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Finding a relationship between physicochemical characteristics and ionic composition of River Nworie, Imo State, Nigeria

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Water has been described as a universal solvent and this is perhaps the strength behind its many uses. Despite this unique property anthropogenic activities along its course and natural factors often determine the composition of water. In the current research the portion of River Nworie having past Owerri town was sampled in the dry season 2017 to determine its ionic composition at predestinated points and to relate such properties to its physicochemical characteristics. Studies relating physicochemical properties and dissolved toxic ions in water could develop a body of knowledge that could enable detection and quantification of potential risk of ions such as heavy metals from natural water to aquatic ecosystem, animal and human health without actually involving aquatic organism, animal and human. Clean sterile plastic bottles were used for collecting surface water. A total of 30 sub-samples from 5 points at 300 m apart were sampled in the morning. Physicochemical properties were determined using standard methods and ionic composition of water was determined according methods of APHA. Results revealed that Ca^{2+} had a mean 23.60±0.67 mg/l and was the highest while K^+ with a mean 0.72±0.30 was the least amongst major cations. Amongst the major anions Cl^- had mean of 31.58±4.47 mg/l while mean of PO_4^{3-} was 1.42±0.13 mg/l. The ionic balance calculate as % balance error showed high values for all sampling sites ranging from 30 to 39.42% indicating that there is massive input from anthropogenic activities. The computed relationships for selected heavy metals, cations and anions revealed that R^2 values were ranging between ±0.012 to 1 indicating some form of relationship existing. The water pH weakly correlated with dissolved cations and anions while moderate with pH only, due to the pH level (5.2-6.2). The cations and anions were more influenced by the water

temperature than the heavy metals. Therefore, high temperature ranges of 31–32.4°C will favour more dissolution of cations and anions in natural water. Cations showed stronger relationship with EC while only heavy metals showed no relationship with DO (Dissolved oxygen). Dissolved oxygen relationship with cations and anions was in the order; $K^+ > Mg^{2+} > Ca^{2+} > Na^+$ while anions was $SO_4^{2-} > NO_3^- > Cl^- > PO_4^{3-}$ respectively. Information here could be used to predict the effects of using this water for various purposes including water for agricultural purpose, in the management of ions polluted waters and also inform on the mitigation process to be taken.

1   **Finding a Relationship between Physicochemical Characteristics and Ionic Composition of**

2   **River Nworie, Imo State, Nigeria**

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9   **Abstract**

10   Water has been described as a universal solvent and this is perhaps the strength behind its many uses. Despite this

11   unique property anthropogenic activities along its course and natural factors often determine the composition of

12   water. In the current research the portion of River Nworie having past Owerri town was sampled in the dry season

13   2017 to determine its ionic composition at predestinated points and to relate such properties to its physicochemical

14   characteristics. Studies relating physicochemical properties and dissolved toxic ions in water could develop a body

15   of knowledge that could enable detection and quantification of potential risk of ions such as heavy metals from

16   natural water to aquatic ecosystem, animal and human health without actually involving aquatic organism, animal

17   and human. Clean sterile plastic bottles were used for collecting surface water. A total of 30 sub-samples from 5

18   points at 300 m apart were sampled in the morning. Physicochemical properties were determined using standard

19   methods and ionic composition of water was determined according methods of APHA. Results revealed that Ca^{2+}

20   had a mean 23.60±0.67 mg/l and was the highest while K^+ with a mean 0.72±0.30 was the least amongst major

21   cations. Amongst the major anions Cl^- had mean of 31.58±4.47 mg/l while mean of PO_4^{3-} was 1.42±0.13 mg/l. The

22   ionic balance calculate as % balance error showed high values for all sampling sites ranging from 30 to 39.42%

23   indicating that there is massive input from anthropogenic activities. The computed relationships for selected heavy

24   metals, cations and anions revealed that R^2 values were ranging between ±0.012 to 1 indicating some form of

25   relationship existing. The water pH weakly correlated with dissolved cations and anions while moderate with pH

26   only, due to the pH level (5.2-6.2). The cations and anions were more influenced by the water temperature than the

27   heavy metals. Therefore, high temperature ranges of 31–32.4°C will favour more dissolution of cations and anions

28   in natural water. Cations showed stronger relationship with EC while only heavy metals showed no relationship with

29   DO (Dissolved oxygen). Dissolved oxygen relationship with cations and anions was in the order; $K^+ > Mg^{2+} > Ca^{2+}$

30    $> Na^+$ while anions was $SO_4^{2-} > NO_3^- > Cl^- > PO_4^{3-}$ respectively. Information here could be used to predict the

31   effects of using this water for various purposes including water for agricultural purpose, in the management of ions

32   polluted waters and also inform on the mitigation process to be taken.

33   **Keywords**: Anions, Anthropogenic, Cations, Correlation, Nutrient loading, Heavy metals, Health effect, Pollution,

34   Water resources, Risk, Regression, Toxicity

35   **1. Introduction**

36   All waters in the environment contain dissolved salts existing in ionic forms. However, some species occur more

37   frequently and at greater concentrations than others. The concentrations of dissolved salts in water are influenced by

38   anthropogenic and natural factors such as industrial and domestic effluents and sewage, agricultural

39   effluents, radioactive wastes, thermal pollution, oil pollution, topography, geology, and inputs through rainwater,

40   water/rock interaction and climate (Verla et. al., 2018; Isiuku and Enyoh, 2019). The occurrence of ions such as

41   cations, heavy metals and anions in excess of natural load is of current concern not only to researchers,

42   governmental and non-governmental organizations. The concern stems from their persistence in the environment

43   and biopersistence when ingested. Therefore, causing damage to ecosystem and posing a serious health threat to the

44   immediate population.

45   The distribution, solubility and mobility of ions in water are of importance to water as a media due to potential

46   toxicity to man, plants and animals (Enyoh et. al., 2017; Isiuku and Enyoh, 2019). The toxicity of dissolved ions

47   such as heavy metals is due to their ability to bind to oxygen, nitrogen, and sulphur groups in proteins, resulting in

48   alterations of enzymatic activity. Most organ/systems are affected by heavy metal toxicity; the most common

49   include the hematopoietic, renal, and cardiovascular organs/systems (Verla et. al., 2019b). Movement and chemical

50   stability of ions in water are controlled by a complex series of biogeochemical processes that depend on

51   physicochemical properties of the water such as pH, temperature, redox potential including adsorption, precipitation

52   and ion exchange reactions in water (Verla et. al., 2017; Enyoh et. al., 2018). Generally, for most metals decreasing

53   pH causes an increase in metal solubility in many forms except metals present in the form of oxyanions or

54   amphoteric species. Studies have shown that metals solubility correlated positively with pH (Enyoh et. al., 2018)

55 and becomes limited at pH range of 5.5 to 6.0 while more distributed at temperature range of 15–35 ∘C (Pérez-

56 Esteban *et al.* 2013, Yang *et al.* 2006, Jing *et al.* 2007; Yuanxing *et. al.*, 2017). Therefore, the distribution, solubility

57 and toxicity of ions in water can be controlled by controlling the physicochemical properties of the water.

58 River system, especially the ones flowing through urban cities is greatly threatened by pollution. Nworie River

59 which flows through Owerri, the capital city of Imo State in South-eastern Nigeria is an example of such river

60 system. Numerous studies have confirmed that the river is polluted by ions such as Cd, Ni, Fe, Hg, As, Co, Cu, Mn,

61 SO_4^{2-}, PO_4^{3-} and NO_3^- (Ukagwu et. al., 2014; Verla et. al., 2019) and without treatment could pose serious health

62 issues to the user. However, study focusing on the distribution of its ionic composition and the relationship with its

63 physicochemical properties is lacking. It is possible to characterize waters by performing a chemical analysis of their

64 ionic composition. Such study reveals the nature of weathering and a variety of other natural and anthropogenic

65 processes. Clearly, the precise chemical composition of the water will depend upon the types of rock and soils with

66 which the water has been in contact and this can be used to characterize particular water by determining its chemical

67 make-up and suggesting pollution problem mitigation strategy. Furthermore, studies focusing on the relationship

68 between physicochemical parameters and ionic compositions of natural water are scarce while laboratory studies

69 have been well conducted. This kind of studies relating physicochemical properties and dissolved toxic ions in water

70 could develop a body of knowledge that could enable detection and quantification of potential risk of ions such as

71 heavy metals from natural water to aquatic ecosystem, animal and human health without actually involving aquatic

72 organism, animal and human.

73 **2.0 Materials and methods**

74 **2.1 Study area**

75 Nworie River is the study area (Figure 1). The river originates from Mbiatolu LGA of Imo State between latitude

76 5∘28N and 5∘31N (Figure 1). It passes through Owerri Municipal of Imo State and then empties into the Otamiri

77 river at Nekede, Owerri West LGA, Imo State. The measured length of the river is approximately 9 kilometers.

