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Investigating the Hydrochemical Characteristics and Pollution Sources Affecting the Water Quality of the Nworie and Otamiri Rivers in Owerri Metropolis, Nigeria

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Abstract

This study investigates the hydrochemical characteristics and pollution sources affecting the water quality of the Nworie and Otamiri Rivers in Owerri Metropolis, Nigeria. These rivers are essential for domestic, industrial, and agricultural uses, but are threatened by both point and non-point source pollution. The study utilized Durov diagrams to analyze water samples, revealing that ion exchange reactions are the primary hydrochemical processes influencing water quality. The samples were predominantly classified as intermediate-type water with chloride-type anions, though variations such as magnesium-rich and sodium plus potassium types were noted. The pH and Total Dissolved Solids (TDS) values exhibited systematic trends, suggesting natural geochemical processes and anthropogenic influences. Increasing activities along the watersheds, including runoff from rainfall carrying pollutants, have transformed previously point-source pollution into more complex non-point source pollution, complicating monitoring and control efforts. As observed in the post-confluence samples, the classification of water samples into different cation and anion types indicates diverse sources and interactions, including potential mixing with seawater in certain areas. The findings underscore the need for comprehensive water quality management strategies to address these rivers' diverse and dynamic contamination sources. Further research, including isotopic analysis and detailed chemical characterization, is recommended to better understand the region's environmental and human factors influencing water quality.

Keywords: Durov diagram, Water, Otammiri, Nworie, Non-point source.

INTRODUCTION

Water is a life resource which is indispensable for life processes (Ekwonu, 2017). Water is life without pollution, but death once polluted (Igwe *et al.,* 2017). It is essential for the wellbeing of mankind and for sustainable development. 97% of the total volume of water available is in the Oceans, 2% stored in the form of ice-sleets and less than 1% is available as fresh water. Its many uses include drinking, domestic uses, industrial cooling, power generation, agriculture (irrigation), transportation and waste disposal (Ekwonu *et al.*, 2019). Unwanted fluids produced by industrial processes are known as industrial effluents and are improperly released into the environment or receiving surface water. Its qualities offer fundamental knowledge about the usefulness of the rivers and streams they flow into (Kanu *et al.,* 2006). In the modern world, the issue of environmental contamination brought on by human (anthropogenic) activity is quickly becoming one that needs to be treated seriously (Okereke, 2007). When released untreated or only partially treated, effluent discharges into the environment with increased concentrations of nutrients and sediments will have a detrimental effect on the quality and life forms of the receiving water body (Forenshell, 2001; Schulz and Howe, 2003). Point source and non-point source were found to be the major types of water pollution; however, point source has proven a track record of effective management by controlling the sewage and industrial wastewater but non-point source management of waste is still not addressed.

Non-point source pollution control requires assessment of the influence of dispersed runoff – contributing areas on surface water quality. Pollution of water happens as a result of events like spillage, percolation from rubbish dumps from, and seasonal variation in storm water characteristics (Ekwonu and Ejike, 2011). Researchers have discovered that some factors compelling and affecting water chemistry are rainfall intensity, wastewater discharges, land use, land cover, and possible pollution build-ups as observed over 5 decades now (Yan *et al.*, 2020).

Owerri Metropolis otherwise referred to Owerri urban is currently viewed as a combination of three distinct government area viz: Owerri Municipal, Owerri West and Owerri North. It is located within the tropical climatic zone of Nigeria nay West Africa. It has a landmass of approximately 142Km2 located, situated and traversed by two prominent rivers known and referred to as Otamiri and Nworie rivers. According to the Census data of 2006, Owerri metropolis is populated with approximately 271, 381 inhabitants. Its known and recorded source of public water supply is the famous Otamiri water Board which has been under the management of the Imo State Water Board. Imo state comprises of 51 reivers/lakes, and they are Ibi river, Ibu River, Efuru River, Ikwo River, Abuba River, Iyba River, Idiu River, Ibu River, Nterere River, Ife River, Izeh River, Ndima River, Alum River, Uyin River, Amayi River, Iyeochara River, Ohia River, Law-Law River, Ugbi River, Ezeze River, Onyimbo River, Biyi River, Upo River, Eme River, Obiyi River, Nfro River, Onuiyiyin River, Asa River, Abadaba River / Lake, Mba River, Okitankwo River, Oramiriukwa River, Njaba River, Imo River, Okuini River, Orashi River, Anamini River, Ahanum River, Iyodo River, Ore River, Awkwa River, Eyin River, Awbana River, Utu River, Onas Creek, Oguta Lake, Osian Lake, Asa River, Nworie River, Ogochie River, and the Otamiri River (Okoro *et al.*, 2014).

