

## Hydrochemical Characteristics and Self-Purification Potential of Iyiechu Stream in Okigwe Area, Southeastern Nigeria

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### ABSTRACT

*Iyiechu stream is a small tropical urban stream that receives both domestic and industrial wastes. The self-purification potential of the stream was determined by evaluating its deoxygenation and reaeration rate coefficients. The methods of study used include dissolved oxygen (DO) measurements, biochemical oxygen demand (BOD) and chemical oxygen demand (COD) tests as well as measurements of hydrological parameters. Deoxygenation rate of 0.20 to 0.42/day were obtained indicating very swift depletion of oxygen in the stream probably as a result of domestic sewage input. The reaeration rate coefficients ranged from 0.01 to 0.84 day and these values suggest deep and slow moving streams. The measured DO values are quite low, indicating high deoxygenation reaction in the stream and minimal dissolved oxygen contribution from other sources such as algal photosynthesis. Spatially, about 66.66% of the stream is dominated by deoxygenation reaction. The chemical oxygen demand ranged from 20 to 40 mg/l. These values are relatively high and show that the process may be partly responsible for the low dissolved oxygen levels in the stream. However, the stream is capable of re-attaining its optimum dissolved oxygen level within a flow time of 0.84 day (20hrs 16minutes) in the rainy season. Thus, a flow time much greater than 0.84 day (20hrs 16minutes) would be required during the dry season. These flow times suggest that the stream has poor self-purification potential.*

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**Keywords:** *Self-purification potential, Reaeration, Deoxygenation, Dissolved oxygen, Biochemical oxygen demand, Chemical oxygen demand, Stream velocity*

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### 1.0. INTRODUCTION

The discharge of both organic and inorganic wastes into a body of surface water (stream, river, sea etc) leads to its pollution. This is more pronounced when the waste bearing capacity of such stream is exceeded by waste loading (Michael, 2010). The continuous discharge of wastes of high organic content into surface water bodies causes water pollution and reduction of dissolved oxygen concentration due to the degradation of organic matter (Izinyon and Akatah, 2023). In trace concentrations, heavy metals which may be contained in these wastes are also important for the

physiological function of living tissues and regulate many biochemical processes (Dauda, 1993; Elaigwe *et al.*, 2007; Yahaya *et al.*, 2009). However, when the concentration exceeds, certain thresholds, it becomes toxic to living tissues and aquatic lives.

Pollutants of the above mentioned nature find their way into these water bodies through an identifiable point source – when they enter through a definite source such as pipes, tunnels, discharges from sewage treatment plants; or through a non-point source – when they enter in varying means. Wastes of this nature are mostly domestic and industrial wastes dumped in or close to the stream channels. These pollutants which also come from agricultural wastes and leached fertilizer elements (Nitrate, Potassium, Phosphate etc) on entry into the water attack aquatic lives like fishes and algal growths by consuming the life-sustaining dissolved oxygen (DO) content of the surface water and hence encouraging the growth of bacteria and other micro-organisms (Churchil *et al.*, 1962). This simply increases the biochemical oxygen demand (BOD) at the expense of the dissolved oxygen (DO). If the organic waste increases continually in the water, purification and eutrophication also increases significantly as well as continuous depletion of oxygen. All these activities occur if the self-purification potential of the stream is severely affected. That is, when the breakdown of the stream's dissolved oxygen (DO) exceeds its natural replenishment by atmospheric oxygen.

Clark *et al.* (1977) stated that as long as the self-purification capacity of stream is not exceeded under the condition of excessive organic waste loading, the organic waste input will be of economic advantage due to the sustenance of aquatic lives. The process and rate of self-purification is significantly influenced by temperature, stream conductivity, nature of organic pollutants and flow characteristics including algal content of the receiving stream (Nwankwor and Okpala, 1993).

The Iyiechu Stream represents a small tropical stream that flows from its upstream source at Ozara Ihube through the Okigwe metropolis where municipal wastes are dumped on its channels to its downstream source at Abo Umulolo where it flows into the Imo River channel.

Investigation into the natural self-purification potentials of streams has become a very important aspect in the quest for a sustainable level of environmental protection through engineering, as its knowledge is required for the design of waste treatment plants by industries that may desire to use streams and other surface water bodies as disposal channels for their effluents (Dikeogu *et al.*, 2014). Thus, this study deals with the chemical, biochemical and hydrological properties of the Iyiechu Stream as a basis for determining its optimal waste loading and self-purification potential. The findings will be very useful in organic waste management by industries that discharge their effluents into the stream.