78 Photographs showing the decline state and anthropogenic activities of some points along River Nworie are shown in

79 Figures 2A-2D and Table 1 respectively.

80 **2.2 Collection of water sample**

81   A total of 30 sub-samples were collected to make five composite (six subsamples per sampling location) samples.

82   Samples were collected following a 'W' shaped design along the longitudinal course of the river using the grab

83   technique (Verla et. al., 2019). From where the river enters the Owerri municipal to where it leaves. Geographically,

84   the sampling points lies between the latitudes 05.52°N and longitude 07.03°E, NDW1 and NDW2 (Amakohia-

85   Alvan), NDW3 (HolyGhost college), NDW4 (Wetheral) lies between 5.479 °N and longitude 07.027 °E , and

86   NDW5 (river leaving the town) (Figure 1). The water samples were collected during the dry season period. The

87   points of sample collection were at least 300m apart, done in morning against the water current. Clean plastic bottles

88   were used for the collection.

89   **2.3 Analytical procedure of water sample**

90   The electrical conductivity was measured using HANNA HI8733 EC METER in μS/cm, which was calibrated using

91   KCl. The electrical conductivity (EC) probe was dipped into the water sample for 60 seconds and readings were

92   recorded on the meter screen.

93   The pH was determined using JENWAY 3510pH METER which was calibrated using buffer 4 and buffer 7 by

94   dissolving one capsule each in 100 ml of distilled water respectively. The pH was determined by introducing the

95   probe of the pH meter into water sample (collected from a large sample) and the reading on the meter screen was

96   recorded.

97   Dissolved oxygen (DO) concentrations were determined with a Jenway 9071 DO analyzer by inserting the probe

98   into the water samples.

99   TDS (Total Dissolved Solids) and TSS (Total Suspended Solid) (mg/L) was determined according method described

100 by Verla *et al.*, (2018a) while phosphate (PO_4^{3-}), nitrate (NO_3^{2-}), chloride was determined according to American

101 Public Health Association method 4110 (APHA, 2005).

102 **2.4 Determination of heavy metals and macro elements**

103 The water sample was digested using aqua-regia ($HCl+HNO_3$ in ratio 3 to 1). 1 mL of the water sample was digested

104 for 3days in a test tube with 24 mL of aqua-regia (Enyoh et. al., 2018; Verla et. al., 2018; Verla et. al., 2019a). The

105 digested filtrates were used for the total metal quantification of Na, K, Mg, Ca, Mn Pb, Cd, Fe, Zn, and Cu using

106   Atomic Absorption Spectrophotometer (Perkin Elmer AAnalyst 400) in mg/l (ppm). The characteristic wavelengths

107   of metals determined were first set using the hollow cathode lamp, then digested filtrates samples was aspirated

108   directly into the flame. To ensure accuracy of data, calibration of the equipment was done for each element using a

109   standard sample prepared as a control with every set of samples. The instrumental parameters for particular metals

110   that were analysed are presented in table 2. The same procedure was done for all five composite samples.

111   **2.5 Data analysis**

112   The data were analyzed for basic descriptive statistics such minimum, maximum, mean and standard deviation of

113   triplicate analysis and level of significance was determined using Microsoft Excel and IBM SPSS statistics version

114   20. Correlation, Principal Component and linear regression analysis were conducted to establish relationship

115   between physicochemical properties and ionic composition at 5 % level of significance. P-values were considered

116   significant when less than 0.05. To interpret the r-value for the correlation and linear relationship, the following

117   classification was adopted, presented in Table 3. Hierarchical Cluster Analysis (HCA) was used also to find

118   similarities between physicochemical properties and ionic composition.

119   **3.0 Results**

120   **3.1 Surface water characteristics**

121   The surface water characteristics are presented in Table 4. The results are compared with World Health Organization

122   standards permissible limit (WHO, 2007). The mean values of temperature and total dissolved solids (TDS)

123   exceeded the recommended limit. Mean pH (5.62) was below the acceptable range while other physicochemical

124   parameters didn't exceed the permissible limit. However, the highest and lowest temperature was recorded at

125   NDW4 and NDW1 respectively. The overlying water in NDW4 had the highest DO value of 3.89 mg/L and in

126   NDW5 the lowest was recorded (2.27 mg/L). The standard DO expected according to WHO permissible limit

127   (2007) is 4 mg/L, hence suggesting relatively poor water quality of river Nworie.

128   **3.2 Ionic composition and distribution**

129   The results for the ionic compositions and percentage distributions are presented in table 5 and Figure 3. Only

130   calcium, iron, nitrate, phosphate and chloride showed lower mean concentrations when compared to WHO

131   permissible limits (Table 5), all others showed higher mean concentrations. The order of ionic composition was Cl^-

132    $> SO_4^{2-} > Ca^{2+} > Zn^{2+} > Mg^{2+} > NO_3^- > PO_4^{3-} > Na^+ > Mn^{2+} >$ others. Chloride, calcium and zinc showed the highest

133   distributions for anions, cations and heavy metals respectively.

3.3 Ion balancing of River

135   When a water quality sample has been analysed for the major ionic species, one of the most important validation

136   tests can be conducted: the cation-anion balance (HPTM, 1999). The principle of electroneutrality requires that the

137   sum of the positive ions (cations) must equal the sum of the negative ions (anions). Thus the error in a cation-anion

138   balance can be written as (1):

139    $$\% \ Balance \ error = \frac{\sum Cations \ in \ the \ river - \sum Anions \ in \ the \ river}{\sum Cations \ in \ the \ river + \sum anions \ in \ the \ river} \qquad (1)$$

140   The computed cation-anion balance is presented in Figure 4. For surface water, the % error should be less than 10.

141   Here, a balance error ranging from 30 to 39.42 % is recorded for the different sampling point of the river. The high

142   balance errors suggest that major ionic concentrations distributed in river Nworie are not equal (i.e major cations ≠

143   major anions).

3.4. Correlation analysis and Principal component analysis of various ions

145   The result for the Pearson's correlation analysis of various ions in River Nworie is presented in table 6. This model

146   has been used well by many researchers in determining contamination sources for pollutants in the environment

147   (Enyoh *et. al*., 2018; Duru *et. al*., 2017; Verla *et. al.,* 2017; Ibe *et. al.,* 2017). The value of *r* is always between +1

148   and –1. Most ions exhibit strong relationships, suggesting that their presence in the water is from similar

149   anthropogenic source(s).   Strong relationship was exhibited by some of the ions. Cations exhibited strong

150   relationship amongst them. Na further showed strong relationship with some heavy metals (Cu, Cd, Mn and Fe) and

151   anion (PO_4^{3-}). Similar relationships were also exhibited Mg^{2+} and Ca^{2+}. Strong relationship was exhibited between

152   heavy metals amongst them and with Cl^- and PO_4^{3-}, except for Zn. Most anions showed negative relationships

153   except for NO_3^- / SO_4^{2-} (0.54). To determine the precise contamination source(s) of ions as predicted by the

154   correlation analysis; we conducted a principal component analysis following standard procedures (Dragović, et. al.,

155   2008; Franco-Uria et. al., 2009). We used the varimax rotation with Kaiser Normalization because it better

156 explained the possible groups or sources that influence the soil system and maximise the sum of the variance of the

157 factor coefficients (Gotelli & Ellinson, 2013). The factor loadings for heavy metals in the river water are shown in

158 Table 7. Three components were extracted based on eigen value > 1, best described the sources.

3.5 Relationship between water characteristics and dissolved ions

160 In order to establish a relationship between the recorded physicochemical properties and ionic composition of river

161 Nworie, multiple linear regression analysis was conducted. Linear regression is a statistical method used to assess a

162 possible linear association between two continuous variables. The analysis gives out a regression coefficient (R^2

163 value) (Enyoh *et. al.,* 2018). R^2 value reveals the extent of influence of river physicochemical properties on the

164 distribution of ions in the river on the basis of closeness to either -1 or $+1$ to indicate a strong enough linear

165 relationship. The computed relationship for cations, anions and heavy metals are presented in Figures 5-7. All ions

166 showed positive relationships at varying level with the water physicochemical characteristics.

3.6. Hierarchical Cluster analysis

168 The result for Hierarchical cluster analysis (HCA) is presented in Figure 8, most the ions showed similarities with

169 measured physicochemical parameters. Only TDS and EC showed some dissimilarity with iron and sulphate.

4.0 Discussion

4.1. Surface water characteristics

172 Only mean values of temperature and total dissolved solids (TDS) exceeded the recommended limit (Table 2). The

173 characteristics of the river are a reflection of the sampling period. High temperature obtained wasn't surprising due

174 sampling season (dry season). Low values of DO have been reported earlier in other studies (Manila and Frank,

175 2009; Duru and Nwanekwu, 2012; Okoro et. al., 2016; Verla et. al., 2019; Verla et. al., 2019a). These studies related

176 the low DO to human activity, causing enrichment of the surface water with high organic content. Electrical

177 conductivity recorded in this study fell below the acceptable limit (100 µS/cm) set by WHO (2007). The

178 conductivity depends on water temperature and is the measure of water capability to pass electric flow. High

179 temperature may cause high EC. The conductive ions may come from dissolved salts and inorganic materials in the

180 River.

181 **4.2 Ionic composition and distribution**

182 Dissolved salt often exists as ions in solution. The ions can be positive or negative. Ions with a positive charge are

183 called "cations" while negative charge is called an "anion". Going by this definition, heavy metals are cations

184 because they are positively charged. However in this study we classified the ions as major cations, heavy metals

185 (often categorized as secondary constituents) and anions. The major cations studied were sodium, potassium,

186 magnesium and calcium; heavy metals were copper, cadmium, manganese, zinc, iron and lead; while anions were

187 nitrate, sulphate, phosphate and chloride. The results for the ionic compositions are presented in table 4. The major

188 cationic and anionic concentrations were low generally when compared to WHO permissible limit (2007) standard

189 except for magnesium. The magnesium concentration ranges from 1.13 mg/L to 2.78 mg/L as opposed to the WHO

190 permissible limit (2007) standard of 0.5 mg/L. Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) ions are both common in

191 natural waters and both are essential elements for all organisms (Hydrology Project Training Module, 1999). They

192 are responsible for the hardness of natural waters when combined with dissolved materials in the water. WHO

193 reported that hard water has no known adverse health effect (Sengupta, 2013) and could provide an important

194 supplementary contribution to total calcium and magnesium intake (Garlan *et. al.*, 2002). However, prolong

195 consumption of water with high magnesium can cause hypermagnesemia if the consumer have significantly

196 decreased ability to excrete magnesium (Chandra *et. al.*, 2013).