The Otamiri river flows in the E-W direction with its source at Egbu community in Owerri North Local Government Area of Imo State. The river located on latitude 5˚23'N and 5˚30'N, and Longitude 6˚58'E and 7˚04'E is a major fresh surface water resource of Owerri metropolis. It took its name from the well-known deity “Ota Miri”. Its mouth is at the Atlantic Ocean as it traverses via meandering pattern through Nekede, Ihiagwa, FUTO, Eziobodo, Obowuumuisu, Mgbirichi, Umuagwo to Ozuzu in Etche Local Government Area of Rivers State.

Nworie River, on the other hand flows in the NW-SE direction covering an average distance of 9.2KM from its source at Ohi to Emmanuel College Owerri where it formed a confluence with the short-travelled Otamiri River. The river lies within latitude 5029’ to 5049’N and longitude 07001’ to 7025’E standing on an elevation of 77m upstream, 55m midstream, and 45m downstream above the sea level; Handheld Global Positioning System (GPS). Nworie River is within the rainforest zone of Owerri (Njoku –Tony *et al.*, 2016). It is a first order stream that runs for a reasonable distance before joining the Otamiri River. Its watershed has an annual rainfall of 2500mm. The Soils are coastal plain sands of Benin formation; the river is about 8km in total length with its source at Ubomiri in Egbeada which joins Otamiri River at Nekede (Nwosu *et al.*, 2021).

Increasing activities within and along the Otamiri and Nworie watersheds have made sources of contaminants’ introduction into the surface water bodies which hitherto were classified as point sources to recently degenerate to non-point sources with their attendant complex mechanisms and techniques that are random and sporadic in occurrence with resultant difficulties in monitoring, simulation, treatment as well as control. The exposure of the river banks through diverse activities within the area has necessitated runoff from rainfall to easily carry along with them contaminants from different sources known as NPS pollutants. These pollutants range from natural to man-made pollutants which are usually deposited into water bodies by runoff water. Pollution from both point and non-point sources has had a negative impact on surface water. For irrigation, drinking, and domestic use, these natural water sources are exploited. Most ambient waters have standards that outline minimum acceptable levels of purity. Due to the negative effects, it has on farm irrigation, it is important to determine the degree of pollution in the Otammiri river watershed which serves as a discharge basin for domestic effluents from the area. In order to analyze the water quality for irrigation and other purposes, this project will result in the creation of a water quality model that will enable the assessment of the pollution level at various locations along the Otammiri River watershed.

Contamination of surface water happens when unwanted natural and antropogenic/man-made activities en-route or occur in them. The health of people is seriously harmed by these undesired items, which are typically in the form of trash from homes, farms, and natural runoffs brought on by climatic change. Non-point pollutants are connected to weather and geographic factors within a catchment, however, and because of the storage properties of the receiving basin, they maintain an active presence within the ecosystem despite being difficult to trace to a source. Numerous studies have been done on how Non-Point Source (NPS) pollutants affect water bodies' quality, but the mechanisms and hydrological processes necessary for pollutant migration are not adequately taken into account in the models that are currently in use, and the relative effects of various land uses on the surface water have not yet been determined and quantified. This demonstrates the necessity of the current study. The work aimed at carrying out a non-point source event-based model to contamination of surface water resources in Owerri metropolis.

MATERIALS AND METHOD

Materials

The materials and equipment used in the course of this research are listed below:

1. Location/Topographic map of the study area.
2. Geologic map of Otamiri and Nworie watersheds.
3. Global position system (GPS) Germin76 CSX for the measurement of coordinates and elevation of sampling points.
4. Measuring tape for measuring distances.
5. Graduated steel stake for water depth measurement.
6. Two and half (2.5) liter plastic bottles for sample collection.
7. Masking tape for labeling of samples.
8. BOD sample collection bottles.
9. Cooler with ice blocks to maintain the sample's ambient temperature throughout the fieldwork.
10. Helmet, hand gloves, and boots to ensure safety throughout the fieldwork.
11. Compass to determine the flow direction of the rivers.
12. Hatch environment for insitu measurements.
13. Petri dish for flow velocity measurement.
14. AAS Equipment
15. Burette
16. Pipette
17. Conical Flask
18. Measuring Cylinder

Methods:

The methods that were adopted in the course of this work were grouped into two (2) viz: 1) field method and 2) laboratory method.

