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Water Quality Index (WQI) Assessment along Inland Fresh Waters of Taylor Creek in Bayelsa State, Nigeria

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Abstract

The overall water quality status of Taylor Creek was determined using water quality index. The river course was characterized by human activities such as artisanal dredging, fish farming, waste dumpsites and farmlands amongst other influences. Samples were collected in the dry season month of December 2018 at two points each across five stations. A total of ten surface water samples were analysed for physicochemical parameters using APHA standard procedures. The assessed water quality parameters depicted the ranges: 73.00 – 79.00 µs/cm EC, 40.20 – 43.65 mg/l TDS, 5.85 – 6.20 pH, 7.00 – 8.00 mg/l TA, 12.00 – 16.50 mg/l TH, 2.10 - 2.73 mg/l Ca, 0.58 – 1.07 mg/l Mg, 6.20 – 8.50 mg/l DO, 16.50 – 24.74 mg/l Cl^-, 3.00 – 3.60 mg/l NO_3^- and 0.50 – 1.71 mg/l BOD_5. Only two water parameters depicted significant difference ($P<0.05$) with the trend: Ca < BOD_5 while significant variation ($P<0.05$) among sample locations revealed the trend: Ogboloma > Okolobiri > Obunagha = Koroama > Polaku. EC showed strong positive correlation with TDS while NO_3^- showed the most positive correlation; its positive correlations with pH, TA, Cl^-, DO and BOD depicts it as an important water quality indicator. Deterioration in water quality status depicted the trend: Koroama < Obunagha < Polaku < Ogboloma < Okolobiri. WQI assessment showed that the water environment was of poor quality which may portend adverse health risks to members of the public who consume it. Consequently, the Creek should be monitored regularly to evaluate trends, establish baseline information and guide against pollution-encroaching activities.

Keywords: Taylor creek, dissolved oxygen (DO), American Public Health Association (APHA), biochemical oxygen demand (BOD), nitrate (NO_3^-)

1 Introduction

Taylor Creek is a non-tidal fresh water environment located in Gbarain clan in Yenagoa Local Government area of Bayelsa State. The creek stretches 16 km north, north east (NNE) of the state capital (Yenagoa) [30]. The geographical coordinates lie within the latitudes 5° 01' to 5° 03' N and longitudes 006° 16' and 006° 20' E and is bound by neighbouring settlements such as Polaku, Koroama, Obunagha, Okolobiri and Ogoloma amongst others. The Taylor Creek is an estuary of the Nun River which enters its course from Polaku community [11, 40] and is home to the Etelebou flow station and Gbarain-Ubie gas plant [14]. The inland creek also receives municipal and agricultural run-offs from waste dumps along the creek line and cultivated farmlands sloping downhill into the waterways.

Ecosystem continues to be ravaged by the numerous oil and gas related installations including flow stations, oil well heads, loading terminals, tank farms [20], and oil pipelines [5-6]. Rivers are often recipients of municipal wastes, human sewage, abattoir effluent and industrial discharges. Streams and rivers most burdened by anthropogenic inputs are those which stretch across areas of notable human pressure which may include farmlands, industries, coastal and metropolitan areas [3, 7, 9]. Most often, rivers serve as fish farms and water source for indigenous residents. Hence, the direct or indirect contamination may be detrimental to the health of those who consume it [4, 27-28], or use it for farm irrigation and recreational (swimming) purposes.

Across the globe, clean water remains a daily and indispensable requirement for everyone and for all communities. Provision of clean portable water for drinking, industrial applications and farm management has become a major source of worry for governments [3, 10, 34], while polluted environments have been observed to portend deleterious effects on human health, fauna and flora species [8-10, 27, 36]. Developing countries are mostly affected by cases of child death resulting from water related diseases [18]. For instance, the potential of water resources in Nigeria is poorly developed and exploited, leading to shortage in clean water supply as against its enormous demand for multipurpose uses. Point sources of water pollution include wastes from human settlements, commercial (boat transport and local

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sand dredging), petroleum industry and precipitation of atmospheric pollutants while non-point sources of water pollution include run-off from agricultural lands treated with fertilizers and pesticides which cause nutrient enrichment and eutrophication of surface waters [22]. Inter-community boat transport and local sand dredging activities were established at the Polaku jetty while the inland shores of the Creek stretching across the other communities showed patches of municipal dumpsites on one end with continuous agricultural farmlands across the creek line.

Even though variations may exist from country to country; global water use pattern has been depicted as: irrigation 73%, industrial uses 21% and public use 6%. Water use is estimated at about 40% industrial use in developed countries while an overwhelming bulk of water is applied through irrigation in developing countries. Water is used in Nigeria for agricultural food supply (as irrigation medium amongst numerous other applications), industrial activities, health care, environmental sanitation, transportation and recreation. Whereas ground water sources are responsible for over 70% of water use in northern Nigeria, the relative proportion of water use in the southern parts has been estimated at about 40 to 50% ground to surface water [22].