197 All heavy metals except for Fe had mean values exceeding the permissible limit set by WHO (Table 5), which is

198 indicative that the water is polluted by these metals. The concentration of Pb ranged from 0.127 to 0.521 mg/l, Fe

199 ranged from 0.091 to 0.191, Cd ranged from 0.002 to 0.180 mg/l, Cu ranged from 0.13 to 0.79 mg/l, manganese

200 ranged from 0.08 to 1.02 and zinc ranged from 1.2 to 2.63 with mean values of 0.22, 0.13, 0.05, 0.35, 0.41 and 2.25

201 mg/l respectively. The solubility of trace metals in surface waters is predominantly controlled by the water pH, the

202 type and concentration of ligands on which the metal could adsorb, and the oxidation state of the mineral

203 components and the redox environment of the system. Ingestion of metals such as lead (Pb) and cadmium (Cd) may

204 pose great risks to human health by interfering with essential nutrients in the body, possibly causing small increases

205 in blood pressure and damaging the kidney. In addition, they can equally affect aquatic fauna and flora (Isiuku and

206 Enyoh, 2019).

207   The percentages of ions are presented in Figure 3. This distribution is showing the abundance of major ions in river

208   Nworie during dry season. Metal ions and anions highly distributed were calcium (26.07 %), sulphate (26.90 %),

209   chlorine (34.88 %), while sodium, potassium, nitrate, phosphate, zinc were within the range of 1 – 3 %. Other heavy

210   metal ions showed distribution of 0 %. These suggest that the presence of heavy metals in river Nworie during dry

211   season is low in the total composition of ions in the River. The low distribution could probably due to the metals

212   forming complexes with organic materials in the water or they could be in abundance in other forms which can be

213   accessed through chemical speciation (Verla et. al., 2019c).

214   **4.2 Ion balancing of River**

215   The ionic balancing of the river is high (mean balance error of 35.62 %) indicating variable dissolution of ions in the

216   river (Figure 4). The obvious reason could be due to pollution by anthropogenic means through dumping of waste

217   and the river finding itself at the receiving end of an effluent discharge from domestic and industrial sources.

218   Fertilizers from farmlands along river Nworie finds their way into the river through surface run-off and increases the

219   anionic concentrations such as PO_4^{3-} and NO_3^- in the river while major cations might undergo complexometric

220   reactions reducing their concentrations in the water. Anthropogenic activities have been reported to significantly

221   alter ionic concentration in water (Manila and Frank, 2009; Enyoh *et. al*., 2018; Verla *et. al*., 2018; Isiuku and

222   Enyoh, 2019).

223   **4.3. Correlation analysis and Principal component analysis of various ions**

224   The result for the Pearson's correlation analysis of various ions in River Nworie showed many ions showing strong

225   relationships suggesting that their presence in the water is from similar anthropogenic source(s). Some association

226   exhibited by the ions has observed in other water studies (Enyoh *et. al*., 2018; Duru *et. al*., 2017; Verla *et. al.,* 2017;

227   Ibe *et. al.,* 2017). Precise contamination source of ions was determined by PCA. Three components were extracted

228   based on the eigen value greater than 1. The three components cumulatively explained 93.324 % of the total

229   variance and generally indicated an anthropogenic source(s) of the studied ions in the river water (Table 7).

230   According to Liu et. al., (2003), components loadings values of > 0.75, 0.75–0.50, and 0.50–0.30 were classified as

231   "strong", "moderate", and "weak respectively. The PC1 explained 62.424 % of total variance and was found to be

232   strongly and positively correlated to Cd^{2+}, Cu^{2+}, Ca^{2+} , Mn^{2+} , Na^+ , Fe^{2+} , PO_4^{2-} and Mg^{2+} (0.71–0.99). This relates to

233   the artisanal activities, metal processing works in the area and agricultural activities; PC2 explained 16.088 % of

234   total variance and showed moderate to strong positive factor loadings for SO_4^{2-} and Pb (0.65–0.90) which also

235   indicate industrial source, activities of scrap metal dealers, recycling of metals as well as lead-acid accumulators,

236   vehicle emissions in urban areas and agricultural activities in the study area. PC3 explained 14.812 % of total

237   variance and showed strong positive factor loadings for NO_3^- and K^+ (0.72–0.81) which could be attributed to

238   atmospheric deposition and agricultural activities involving the use of fertilizers.

239   **4.4 Relationship between water characteristics and dissolved ions**

240   The computed relationship for cations, anions and heavy metals are presented in Figures 5-7.

241   *4.4.1 Temperature*

242   Different researches have reported different result for temperature effects on metal distribution in water. most

243   studies have been conducted under laboratory conditions. Lourino-Cabana *et al.*, (2014) and Green-Ruiz *et al.*

244   (2008) reported that the distribution of metals changed with temperature variation while also some research reported

245   that the influence of temperature on metal distribution was not evident (Aston *et al.* 2010, Biesuz *et al.* 1998, Zhang

246   *et al.* 2013). Another studies by Echeverrıa *et al.* (2003) and Echeverría *et al.* (2005) found that increased

247   temperature resulted in a higher maximum sorption of metals by minerals. In the current study, the temperature

248   relationship was measured under ambient field/natural conditions. Our results showed that temperature relationship

249   was weakly positive especially with heavy metals distribution with R^2- value < 0.1 (Figure 5). We also observed a

250   strong positive relationship existed with anions such as NO_3^- (0.922) and Cl^- (0.749) (Figure 6) while only K^+

251   (0.379) was more significant for major cations (Figure 5). Haiyan *et. al.*, (2013) reported that at temperature range of

252   4–25°C, there is a weak temperature-dependence of metal distributed. However in this study high temperature

253   ranges of 31–32.4°C were recorded (Table 4), which fell between the temperature ranges of 15-35 °C reported by

254   Yuanxing *et. al.*, (2017), who observed that distribution rates of ions such Zn, Cu, Pb, Cr, and Cd were greater in

255   high temperatures than at low temperature.

256   *4.4.2 pH*

257   Different studies have shown that heavy metals are generally associated with contaminated water (Bouma *et al.,*

258   2003; Lors *et al.*, 2004). Yuanxing *et. al.*, (2017) explains that when pH decreases (< 5), the competition between H^+

259 and the dissolved metals for ligands (e.g., OH^-, CO_3^{2-}, SO_4^{2-}, Cl^-, S_2^- and phosphates) becomes more and more

260 significant thus increasing the mobility of heavy metals (Bouma *et al.,* 2003). This explanation had been supported

261 by many researchers (Butler 2009, Watmough *et al*. 2007, Pérez-Esteban *et al*. 2013, Yang *et al.* 2006, Jing *et al*.

262 2007). However, the low pH instances are very rare in natural environment (Yuanxing *et. al.*, 2017) where pH

263 values cannot be easily controlled. A critical look at figures 5-7 for effects of pH, it would be observed that the

264 relationship was more pronounced with heavy metals especially with Pb (0.785) and Fe (0.342), then major cations

265 followed the order; Ca^{2+} (0.212) > Mg^{2+} (0.080) while generally low with anions (< 0.2). Most of these anions

266 serves as ligands for complex formation with metals and thus could be reason for the poor relationship. Yuanxing *et.*

267 *al*., (2017) in a controlled experiments reported that at low-pH (pH = 4), the distribution of some metals especially

268 Zn in solution was much larger than at high-pH or mid-pH. The pH recorded in our study was 5.2 to 6.2, which

269 could possibly be the reason for general low distribution hence suggesting low pH-dependence.

270 *4.4.3. EC*

271 The effects of EC on ionic distributions are presented in Figures 5-7. The EC showed positive correlations with the

272 ions studied and followed the order; cations (0.28) > anions (0.12) > heavy metals (0.09) respectively. These suggest

273 that EC-dependence for ion distribution was more significant with cations. This however isn't surprising since EC

274 measures electrolytes in water and majorly controlled by cations (especially Ca^{2+}, Mg^{2+} and $Na^{+)}$ and anions which

275 are more soluble than heavy metals.