Field method

The field method involved mobilizing equipment and crew to the field were insitu measurements were carried out obtained samples for subsequent analysis in the laboratory. This field method was grouped into three (3) phases as follows:

1. Desk work/ reconnaissance survey phase
2. Field mapping phase
3. Field sample collection phase.

Desk work /Reconnaissance survey phase

During this phase, materials including literature materials were sourced. Topographic/location and geologic maps were produced to serve as a field guide. The Landsat imageries of ETM 30 by 30 m resolution of 2019 were obtained from Landsat Global Land-Use and Land Cover Facility (www.gltc.com) and processed using ARC GIS 9.3 software to yield their respective Land Use/Land Cover of the study area.

A day reconnaissance survey was embarked on to have a general knowledge of the extent of the Otamiri and Nworie watersheds to be studied. During this reconnaissance survey, acquaintances were made with relevant individuals like traditional rulers of some communities via which the two rivers to be studied traversed. Different households were met and intimated of the intended fieldwork. Individuals working at the sand mining and dredging sites were equally met and discussions were held about the fieldwork and the essence to humanity. Discussions were held with farmers cultivating cash crops and vegetables for corporation and assistance. As soon as these acquaintances were made, cordial relationships established and appropriate entry permissions sought and obtained, the field mapping was immediately carried out without any further delay.

Field Mapping Phase

This stage involved moving the research crew to the field to map out the entire axis of the Otamiri and Nworie watersheds and take routing measurements as well as proper documentation of the flow patterns and directions, activities going on at different locations along the full length of the watersheds as well as the land use pattern within the entire watershed. The different land use/land cover patterns around the Otamiri and Nworie watersheds were established.

It is believed that different activities constitute different events operating within and around the river course which in no doubt contributed to the anthropogenic activities going on in the rivers, posing threats to the entire chemistry of the water bodies.

This field mapping exercise automatically ushered in the real fieldwork for the collection of water samples for laboratory and analytical operations.

The three-point method of slope determination were adopted during the field mapping stage to estimate the slope of the watershed along the flow path of both Otamiri and Nworie rivers for only the exposed portions of the river bank. Two-point elevation collection were utilized at locations with thick vegetation that had hitherto been classified as fallow lands.

Field Sample Collection Phase

Immediately after the mapping exercise was completed, sampling materials were mobilized to the field for insitu measurements and collection of water samples. At every sampling point, the following measurements were carried out; depth of the river, coordinates (latitude and Longitude) of the location, elevation of the sampling points above the mean sea level, elevation of peak area within the vicinity of the sampling point for slope analysis; insitu measurement of potential Hydrogen (pH), Temperature, Conductivity, Dissolved Oxygen (DO) and Total Dissolved Solids (TDS) using the right equipment.

The sampling procedure that was adopted in this study were the surface grab method cum semi-immersion method. The water samples were obtained in a white plastic bottle with tight rubber stoppers and corks. The capacity of each container that was used is about 2.5 liters. Each sample collected were carefully and routinely corked under the water to avoid atmospheric contact. The white plastic containers were used to collect water samples for the determination of the physical, chemical and microbial parameters in the laboratory. A second bottle was used to collect water samples meant for laboratory determination of Dissolved Oxygen (DO) and consequently Biochemical Oxygen Demand (BOD). The samples collected were safely transported to the laboratory for further studies.

