basin are the two primary sub-basins within the basin (Uma, 1989).

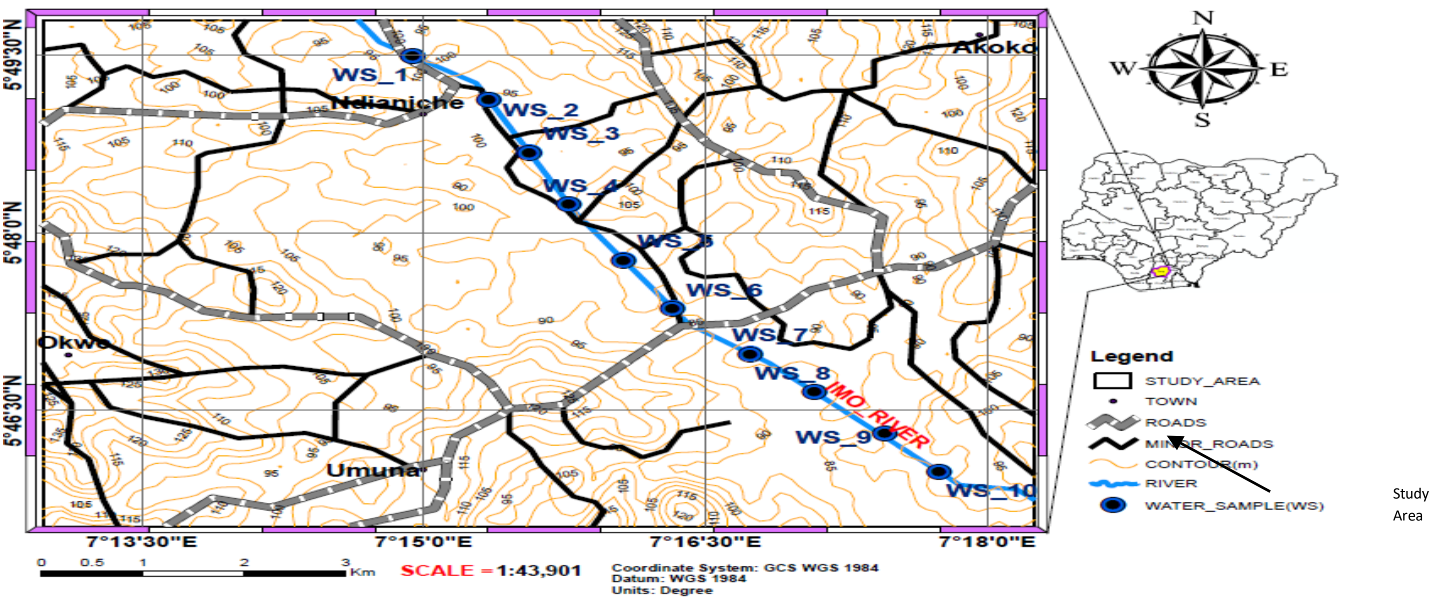

Fig. 1: Physiographic/Location map of the study area (After NGSA, 2002)

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Orographic rainfall is widespread in the area, which covers more than 25km2 of land, with the windward sides of hills receiving more rain than the leeward landscape. The mean annual rainfall is between 1800mm and 2500mm while the mean annual temperature is above 20°C. It contains a thinly vegetated shrubby rainforest, with taller and more diverse plant species growing at district levels on the windward slopes of hills.

OBJECT ID	SHAPE	NAME	LAT.	LONG.
1	Point	WS_1	5.824848	7.249022
2	Point	WS_2	5.818754	7.255788
3	Point	WS_3	5.811308	7.259382
4	Point	WS_4	5.803998	7.262911
5	Point	WS_5	5.796190	7.267720
6	Point	WS_6	5.789409	7.272068
7	Point	WS_7	5.782995	7.278971
8	Point	WS_8	5.777613	7.284690
9	Point	WS_9	5.771852	7.290907
10	Point	WS_10	5.766399	7.295739

Table 1: Coordinates of water sample at ten (WS_1-WS_{10}) sampling stations

B. The Geology and Hydrogeology of the Study Area

The bedrock of the Imo River is made up of a 5.5-kilometer-thick succession of sedimentary rocks ranging in age from the Upper Cretaceous to Recent (Uma, 1989). The creation of the rift-like Benue Trough of Nigeria in the Mesozoic is linked to the opening of the South Atlantic Ocean and the deposition of these sedimentary rocks (Emberga, 2019). In general, the Imo River Basin is underlain by two types of formations (Uma, 1989). Coastal Plain Sand, the Benin Formation, which is formed of non-indurated sediments represented by the Benin and Ogwashi-Asaba Formations, and alluvial deposits in the Imo River Basin's southern end, make up around 80% of the basin (Uma, 1989). The remaining 20% is underlain by a sequence of sedimentary rock units that get progressively younger as they move southwestward, parallel to the formations' regional dip (Uma, 1989). The geology of the study area is very complicated and consists of six lithostratigraphic units that consist of the Ajali, Nsukka, Imo Shale, Ameki, Ogwasi, and Benin Formations (Figure 2).

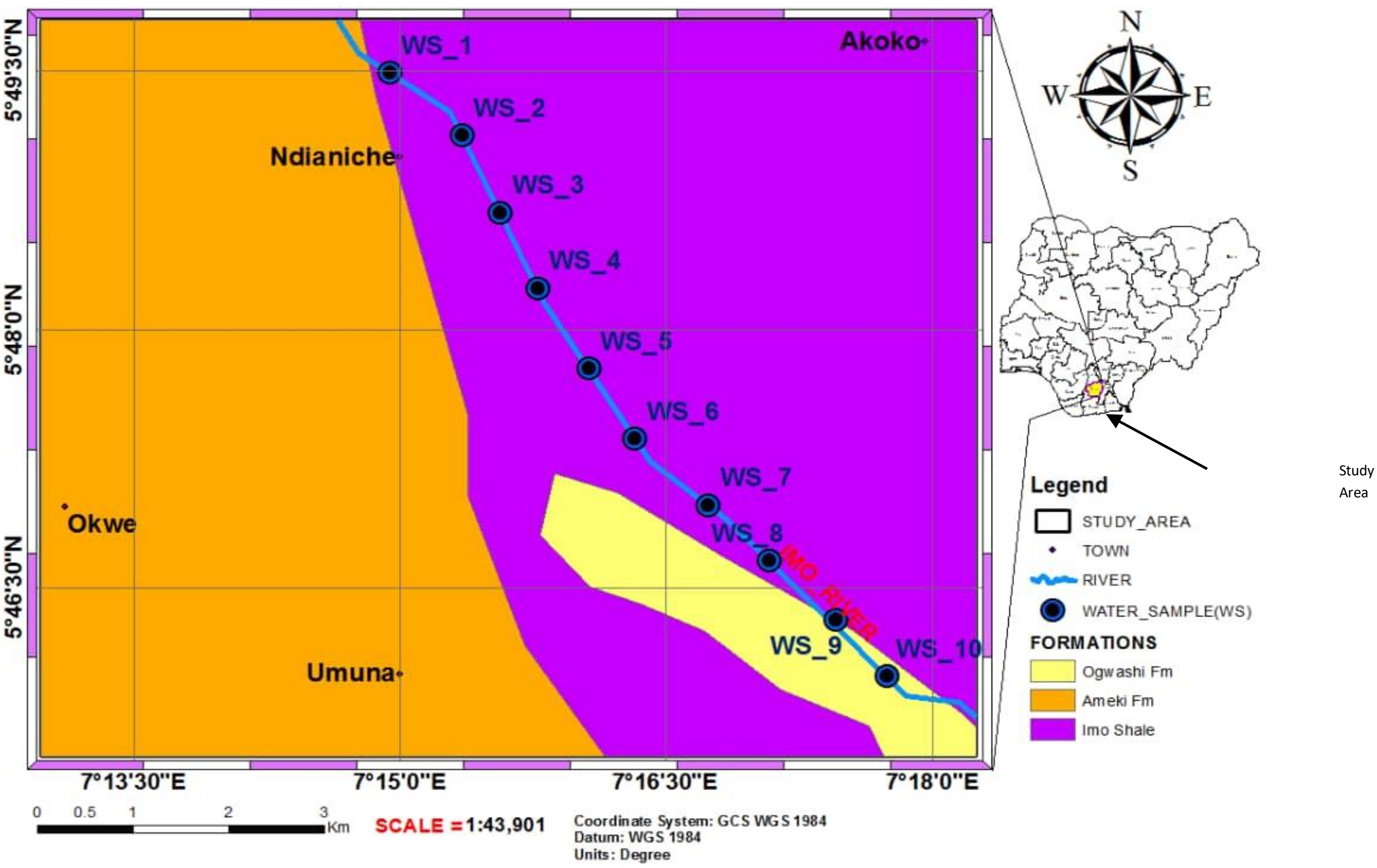

Fig. 2: Geological map of the study area (After NGSA, 2002)

In Table 2, the Imo River's geologic succession is depicted. The Benin Formation contains unconsolidated sands/sandstones with significant porosity and permeability, often known as coastal plain sands (Ekwe and Opara, 2012).

Age	Formation	Maximum Appropriate Thickness	Characteristics
Miocene -Recent	Benin	2000	Unconsolidated, yellow and white sands, occasionally pebbly with lenses of grey sandy clay.
Oligocene – Miocene	Ogwashi/ Asaba	500	Unconsolidated sandstones with carbonaceous mudstones, sandy clays and lignite seams
Eocene	Ameki	1460	Sandstones grey to green argillaceous sandstones, shales and thin limestone
Paleocene	Imo	1200	Blue to dark grey shales and subordinate Sandstones. It includes two sandstone members: the Umuna and Ebenebe sandstones.
Upper Maestrichtian	Nsukka Formation	350	White to grey coarse-to-medium-grained sandstone; carbonaceous shales; sandy shales; subordinate coals; and thin limestones.
	Ajali Sandstone	350+	Medium-to-coarse-grained sandstones, poorly consolidated with subordinate white and pale grey shale bands.