276 *4.4.4. DO*

277 The effects of DO on the ionic compositions are generally low but positive. However, no effect was recorded for

278 heavy metals in the river with coefficient of zero (0) (Figure 5). Haiyan *et. al*., (2013) in a controlled experiment

279 reported that the release of some heavy metals such as Cu, Pb, and Cr was much faster at DO > 5 mg/L than DO < 5

280 mg/L. Therefore, no effect recorded here on the distribution of studied heavy metals could be due to the low DO

281 (2.78 to 3.89 mg/L) of the river at the time of study. However, the effect of DO on the distribution of major cations

282 followed the order; K^+ (0.753) > Mg^{2+} (0.280) > Ca^{2+} (0.086) > Na^+ (0.020) (Figure 5) while anions followed the

283 order SO_4^{2-} (0.283) > NO_3^- (0.078) > Cl^- (0.032) > PO_4^{3-} (0.004) respectively (Figure 6).

284 *4.4.5. TDS and TSS*

285   The effects of TDS and TSS on ionic compositions are presented in Figures 5-7. The TDS-dependence followed the

286   order; Heavy metals (0.327) > anions (0.057) > cations (0.057), while the TSS-dependence followed the order;

287   anions (0.186) > cations (0.133) > heavy metals (0.100). This could be from the weight of the ions. Heavy metals

288   are heavier (with atomic weights between 63.546 and 200.590) and less dissolved in water when compared to anions

289   and cations.

290   **4.4. Hierarchical Cluster analysis**

291   Hierarchical cluster analysis (HCA) based on Square Euclidian Distance (SED) was carried out to show the

292   similarities and/or dissimilarities between the physicochemical characteristic data and ionic concentrations in the

293   river water. The SED was adopted since it is based on the Euclidian Distance between two observations, which is

294   the square root of the sum of squared distances, thereby increases the importance of large distances, while

295   weakening the importance of small distances. The results obtained from this analysis are presented as dendrogram

296   shown in Figure 8. A dendrogram is a branch diagram that represents the level of relationships or similarity among

297   parameters arranged like the branches of a tree (Ibe et. al., 2019). From figure 8, based on the rescaled distance of

298   cluster combined, it can be seen that most the ions showed similarities with measured physicochemical parameters.

299   Only TDS and EC showed some dissimilarity with iron and sulphate. The similarities exhibited by most parameters

300   further highlighted the relationships existing between the physicochemical and ionic parameters.

301   **5. Conclusion**

302   The study has shown that the physicochemical properties of river water from Nworie river influences ionic

303   composition under ambient natural/field conditions. The presence of ions dissolved in the river water as revealed by

304   the PCA and HCA was from anthropogenic activities including atmospheric deposition, application of fertilizer on

305   nearby farming, artisanal and automechanic activities. The ions showed varying relationship with the water

306   characteristics. The water pH weakly correlated with dissolved cations and anions while moderate with pH only, due

307   to the pH level (5.2-6.2). The cations and anions were more influenced by the water temperature than the heavy

308   metals. Therefore, high temperature ranges of 31–32.4°C will favour more dissolution of cations and anions in

309   natural water. Cations showed stronger relationship with EC while only heavy metals showed no relationship with

310   DO. Dissolved oxygen relationship with cations and anions was in the order; $K^+ > Mg^{2+} > Ca^{2+} > Na^+$ while anions

311   was $SO_4^{2-} > NO_3^- > Cl^- > PO_4^{3-}$ respectively. The TDS and TSS had more influence on heavy metals and anions

312 respectively. All the factors studied in this study merit attention in the management of metals and anions polluted

313 waters and also inform on the mitigation process to be taken.

314 **References**

315 APHA, (2005). Standard Methods for the Examination of Water and Wastewater 18th Edition American Public

316 Health Association, American water Works Association and Water Environment Federation, Washington, DC.

317 Aston, J.E., Apel, W.A., Lee, B.D. & Peyton, B.M. (2010) Effects of cell condition, pH, and temperature on lead,

318 zinc, and copper sorption to Acidithiobacillus caldus strain BC13, Journal of Hazardous Materials, 184(1–3), pp.

319 34–41.

320 Biesuz, R., Pesavento, M., Gonzalo, A. & Valiente, M. (1998) Sorption of proton and heavy metal ions on a

321 macroporous chelating resin with an iminodiacetate active group as a function of temperature, Talanta, 47(1), pp.

322 127–136.

323 Borma L. D. S., Ehrlich M., and Barbosa M. C. (2003). Acidification and release of heavy metals in dredged

324 sediments," Canadian Geotechnical Journal, vol. 40, pp. 1154–1163,.

325 Butler, B.A. (2009) Effect of pH, ionic strength, dissolved organic carbon, time, and particle size on metals release

326 from mine drainage impacted streambed sediments, Water Research, 43(5), 1392–1402.

327 C. Lors, C. Tiffreau, and A. Laboudigue (2004). Effects of bacterial activities on the release of heavy metals from

328 contaminated dredged sediments. Chemosphere, vol. 56, no. 6, pp. 619–630.

329 Chukwuma E, R., Nwokedi, C. L. and Noah, U. T. (2015). Monitoring of metals in Tilapia nilotica tissues, bottom

330 sediments and water from Nworie River and Oguta Lake in Imo State, Nigeria. African Journal of Environmental

331 Science and TechnologyVol. 9(8), pp. 682-690, DOI: 10.5897/AJEST2015.1894

332 Duru, C. E., Okoro, I. P., and Enyoh C. E. (2017). *Quality Assessment of Borehole Water within Orji Mechanic*

333 *Village Using Pollution and Contamination Models*. International Journal of Chemistry, Material and Environmental

334 Research (IJCMER), 4 (3): 123-130.

335   Duru, M. and Nwanekwu, K. (2012). Physicochemical and microbial status of Nworie River, Owerri, Imo State,

336   Nigeria, Asian Journal of Plant Science and Research, 2 (4):433-436.

337   Dragović, S., Mihailović, N., & Gajić, B. (2008). Heavy metals in soils: Distribution, relationship with soil

338   characteristics and radionuclides and multivariate assessment of contamination sources. Chemosphere, 72, 491–495.

339   doi:10.1016/j.chemosphere.2008.02.063

340   Echeverrıa, J., Indurain, J., Churio, E. & Garrido, J. (2003). Simultaneous effect of pH, temperature, ionic strength,

341   and initial concentration on the retention of Ni on illite, Colloids and Surfaces A: Physicochemical and Engineering

342   Aspects, 218(1–3), pp. 175–187.

343   Echeverría, J.C., Zarranz, I., Estella, J. & Garrido, J.J. (2005) Simultaneous effect of pH, temperature, ionic strength,

344   and initial concentration on the retention of lead on illite, Applied Clay Science, 30(2), pp. 103–115.

345   Enyoh, C.E, Ihionu, E.A, Verla, A.W & Ebosie, N.P. (2017). Physicochemical Properties of Palm Oil and Soil from

346   Ihube Community, Okigwe, Imo State, Nigeria. International Letters of Natural Science,Volume 62. Pp 35-49.

347   Enyoh C. E, Verla A. W, Egejuru N. J (2018). *pH Variations and Chemometric Assessment of Borehole Water in*

348   *Orji, Owerri Imo State, Nigeria*. J Environ Anal Chem 5: 238. doi:10.4172/2380-2391.1000238

349   Franco-Uría, A., López-Mateo, C., Roca, E., Fernández-Marcos, M. L. (2009). Source identification of heavy metals

350   in pastureland by multivariate analysis in NW Spain. Journal of Hazardous Materials, 165, 1008–1015.

351   doi:10.1016/j.jhazmat.2008.10.118

352   Gotelli, N. J., and Ellinson, A. M. (2013). Summary for policymakers. In Intergovernmental Panel on Climate

353   Change (Ed.), Climate Change 2013—The physical science basis (2nd ed., Vol. 53, pp. 1–30). Cambridge, MA:

354   Cambridge University Press. doi:10.1017/CBO9781107415324.004

355   HPTM, (1999). Major Ions in water. Hydrology project training module. Training module # WQ – 28: 1-4.

356   cwc.gov.in/main/HP/download/28%20Major%20Ions%20in%20Water.pdf

357   Ibe, F.C., Isiukwu, B.O. & Enyoh, C. E. (2017). Trace metals analysis of soil and edible plant leaves from

358   abandoned municipal waste dumpsite in Owerri, Imo state, Nigeria. World News of Natural Sciences (WNOFNS)

359   volume 13. Pp 27-42.

360   Ibe Francis Chizoruo, Alexander Iheanyichukwu Opara , Chidi Edbert Duru , Isiuku Beniah Obinna, Margaret

361   Chinyelu Enedoh (2019). Statistical analysis of atmospheric pollutant concentrations in parts of Imo State,

362   Southeastern Nigeria, Scientific African, doi: https://doi.org/10.1016/j.sciaf.2019.e00237

363   Isiuku B.O. and Enyoh C.E. (2019). Water pollution by heavy metal and organic pollutants: Brief review of sources,

364   effects and progress on remediation with aquatic plants. Methods in Environmental Chemistry Journal, 2: 5-38.

365   https://doi.org/10.24200/amecj

366   Jing, Y.D., He, Z.L. & Yang, X.E. (2007) Effects of pH, organic acids, and competitive cations on mercury

367   desorption in soils, Chemosphere, 69(10),1662–1669

368   Lenntech (2018). Zinc – Zn; Chemical properties of zinc, Health effects of zinc and Environmental effects of zinc.

369   Accessed 24/06/2018 via https://www.lenntech.com/periodic/elements/zn.htm

370   Liu, C. W., Lin, K. H., and Kuo, Y. M. (2003). Application of factor analysis in the assessment of groundwater

371   quality in a blackfoot disease area in Taiwan. Science of The Total Environment, 313, 77–89.