Consistent quantitative and qualitative evaluation of the physical and chemical parameters of surface water bodies is essential to identifying alterations in the quality of water, especially along inland creeks and rivers that receive municipal run-offs and industrial effluents. Adequate information on the physicochemical characteristics of the water body may aid in its management and conservation [7, 29]. Water quality parameters have been used to determine the overall quality of water across the globe [10, 16, 26, 37). These physicochemical parameters are compared with their respective regulatory standardization limits to generate a single value which depicts the quality status of a water source. Water quality index (WQI) calculation is preceded by the choice of physicochemical parameters, calculation of sub-indices, assignment of parametric weights and summation of sub-indices to determine an overall index [10, 16]. WQI serves the purpose of reflecting the combined influence of different water quality parameters for determining water quality status. Also, it is an indication of water quality wherein index numbers are used to represent overall water quality and its most suitable use. The application of this index is useful for identifying space and time dynamics in the quality of water; it also uses simple terms (such as: excellent, good, poor, very poor, etc) to classify water quality. The indices is one of the most simplified methods of communicating water quality classification to the general public or those in authority [10, 28, 33].

Several authors have applied water quality index (WQI) in different water sources across the Niger Delta region of Nigeria. [12, 21, 24-25, 28, 31, 42] amongst others had previously evaluated the water quality status of different rivers across the Niger Delta region of Nigeria. Also, [1, 24, 41, 43] amongst others assessed underground water WQI in the region.

This study is aimed at using water quality index (WQI) to identify the changes in water quality status of inland fresh waters of the Taylor creek as river flows downstream from Polaku jetty and cuts across other communities.

2 Materials and Method

2.1 Study Area and Sample Collection

The Taylor Creek is located in Yenagoa Local Government Area of Bayelsa State. Its climate is characterized by the dry and wet seasons with temperatures reaching about 35°C all through the year [30]. The vegetation consists of surrounding tropical swamp forests. Surface water samples were established to reflect the prevalent flow direction of water from upstream at the Polaku jetty towards downstream at Ogboloma community. The sampling rationale was aimed at capturing the possible flow of contaminants and its resultant effect on the quality status of the water body. Sampling was carried out in the month of December 2018 to represent the dry season. Each of the duplicate samples was collected at spatially different geo-referenced points across the five communities stretching the Taylor Creek. Each sample was collected separately into pre-washed 1 litre plastic containers (for physicochemical parameters), 250 ml wide-mouth amber bottles (for Biochemical Oxygen Demand) and 100 ml sample vials acidified with nitric acid, HNO_3 (for calcium and magnesium). In-situ measurements were taken on site and samples were stored in ice-packed coolers before been transported to the laboratory. Each sampling point was geo-referenced with a hand-held Garmin Etrex model GPS (Table 1).

2.2 Statistical Analysis

In order to determine the association and variation across physicochemical parameters of Taylor Creek water, descriptive statistical analysis was carried out using statistical package for social science (SPSS) version 20. Data was expressed as mean ± standard deviation. The range (minimum and maximum) of the values obtained across the sampling points was also presented. One way analysis of variance (ANOVA) was used to show significant variation at $P<0.05$. Where significant variation occurred, Waller-Duncan statistics was used to compare mean values of each test parameter under investigation. Hierarchical cluster analysis was carried out using Euclidean distance based on average linkage between groups. The cluster analysis was carried out for two variables (sample locations and physicochemical variables) across the Taylor Creek.

Figure 1: The Polaku jetty front

2.3 Procedure for physicochemical analysis of water

Test procedures for the analysis of surface water samples are as described in Standard Methods for the Examination of Water and Wastewater [13]. The physicochemical parameters analysed were: electrical conductivity (EC), total dissolved solids (TDS), pH, total alkalinity (TA), total hardness (TH), calcium (Ca), magnesium (Mg), dissolved oxygen (DO), chloride (Cl^-), nitrate (NO_3^-) and biochemical oxygen demand (BOD_5). Some physicochemical parameters were measured electrometrically using pH (Hanna HI 8314 model), EC (Hanna HI 98303 model), TDS (Hanna HI 98303model) and DO (Extech 407510A model) meters respectively on site (in-situ) according to standard procedures [19]. Temperature, EC, pH and DO were recorded in situ while on field with the appropriate instruments. Samples for BOD_5 were measured for DO after 5days of incubation at 20^{o}C (using a Memmert UNB200 model incubator). The calculated difference: DO (Day 1 - Day 5) was reported as the concentration of BOD_5 in mg/l units. TA, TH and Cl^- concentrations were determined using titrimetric methods. Total alkalinity (TA) was determined by the titration of 100 ml water sample with 0.1 M hydrochloric acid (HCl) to an orange-coloured end-point using methyl orange as indicator while total hardness (TH) was analysed by the titration of 100 ml water sample with 0.01 M EDTA using Eriochrome black T (ECBT) as indicator. An observed blue colour was used to denote end-point. The chloride (Cl^-) content was determined by argentometric titration method. The sample was titrated with 0.01 N silver nitrate ($AgNO_3$) using potassium chromate ($KCrO_4$) indicator. Sample was titrated to a pinkish yellow end-point. During each titration protocol a reagent blank was analysed (containing distilled water and reagents) for quality assurance purposes. All concentrations were calculated and expressed as mg/l units. Nitrate (NO_3^-) was analysed using HACH DR 890 colorimeter. Firstly, turbid samples were filtered and eluted through column after been mixed with 75 ml of ammonium chloride-EDTA solution. A mixture of 50 ml sample and 2 ml colour reagent was read in mg/l units NO_3^- after 10 minutes at wavelength of 543 nm using distilled water as blank reagent. Using hot plate, exactly 20 ml water was digested by adding 5 ml nitric acid (HNO_3) and heating to slow boil until near-dryness. The filtered extracts were diluted with distilled water to 20 ml mark in a graduated measuring cylinder. The cationic contents (Ca and Mg) were determined using GBC Avanta PM A6600 type Flame Atomic Absorption Spectrometer (FAAS) via air-acetylene flame atomization, while concentrations of elements of interest were acquired subject upon prior calibration of the instrument with metal specific standard solutions (prepared from a stock solution of 1,000 mg/l AccuNoHaz standards for Ca and Mg). Elemental concentrations were analysed at wavelengths of 422.7 and 285.2 (nm) for Ca and Mg respectively and concentration units expressed as mg/l. Reagent blank was also aspirated into the FAAS for quality assurance purposes. Water Quality Status (WQS) applied in this study was based on Water Quality Index (WQI) previously adopted by [17, 23, 31-32, 38].