## **2.0. DESCRIPTION OF STUDY AREA**

### **2.1. Location and Accessibility**

Iyiechu Stream (Figure 1) is located in the northeastern part of Okigwe in Imo State, Southeastern Nigeria. It lies between latitude 5<sup>0</sup>48' and 5<sup>0</sup>52' N and longitude 7<sup>0</sup>20' and 7<sup>0</sup>25' E. The stream is accessible through a network of roads including the Owerri - Okigwe Road that links the downstream (Abo - Umulolo) to the midstream (Ubahu) while the upstream (Ihube) is accessible

through the Enugu - Port Harcourt Road. The stream can also be accessed through minor roads and pathways in the area.



Fig. 1: Iyiechu Stream

## 2.2. Geology, Physiography and Climate

The stream traverses Ihube, Ubahu and Abo - Umulolo in Okigwe area and these locations belong to the Nsukka Formation of late Maastrichtian - Danian age. The upstream location consists of alternating successions of sandstones, dark shales and scattered sandy shale admixtures. The midstream location is mostly fine-textured sandy shales and iron-stained sandstones whereas the downstream consists of iron-stained sandstones with minor occurrences of sandy shales and lateritic mudstones.

The stream has a discharge rate of  $0.496\text{m}^3/\text{second}$ . It is a geomorphic first-order stream within the Imo River drainage basin with possible adjoinment of other minor streams. It flows southwestwards from the northeastern axis through a distance of 5.5km. The channel is sinuous, rarely braided and shows significantly less depth and width variations over some segments of flow. The area has a rugged topography with massively elevated landforms.

The area has an average annual rainfall of 1933 mm. The wet season occurs between the months of May and October with an average temperature of  $27^{\circ}\text{C}$  whereas the dry season falls between November and April with relatively high average temperature of  $29^{\circ}\text{C}$ .

The area is in the Tropical Rainforest vegetation belt of Southeastern Nigeria, and generally tends towards the Guinea Savannah type due to the extensive deforestation being carried out in the area as a result of farming and construction of residential houses. Figure 2 shows the geology of the area and the data points.