372   https://doi.org/10.1016/S0048-9697(02)00683-6

373   Lourino-Cabana, B., Billon, G., Lesven, L., Sabbe, K., Gillan, D.C., Gao, Y., Leermakers, M. & Baeyens, W. (2014)

374   Monthly variation of trace metals in North Sea sediments. From experimental data to modeling calculations, Marine

375   Pollution Bulletin, 87(1–2), pp. 237–246.

376   Manila P.M.; Frank O.M., (2009). The chemical analysis of the water and sediments of Nworie river in Owerri, Imo

377   State, J. Chem. Soc. Nig., 34(2): 94–100

378   Okoro, B. C., Uzoukwu, R. A. and Ademe, C. K. (2016). Investigation of surface water quality in owerri

379   municipal, imo state, Nigeria for human consumption, ARPN Journal of Engineering and Applied Sciences, vol 11,

380   no 13.

381   Pérez-Esteban, J., Escolástico, C., Moliner, A. & Masaguer, A. (2013) Chemical speciation and mobilization of

382   copper and zinc in naturally contaminated mine soils with citric and tartaric acids, Chemosphere, 90(2), 276–283.

383   Ukagwu, J.I; Onuoha, G.U.C; Asonye, N.C and Ojulam, G.C (2014). Water Quality Characteristics Of Nworie River

384   For Fish Survival: A Wet Season Study. International Journal of Science, Environment and Technology, 3(5), 1817

385   – 1825.

386   Verla A.W., E.N. Verla, C. MedoAjero, K. ChiomaLele, N.O. Stellamarris, C.E. Ebere. (2019b). Biomonitoring of

387   Heavy Metals in Blood and Urine of African Children from Owerri Metropolis. *Eastern Nigeria. Journal of*

388   *Chemical Health Risks*,vol. 9(1), pp. 11-26.

389   Verla A.W., E.N. Verla, C.E. Amaobi, C.E. Ebere. (2018). Water Pollution Scenario at River Uramurukwa Flowing

390   Through Owerri Metropolis, Imo State, Nigeria. *International Journal of Applied Scientific Research* (IJASR), vol.

391   3(3), pp. 40-46.

392   Verla A.W., E.N. Verla, C.E. Enyoh, K. Leizou, N.O. Peter (2019).   Using physicochemical properties in

393   assessment of river water for consumption and irrigation in Nigeria, Eurasian J. of Anal. Chem. Accepted

394   manuscript.

395   Verla Andrew Wirnkor, Enyoh Christian Ebere, Verla Evelyn Ngozi, Peter Ndu Okeke, Shirish S. Pingale (2019a).

396   Chemometric Assessment of Orashi River after Confluence with Oguta Lake. Indones. J. Fundam. Appl. Chem.,

397   4(3), 91-103. https://10.24845/ijfac.v4i3.91

398   Verla Evelyn Ngozi, Verla Andrew Wirnkor, Osisi Adaku Felicia, Okeke Peter Ndu, Enyoh Christian Ebere

399   (2019c). Finding a relationship between mobility factors of selected heavy metals and soil particle size in soils from

400   children's playgrounds. Environ Monit Assess, 191(742):1-11. https://doi.org/10.1007/s10661-019-7937-7

401   Verla, E.N., Verla, A. W.& Enyoh, C. E. (2017). *Pollution Assessment Models Of Soils In Portharcourt City, Rivers*

402   *State, Nigeria.* World News of Natural Sciences (WNOFNS) volume 12. Pp 1-23.

403   Watmough, S.A., Eimers, M.C. & Dillon, P.J. (2007) Manganese cycling in central Ontario forests: Response to soil

404   acidification, Applied Geochemistry, 22(6), 1241–1247.

405   WHO (2007). Guideline for Drinking Water quality (electronic Resource). Incorporating first Addendum 1,

406   Recommendations 3rd. http://www.whglibdoc.who.int/publications/2007/9241546- 964.eng.pd

407   Yang, J.Y., Yang, X.E., He, Z.L., Li, T.Q., Shentu, J.L. & Stoffella, P.J. (2006). Effects of pH, organic acids, and

408   inorganic ions on lead desorption from soils. Environmental Pollution, 143(1), pp. 9–15

409   Zhang, D., Lee, D.-J. & Pan, X. (2013) Desorption of Hg(II) and Sb(V) on extracellular polymeric substances:

410   Effects of pH, EDTA, Ca(II) and temperature shocks, Bioresource Technology, 128(0), pp. 711–715.

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The Effects of Pesticides Mixture on Aquatic Organisms in Thailand Classification system for the correlation and linear regression analysis

Table 1: The description and activities carried out within the study area

Sampling points	Major Landmark	Human activity	Vegetation	Extent of Human destruction of Natural ecosystem
NDW1	Fly-over bridge	Road expansion/construction, waste dumpsites, automechanic activities	Grassland and patches of dead grass.	*****
NDW2	Fly-over bridge	Road expansion/construction, waste dumpsites and automechanic activities	Grassland and patches of dead grass.	*****
NDW3	Bridge	Road expansion/construction, waste dumpsites and automechanic activities	Shrubs	****
NDW4	Bridge, Mbari Kitchen restaurant and Umezurike Hospital	Road expansion/construction waste dumpsites, Dredging, sand mining and automechanic activities	Shrubs	*****
NDW5	Bridge and Emmanuel college	Road expansion/construction waste dumpsites and automechanic activities	Shrubs	*****

2   ***** means Very severe, **** means Severe.

The Effects of Pesticides Mixture on Aquatic Organisms in Thailand Characteristics of River Nworie

RAW DATA

Table 2. Optimal Instrumental parameters for AAS determination of the metals

Metal symbols	Wavelength (nm)	Spectral Band Width (nm)	Flame gases	Time of measurement (secs)	Atomization flow rate (L/min)
Ca	422.7	0.7	Air-Acetylene	4	1.2
K	766.5	0.7	Air-Acetylene	4	1.2
Mg	285.2	0.7	Air-Acetylene	4	1.1
Na	589.0	0.2	Air-Acetylene	4	1.2
Pb	283.3	0.7	Air-Acetylene	4	0.9
Cu	324.8	0.7	Air-Acetylene	4	0.9
Fe	248.3	0.2	Air-Acetylene	4	0.9
Mn	279.5	0.2	Air-Acetylene	4	0.9
Zn	213.9	0.7	Air-Acetylene	4	0.9
Cd	228.8	0.7	Air-Acetylene	4	0.9

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The Effects of Pesticides Mixture on Aquatic Organisms in Thailand Ionic composition of water from Nworie in the dry season

RAW DATA

1 **Table 3. Classification system for the correlation and linear regression analysis**

R^2-value	Indication
-1	A perfect negative linear relationship; dissimilar source of contamination
≥ -0.70	A strong negative linear relationship; dissimilar source of contamination
≥ -0.50	A moderate negative relationship; dissimilar source of contamination
≥ -0.30	A weak negative linear relationship; dissimilar source of contamination
0	No linear relationship
≥ 0.30	A weak positive linear relationship; similar source of contamination
≥ 0.50	A moderate positive relationship; similar source of contamination
≥ 0.70	A strong positive linear relationship; similar source of contamination
+1	A perfect positive linear relationship; similar source of contamination

Chemistry Journals

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correlation

1   Table 4. Characteristics of River Nworie

Parameters	NDW1	NDW2	NDW3	NDW4	NDW5	WHO (2007)	Max	Min	Mean	SDV
Temp (^{o}C)	31	32	32	32.4	32	20-30	32.4	31	31.88	0.55
pH	5.61	5.48	6.2	5.59	5.2	6.5-9.0	6.2	5.2	5.62	0.37
EC (μS/cm)	90	91	92	92	97	100	97	90	92.40	2.70
DO (mg/L)	2.78	2.98	2.85	3.89	2.27	4	3.89	2.27	2.95	0.59
TDS (mg/L)	123.94	123.84	143.78	122	123.98	250	143.78	122	127.51	9.13
TSS (mg/L)	87.74	86.64	96.74	96.43	87.44	50	96.74	86.64	90.99	5.12

2   *EC-Electrical conductivity, DO-Dissolved Oxygen, TDS-Total Dissolved Solids, TSS-Total Suspended
3   solids