2.4 Quality assurance/Quality control protocol for Ca and Mg analysis

The quality assurance and control protocols used during analysis include the use of reagent blanks, sample triplicate run and method of spike recovery. The reagent blank (digested acid reagent only) was analyzed after each metal run; this was applied for correcting background metal levels which may have resulted from reagent impurities.

Table1: Description of water sampling points and activities within the Taylor Creek

Sample Location(s)	River flow direction	Possible sources of pollution	Sample Code(s)	Longitude	Latitude
Polaku	Upstream	Close proximity to gas flare stack from nearby oil facility, boat transport, local sand dredging and nearby sloping farmlands	Polaku1	N5º 1′49.321″	E6º 16′50.795″
	Upstream	Nearby sloping farmlands	Polaku2	N5º 1′52.709″	E6º 16′43.728″
Koroama town	Midstream A	Nearby municipal waste dump and sloping farmlands	Koroama1	N5º 2′22.728″	E6º 17′45.785″
	Midstream A	Boat transport and nearby sloping farmlands	Koroama2	N5º 2′18.702″	E6º 17′47.579″
Obunagha town	Midstream B	Nearby municipal waste dump and sloping farmlands	Obunagha1	N5º 2′1.933″	E6º 18′32.621″
	Midstream B	Nearby municipal waste dump and sloping farmlands, storm water channel from community	Obunagha2	N5º 2′3.655″	E6º 18′43.877″
Okolobiri town	Midstream C	Nearby sloping farmlands	Okolobiri1	N5º 2′9.522″	E6º 18′57.773″
	Midstream C	Nearby municipal waste dump and sloping farmlands	Okolobiri2	N5º 2′19.404″	E6º 19′10.765″
Ogboloma town	Downstream	Nearby multiple waste dumps and sloping farmlands, recreational use of water (bathing, laundry and swimming)	Ogboloma1	N5º 3′13.212″	E6º 19′58.717″
	Downstream	Nearby waste dumps and sloping farmlands	Ogboloma2	N5º 21′59.958″	E6º 20′11.557″

Table 2: Working conditions of the FAAS

						Flame Composition				
Metals	**Slit width (nm)**	**Noise**	**Wave length (nm)**	**Lamp current (mA)**	**Calibration range (µg/ml)**	**Acetylene flow rate (L/min)**	**Air flow rate (L/min)**	**Nebulizer uptake rate (ml/min)**	**Characteristic concentration (mg/L)**	**Concentration of Check standard solution (mg/L)**
Ca	0.50	1.0	422.7	5.00	0.01-4.0	2.00	10.00	5.0	0.001	0.5
Mg	0.50	1.0	285.2	3.00	0.01-0.4	2.00	10.00	5.0	0.001	0.1

The method of spike recovery was applied using standard solutions of elements prior to sample digestion and analysis. This was used for optimizing sample preparation protocol. The percentage spike recoveries of the different metals are listed in Table 3. The values obtained ranged from 94.03 – 98.80 % which is acceptable. The relative standard deviation between analyses was ± 3.7 %. The limits of detection and quantification (LODs and LOQs respectively) were evaluated on the basis of the noise obtained for the analysis of the blank samples (n=3). The LOD and LOQ were defined as the concentration of analyte that results in a signal-to-noise ratio of 3 and 10 respectively. The value of LOD and LOQ (in mg/kg) for each test metal is given in Table 3 below.