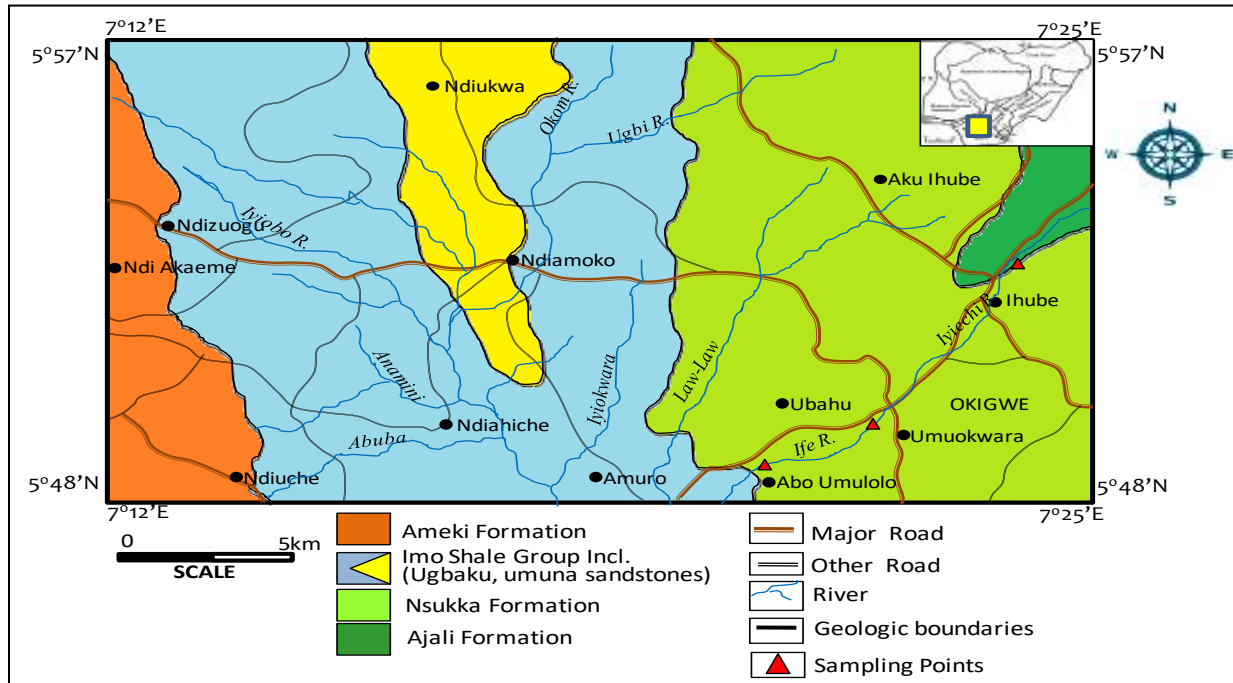


Fig. 2: Geologic map of the study area showing sampling points (adapted from Nigeria Geological Services Agency, 2021).

### 3.0. MATERIALS AND METHODS

#### 3.1. Sampling Network and Sample Collection

Water sampling network was based on hydrological factors such as stream channel geometry, flow velocity, seasonality of climatic factors and distribution of points of waste discharge into the stream.

The reconnaissance survey showed three (3) distinct stream reaches based on flow system, channel geometry and pollutant source (Figure 2). These are upstream (Ihuba), midstream (Ubahu) and downstream (Abo Umulolo). A total of nine (9) samples were collected; three (3) samples from each reach. These samples were used for physico-chemical and dissolved oxygen (DO) measurements, chemical oxygen demand (COD) and biochemical oxygen demand (BOD) tests.

The samples were collected with fresh plastic water cans at strategic points with distinct geomorphic features such as depth, flow regime, and pollutants' input source points.

#### 3.1. Hydrological Parameters

The hydrological parameters investigated include stream depth, stream flow velocity and cross section geometry. The water depth was measured using a graduated pole at strategic points within the three (3) stream reaches.

The stream flow velocity was determined using a float. The time taken for the float to move from a given point to another pre-determined distance provided the flow rate or velocity of the stream. However, the mean velocity flow depth was estimated from the relation (Linsley *et al.*, 1982):

$$V^1 = V_{\max} \frac{Z}{h} 1/7 \dots\dots\dots(1)$$

where  $V_{\max}$  is the velocity as measured by the float,  $V^1$  is the mean velocity at mean velocity flow depth,  $h$  is the depth corresponding to 60% of maximum water depth along the cross section, and  $Z$  is the stream-bed roughness coefficient normally given as 0.000767 for natural streams.

The channel cross-section geometries were estimated from measurements of water depth made at several points in each location within a given reach. Variations in depth across the channel as determined with the use of pole are expected to give reasonable approximations of the channel cross section geometry.

### 3.2. Laboratory Analysis

The methods for physico-chemical analysis are of international standards and include those of American Public Health Association and American Standards for Testing and Materials. Cations and anions were analysed respectively using Atomic Absorption Spectrophotometer and Calorimetric methods with UV-Visible Spectrophotometer.

Dissolved oxygen measurements were carried out using water samples collected in one (1) litre plastic containers that were tightly closed in order to shut out air bubbles. The samples were forthwith pretreated with the addition of 1cm<sup>3</sup> of manganese sulphate and sodium iodide. Preceding precipitate was dissolved by the addition of 1cm<sup>3</sup> of concentrated sulphuric acid. The pretreated samples were analysed in the laboratory using the Winkler method.

Biochemical oxygen demand (BOD) was determined by the DO deficit method in which water samples were incubated for a 5-day period (BOD<sub>5</sub>). The bulk water sample was homogenized by vigorous shaking and apportioned into five (5) brownish bottles. One of the bottles was immediately analysed for DO using the DO deficit method whereas the remaining four (4) bottles were analysed on the 2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup> and 5<sup>th</sup> day after storage. This provided the basis for determining the cumulative dissolved oxygen continually utilized for the oxidation of organic matter during the period of test. The amount of oxygen so consumed formed the 5-day BOD value at a laboratory temperature of 20<sup>o</sup>C. Based on this, the deoxygenation rate coefficient of the stream was determined.

Chemical oxygen demand (COD) tests were carried out on the samples with portable digital spectrophotometer using also, the Winkler method.

### 3.3. Self-Purification Parameters

The deoxygenation rate coefficient  $k_1$ , reaeration rate coefficient  $k_2$ , and Fair's number ( $f = (k_2/k_1)$ ) were the self-purification parameters used in the study. The value of  $f$  expresses the degree of

predominance of reaeration over deoxygenation (Nwankwor and Okpala, 1993). The  $k_2$  values were computed for the stream reaches using the method developed by Owens *et al.* (1962). The formula is of the form:

$$K_2 = 9.4 V^{0.67} h^{1.85} \dots\dots\dots(2)$$

where h is mean flow depth (m) and V is mean stream velocity (m/s).