Table

1   Table 5. Ionic composition of water from Nworie in the dry season

Ions	NDW1	NDW2	NDW3	NDW4	NDW5	WHO (2007)	Max	Min	Mean	SDV
Major cations										
Na^+(mg/L)	1.33	1.673	1.37	1.30	1.37	N/A	1.673	1.3	1.41	0.15
K^+(mg/L)	0.89	0.791	0.898	0.189	0.819	N/A	0.898	0.189	0.72	0.30
Mg^{2+}(mg/L)	2.23	2.78	2.27	2.22	1.13	0.5	2.78	1.13	2.13	0.60
Ca^{2+} (mg/L)	23.2	24.6	23.8	23.5	22.92	70	24.6	22.92	23.60	0.67
Heavy metals										
Cu (mg/L)	0.13	0.79	0.53	0.15	0.13	0.3	0.79	0.13	0.35	0.30
Cd (mg/L)	0.002	0.180	0.072	0.006	0.012	0.003	0.18	0.002	0.05	0.08
Mn (mg/L)	0.08	1.02	0.78	0.085	0.089	0.4	1.02	0.08	0.41	0.45
Zn (mg/L)	2.6	1.2	2.21	2.61	2.63	<0.1	2.63	1.2	2.25	0.61
Fe (mg/L)	0.097	0.19	0.191	0.097	0.091	0.3	0.191	0.091	0.13	0.05
Pb (mg/L)	0.127	0.178	0.521	0.123	0.127	0.01	0.521	0.123	0.22	0.17
Major anion										
NO_3^- (mg/L)	1.96	1.91	1.92	1.91	1.916	10	1.96	1.91	1.92	0.02
SO_4^{2-}(mg/L)	24.8	23.4	24.8	23.98	24.8	250	24.8	23.4	24.36	0.64
PO_4^{3-} (mg/L)	1.37	1.65	1.36	1.34	1.37	5	1.65	1.34	1.42	0.13
Cl^- (mg/L)	24.15	32.24	36.19	33.16	32.18	250	36.19	24.15	31.58	4.47

2   *WHO=World Health Organization

Correlation table

Table 6. Correlation matrix of various ions in River Nworie

	Na$^+$	K$^+$	Mg^{2+}	Ca^{2+}	Cu	Cd	Mn	Zn	Fe	Pb	NO$_3^-$	SO$_4^{2-}$	PO$_4^{3-}$	Cl$^-$
Na$^+$	1													
K$^+$	0.291	1												
Mg^{2+}	**0.515**	-0.081	1											
Ca^{2+}	**0.834**	0.032	**0.838**	1										
Cu	**0.864**	0.306	**0.675**	**0.942**	1									
Cd	**0.953**	0.272	**0.638**	**0.938**	**0.975**	1								
Mn	**0.805**	0.357	**0.643**	**0.907**	**0.992**	**0.941**	1							
Zn	**-0.968**	-0.240	**-0.676**	**-0.942**	**-0.951**	**-0.993**	**-0.907**	1						
Fe	**0.671**	0.371	**0.635**	**0.850**	**0.949**	**0.856**	**0.979**	**-0.808**	1					
Pb	-0.012	0.374	0.215	0.289	0.462	0.259	**0.567**	-0.167	**0.715**	1				
NO$_3^-$	-0.359	0.439	0.013	-0.411	-0.405	-0.424	-0.386	0.377	-0.338	-0.130	1			
SO$_4^{2-}$	**-0.726**	0.431	**-0.640**	**-0.789**	**-0.596**	**-0.700**	**-0.502**	**0.747**	-0.371	0.288	0.544	1		
PO$_4^{3-}$	**0.989**	0.223	**0.568**	**0.831**	**0.818**	**0.923**	**0.745**	**-0.954**	**0.602**	-0.119	-0.298	**-0.780**	1	
Cl$^-$	0.143	-0.220	-0.012	0.345	0.429	0.334	0.475	-0.245	**0.524**	**0.598**	**-0.858**	-0.193	0.039	1

2 *Bold numbers are significant at 5 %.

PCA table

1   **Table 7. Principal Component Matrix using varimax rotation of ions in the river water**

Parameter	Principal Component		
	PC1	**PC2**	**PC3**
Cd^{2+}	.990	-	-
Cu^{2+}	.985	.166	-
Zn^{2+}	-.978	.119	-.147
Ca^{2+}	.975	-	-
Mn^{2+}	.958	.285	-
Na^+	.901	-.223	.223
Fe^{2+}	.894	.427	-
PO_4^{2-}	.873	-.343	.264
SO_4^{2-}	-.726	.647	.215
Mg^{2+}	.711	-.158	.161
Pb^{2+}	.329	.904	-.160
NO_3^-	-.506	-	.814
Cl^-	.406	.404	-.804
K^+	.173	.579	.718
Eigen value	8.739	2.252	2.074
% Variance	62.424	16.088	14.812
% Cumulative	62.424	78.512	93.324

3   .

Figure 1

Map showing Nworie River (Chukwuma et. al., 2015 with slight modification)
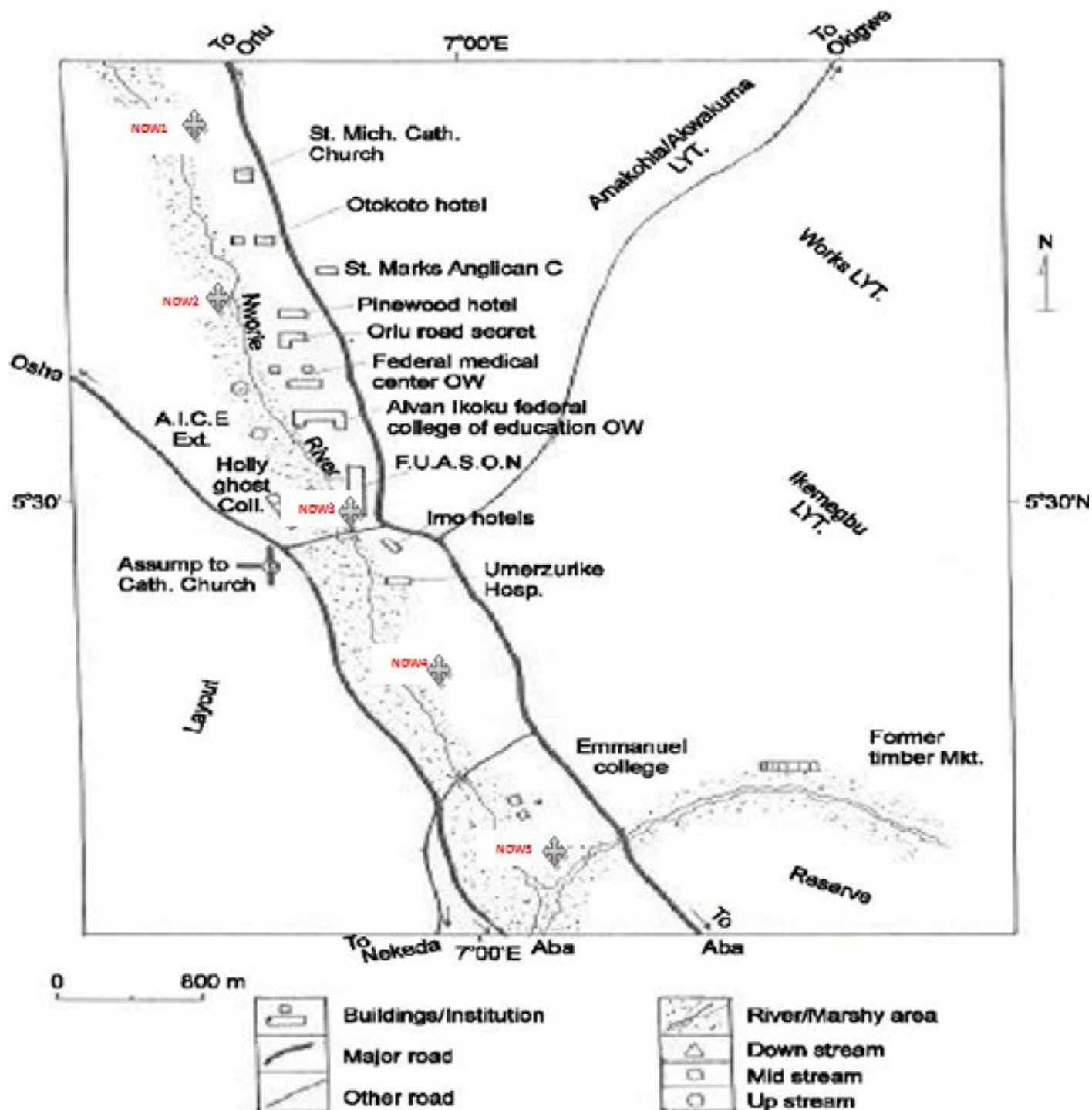
Figure 2

Photographs of some points along River Nworie

(A)

(B)

(C)

(D)