Table 2: Regional stratigraphic sequence of the Imo River Basin (Uma, 1989)

III. MATERIALS AND METHODS

A. Sample Collection and Analysis

Water samples were obtained at ten (10) strategic gauge stations designated WS_1-WS_{10}along the stretch of the riverover a 100-meter stretch of the river.Sterilized 1.5-litre plastic containers were used to collect samples. The samples were promptly corked under water to prevent oxidation of the constituents and then delivered to the laboratory for analysis within 24 hours. Dump sites and other land use aspects were also visited and analyzed.

The Atomic Absorption Spectrophotometer was used to evaluate the gathered water samples (AAS). A global positioning system was used to geo-reference the sampling spots (GPS).

The Sodium Absorption Ratio was calculated using the amounts of Ca2+, Mg2+, and Na+ in milli equivalent/litre (SAR). Turbidity was measured using a turbidimetric approach. Physical factors such as pH and dissolved oxygen were measured with appropriate standard meters in the field. The titrimetric approach was used to estimate anions such as HCO3.Turbidity, odour, appearance, conductivity, total dissolved solids, Iron (Fe2+), Calcium (Ca2+), Chloride (Cl-), Bicarbonates (HCO3-), total hardness, and Sodium (Na+) were among the metrics studied. Cadmium, Lead, Zinc, Iron, Silver, and Nickel were among the heavy metals examined.

<u>Calculations</u>

The concentrations of the major constituent anions and cations in milligram/liter (mg/l) were converted to milliequivalent/liter (meq/l) using the equation (3.1) formulated by Todd (1980)

$$\textbf{Concentrations (meq/l)} = \frac{\text{Concentrations (mg/l)}}{\text{Equivalent mass}} \ldots\ldots\ldots\ldots\ldots\ldots \quad \textbf{(3.1)}$$

The concentrations in meq/l were used to prepare Piper trilinear, Durov, Schoeller, and Stiff diagrams as well as calculation of Sodium Adsorption Ratio (SAR).

The SAR was evaluated using the equation (3.22) (Wilcox, 1955).

$$\textbf{SAR} = \frac{Na^+}{\frac{\sqrt{Ca^{2+} + Mg^{2+}}}{2}} \ldots\ldots\ldots\ldots\ldots\ldots \quad \textbf{(3.2)}$$

The total hardness as ($CaCO_3$) of the Imo River water at Okigwe, Arondizuogu village wasevaluated using the equation (3.3) developed by Todd (1980). Total hardness as

$$\textbf{CaCO}_3\ \textbf{mg/l} = 2.5\,[Ca^{2+}] + 4.1\,[Mg^{2+}] \ldots\ldots\ldots\ldots\ldots\ldots \quad \textbf{(3.3)}$$

The pollution index (PI) of the water samples was calculated using the concentrations of pH, total alkalinity, total dissolved solids (TDS), Total Hardness, sulphate, and chloride in mg/l. This was accomplished using the following method:The parameters considered for the determination of the pollution index (PI) of the Imo River water samples at Arondizuogu village, Okigwe area,

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were pH, Total Alkalinity, Total Chloride, Total dissolved solids (TDS), sulphate and chloride. The PI was calculated using the equation (3.4) formulated by Horton (1965).

$$\mathbf{PI} = \sqrt{\frac{\left(\frac{maxCij}{Lij}\right)^2 + \left(\frac{meanCij}{Lij}\right)^2}{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.4)$$

Where:**Ci** = concentration of chemical parameters **Lj** = World Health Organization (2011) permissible limit.

IV. RESULTS AND DISCUSSION

A. *Physiochemical Parameters*

The results of physiochemical characteristics of the Imo River at ten (10) strategic gauge stations designated WS_1-WS_{10} with their respective means are shown in table 3, while the Pollution Index (PI) and Sodium Adsorption Ratio (SAR) are shown in tables 6 and 7a respectively.

	Stations											WHO Standards
Parameters	1	2	3	4	5	6	7	8	9	10	Mean	(2011)
pH	5.60	5.45	5.70	5.65	5.48	6.00	6.25	6.20	5.95	6.30	5.85	8.2 - 8.8
Turbidity, NTU	11.0	12.5	11.0	10.8	12.2	10.4	10.6	10.6	11.2	12.0	11.23	1.00
EC,µohms	24.0	28.0	33.6	27.60	17.0	19.6	18.3	20.6	20.0	18.0	22.67	1400
TDS, mg/L	14.4	16.8	20.2	16.6	10.2	11.8	11.0	12.4	12.0	10.8	13.62	1500
Ca^{2+}, mg/L	2.6	2.4	2.2	2.4	2.6	2.8	2.4	2.9	3.0	3.2	2.65	200
Na^{+}, mg/L	6.85	6.75	6.90	6.83	6.60	6.40	6.20	6.50	6.60	6.80	6.64	200
Mg^{2+}, mg/L	0.024	0.026	0.020	0.023	0.030	0.026	0.028	0.030	0.026	0.024	0.025	100
K^{+}, mg/L	3.79	3.81	3.74	3.78	3.80	3.60	3.40	3.84	3.90	3.64	3.73	50 – 70
HCO_3^{-}, mg/L	14.50	14.30	14.00	14.48	14.88	14.60	14.54	14.58	14.60	14.72	14.52	50
SO_4^{2-}, mg/L	3.20	3.24	3.60	3.20	3.00	3.24	3.26	3.22	3.26	3.30	3.25	200 – 400
Cl^{-}, mg/L	7.95	8.01	7.88	7.95	7.80	7.86	7.80	7.88	6.80	6.88	7.68	400
Cd^{2+}, mg/L	0.01	0.02	0.04	0.03	0.02	0.01	0.04	0.03	0.02	0.03	0.025	0.003
Pb^{2+}, mg/L	0.06	0.05	0.02	0.01	0.03	0.04	0.05	0.04	0.05	0.03	0.038	0.01
Zn^{2+}, mg/L	1.00	2.00	1.50	2.00	2.40	2.30	2.40	2.20	2.10	1.80	1.97	5.0
Cu^{2+}, mg/L	0.001	0.002	0.001	0.002	0.003	0.003	0.002	0.001	0.002	0.002	0.002	2.0
Hg^{2+}, mg/L	0.001	0.003	0.002	0.003	0.004	0.006	0.005	0.004	0.005	0.003	0.0036	
Cn^{2+}, mg/L	0.02	0.02	0.01	0.02	0.03	0.04	0.04	0.03	0.02	0.01	0.024	

Table 3: Physicochemical characteristics of Imo River at Ten (WS_1-WS_{10}) sampling stations and their mean

B. *H and Turbidity*

The hydrogen index (pH) is a measurement of how acidic or alkaline a water sample is. For any water to be deemed acceptable for drinking and other domestic applications, the operating guideline suggests a pH range of 6.5 - 9.0. (WHO, 2006). This is to ensure that water used for drinking and for domestic purposes is not corrosive or capable of causing facility incrustation.

The pH of the river water at stations WS1-WS10 ranges between 5.45 and 6.30, exceeding the World Health Organization's (WHO) 2011 safe drinking water criterion (Table 3 and Figure 3). This signifies that the water is acidic. Although most aquatic species require a pH range of 6.5-9.0, some can survive in water with a pH outside of this range (Ahiarakwem et al., 2013). When pH falls outside of this range (up or down), animal systems are stressed, and hatching and survival rates suffer (Ahiarakwem et al., 2013).

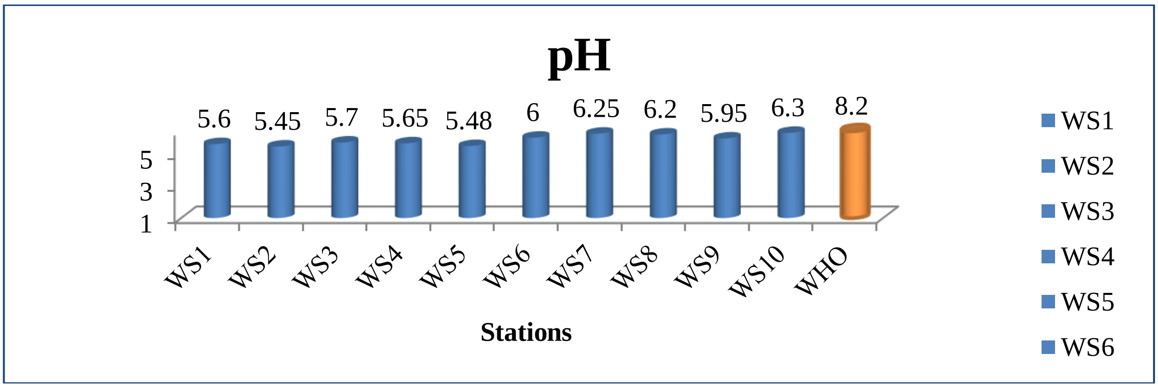

Fig. 3: Bar chart showing the pH trend of all ten stations.

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Turbidity values range from 10.4 to 12.5 NTU respectively which exceeds the World Health Organization (WHO) 2011 safe standard for drinking water (Table 3 and Figure 4).