Laboratory Method/ Analysis

The researcher investigated the presence of these physio-chemical and biological parameters in the water samples that were collected using standard laboratory procedures:

1. PH
2. Conductivity
3. Color
4. Turbidity
5. DO
6. BOD
7. COD
8. Appearance
9. Total solids
10. Total dissolved solids
11. Total suspended solids
12. Total hardness
13. Calcium hardness
14. Magnesium hardness
15. Total Alkalinity
16. Total chloride
17. Nitrate
18. Nitrite
19. Ammonia
20. Phosphate
21. Sulphate
22. Bicarbonate

Metallic ions Like:

i) Iron (Fe^{2})
ii) Sodium (N_a^{+})
iii) Lead (Pb^{2+})
iv) Chromium (Cr^{2+})
v) Manganese (Mn^{+})
vi) Copper (Cu^{2+})
vii) Zinc (Zn^{2+})
viii) Calcium (Ca^{2+})
ix) Potassium (K^{+})
x) Magnesium (Mg^{2+})

- Heavy Metals
- Total Bacteria Count
- Total Coliform
- E Coli
- Salmonella and shigella Agar

Analytical Methods

The researcher adopted full and accepted analytical procedures and notable methodology in carrying out the laboratory analysis of the water samples to be collected. The Laboratory equipment that was used in analyzing the samples are but not limited to:

1. AAS Equipment
2. Burette
3. Pipette
4. Conical Flask
5. Measuring Cylinder

Water Quality Standards

Water resource (both surface and groundwater) monitoring becomes meaningful only when the results obtained after adequate analysis for water quality are compared with some notable and useful reference points. Such standards are being presented by regulatory agencies such as the World Health Organization (WHO), United States Environmental Protection Agency (U, SEPA), European Union (E.U), Saskatchewan Drinking Water Objective (SK), Canadian Drinking Water Quality Guideline (CDWOG), Federal Environmental Protection Agency (FEPA), Nigerian Standard for Drinking Water Quality (NSDWQ), just to mention but a few.

To understand better, the standards that can be applied, a simple and succinct definition of some of the basic terms is quite appropriate. The Safe Drinking Water Act states that the term primary drinking water regulation means a regulation which:

a) Applies to public water system
b) Specifies contaminants that may have adverse effects on the health of persons.
c) Specifies for each contaminant, either a maximum contaminant level or a reduced level based on treatment and
d) Contains criteria and procedures to ensure a supply of drinking water that will comply with the maximum contaminant level (MCL) and the requirements for the minimum quality of water that can be taken into the system (source U.S.EPA, 2022; WHO 2017).

Similarly, the secondary drinking water regulations also defined in the Safe Drinking Water Act (SDWA, 2022) are herein defined as regulations that apply to public water systems which are requisites to protect the public warfare. This simply applies to any contaminant in drinking water which may influence the environment. Also, it applies to the effect of pollutants which can be useful in deriving regulating requirements based on consideration of water quality impacts. They are therefore comparable to the MCLG, as they are not based on technology or cost but on health goals. These standards can be used when the protection of a drinking water source is not the sole objective and they can be applied to water quality based on effluent limitations and toxic pollutant effluent standards.

The term "Maximum Contamination Level (MCL)" refers to the maximum permissible level of a user public water system. These are enforceable standards that are set as close to Maximum Contamination Limit Goals (MCLG) as feasible. These standards are often applied to groundwater that is used for drinking water purposes regardless of whether it is supplied by a public system or a private well. The Maximum Contaminant Level Goal (MCLG) formerly known and addressed as the Recommended Maximum Level Goals (RMCLs) is the maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on the health of persons could occur, which allows for an adequate margin of safety. They are often referred to and usually documented as non-enforceable goals.

Hardware

The following computer hardware were used for this research;

A computer system comprising of a Visual Display Unit (VDU), a keyboard, a mouse and Central Processing Unit (CPU). A Scanner, A Digitizer, A global positioning system device with plugins, printer, photocopier.

Software Packages

The following software packages were used for the work; Marthe, Arc Catalog, Surfer 13.1, Arc GIS 10.2, Arc Map 9.3, ENVI 4.5, Visual Modflow Flex, Visual Bluebird 2.0, Microsoft Excel 2007 Version, Microsoft Access 2007 Version, Microsoft Word 2007 Version.

RESULT AND DISCUSSION

Durov Diagram

The interpretation of the Durov diagram is simply done by visualizing the grouping of samples in the Durov projection. Those originating from similar clusters are assumed to be of the same ionic compositions.

The Durov diagram is generated by making projections of two ternary plots for cations and anions which are perpendicularly drawn unto a square referred to as the Durov projection square. This type of display assists in indicating clusters of samples close to one another in the Durov projection are assumed to have similar compositions of cations and anions.