2.5 Calculation of Water Quality Index (WQI)

The Water Quality Index (WQI) was calculated through a series of steps. Firstly, the unit weight (Wi) was assigned to each parameter analyzed in the water samples. This was done in accordance to their relative importance in the overall quality of water. This was done in accordance to their relative importance in the overall quality of water as applied by [17, 23, 31-32, 38]. In this study, unit weights for each of the eleven (11) parameters been considered (EC, TDS, pH, TA, TH, Ca, Mg, DO, Cl^-, NO_3^- and BOD_5) were assigned using the formula:

$$Wi = k/Si \quad (1)$$

where, Si is standard permissible value of i^{th} water quality parameter and k is constant of proportionality and it is calculated by using the expression:

$$k = [1/ (\Sigma\ 1/ Si=1, 2,..i)] \quad (2)$$

Subsequently, calculation of WQI was carried out using the expression given in Equation (3).

$$WQI = \Sigma\ Qi \bullet Wi / \Sigma\ Wi \quad (3)$$

where, Qi is quality rating of i^{th} water quality parameter and Wi is unit weight of i^{th} water quality parameter. The quality rating (Qi) is calculated using the expression given in Equation (4).

$$Qi = [(Vi – Vid) / (Si - Vid)] \times 100 \quad (4)$$

where, Vi is estimated value of i^{th} water quality parameter at a given sample location, Vid is ideal value for i^{th} parameter in pure water (note: Vid for pH = 7, DO = 14.6, and 0 for all other parameters) and Si is standard permissible value of i^{th} water quality parameter.

3 Result and Discussion

Spatial variations of physicochemical parameters in surface waters of Taylor Creek are illustrated in Table 5. The calcium concentration ranged from 2.10 - 2.73 mg/l. Calcium showed no significant difference ($p>0.05$) except for Polaku community. This may be due to increased human activities such as artisanal dredging and boat sails which are dominant at the Polaku jetty when compared to other nearby settlement towns (Figure 1).

BOD_5 levels ranged from 0.50 – 1.71 mg/l (Table 5). Apart from Okolobiri and Ogboloma communities which depicted significant variation ($p<0.05$) for BOD_5 across the Taylor Creek, all other sampling stations indicated similarities in activities responsible for oxygen demand.

Table 3: Spike recovery, limits of detection for Ca and Mg quantification

Metals	**LOD (mg/kg)**	**LOQ (mg/kg)**	**Quantity of standard added (mg/kg)**	**Quantity determined (mg/kg)**	**Sample concentration (mg/kg)**	**Percentage recovery (%)**
Ca	0.001	0.001	0.50	2.10	2.57	98.80
Mg	0.001	0.001	0.10	0.63	0.67	94.03

$$\% \, Recovery = \frac{amount \ of \ pure \ product \ recovered \ (g}{Amount \ of \ crude \ materials \ used \ (g)} \times 100$$

Table 4: WQI and its respective water quality status

Water Quality Index Level	Water Quality Status
0 – 25	Excellent water quality
26 – 50	Good water quality
51 – 75	Poor water quality
76 – 100	Very poor water quality
> 100	Unsuitable for drinking

The multiple dumpsites between Okolobiri and Ogboloma (midstream C and downstream locations of the river stretch), the flow direction of the river downstream, as well as recreational activities (bathing, swimming and laundry) (Table 1) may have been responsible for these significant variations. All other physicochemical variables that were evaluated showed no significant difference (p>0.05) across the stretch of the Taylor Creek. The parameters reportedly reflected the ranges: EC (73.00 – 79.00 µs/cm), TDS (40.20 – 43.65 mg/l), pH (5.85 – 6.20), TA (7.00 – 8.00 mg/l), TH (12.00 – 16.50 mg/l), Mg (0.58 – 1.07 mg/l), DO (6.20 – 8.50 mg/l), Cl^- (16.50 – 24.74 mg/l) and NO_3^- (3.00 – 3.60 mg/l). The significant difference between physicochemical variables can be summarized as: Ca < BOD_5 while the significant variation among sample locations were: Ogboloma > Okolobiri > Obunagha = Koroama > Polaku (Table 5).

EC showed the most significant negative correlation with Cl^- (r=-0.107, p<0.05) and depicted the most significant positive correlation with TDS (r=1.000, p<0.01). TDS showed the most significant negative correlation with Cl^- (r=-0.107, p<0.05) and depicted the most significant positive correlation with NO_3^- (r=0.716, p<0.05). Water pH showed the most significant negative relationship with Ca (r=-0.551, p<0.05) and depicted the most significant positive correlation with NO_3^- (r=0.347, p<0.05). TA showed the most significant negative correlation with TH (r=-0.222, p<0.05) while depicting the most significant positive correlation with NO_3^- (r=0.531, p<0.05). TH showed the most significant negative correlation with BOD (r=-0.470, p<0.05) while reflecting the most significant positive correlation with Ca (r=0.590, p<0.05). Ca revealed the most significant negative correlation with NO_3^- (r=-0.537, p<0.05) and depicted the most significant positive correlation with DO (r=0.372, p<0.05). Mg revealed the most significant negative (r=-0.225, p<0.05) and positive (r=0.360, p<0.05) correlation with Cl^- and DO respectively. DO showed the most significant negative correlation with Cl^- (r=-0.355, p<0.05) and reflected the most significant positive correlation with NO_3^- (r=0.264, p<0.05). Cl- showed negative (r=-0.145, p<0.05) and positive (r=0.256, p<0.05) correlation with NO_3^- and BOD respectively. NO_3^- showed positive correlation with BOD (r=0.175, p<0.05) (Table 5).