The  $k_1$  was determined using Nemerow’s two-point method. The f values were computed using the  $k_2$  values as determined with equation (2) and  $k_1$  as computed using Nemerow’s two-point method.

#### 4.0. RESULTS AND DISCUSSION

##### 4.1. Physico-chemical analysis

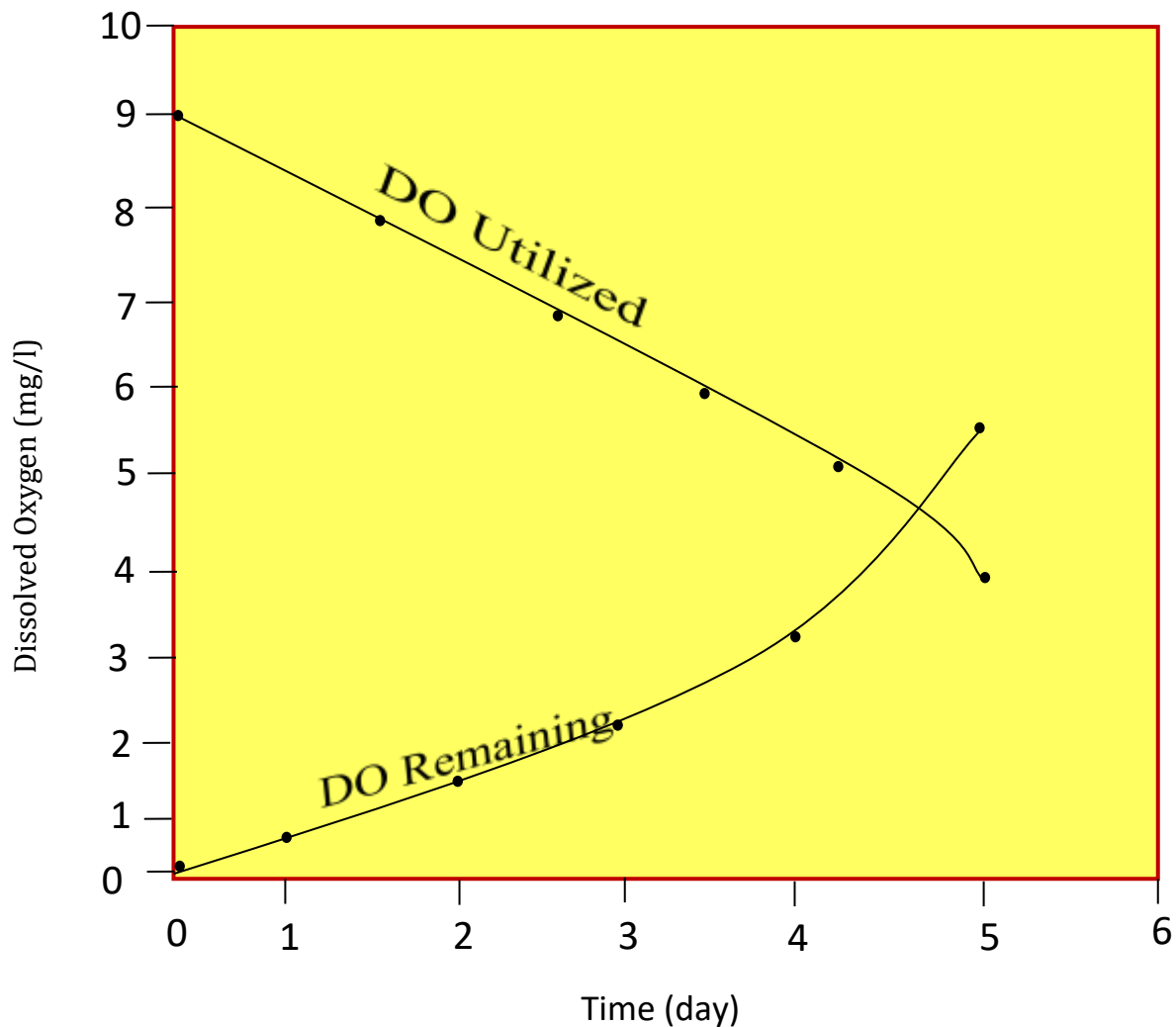
Table 1 shows the results of the physico-chemical tests carried out on the stream’s water samples. The term “Action level” refers to the level above which the reasons for the presence of the substance should be investigated.