From the Durov plot of Nworie river samples [Figure 4.4], considering the cation ternary, all the samples fell within the intermediate type water class while a look at the anion ternary, all the samples fell within the chloride type water class. When placed on the DUROV.

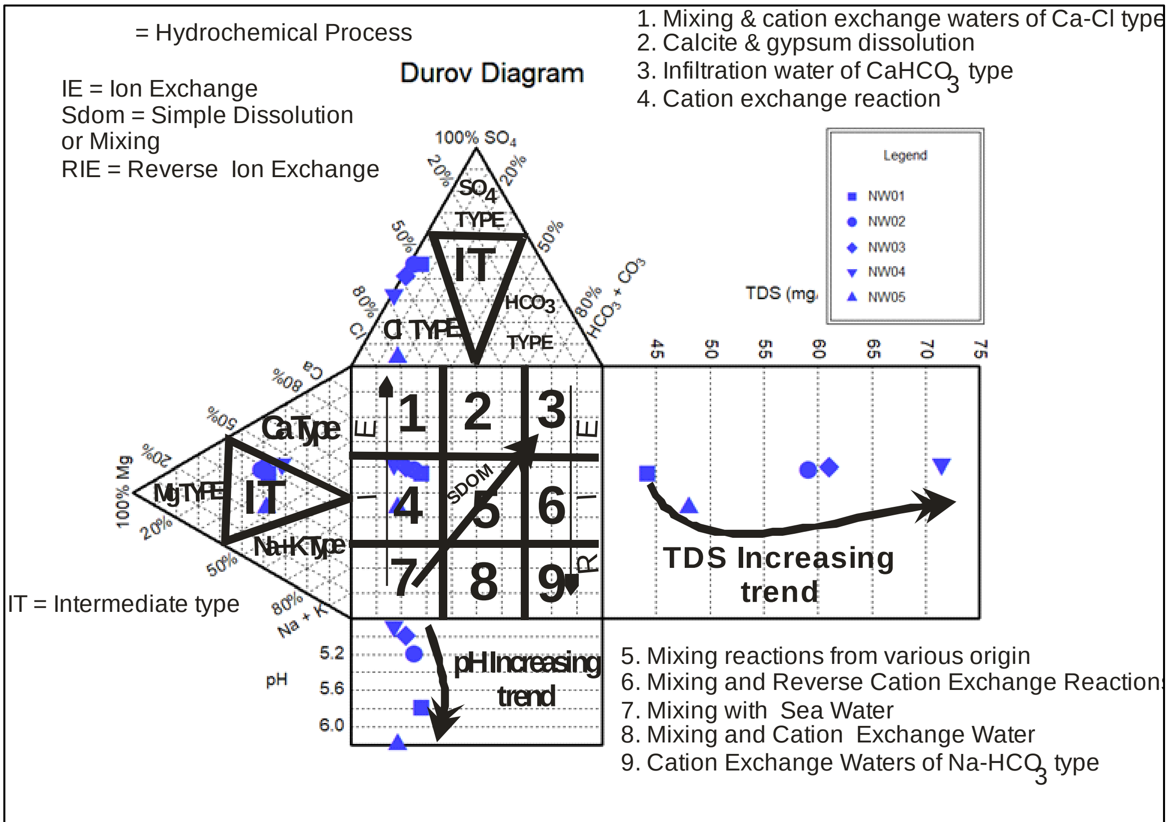

Figure... Durov Plot of Nworie River Samples

Figure 4.1: Durov Plot of Nworie River Samples

Projection square, the entire water samples from Nworie River fell within the 4th square indicating water type that shows preponderance of cation exchange reaction as depicted by pronounced ion exchange as the major hydrochemical process. From the PH adjoining rectangle of the Durov diagram the increasing trend of the Durov diagram the increasing trend of PH of Nworie water samples was observed to follow an arc clockwise increasing trend with NWO4 and NWO5 occupying the two ends of the arc. A closer look at the TDS rectangular subsection of the Durov diagram, a semi-parabolic trend was observed for the increasing TDS character with the NWO4 sample displaying the highest value.

From the Durov diagram of Otamiri River samples [figure…], a closer look at the cation ternary of the diagram shows the majority of the Otamiri water sample plotting within an intermediate.