Clustering techniques are used to isolate objects associated with a specific cluster; such objects should be quite similar. Physical and chemical variables of mutual dependence show similarity or closeness in characteristics (or association) while those of mutual independence reflect differing characteristics. Physicochemical parameters which were analysed in the fresh water environment of Taylor Creek revealed strongest mutual dependence for (EC and TDS), (TH and Cl^-) (Figure 2). Consequently, these pairs of parameters are directly proportional one to another. Hence, an increase in one will lead to an increase in the other. EC and TDS have been reported to show strong linear correlation in natural waters [35, 39]. Also, [15] had shown Cl- to bear significant positive correlation with TH in Kosi river water.

Table 5: Physicochemical analysis of surface water samples from Taylor Creek

Parameters	Polaku	Koroama	Obunagha	Okolobiri	Ogboloma
EC (µs/cm)	79.00±9.90a	75.50±3.54a	76.00±7.07a	73.00±2.83a	78.00±2.83a
TDS (mg/l)	43.65±5.16a	41.60±1.98a	42.05±4.17a	40.20±1.56a	43.00±1.41a
pH	6.20±0.14a	6.10±0.00a	6.00±0.00a	5.85±0.21a	6.10±0.14a
TA (mg/l)	8.00±0.00a	7.00±1.41a	8.00±0.00a	7.50±0.71a	8.00±0.00a
TH (mg/l)	12.50±3.54a	16.50±2.21a	16.50±4.95a	14.00±1.41a	12.00±1.41a
Ca (mg/l)	2.10±0.09a	2.40±0.05ab	2.73±0.37ab	2.33±0.02ab	2.29±0.16ab
Mg (mg/l)	1.07±0.33a	0.67±0.09a	1.03±0.42a	0.58±0.12a	0.98±0.28a
DO (mg/l)	7.20±0.28a	8.50±0.42a	7.20±2.55a	6.20±1.13a	6.80±1.13a
Cl^- (mg/l)	16.50±4.66a	21.44±2.33a	19.80±9.33a	19.80±9.33a	24.74±2.33a
NO_3^- (mg/l)	3.60±0.28a	3.30±0.57a	3.00±0.28a	3.15±0.21a	3.55±0.21a
BOD_5 (mg/l)	0.50±0.29a	0.65±0.09a	0.63±0.06a	1.13±0.18ab	1.71±0.65b

Data is expressed as mean ± standard deviation; Different letter along the column indicates significant difference (P<).05) according to Duncan statistic

Table 6: Spearman's rho correlation of physicochemical parameters along the Taylor Creek

Parameters	EC	TDS	pH	TA	TH	Ca	Mg	DO	Cl^-	NO_3^-	BOD
EC	1.000										
TDS	1.000**	1.000									
pH	0.044	0.044	1.000								
TA	0.456	0.456	0.014	1.000							
TH	0.455	0.455	-0.383	-0.222	1.000						
Ca	0.036	0.036	-0.551	-0.121	0.590	1.000					
Mg	0.468	0.468	0.247	0.493	-0.068	0.030	1.000				
DO	0.569	0.569	0.121	0.074	0.594	0.372	0.360	1.000			
Cl^-	-0.107	-0.107	-0.206	0.183	-0.103	0.175	-0.225	-0.355	1.000		
NO_3^-	0.716*	0.716*	0.347	0.531	-0.131	-0.537	0.256	0.264	-0.145	1.000	
BOD	-0.083	-0.083	-0.115	0.170	-0.470	-0.239	-0.147	-0.166	0.256	0.175	1.00

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
(N=10).

They had also suggested that TH of water samples is mainly due to the presence of the $MgCl_2$ and NaCl. On the other hand, the strongest mutual independence was observed between TDS and Mg. Similarly, the content of Mg in Kosi water showed negative correlation with TDS and was only positively correlated with turbidity, pH, TH and sulphate (SO_4^{2-}).

The settlements along the stretch of the Taylor Creek were assessed for points of close association (mutual dependence) (Figure 3). The following pairs of communities depicted mutual dependence and close characteristics: (Polaku 1 and Okolobiri 1), (Koroama 2 and Ogboloma 1), and (Okolobiri 2 and Ogboloma 2). This may be due to the resemblance in the pollution sources and dominant activities within each of the paired settlements. In the same manner, the water environment tends to redistribute its mineral content and pollutants across the flow direction of Taylor Creek (from upstream at Polaku towards downstream at Ogboloma). Also, (Polaku 1) and (Obunagha 1) showed the strongest mutual independence. This may have resulted from the presence of municipal waste dumps at (Obunagha 1) and the relative absence of dumpsite leachate encroachments observed at (Polaku 1) community (Table 1).