Table 1: Physico-chemical parameters of the stream’s water samples.

Parameter	Unit	Samples			WHO’s Action Level
		Upstream	Midstream	Downstream	
Iron	Mg/l	0.07	0.05	0.001	0.3
Copper	Mg/l	2.28	1.09	3.60	1.0
Zinc	Mg/l	0.23	14.64	0.38	5.0
Sulphate	Mg/l	12.51	0.09	14.11	200
Calcium	Mg/l	1.60	4.20	12.21	75
Sodium	Mg/l	21.88	15.71	24.65	200
Magnesium	Mg/l	0.50	0.72	0.56	50
Chloride	Mg/l	10.22	11.11	18.71	200
Nitrate	Mg/l	2.93	3.64	2.41	40
Phosphate	Mg/l	0.82	0.73	0.72	-
Total Hardness	Mg/l	6.03	13.23	32.45	500
TDS	Mg/l	14.92	19.22	52.47	1500
TSS	Mg/l	3.15	1.86	1.32	500
Temperature	<sup>0</sup> C	22	29	28	-
Turbidity	NTU	17.9	0.7	1.1	5
Conductivity	ug/cm	32.3	41.8	113.4	-
pH at 28 – 29 <sup>0</sup> C	-	5.78	6.23	6.38	6.5 – 8.5

#### 4.2. Dissolved Oxygen Measurement

Table 2 shows the organic matter oxidized and stabilized at time,  $t$  whereas Figure 3 shows the exertion curves for cumulative oxygen utilized. The exertion curves are plotted against biochemical degradation of the dissolved oxygen and formed the basis for the determination of the deoxygenation coefficient ( $k_1$ ) that enabled the computation of the dissolved oxygen (DO) sag and self-purification potential of the stream.



**Fig. 3:** Exertion curves for the upstream showing DO utilized and DO remaining.

#### 4.3. Chemical Oxygen Demand Measurement

The chemical oxygen demand (COD) ranged from 20 mg/l at the upstream to 40 mg/l at the midstream. The COD profile (Figure 5) shows a peak value of 40 mg/l at the midstream, about

4.4km away from the upstream. The presence of chemical oxygen demand in a river diminishes dissolved oxygen level (Uzoigwe *et al.*, 2015). The relatively high COD in the stream may have contributed to the low DO level in the stream.

Table 2: Dissolved oxygen data measured during the BOD<sub>5</sub> test for the stream water samples.

Time (Days)	Upstream		Midstream		Downstream	
	DO Utilized (mg/l)	DO Remaining (mg/l)	DO Utilized (mg/l)	DO Remaining (mg/l)	DO Utilized (mg/l)	DO Remaining (mg/l)
0	0.00	5.49	0.00	8.60	0.00	8.87
1	0.52	4.97	0.73	7.87	0.84	8.03
2	1.57	3.92	2.15	6.45	1.75	7.12
3	2.55	2.94	3.52	5.08	2.93	5.94
4	3.42	2.07	4.57	4.03	4.00	4.87
5	4.01	1.48	5.76	2.84	5.49	3.38
		$BOD_5 = 5.49 - 1.48 = 4.01$	$BOD_5 = 8.60 - 2.84 = 5.76$		$BOD_5 = 8.87 - 3.38 = 5.49$	

#### 4.2. Computed Reaction Rate Coefficients

The deoxygenation coefficients,  $k_1$ , determined using Nemerow's two-point method and the reaeration coefficients,  $k_2$ , computed using the method developed by Owens *et al.* are shown in Table 3.

Table 3: Stream velocity, depth, calculated  $k_1$  and  $k_2$  values for the reaches.

Reach	Mean velocity (m/s)	Mean flow depth (m)	$k_1$ values (per day)	$k_2$ values (per day)
Upstream	0.081	0.004	0.20	0.01
Midstream	0.207	0.48	0.36	0.84
Downstream	0.157	0.25	0.42	0.31

The  $k_1$  values ranged from 0.20 in the upstream to 0.42 in the downstream. The  $k_2$  values ranged from 0.01/day in the upstream where flow is less active to 0.84/day in the midstream where flow is relatively faster. Reaeration coefficient,  $k_2$ , varies from one stream reach to another considering that stream velocity and depth are the two (2) major factors that control the degree of reaeration.