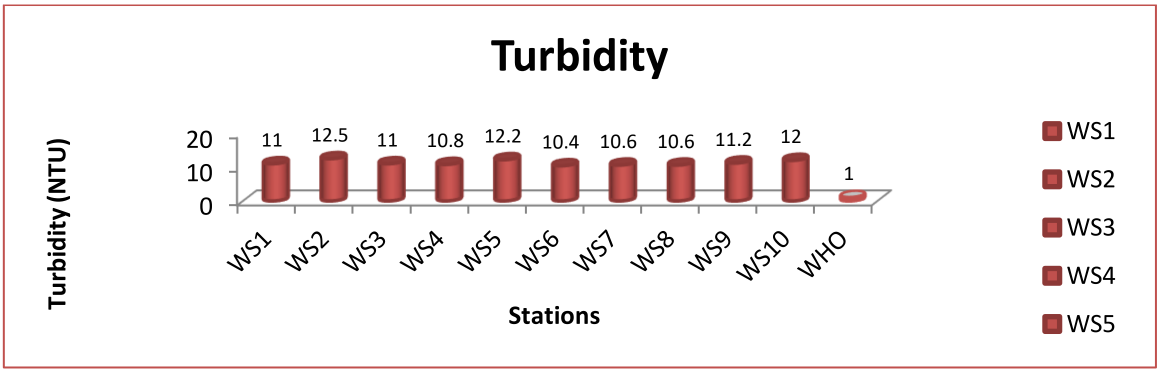

Fig. 4: Bar chart showing the turbidity trend of all ten stations.

C. Electrical Conductivity and Total Dissolved Solids

The electrical conductivity of the 10 stations ranged from 17.0 to 33.6 µohms respectively (Table 3and Figure 5) and were within the WHO (2011) standard for drinking water.

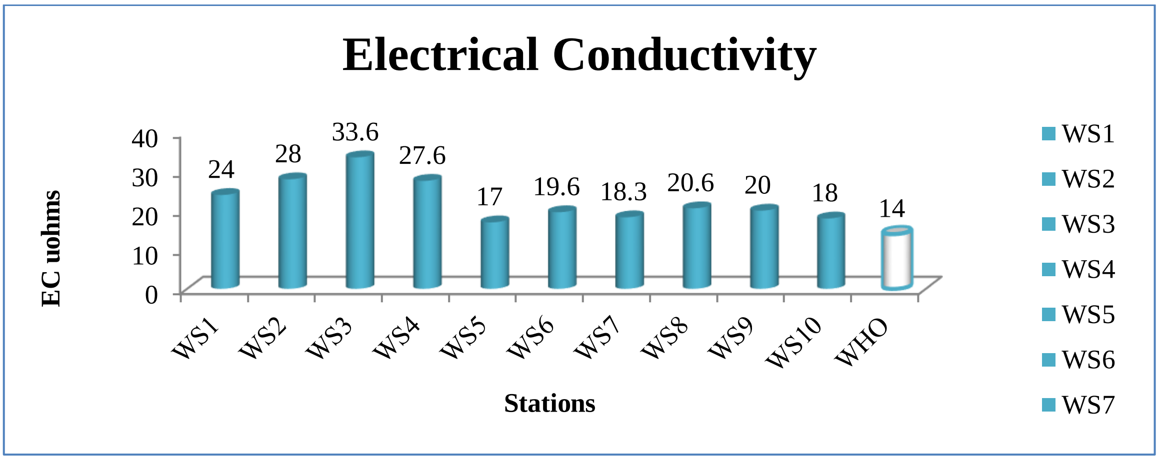

Fig. 5: Bar chart showing the Electrical Conductivity trend of all ten stations.

The total dissolved solids ranged from 10.2 to 20.2 mg/l, which were all within the WHO (2011) drinking water standard (Table 3 and Figure 6). Excessive exposure to salty water (TDS 500 mg/L) can cause kidney stones, according to Sharma and Bhattacharya (2017). Fresh water samples have a TDS range of 0 to 1,000 (Carrol, 1962); therefore, the Imo River water at the ten sites is classified as fresh based on the TDS values reported in table 4 below:

TDS in PPM	**Water quality**
0 – 100	Fresh water
1000 – 10,000	Brackish water
10,000 – 100,000	Salty water
>100,000	Brine

Table 4: Water quality classification based on TDS content (After Carrol, 1962)

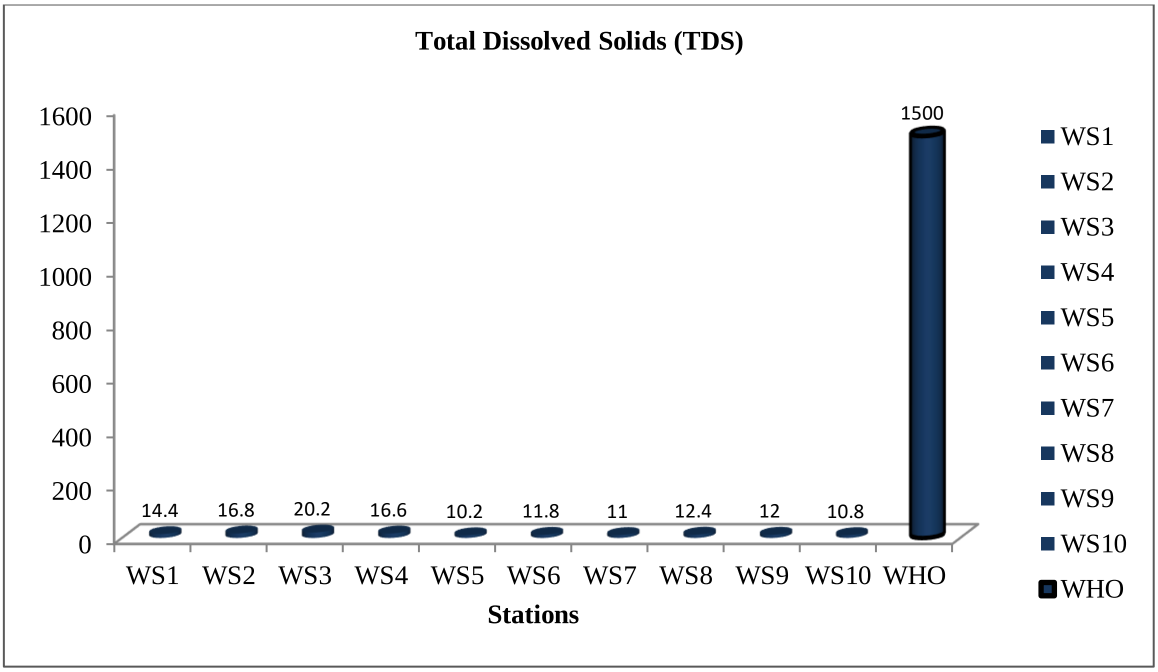

Fig. 6: Bar chart showing the Total Dissolved Solids trend of all ten stations.

D. Major cations and anions

For cations, the values for Ca^{+2} ranges from 2.2 to 3.0 mg/l respectively (Table 3and Figure 7). The value of Na^{+} ranges from 6.20 to 6.90 mg/l respectively. The value of Mg^{+2} ranges from 0.020 to 0.030 mg/l. K^{+} ranges from 3.40 to 3.84 mg/l. While for anions, HCO_3^{-}values ranges from 14.00 to 14.88 mg/l respectively (Table 3 and Figure 8). The values of SO_4^{2-} ranges from 3.00 to 3.60 mg/l. While for Cl^{-}, the values ranges from 7.80 to 8.01 mg/l. The whole ranges for both cations and anions were within the WHO (2011) standard for drinking water at the ten stations.

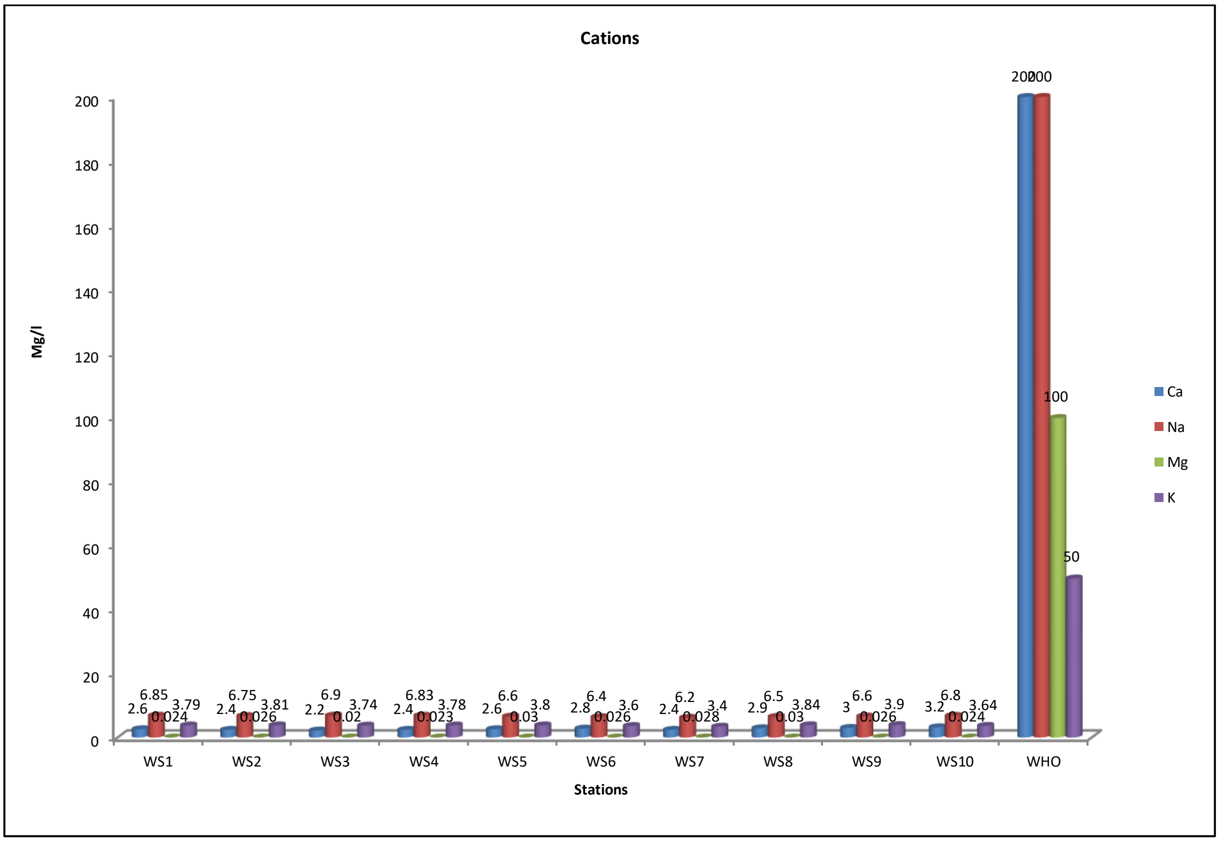

Fig. 7: Bar chart showing the Cations trend of all ten stations.