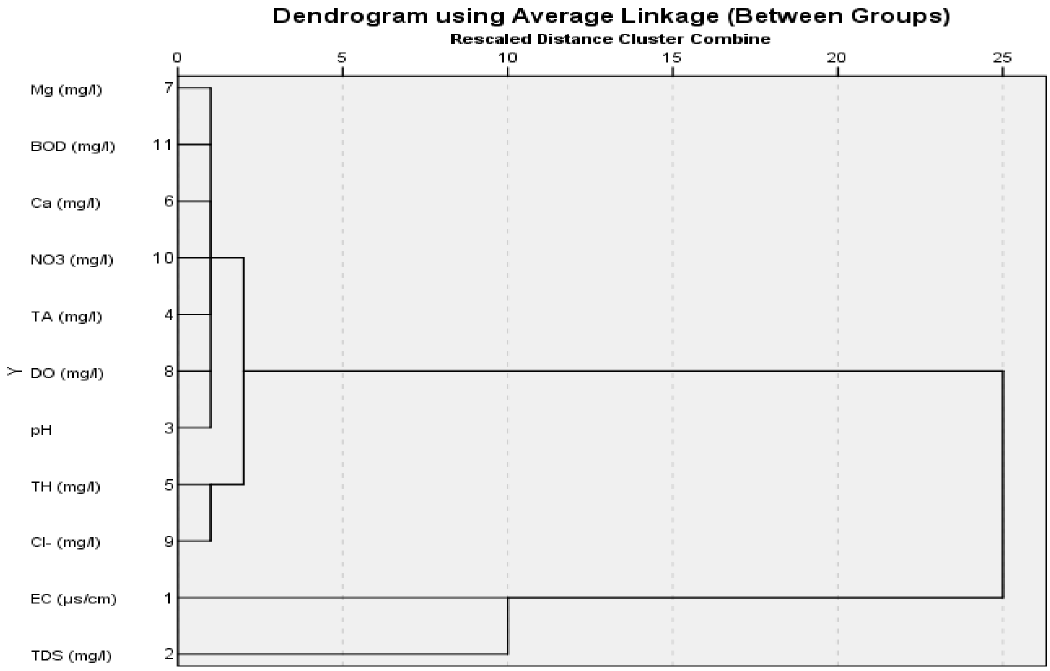

Figure 2: Hierarchical dendograms of different physicochemical variables in Taylor Creek

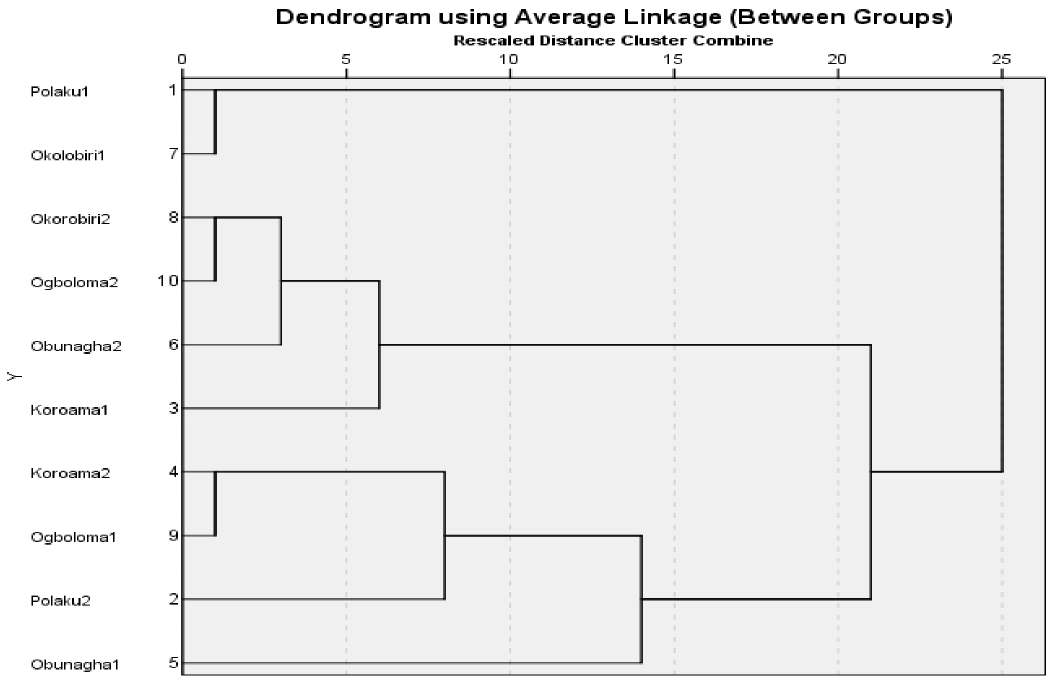

Figure 3: Hierarchical dendograms of different settlements within the Taylor Creek

Table 7: Calculated water quality index (WQI) for Polaku

Parameters	Observed value (Vi) (Upstream)	Standard value (Si)	Recommending Agency for (Si)	Ideal value (Vid)	k value	Unit weight (Wi)	Quality Rating (Qi)	Qi•Wi
EC	79.0	900	WHO	0	1.645	0.0018	10.65	0.01917
TDS	44.7	500	DPR	0	1.645	0.0033	9.82	0.03241
pH	6.2	8.5	DPR	7	1.645	0.1935	-34.78	-6.72993
TA	8.0	100	WHO	0	1.645	0.0165	8.70	0.14355
TH	12.5	100	WHO	0	1.645	0.0165	14.29	0.23579
Ca	2.101	75	WHO	0	1.645	0.0219	2.88	0.06307
Mg	1.075	20	WHO	0	1.645	0.0823	5.68	0.46746
DO	7.2	5.0	DPR	14.6	1.645	0.3290	336.36	110.66
Cl^-	16.50	250	WHO	0	1.645	0.0066	7.07	0.04666
NO_3^-	3.6	10	WHO	0	1.645	0.1645	56.25	9.25313
BOD_5	0.500	10	DPR	0	1.645	0.1645	5.26	0.86527
						ΣWi=1		ΣQi•Wi=115.07
WQI = ΣQi•Wi / ΣWi = 115.07 (unsuitable for drinking)								