### 4.3. Hydrologic Parameters and Channel Cross-section Geometries

The replenishment of oxygen in surface water is dependent on stream flow velocity, water depth and channel geometry (Clark et al., 1977). The mean flow depth is estimated as the depth that corresponds to 60% of maximum water depth along the cross-section.

The mean velocity and mean flow depth for the three (3) reaches are shown in Table 3 whereas the channel cross-section geometry of the midstream as estimated from measurements of water depth within the reach is shown in Figure 4.

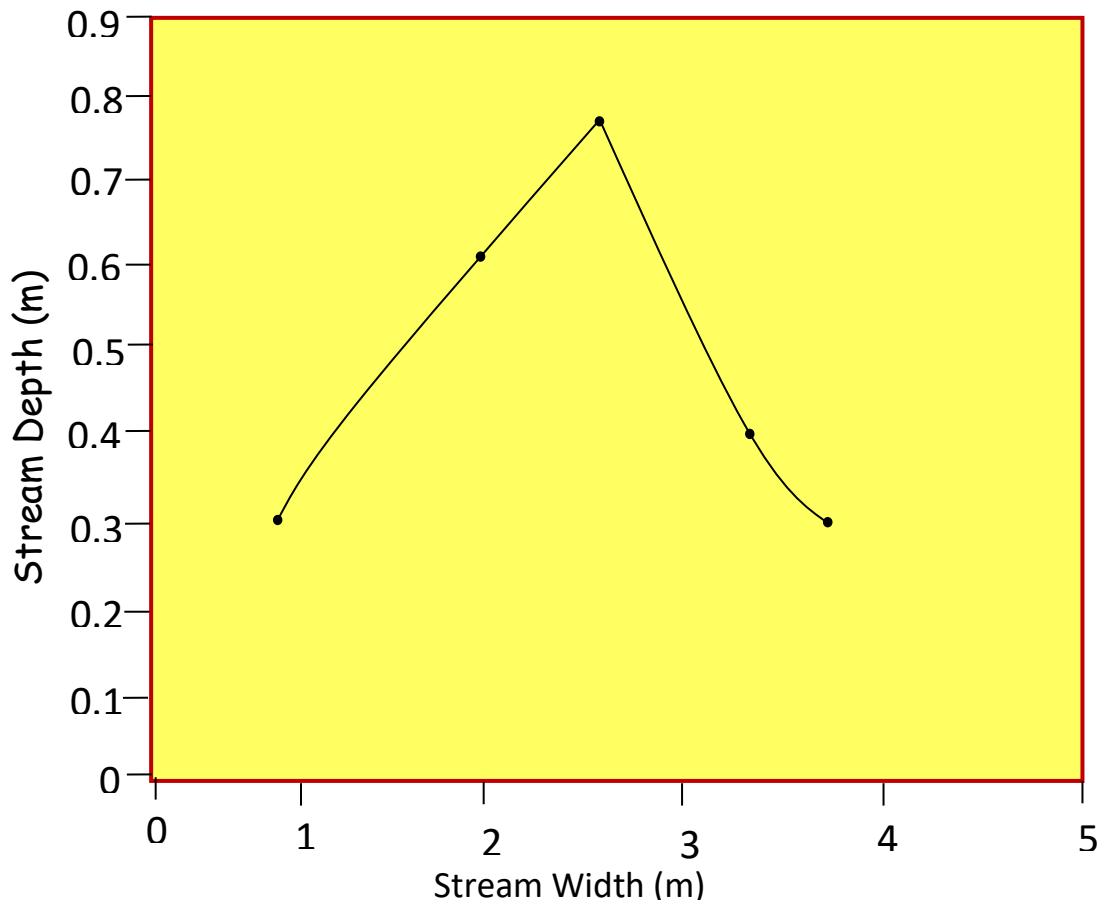


Fig 4: Channel cross-section geometry of the midstream.

### 4.4. Fair's Number

Fair's number,  $f$ , less than 1.0 depicts predominance of deoxygenation over reaeration whereas values greater than 1.0 indicate predominance of reaeration over deoxygenation. Thus, it is expected that at  $f$  value of 1.0, the rate of reaeration equals that of deoxygenation. Table 4 shows the  $f$  value for the reaches. The values ranged from 0.0305 (for upstream) to 2.35 (for midstream).

It is apparent from the table that deoxygenation predominates in the upstream and downstream sections of the stream.

Table 4: Fair’s Number for the reaches.