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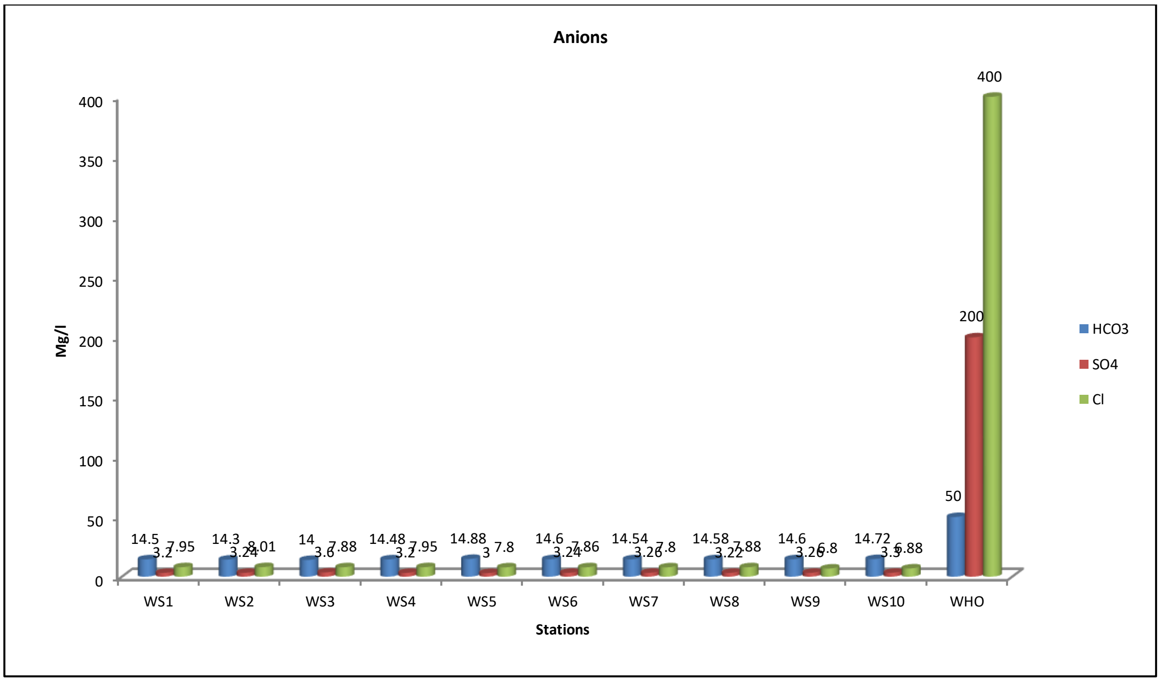

Fig. 8: Bar chart showing the Anions trend of all ten stations.

E. *Heavy Metals*

Heavy metals are one of the most significant sources of pollution in the environment (Yang et al., 2018; Karahan et al., 2020). In terms of heavy metals, Cd^{2+} values at station WS_1-WS_{10} ranges from 0.01 to 0.04 mg/l. Pb^{2+} ranges from 0.01 to 0.05 mg/l (Table 3). The values for Zn^{2+} ranges from 1.00 to 2.40 mg/l. For Cu^{2+}, the values range from 0.001 to 0.003 mg/l. Hg^{2+} values ranges from 0.001 to 0.006 mg/l. The value for Cn^{2+} ranges from 0.01 to 0.04 mg/l. Except for Cd^{2+} which ranges slightly beyond the WHO (2011) standard for drinking water, the other heavy metals were within the acceptable limit (Figure 9).

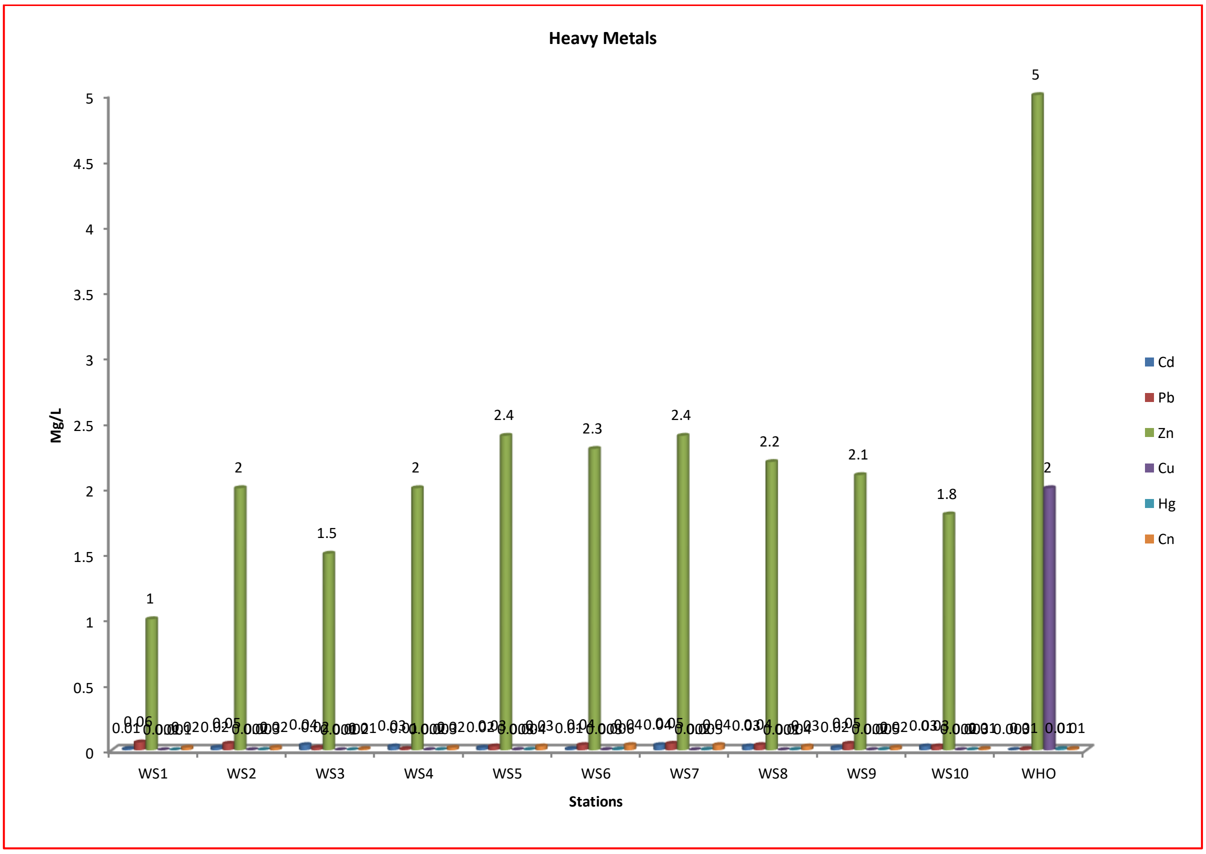

Fig. 9: Bar chart showing the heavy metals trend of all ten stations.

F. Pollution Index (PI)

The pollution index (PI) for the ten stations varies between 0.60 and 0.70. (Table 6). The critical value of the pollution index is one; thus, a pollution index of higher than one indicates a very high level of pollution (Horton, 1965). Although the PI has not yet reached the critical value of 1, it is necessary to monitor it because it is quickly approaching 1

Parameters	Equivalent Mass	1		2		3		4		5		6		7		8		9		10		Mean	
		mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
Ca	20	2.6	0.13	2.4	0.12	2.2	0.11	2.4	0.12	2.6	0.13	2.8	0.14	2.4	0.12	2.9	0.145	3.0	0.150	3.2	0.16	2.65	
Na	23	6.85	0.29	6.75	0.29	6.90	0.30	6.83	0.29	6.60	0.28	6.40	0.27	6.20	0.28	6.50	0.28	6.60	0.27	6.80	0.29	6.64	
Mg	12.2	0.024	0.001	0.026	0.002	0.020	0.001	0.023	0.001	0.030	0.002	0.026	0.002	0.028	0.002	0.030	0.002	0.026	0.002	0.024	0.001	0.025	
K^+	39.1	3.79	0.09	3.81	0.09	3.74	0.09	3.78	0.09	3.80	0.09	3.60	0.10	3.40	0.09	3.84	0.10	3.90	0.09	3.64	0.09	3.73	
			0.511		0.502		0.500		0.500		0.500		0.512		0.492		0.527		0.512		0.541		
HCO_3	61	14.50	0.23	14.30	0.23	14.00	0.22	14.48	0.23	14.88	0.24	14.60	0.23	14.54	0.22	14.58	0.24	14.60	0.24	14.72	0.25	14.52	
SO_4^{2-}	48	3.20	0.06	3.20	0.06	3.60	0.07	3.20	0.06	3.00	0.06	3.24	0.06	3.26	0.06	3.22	0.06	3.26	0.07	3.30	0.07	3.25	
Cl^-	35.5	7.95	0.22	7.95	0.22	7.88	0.22	7.95	0.22	7.80	0.21	7.86	0.22	7.80	0.22	7.88	0.22	6.80	0.19	6.88	0.193	7.68	
			0.510		0.510		0.510		0.510		0.510		0.511		0.500		0.520		0.500		0.514		