Table 8: Calculated water quality index (WQI) for Koroama

Parameters	Observed value (Vi) (Midstream A)	Standard value (Si)	Recommending Agency for (Si)	Ideal value (Vid)	k value	Unit weight (Wi)	Quality Rating (Qi)	Qi•Wi
EC	75.5	900	WHO	0	1.645	0.0018	9.16	0.01649
TDS	41.6	500	DPR	0	1.645	0.0033	9.08	0.02996
pH	6.1	8.5	DPR	7	1.645	0.1935	-37.50	-7.25625
TA	7.0	100	WHO	0	1.645	0.0165	7.53	0.12425
TH	16.5	100	WHO	0	1.645	0.0165	19.76	0.32604
Ca	2.402	75	WHO	0	1.645	0.0219	3.31	0.07249
Mg	0.666	20	WHO	0	1.645	0.0823	3.44	0.28311
DO	8.5	5.0	DPR	14.6	1.645	0.3290	174.29	57.34
Cl^-	21.44	250	WHO	0	1.645	0.0066	9.38	0.06191
NO_3^-	3.3	10	WHO	0	1.645	0.1645	49.25	8.10163
BOD_5	0.646	10	DPR	0	1.645	0.1645	6.91	1.13670
						ΣWi=1		ΣQi•Wi=60.24
WQI = ΣQi•Wi / ΣWi = 60.24 (poor water quality)								

Table 9: Calculated water quality index (WQI) for Obunagha

Parameters	Observed value (Vi) (Midstream B)	Standard value (Si)	Recommending Agency for (Si)	Ideal value (Vid)	k value	Unit weight (Wi)	Quality Rating (Qi)	Qi•Wi
EC	76.0	900	WHO	0	1.645	0.0018	9.22	0.01660
TDS	42.1	500	DPR	0	1.645	0.0033	9.19	0.03033
pH	6.0	8.5	DPR	7	1.645	0.1935	-40.00	-7.74000
TA	8.0	100	WHO	0	1.645	0.0165	8.70	0.14355
TH	16.5	100	WHO	0	1.645	0.0165	19.76	0.32604
Ca	2.730	75	WHO	0	1.645	0.0219	3.78	0.08278
Mg	1.026	20	WHO	0	1.645	0.0823	5.41	0.44524
DO	7.2	5.0	DPR	14.6	1.645	0.3290	336.36	110.66
Cl^-	19.80	250	WHO	0	1.645	0.0066	8.60	0.05676
NO_3^-	3.0	10	WHO	0	1.645	0.1645	42.86	7.05047
BOD_5	0.625	10	DPR	0	1.645	0.1645	6.67	1.09722
						ΣWi=1		ΣQi•Wi=112.17
WQI = ΣQi•Wi / ΣWi = 112.17 (unsuitable for drinking)								

Table 10: Calculated water quality index (WQI) for Okolobiri

Parameters	Observed value (Vi) (Midstream C)	Standard value (Si)	Recommending Agency for (Si)	Ideal value (Vid)	k value	Unit weight (Wi)	Quality Rating (Qi)	Qi•Wi
EC	73.0	900	WHO	0	1.645	0.0018	8.83	0.01589
TDS	40.2	500	DPR	0	1.645	0.0033	8.74	0.02884
pH	5.9	8.5	DPR	7	1.645	0.1935	-42.31	-8.18699
TA	7.5	100	WHO	0	1.645	0.0165	8.11	0.13382
TH	14.0	100	WHO	0	1.645	0.0165	16.28	0.26862
Ca	2.333	75	WHO	0	1.645	0.0219	3.21	0.07030
Mg	0.577	20	WHO	0	1.645	0.0823	2.97	0.24443
DO	6.2	5.0	DPR	14.6	1.645	0.3290	700.00	230.30
Cl^-	19.80	250	WHO	0	1.645	0.0066	8.60	0.05676
NO_3^-	3.2	10	WHO	0	1.645	0.1645	47.06	7.74137
BOD_5	1.125	10	DPR	0	1.645	0.1645	12.68	2.08586
						ΣWi=1		ΣQi•Wi=232.76
WQI = ΣQi•Wi / ΣWi = 232.76 (unsuitable for drinking)								