Reach	Fair’s Number ( $f = k_2/k_1$ )
Upstream	0.0305
Midstream	2.35
Downstream	0.735

## 4.5. DISCUSSION

### 4.5.1. Chemical composition

The chemical compositions of the stream water samples show that except copper, none of parameters exceeded World Health Organization (WHO) action level for potable water. High copper content can aid stream self-purification (Mercer, 2011), as it bonds with the suspended solids and get discharged at the stream banks as sediments. This process enhances the filtering of stream water along its course.

### 4.5.2. Deoxygenation reaction

The deoxygenation reaction coefficient,  $k_1$  of the stream ranged from 0.20/day in the upstream to 0.42/day in the downstream (Table 3). The least value of 0.20/day is slightly higher than 0.17/day at a temperature of 20°C given by Tebbut (1998) as the deoxygenation rate coefficient for domestic sewage. This implies that waste input in the stream is composed mainly of domestic waste. The  $k_1$  values suggest very swift depletion of oxygen in the stream.

### 4.5.3. Reaeration reaction

The reaeration coefficients determined using Owen’s method are shown in Table 3. The  $k_2$  values which ranged from 0.01 at the upstream where flow is inactive to 0.84 at the midstream where flow is very active suggest deep and slow moving streams at the upstream and downstream sections and relatively fast fluxes at the midstream.

### 4.5.4. Dissolved oxygen and chemical oxygen demand profile

The results of the DO measurements along the stream profile based on the three (3) distinct reaches are shown in Table 2. The equation for the DO sag is:

$$\frac{dD}{dt} = k_1L - k_2D \dots\dots\dots(3)$$

where D is the dissolved oxygen deficit, and L is the amount of BOD remaining at time, t. At the point of maximum sag, the reaeration rate equals the deoxygenation rate. Thus, equation (3) can be integrated to yield;

$$D_c = \frac{k_1}{k_2} \dots\dots\dots(4)$$

where  $D_c$  is the DO deficit at the point of maximum sag.

Figure 5 shows the DO profile for the stream. The profile suggests that the upstream constitute the point of DO sag as the dissolved oxygen increased continually from the upstream towards the downstream. The DO profile of a stream describes both the characteristics of the stream as well as the level of pollution in the stream (Babamiri *et al.*, 2021; Nishimura *et al.*, 2021). The measured DO values are very low and indicate low dissolved oxygen concentration and poor atmospheric reaeration in the stream. The lack of fluctuation in the observed profile as well as the steady rise in dissolved oxygen level from the upstream to the downstream indicate an increase in reaeration and possibly, reduced waste input towards the downstream.