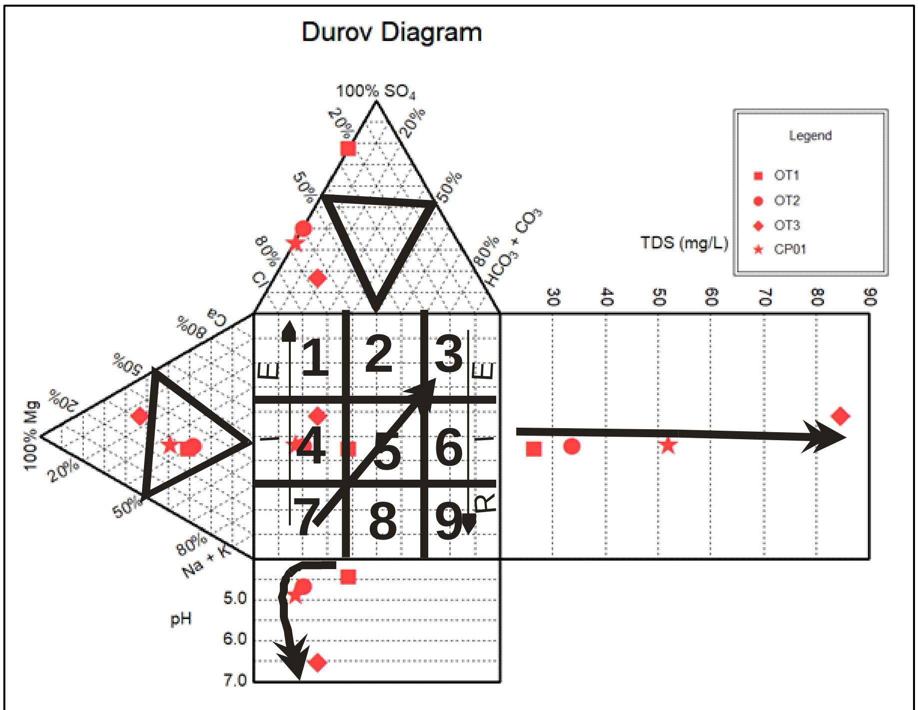

Figure... Durov Plot of Otamiri River Samples

Figure 4.2: Durov Plot of Otamiri River Samples

Section of the diagram except for the OT3 water sample that is plotted within the magnesium-rich type water section.

Also, considering the anion ternary section of the Durov plot, all the samples plot within the chloride-type water except OT1 which is plotted with a rich sub-triangle. A direct projection into the Durov projection square shows all the samples plotting with the 4th sub-square indicating cation exchange reactive water type except OT1 which fell into the 5th sub-square. This indicates a water type that is dominated by simple dissolution or mixing of ionic constituents. This sub-square 5 is characterized by water type of mainly mixing reactions from various origins. The PH rectangular subsection of the Durov diagram shows an arc of anticlockwise increasing pattern with OT1 and OT3 occupying its dual ends. The TDS rectangular subsection of the Durov diagram showed a continuous linear increase in TDS OT1 and OT3 occupying the ends as OT3 displayed the highest value of TDS.

From the DUROV diagram of the post-confluence water samples [figure…], the cation ternary plot showed that all the samples fell within the intermediate water type except ON6 which fell within the sodium plus potassium type water. Similarly, too, a look at the anion ternary showed all the samples fell within the chloride-type water. A plot into the Durov projection displayed all the samples in the 4th square showing a pronounced ionic exchange hydrochemical process typifying cation exchange reaction water facies. Only ON6 plotted within the 7th Durov sub-square indicating a tendency of mixing with seawater.

The PH rectangular section of the Durov diagram indicated a linear increase in the PH values of the post-conference waters samples with ON2 and ON5 samples occupying the ends as ON5 displayed the hyles PH value. From the TDS rectangle of the Durov diagram, an arc was observed trending in the clockwise direction with ON6 and ON2 occupying the ends of the arc as ON2 displayed the highest value of TDS. The Durov plot of the combined water samples is shown in Figure 4.4.