Table 5: The Concentrations 0f Constituents at the ten sampling stations in Milliequivalent/Liter (meq/l)

Parameters	Lij (WHO)	Cij1	Cij2	Cij 3	Cij 4	Cij5	Cij6	Cij7	Cij8	Cij9	Cij10	Cij/Lij 1	Cij/Lij 2	Cij/Lij 3	Cij/Lij 4	Cij/Lij 5	Cij/Lij 6	Cij/Lij 7	Cij/Lij 8	Cij/Lij 9	Cij/Lij 10
pH	6.5	5.60	5.45	5.70	5.65	5.48	6.00	6.25	6.20	5.95	6.30	0.86	0.83	0.87	0.86	0.84	0.92	0.96	0.95	0.91	0.97
TDS (mg/L)	500	14.4	16.8	20.2	16.6	10.2	11.8	11.0	12.4	12.0	10.8	0.028	0.033	0.040	0.033	0.020	0.023	0.022	0.024	0.024	0.021
Sulphate (mg/L)	400	3.20	3.24	3.60	3.20	3.00	3.24	3.26	3.22	3.26	3.30	0.008	0.0081	0.009	0.008	0.007	0.0081	0.008	0.008	0.008	0.0082
Chloride (mg/L)	250	7.95	8.01	7.88	7.95	7.80	7.86	7.80	7.88	6.80	6.88	0.031	0.032	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031
Total Alkalinity (HCO_3), mg/L	100	14.50	14.30	14.00	14.48	14.88	14.60	14.54	14.58	14.60	14.72	0.145	0.143	0.140	0.144	0.148	0.146	0.145	0.145	0.146	0.147
Mean Cij/Lij												0.214	0.209	0.218	0.215	0.209	0.225	0.233	0.231	0.223	0.235
Max Cij/Lij												0.86	0.83	0.87	0.86	0.84	0.92	0.96	0.95	0.91	0.97
PI												0.62	0.60	0.64	0.63	0.61	0.67	0.69	0.68	0.66	0.70

Table 6: Showing Pollution Index for all Stations

G. Sodium Adsorption Ratio (SAR)

The river's sodium adsorption ratio (SAR) values at the ten stations range from 1.0 to 1.28, as shown in table 7a. Water resources with a SAR value of 0 to 10 (as in the case of the Imo River at the ten stations) are classified as excellent (Table 7b) for irrigation, while those with a SAR value of more than 26 are classified as poor.

Stations	SAR values
1	1.16
2	1.20
3	1.28
4	1.20
5	1.12
6	1.03
7	1.16
8	1.03
9	1.00
10	1.03

Table 7a: SAR values of the Ten points along the River

SAR Range	**Description**
0-10	**Excellent**
10 - 18	**Good**
18 – 26	**Fair**
>26	**Poor**

Table 7b: Standard SAR values (Wilcox, 1955)

H. *Geochemical Plots*

a) Piper Diagram

Piper Diagrams (Piper, 1944) are a combination of anion and cation triangles that lie on a common baseline diamond shape between them and can be used to reach a preliminary conclusion on the origin of the water represented by the analysis as well as to characterize distinct water types. The Piper classified waters into four categories based on their location near the diamond's four corners. The majority of the water samples from the ten stations fall within the right hand side of the plot, indicating that the Na+ + K+ Cl– water type is the dominant water type in the research area. (See Figure 10).

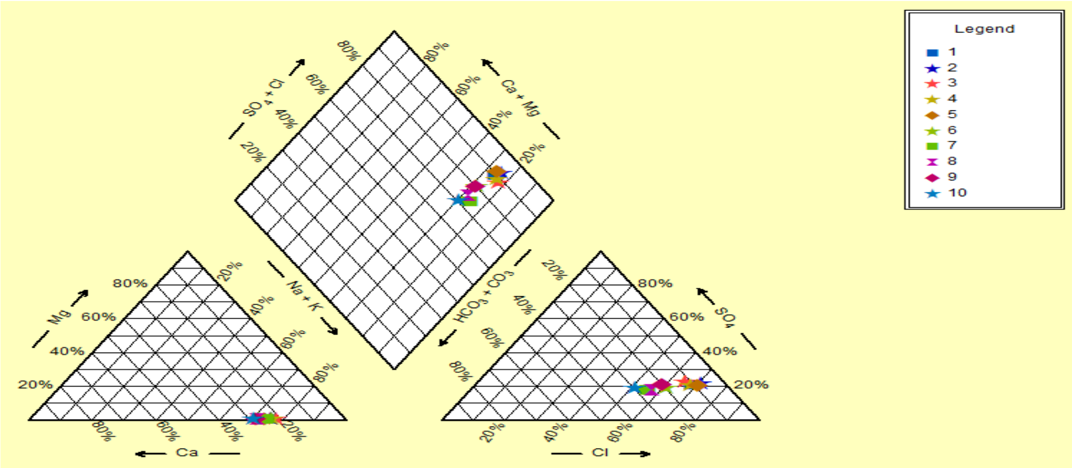

Fig. 10: Piper Diagram for all 10 stations

b) Durov Diagram

This diagram was proposed by Durov (1948) to provide more information on the hydrochemical facies by assisting in the identification of water types and displaying some possible geochemical processes that could aid in the study and evaluation of groundwater quality. The diagram is a composite plot made up of two ternary diagrams in which the cations of interest are plotted against the anions of interest. The sides form a binary plot of total cation against total anion concentrations; the expanded version adds electrical conductivity (S/cm) and pH data to the sides of the binary plot to allow for more comparisons.The pH section of the plot reveals that the water in the river is acidic, making it unsafe to drink. The river's electrical conductivity is within the WHO's (2011) standard for drinking water (Figure 11).

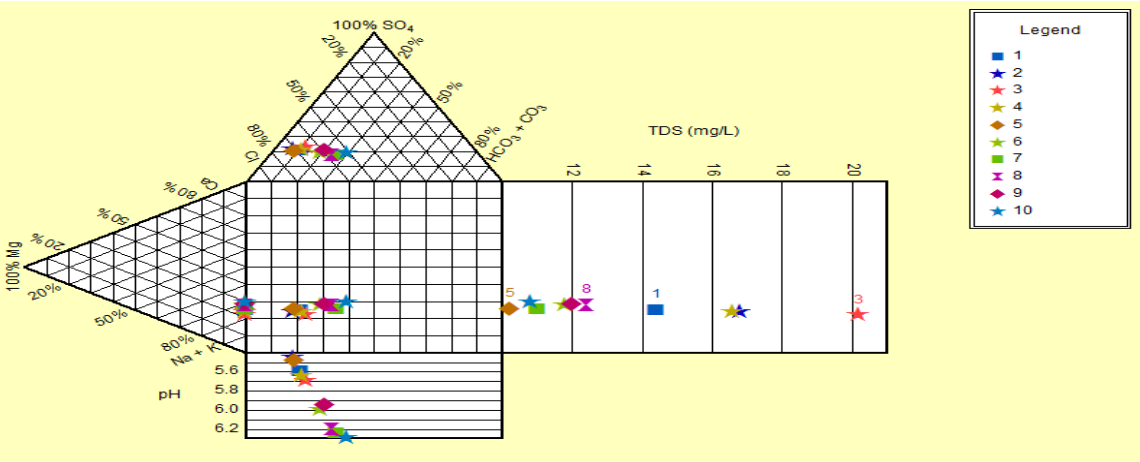

Fig. 11: Durov Diagram for all 10 stations

c) Schoeller Diagram

The Schoeller (1977) diagram is also used to present the average chemical composition of the water samples at the ten stations along the river. The relative tendency of ions in mg/l shows Na^+ $^-K^+$> Cl^->Ca^{2+} > HCO_3^-> SO_4^{2-}> Mg^{2+}.

The water type Na^++K - Cl- is the most common hydrogeochemical facies found in the research area, as indicated in the plotted Schoeller diagram below (Figure 12).

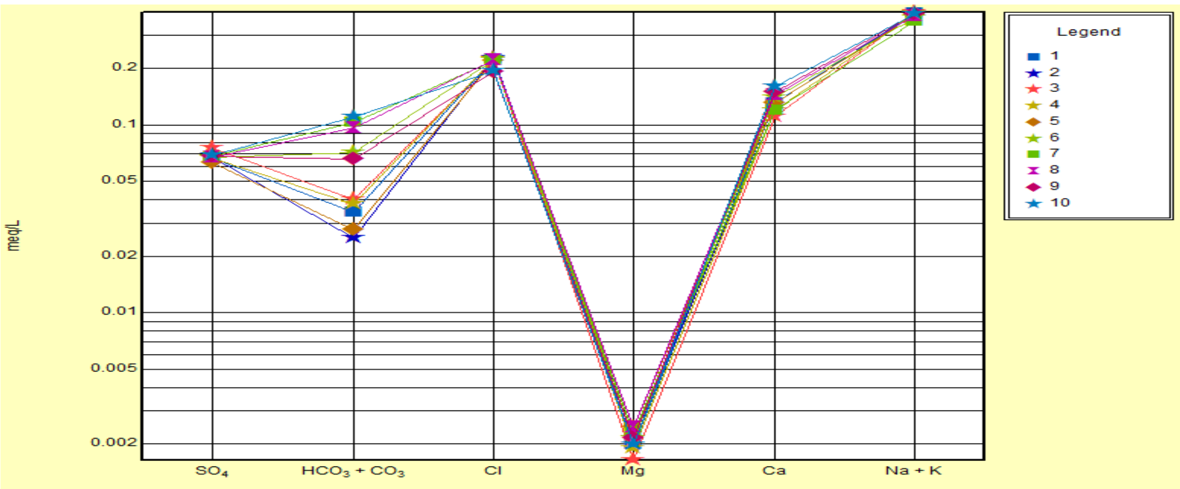

Fig. 12: Schoeller Diagram for all 10 stations

d) Stiff Diagrams

The Stiff (1951) diagram is a graphical representation of the different water ions. The average ionic composition analysis by stiff diagram (Figure) signifies dominance of Na+ K – Cl-. The hydrogeochemical water types interpreted are based on the respective shapes of the different Stiff plots (Figure 13–22).