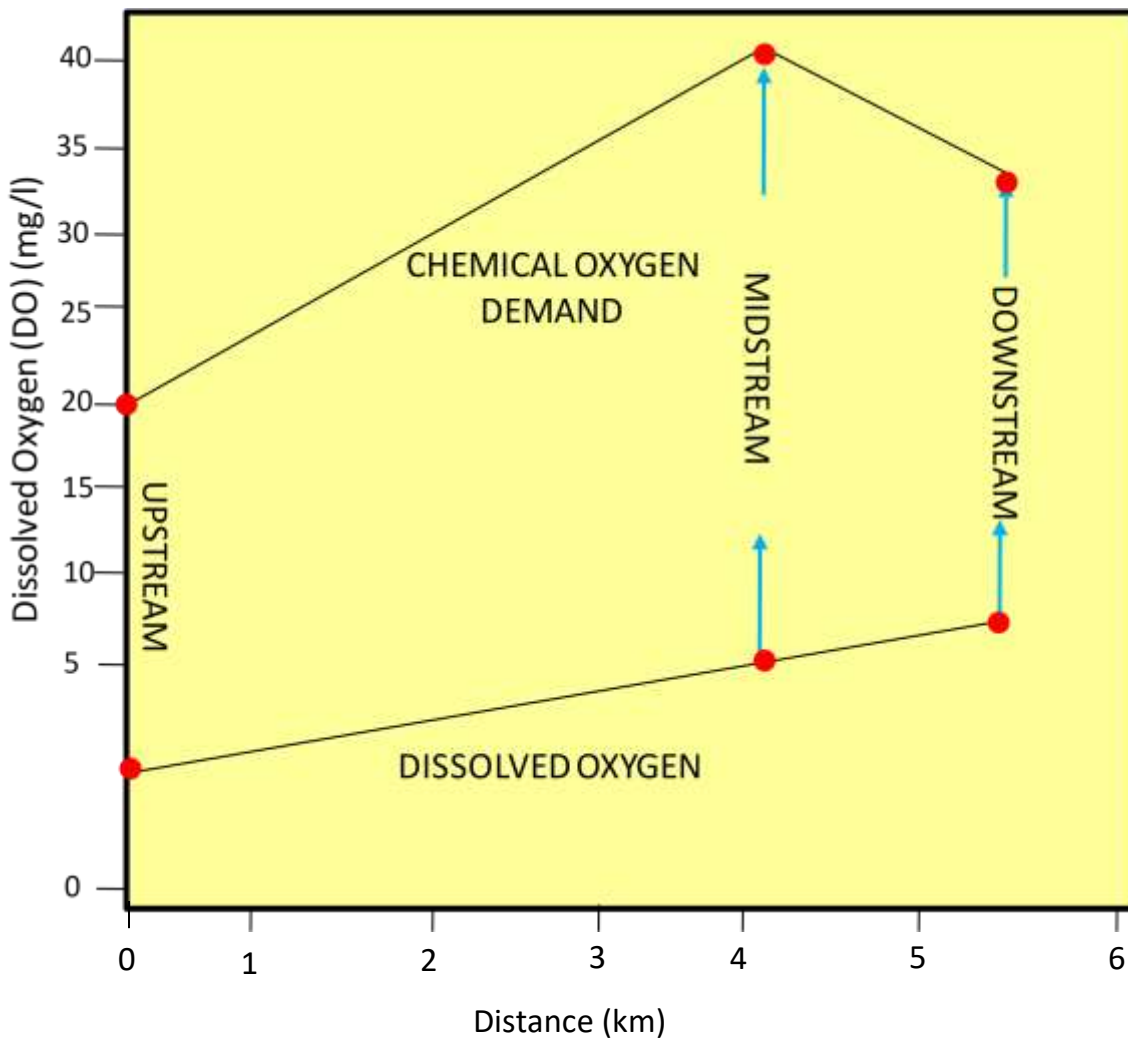


Fig. 5: Dissolved Oxygen profile of the stream.

#### 4.5.5. Self-Purification potential

The DO profile shows that the dissolved oxygen concentration at the upstream which constitute the maximum point of sag is 3.0 mg/l. This value compared to optimum DO value of 8.87 mg/l for the stream gives deficit of 5.87 mg/l. Using equation (3) to calculate the DO deficit where  $L = 5$  days gives deficit value of 2.59 mg/l for the stream. The calculated value is slightly lesser than the measured value as can be deduced from the DO profile. This indicates that dissolved oxygen in the stream originates mainly from reaeration reactions with very minimal contributions from other sources such as algal photosynthesis.

Self-purification potential can also be expressed in terms of time of flow required for the stream to re-attain its optimum DO level (Nwankwor and Okpala, 1993). Taking into consideration variations in velocity along the stream reaches, the stream can re-attain its optimum DO level within a time interval of 0.84 day (20hrs 16minutes) in the rainy season and a flow time much greater than 0.84 (20hrs 16minutes) in the dry season. These flow times indicate poor self-purification potential.

Self-purification potential can also be expressed in terms of spatial predominance of the reaction coefficients (Dikeogu *et al.*, 2014). It is apparent from Table 4 that only the midstream had Fair's number greater than 1, indicating predominance of reaeration over deoxygenation. Assuming equal spatial delineation for the three stream reaches, it can be concluded that about 66.66% of the stream is under deoxygenation predominance. This condition indicates poor self-purification potential and accounts for the very low dissolved oxygen levels in the stream.

### 5.0. CONCLUSION AND RECOMMENDATIONS

Dissolved oxygen profile of the stream suggests poor dissolved oxygen levels and poor atmospheric reaeration in the stream. If equal spatial delineation of the stream reaches is assumed, about 66.66% of the stream is under deoxygenation predominance. Dissolved oxygen in the stream originates mainly from reaeration reactions with very minimal contributions from other sources such as algal photosynthesis. The stream is capable of re-attaining its optimum dissolved oxygen level within a flow time of 0.84 day (20hrs 16minutes) in the rainy season. Thus, a flow time much greater than 0.84 day (20hrs 16minutes) would be required during the dry season. These flow times suggest poor self-purification potential.

Discharge of wastes especially untreated sewage into the stream should be discouraged. Relevant government agencies should provide land for construction of landfills for waste disposal, as it will reduce the discharge of wastes into the stream.

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