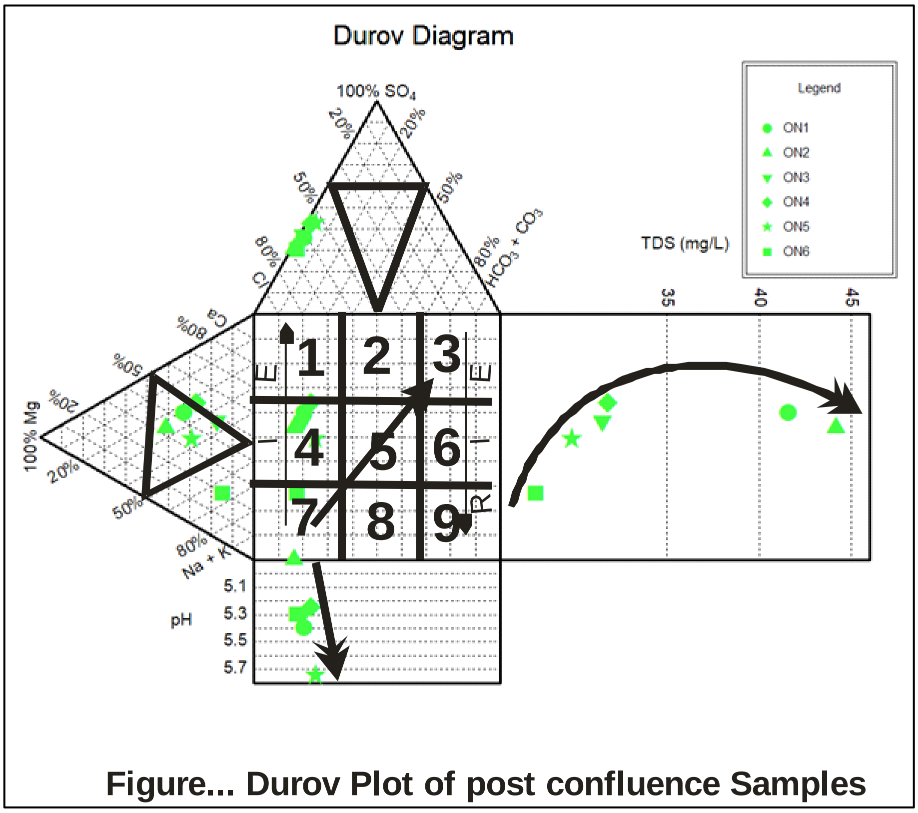

Figure 4.3: Durov Plot of Post Confluence River Samples

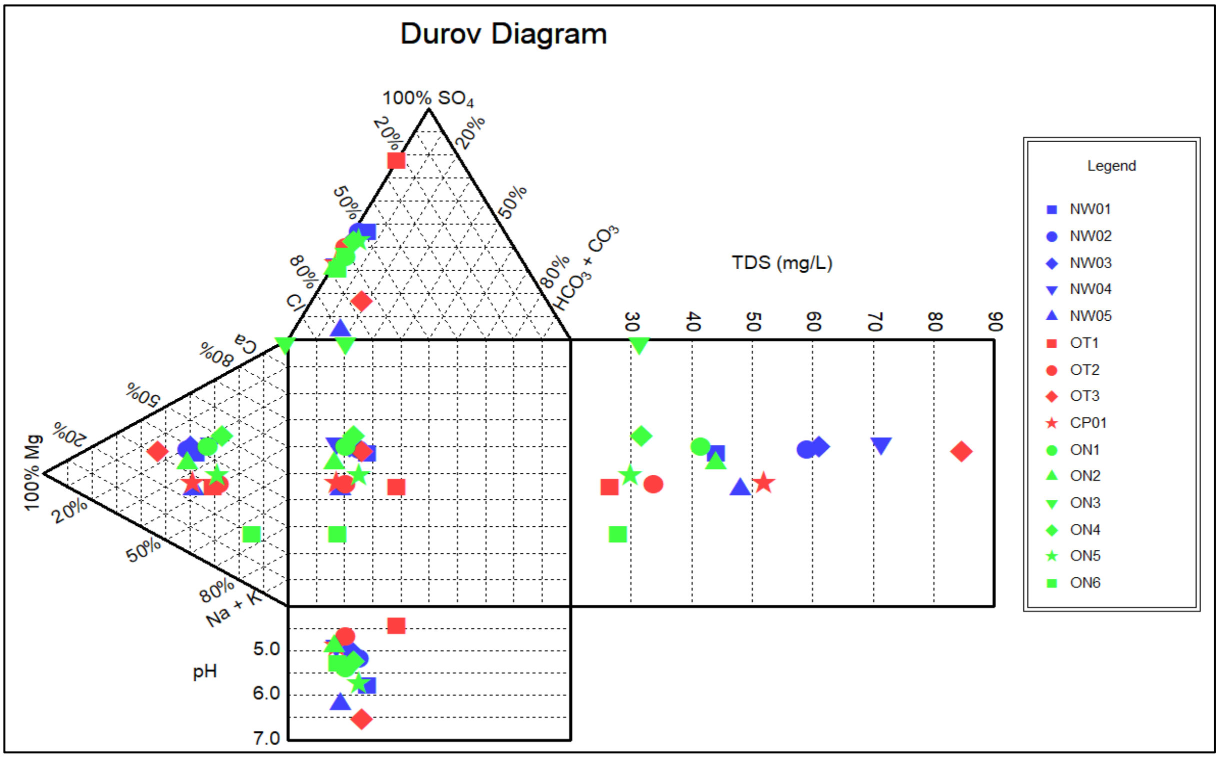

Figure 4.4: Durov Plot of the combined River Samples

DISCUSSION

The Durov diagrams for the Nworie, Otamiri, and post-confluence river water samples reveal distinct hydrochemical characteristics and processes governing the water quality in these regions.

The Durov plot for Nworie River indicates that the water samples predominantly fall into the 4th square, characterized by a cation exchange reaction. This suggests that the water chemistry is primarily influenced by ion exchange processes. The samples in the cation ternary diagram are classified as intermediate-type water, while the anion ternary diagram places them in the chloride-type water class. The pH values of the samples show an increasing trend following an arc, with the samples NWO4 and NWO5 marking the extremes. Similarly, the TDS values exhibit a semi-parabolic trend, with NWO4 having the highest TDS value.

The Otamiri River samples display a similar pattern in the Durov plot, with most samples falling into the 4th square, indicating cation exchange reactions as the dominant hydrochemical process. The cation ternary plot classifies the water mainly as intermediate-type, except for OT3, which falls into the magnesium-rich type. The anion ternary plot classifies the water primarily as chloride-type, except for OT1, which falls into a rich sub-triangle. The pH values form an arc with an anticlockwise increasing pattern, with OT1 and OT3 at the ends. The TDS values show a linear increase, with OT3 having the highest value.

The post-confluence river samples also predominantly fall into the 4th square, indicating cation exchange reactions. The cation ternary plot places all samples in the intermediate-type water class, except ON6, which falls into the sodium plus potassium type. The anion ternary plot classifies the water as chloride-type. ON6 stands out in the 7th sub-square, suggesting mixing with seawater. The pH values show a linear increase, with ON5 having the highest pH. The TDS values form an arc with a clockwise trend, with ON2 displaying the highest TDS value.