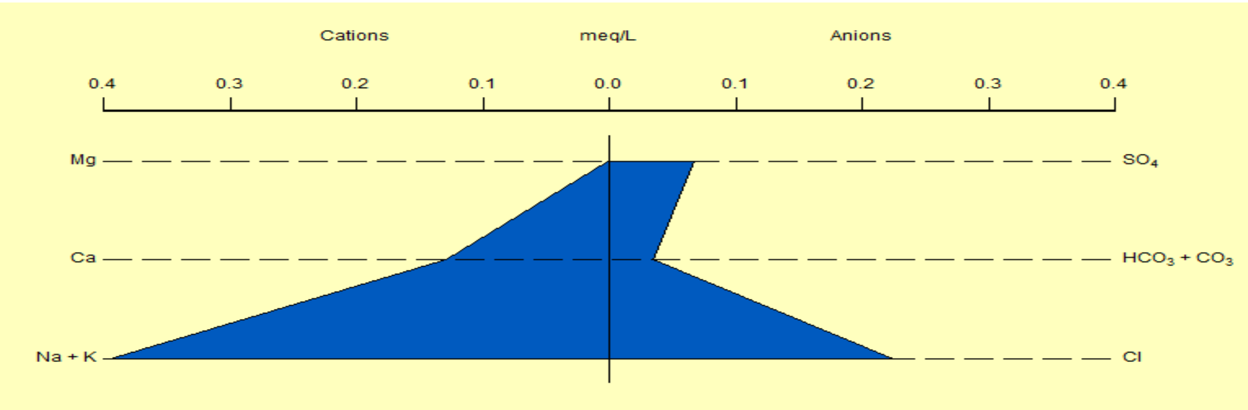

Fig. 13: Stiff Diagram of Station 1

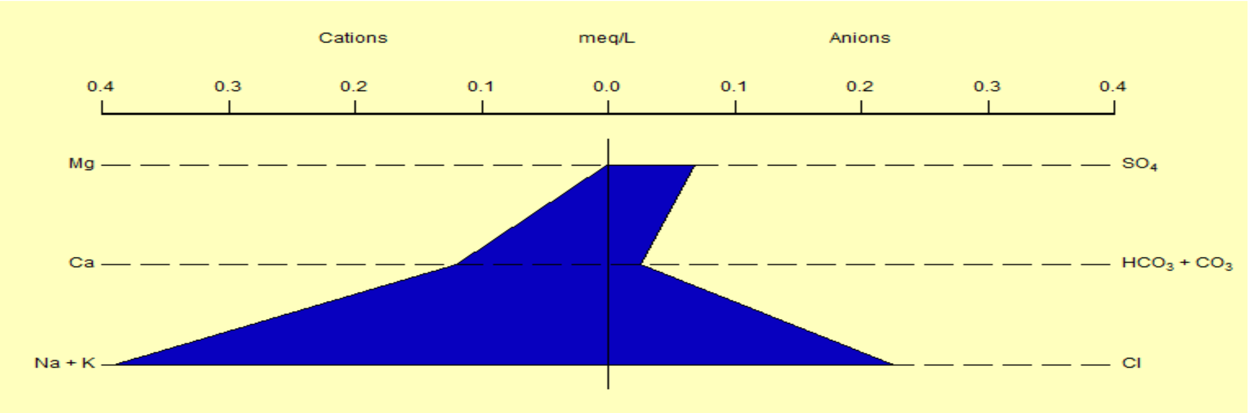

Fig. 14: Stiff Diagram of Station 2

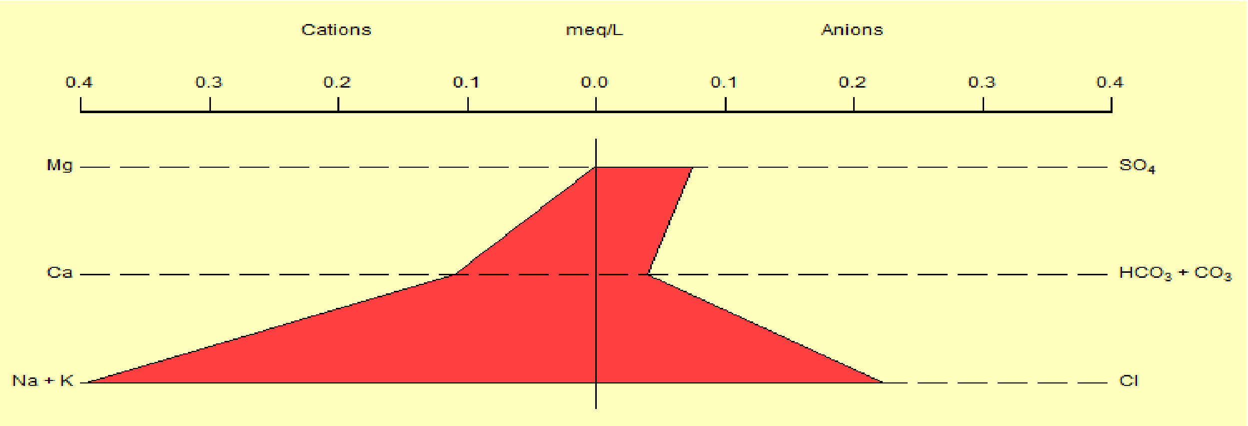

Fig. 15: Stiff Diagram of Station 3

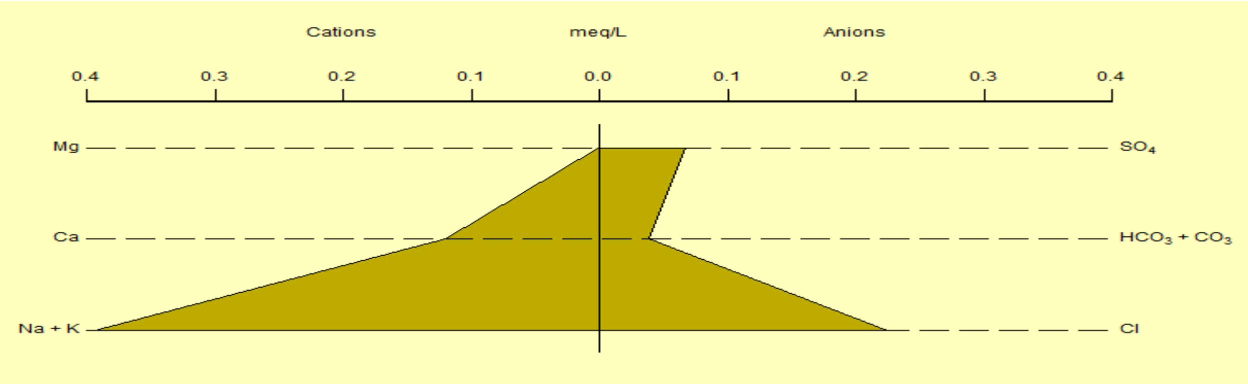

Fig. 16: Stiff Diagram of Station 4

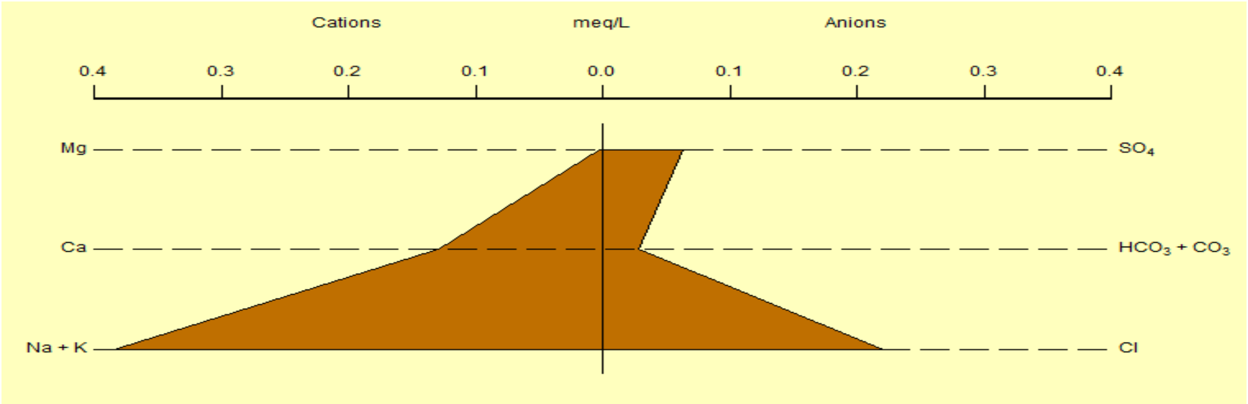

Fig. 17: Stiff Diagram of Station 5

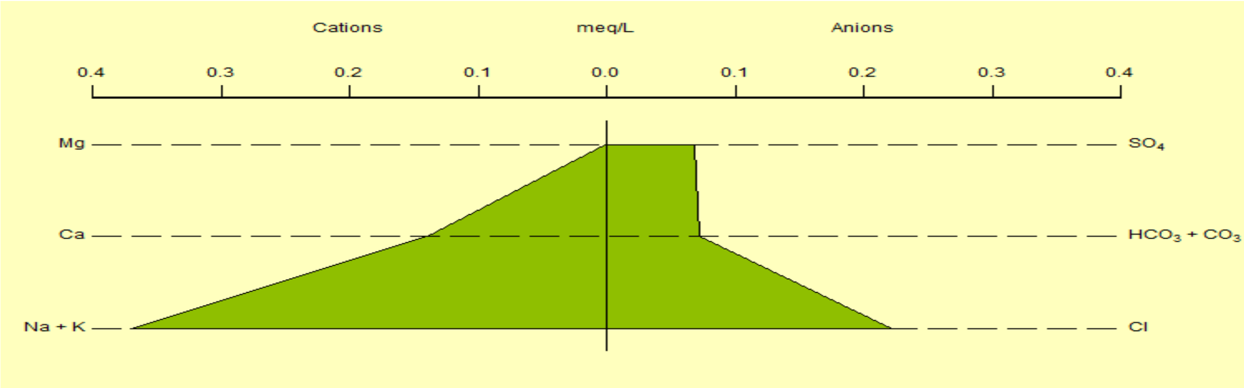

Fig. 18: Stiff Diagram of Station 6