Figure 3

Ionic distribution in river Nworie

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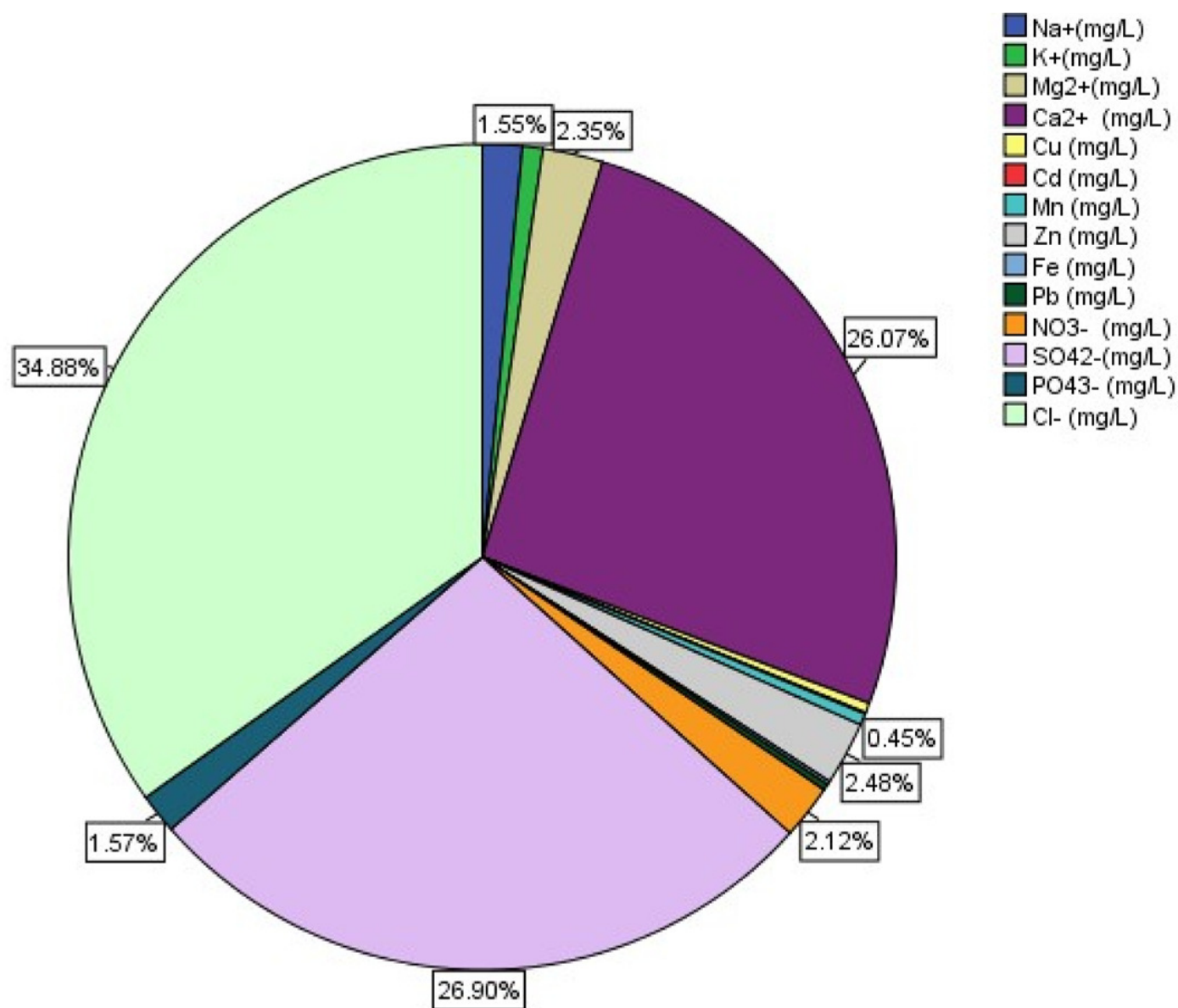
Figure 4

Computed ion balance error at the different sampling points of river Nworie
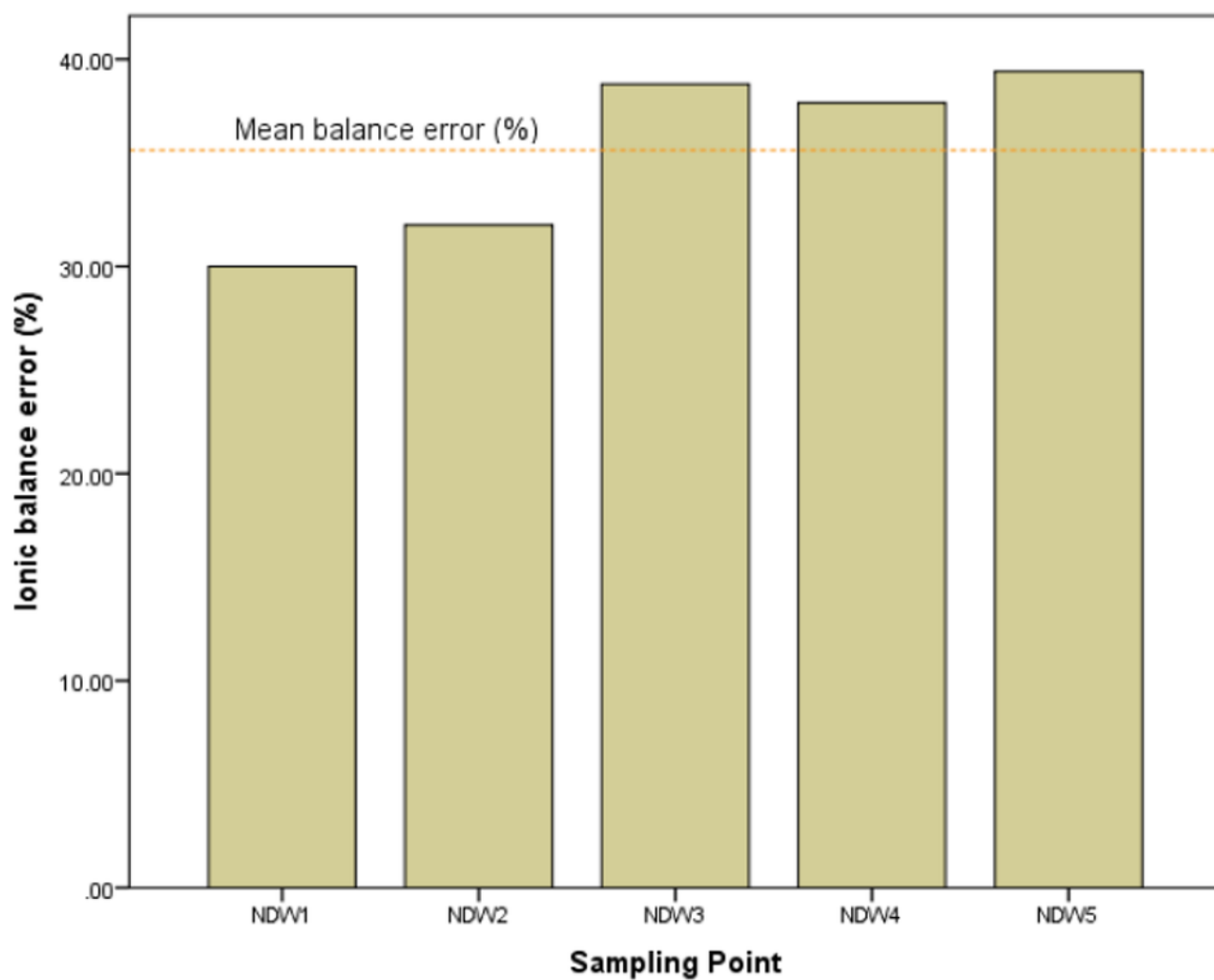
Figure 5

Relationship between cations and water characteristics of river Nworie
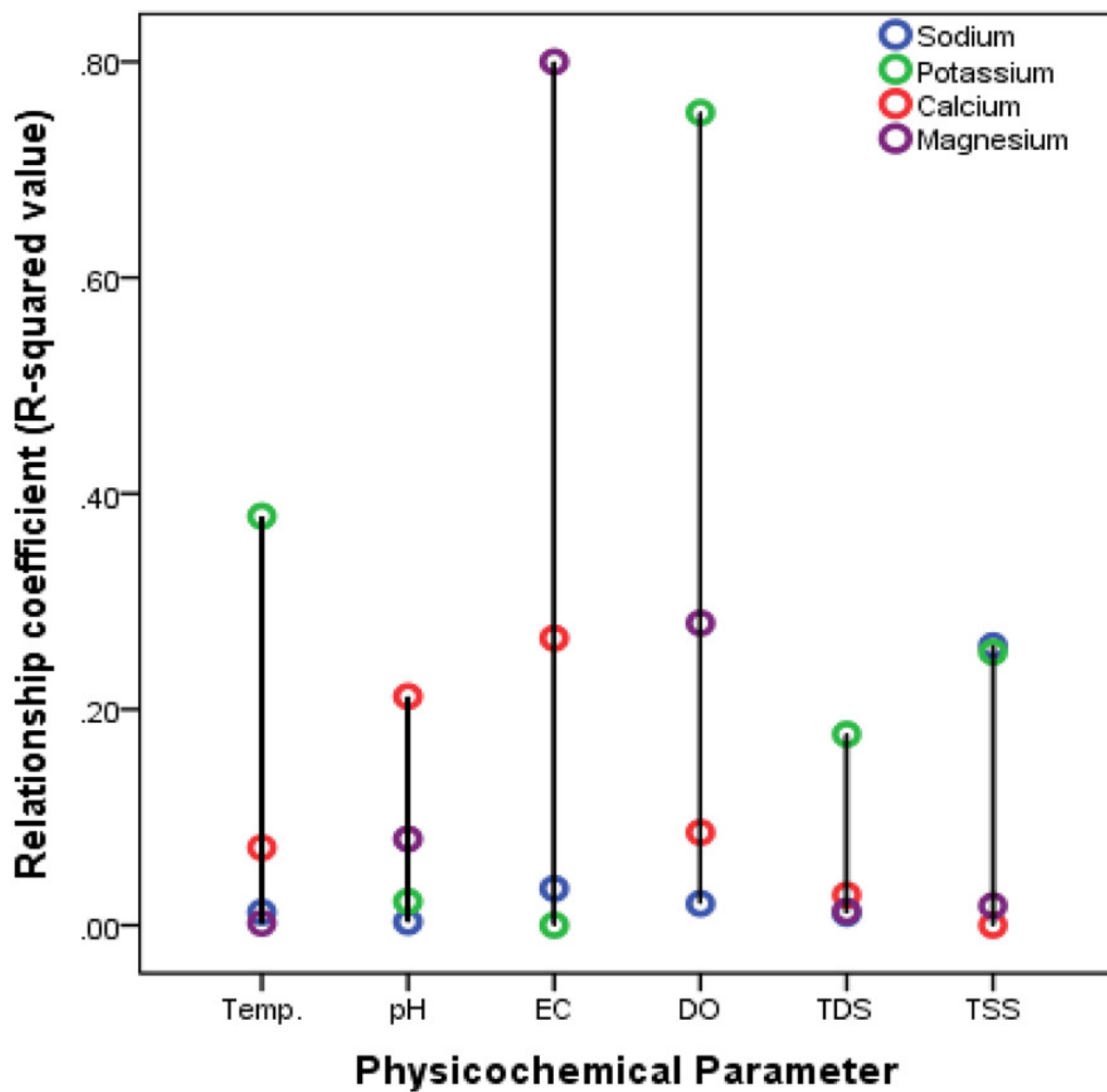
Figure 6