CONCLUSION

The analysis of the Durov diagrams for the Nworie, Otamiri, and post-confluence river water samples reveals that the water chemistry is primarily influenced by ion exchange processes, as indicated by the dominance of the 4th square in the Durov plots. This suggests that the water is characterized by a cation exchange reaction, likely due to the interaction of the water with geological formations rich in exchangeable cations. The variations in the cation and anion types among the different rivers and even within the same river system (e.g., the post-confluence samples) indicate the influence of local geological formations, anthropogenic activities, and possibly the mixing of waters from different sources. The presence of samples in different sub-squares, such as the magnesium-rich type in Otamiri (OT3) and sodium plus potassium type in the post-confluence (ON6), highlights the diverse geochemical environments within the region.

The trends in pH and TDS values provide further insights into the hydrochemical processes at play. The arcs and linear trends observed in the pH and TDS diagrams suggest systematic variations in water quality, possibly due to natural geochemical processes, anthropogenic influences, or seasonal changes. Overall, the Durov diagram analysis indicates that the river water in the studied region is subject to significant cation exchange reactions and exhibits diverse hydrochemical characteristics influenced by both natural and anthropogenic factors. Further studies, including isotopic analysis and more detailed chemical characterization, would be beneficial to fully understand the sources and processes affecting the water chemistry in these rivers.

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