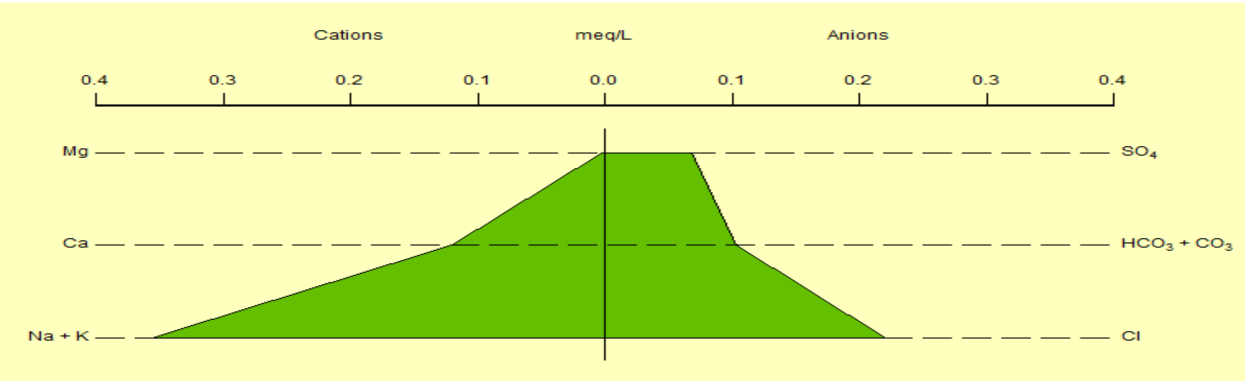

Fig. 19: Stiff Diagram of Station 7

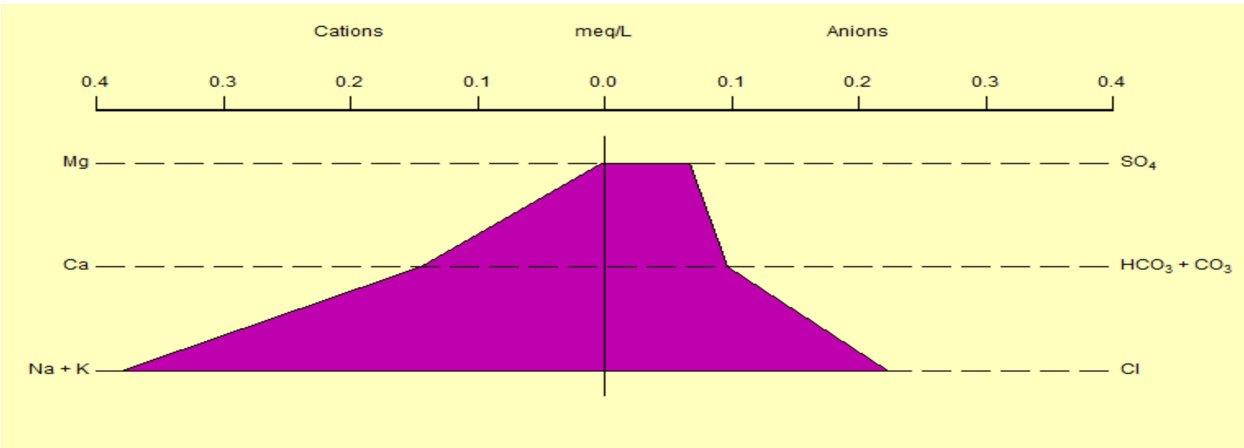

Fig. 20: Stiff Diagram of Station 8

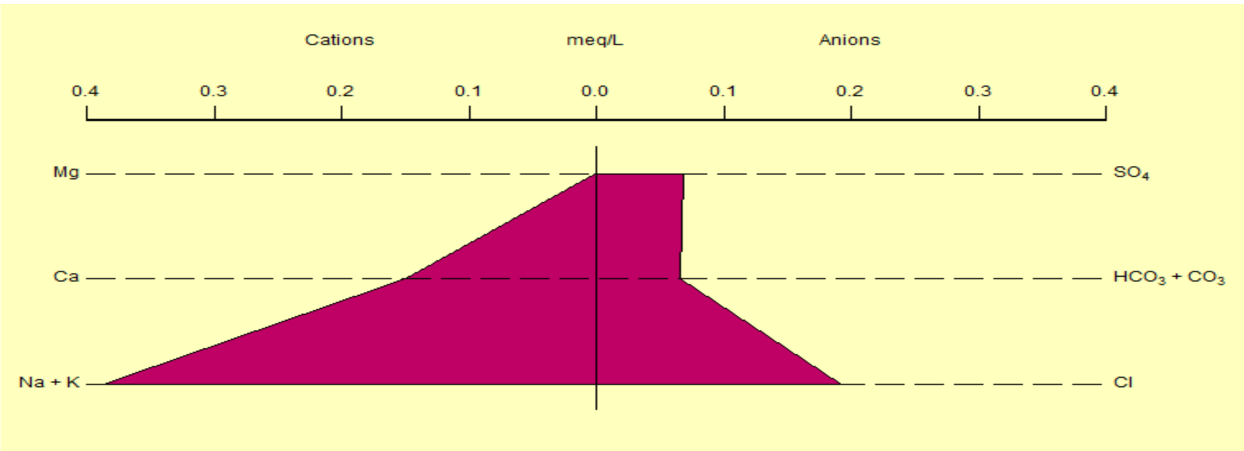

Fig. 21: Stiff Diagram of Station 9

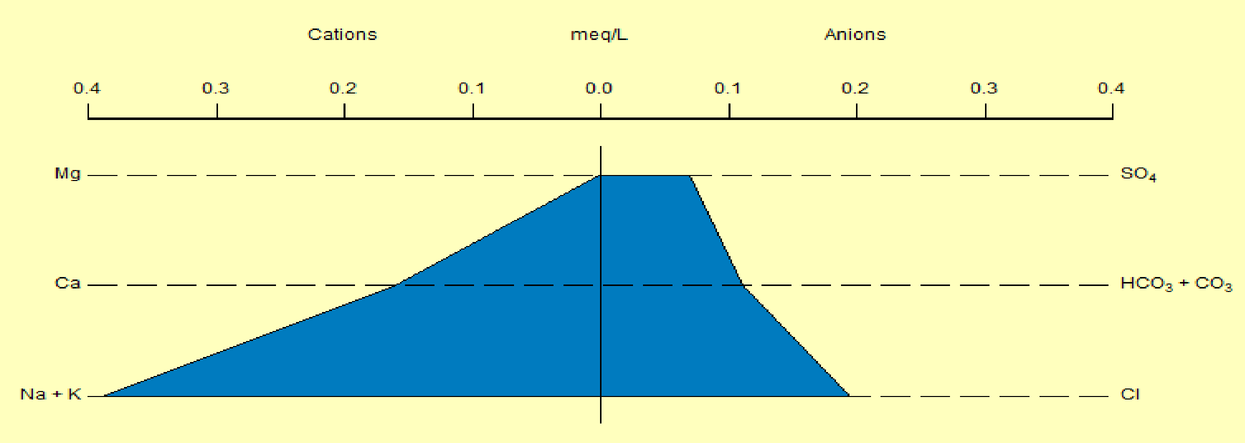

Fig. 22: Stiff Diagram of Station 10

e) Ionic Balance

This diagram depicts the cation and anion balance in the river water sample taken at various points (Figure 23-32).