Relationship between Anions and water characteristics of river Nworie
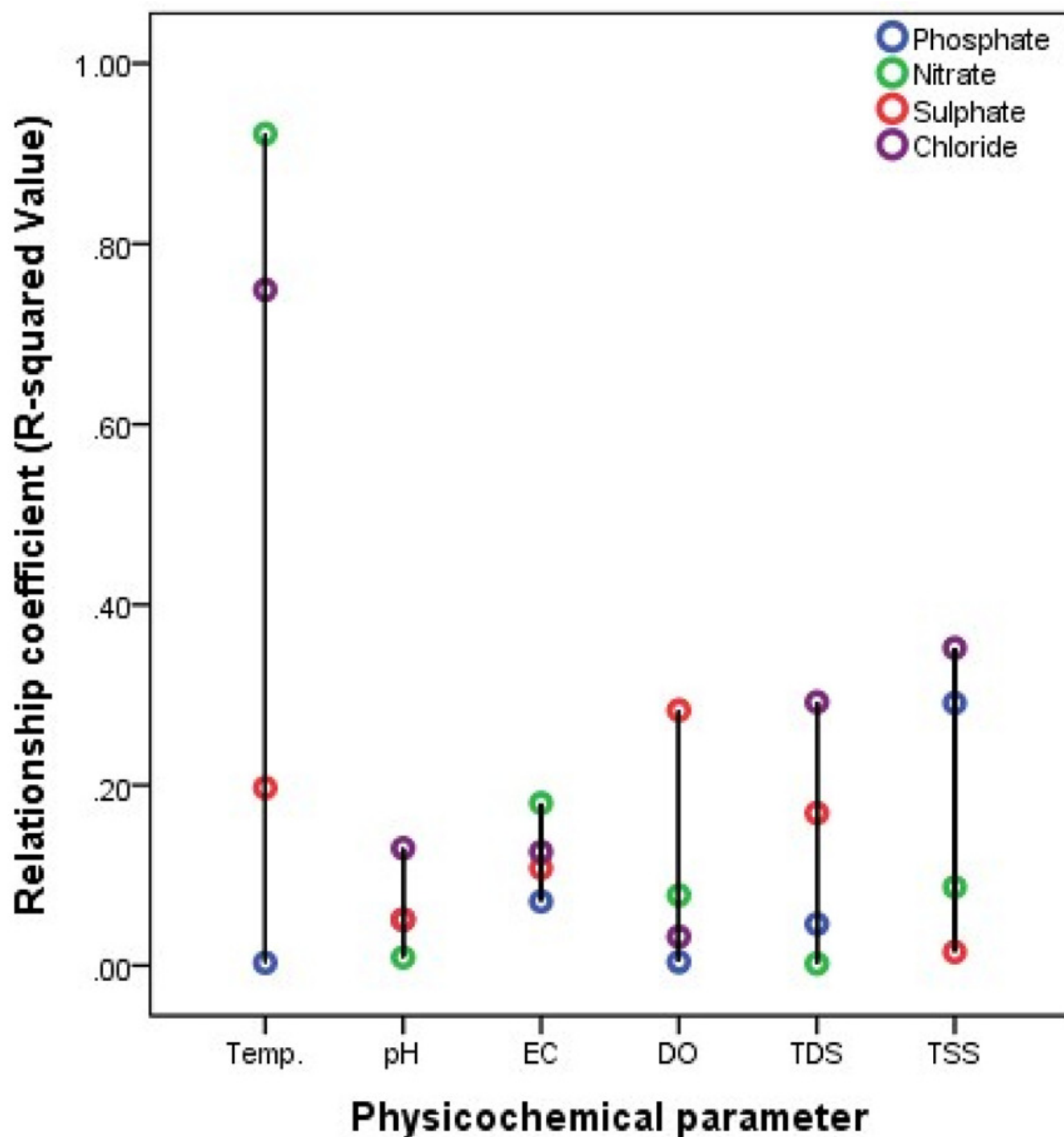
Figure 7

Relationship between heavy metals and water characteristics of river Nworie
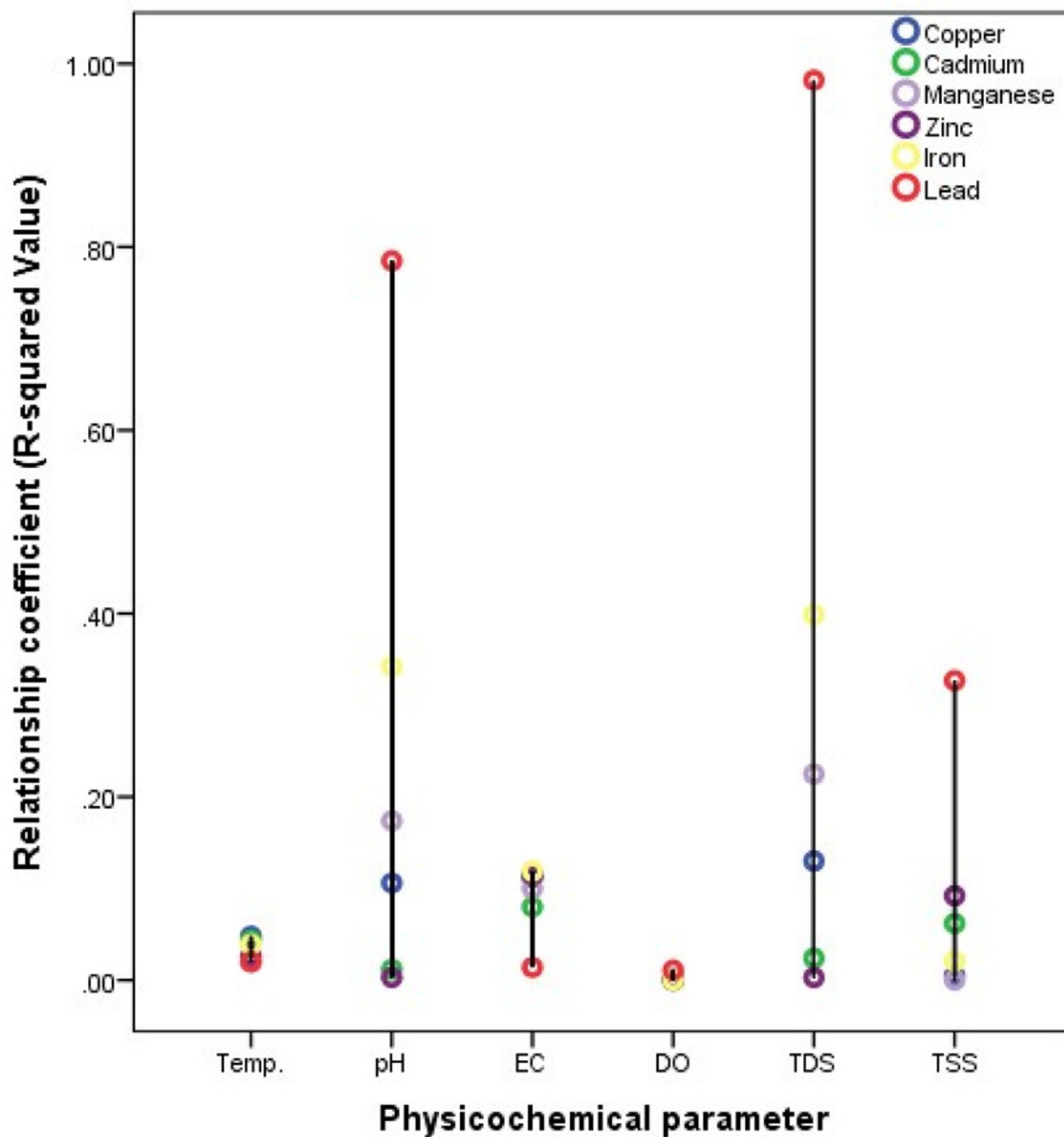
Figure 8

Dendrogram of physicochemical and ionic properties