Table 11: Calculated water quality index (WQI) for Ogboloma

Parameters	Observed value (Vi) (Downstream)	Standard value (Si)	Recommending Agency for (Si)	Ideal value (Vid)	k value	Unit weight (Wi)	Quality Rating (Qi)	Qi•Wi
EC	78.0	900	WHO	0	1.645	0.0018	9.49	0.01708
TDS	43.0	500	DPR	0	1.645	0.0033	9.41	0.03105
pH	6.1	8.5	DPR	7	1.645	0.1935	-37.50	-7.25625
TA	8.0	100	WHO	0	1.645	0.0165	8.70	0.14355
TH	12.0	100	WHO	0	1.645	0.0165	13.64	0.22506
Ca	2.300	75	WHO	0	1.645	0.0219	3.16	0.06920
Mg	0.980	20	WHO	0	1.645	0.0823	5.15	0.42385
DO	6.8	5.0	DPR	14.6	1.645	0.3290	433.33	142.57
Cl^-	24.80	250	WHO	0	1.645	0.0066	11.01	0.07267
NO_3^-	3.6	10	WHO	0	1.645	0.1645	56.25	9.25313
BOD_5	1.709	10	DPR	0	1.645	0.1645	20.61	3.39035
						ΣWi=1		ΣQi•Wi=148.94
WQI = ΣQi•Wi / ΣWi = 148.94 (unsuitable for drinking)								

Communities of the Taylor Creek revealed similarities in trend. Nonetheless, the presence of nitrate (ranging between 3.0 and 3.6 mg/l) is an indication of the presence of anthropogenic activities (such as waste dumpsites at close proximity to the river and possible pesticide leaching from agricultural run-offs). Similar values of nitrate concentration were obtained at Nwaja creek in Port Harcourt, Nigeria [2]. All the examined water quality parameters were within WHO/DPR limit except for pH (5.9 - 6.2) which was observed below DPR limit and DO (6.2 – 8.5 mg/l) which exceeded the recommended daily minimum of 5.0 mg/l [19, 44] (Tables 7-11). The pH values reported for Taylor Creek was within the range reported for Kwale, Ashaka and Osemele rivers in Delta State, Nigeria (5.45 – 5.90) during the dry season month of December [31]. Contrary to the findings from this study, [28] had obtained near-neutral pH units for the Brass River in Bayelsa State, Nigeria. Also, [31] had reported DO values ranging from 5.45 – 12.00 in the Kwale, Ashaka and Osemele rivers thereby exceeding DPR daily minimum. From the foregoing, there is need for routine monitoring of the Taylor Creek because of its socio-economic importance to the people. More so, the result of the calculated water quality index (WQI) falls within the range of (60.24 – 232.76) (Tables 7 - 11) which indicates water quality status tending from “poor water quality” to “unsuitable for drinking”. Apart from Koroama community which showed poor water quality, all other communities depicted a water environment clearly unsuitable for drinking. Similarly, [12] had reported WQI of Otamiri and Oramiriukwu rivers in Rivers State to be very bad as it was calculated as 174.49. The quality of Ase River was observed to be bad while the degree of deterioration was higher downstream than at the upstream [31]. River Orashi depicted marginal level of pollution as about 50% of parameters considered failed to meet required standard [21, 24] had applied WQI assessment on six selected water bodies in Warri, Delta State and reported them to be poor and very unfit for human use. Also, Brass River in Bayelsa State was considered to be far from excellent [28]. On the other hand, Isiodu River in Niger Delta was not considered polluted even during the process of dredging [25]. From this study, deterioration in water quality status depicted the trend: Koroama < Obunagha < Polaku < Ogboloma < Okolobiri (Tables 7 – 11). The presence of multiple dumpsites throughout Okolobiri community may be responsible for the poor degradation in water quality. Consequently, water from the vicinity of the Taylor Creek is not fit for human consumption. Also, its use for recreational purposes (such as swimming) among settlement dwellers should be discouraged.

4 Conclusions

Taylor creek depicts a slightly acidic water environment that contains nitrate loading mostly from leachates emanating from multiple dumpsites along the stretch of the river. Even though its water quality parameters fall within stipulated regulatory limits with the exception of pH, the objectionable levels of colour and unsightly appearance of its waters especially at locations within the vicinity of waste dumps is a cause for concern for settlement dwellers who may rely on it for drinking and daily recreational activities. In addition, WQI assessment reflects water environment in a state of poor quality and generally unsuitable for public consumption. Expectedly, EC showed the most significant positive correlation with TDS. However, NO_3^- was the most positively correlating water quality parameter in the Taylor Creek; it positively correlated with pH, TA, Cl^- DO and BOD. Consequently, its presence in the environment may determine the levels at which other water quality variables are detected. The significant variation of Ca at Polaku may have been due to artisanal dredging at the jetty front area. Human activities like bathing, swimming and laundry may be responsible for observed significant variations in BOD level at Okolobiri and Ogboloma. Likewise, the position of both communities towards the downstream ends of the creek may have increased their susceptibility to the influx of transportable pollutants which may be responsible for varying dissolved oxygen levels. Cluster analysis revealed (EC/TDS) and (TH/Cl^-) to be the water quality parameters of closest association. Spatially, Obunagha was the only community of mutual independence. Overall, WQI assessment revealed that water derived from the Taylor Creek is unsuitable for drinking as it may portend serious health risks. It is therefore necessary to regularly monitor the Creek in order to evaluate trends, establish baseline data and guide against pollution-encroaching activities.

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Competing interests

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution for sample collection. Corresponding author was responsible for data collection, data analyses and manuscript writing, while an in-depth review was carried out by the co-author.

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