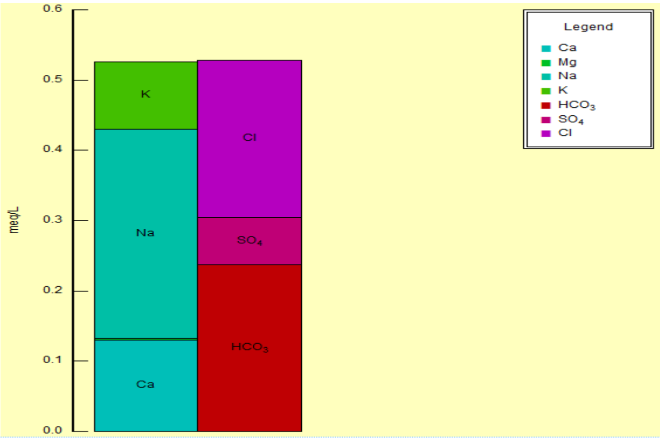

Fig. 23: Ionic Balance of Station 1

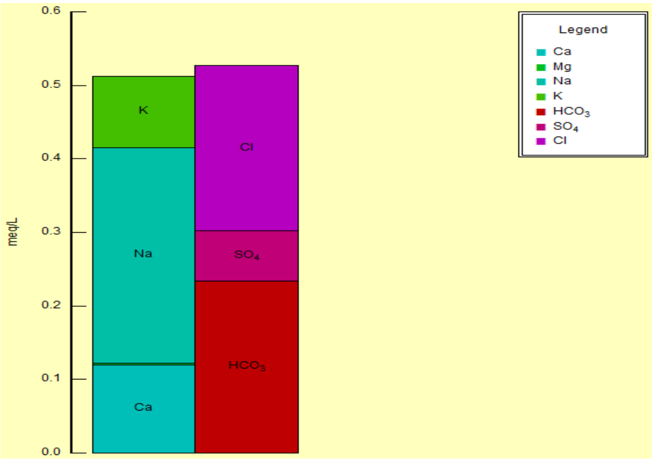

Fig. 24: Ionic Balance of Station 2

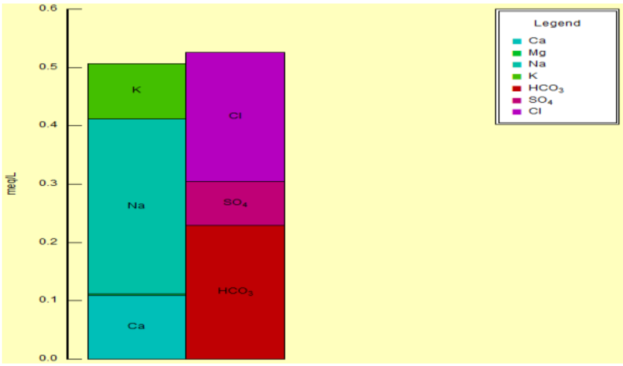

Fig. 25: Ionic Balance of Station 3

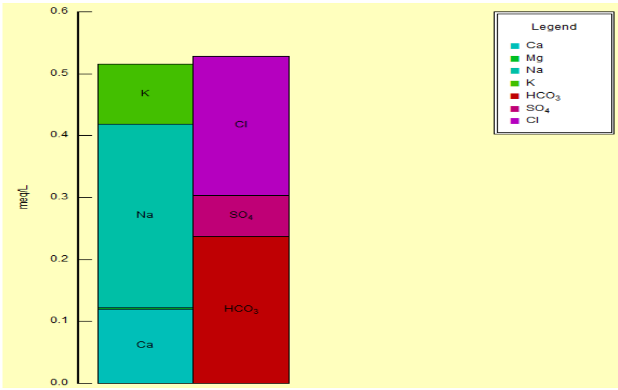

Fig. 26: Ionic Balance of Station 4

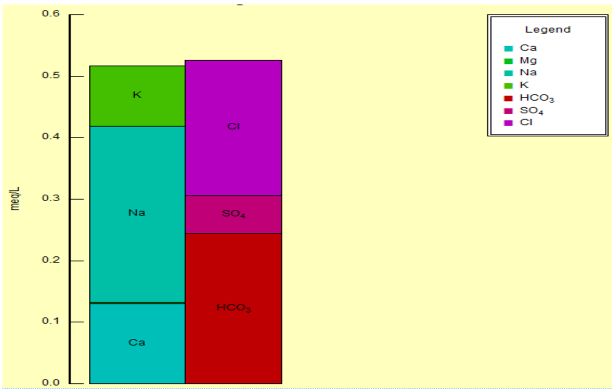

Fig. 27: Ionic Balance of Station 5

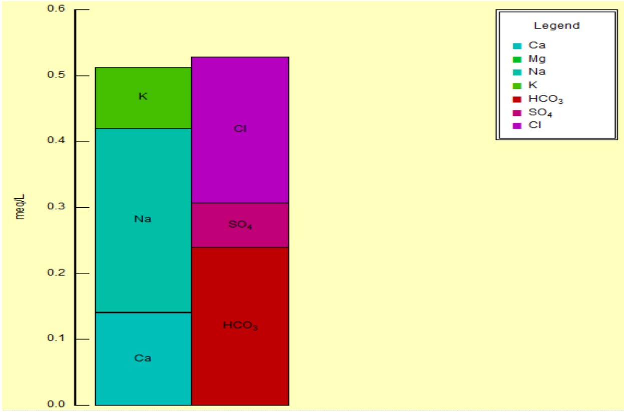

Fig. 28: Ionic Balance of Station 6

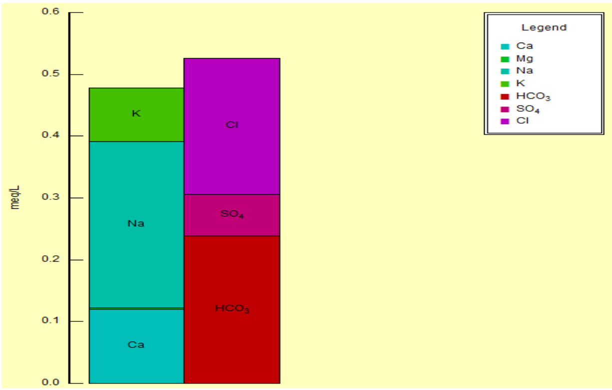

Fig. 29: Ionic Balance of Station 7

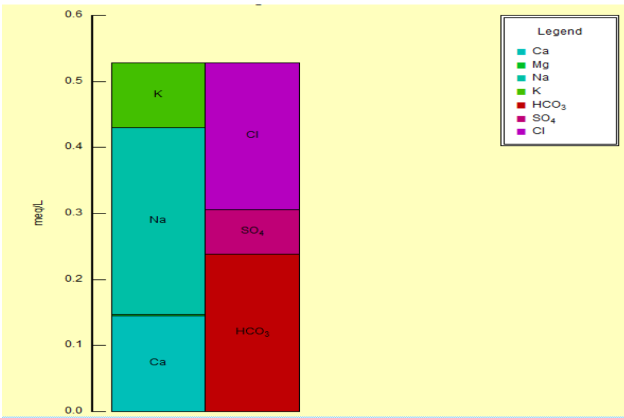

Fig. 30: Ionic Balance of Station 8

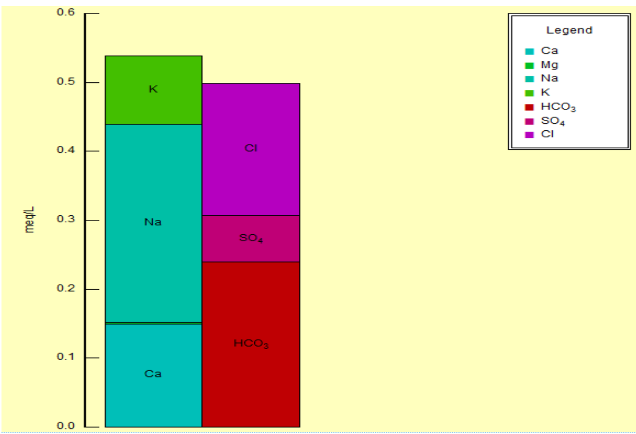

Fig. 31: Ionic Balance of Station 9

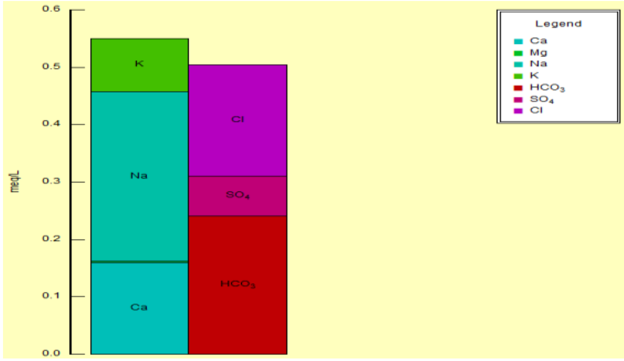

Fig. 32: Ionic Balance of Station 10

V. CONCLUSION

Every day, 2 million tons of sewage, industrial, and agricultural waste are dumped into the world's water, according to a UN report published in 2003 (UN WWAP, 2003). In the case of the river water samples at the ten stations, the major activity within the area is agricultural in nature.

The physiochemical parameters of river water samples collected from ten stations (WS1-WS10) after comparison fell within the WHO (2011) standard for quality water, indicating that the water samples are safe for domestic, industrial, and agricultural use, with the exception of pH, which was slightly acidic, high turbidity, and high levels of Pb2+ and Cd2+ in some of the sampling stations.

Different calculations and plots were also made ranging from numerical calculations of the chemical models such as pollution index (PI) which is to evaluate the extent of degradation of the river water. Although the PI value between 0.6 and 0.7 has not yet reached the critical value of 1, it is necessary to keep an eye on it because it is quickly approaching 1. The figures for sodium adsorption ratio (SAR) were deemed excellent for irrigation purposes. While graphical methods such as: Piper (all ten stations fell at the right hand side indicating that they are typically $Na^+ + K^+ – Cl^-$ waters), Durov (the pH part of the plot reveals that the water in the river is acidic, which is not good for drinking: the river's electrical conductivity is within the range of WHO (2011) drinking water standards), Schoeller (the relative tendency of ions in mg/l shows Na+ -K+> Cl- >Ca2+ > HCO3- > SO42- > Mg2+), and Stiff diagrams (the hydrogeochemical facies identified in the study area is primarily the water type Na^++K - Cl^-) etc. were used to acquire a better understanding of the hydrogeochemical processes operating in the river water samples. The hydrogeochemical characteristics of the major and minor ions was carried out in view of determining the water types with respect to chemistry of the water.

Finally, agricultural practices, dumpsites, and human excrement are the principal sources of contamination within the research area, according to field observations. Fertilizers containing trace chemicals may have been washed into the river as a result of agricultural operations. Biodegradable trash, as well as electronic wastes, may have been washed into the river from surrounding dumpsites.

- Based on the findings, certain improvements to the chemical quality of the research area's water resource can be implemented, such as: Ensuring proper treatment before consumption and for domestic use.
- Treating the water before use by adding lime($Ca(OH)_2$) as well as chlorinating the water to reduce its acidity.
- Carrying out a detailed survey of the rock through which River water flows in order to evaluate its mineralogical and geochemical composition.
- Discouraging open waste dumping and open defecation method.

VI. ACKNOWLEDGEMENTS

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