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Evaluation of Surface Water Quality in Ugwere-Boule, Khana Local Government Area, Nigeria

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Abstract: *The disastrous effects of pollution on the environment have been a major concern for industrial places globally, despite the great economic benefits of industrial activity. The nature and severity of water pollution are often closely associated with human activity, which can be quantified by the type and intensity of land use in the water's source locations. This study assessed the surface water quality in Ugwere-Boule, Khana Local Government Area, Rivers State with nine (9) sampling points (Upstream – A, B, and C; Midstream – D, E and F; and Downstream – G, H, and I) with three duplicates each made up the design, which resulted in a total of 27 points. Water samples were collected at nine different points along the river, with a distance of 0, 10, and 20 meters at each location. The concentrations of ammonia nitrogen (NH_3-N), suspended solids (SS), biological oxygen demand (BOD_5), and dissolved oxygen (DO) were all measured in accordance with their respective standards. On the other hand, the surface water quality was determined using the river pollution index (RPI) approach, and the pollution index integral value (S) was utilized to compare the parameters' standards. In order to estimate DO, the Streeter-Phelps model was also employed. All levels, with the exception of ammonia nitrogen (NH_3-N), were within the WHO recommended range for dissolved oxygen (DO), biological oxygen demand (BOD_5), and suspended solids (SS) according to the research's findings. The study also used the Rivers Pollution Index (RPI) and Integral value (S) to show that the river was contaminated, except at sample location I. Additionally, the model prediction obtained in this investigation (r^2 = 0.9705) for a high coefficient of determination can be categorized as almost good. These demonstrate the model's ability to predict DO in surface water in Ugwere-Boule.*

Keywords- Water Pollution, Surface Water Quality Assessment, River Pollution Index

1. INTRODUCTION

Water is essential to the survival of all living things, including aquatic and terrestrial life. Thus, it becomes essential to preserve and safeguard water resources in order to maintain them clean and to guarantee the safety of aquatic life [1]. Water is another vital natural resource that is necessary for human survival, along with air. Since water is the most prevalent element in the protoplasm, which is what plants and animals are made of, there would actually be no organic matter if it weren't for water [2]. Although humans depend on water, human activity has seriously degraded the quality of that resource. Direct or indirect pollution of the aquatic environment has detrimental effects on aquatic life, including health risks to humans, obstructions to aquatic activities like fishing, and deterioration of water quality that affects the use of the water for commercial, industrial, and agricultural purposes [3].

While water monitoring, surveying, and surveillance are all based on data collection, water quality assessment is the overall process of evaluating the physical, chemical, and biological nature of the water. These variables are typically described as longitudinal and latitudes of sampling or measurement site (x and y coordinates), and further characterized by the depth at which the sample was taken [4]. Monitoring surface water quality is a useful tool for assessing the baseline quality of the water, identifying and assessing the affects upstream and downstream, and determining the amount, origins, and movement of pollutants such as salt, fertilizers, and pesticides.

In vast bodies of water, monitoring aids in surface water management. Additionally, it aids in the analysis of all data and provides details on any potential limitations derived from the findings. This aids in alerting one to potential issues with water quality that might require attention in light of the findings. Due to the uncontrolled discharge of urban effluents, runoff, atmospheric deposition, municipal, and industrial effluent into marine, stream, and river water bodies, water quality monitoring has become an issue [5]. Surface water contamination is caused by a variety of sources, including both natural and man-made activity. Urban runoff is one of these processes, and it becomes more important during wet and floody seasons [6]. Like most water bodies, the Ugwere-Boule surface water in Khana Local Government Area, Rivers State, the Niger Delta state of Nigeria, is subject to activities that have the potential to contaminate it.

In their investigation of the New Calabar River, [7] it was found out that locations around the river, which have high population densities and increased industrial activity, also serve as disposal sites for all types of garbage since the nearby companies release their effluents into the river. It was shown that the most significant factor in predicting the parameters related to water quality was the use of commercial and industrial land [8].

Pollution of the aquatic environment directly or indirectly, results to damaging effects in living organisms, which include hazard to human health, hindrance to aquatic activities including fishing, impairment of water quality with respect to its use in agricultural, industrial and other economic activities [3]. Water pollution in developing countries has become a serious problem, it has reached an alarming situation and Nigeria is no exception [9]; it threatens the health and wellbeing of humans, plants and animals.

At the present time, an increased emphasis has been placed upon the development of water- quality indices. Much of the effort in developing quality indices is directed towards quantifying such terms as "good" and "bad" and the values between these extremes; hence a water index is a grading system for comparison of various water bodies [10]. The objective of WQI is to turn complex water quality data into information that is understandable and usable by the public [11]. A number of indices such as modeling and software for contaminants have been developed to summarize water quality data in an easily expressible and easily understandable format [12-13]. The analysis of microbial water quality often includes microbiological test for faecal analysis of microorganisms, evaluation of particular pathogen density and Escherichia coli, which comes through faecal pollution [14]. Water quality varied significantly thereby; systems are expected to fail occasionally. For instance, during rainfall microbial contamination may increase rapidly in source water due to water runoff on soil surface [6]. The increasing concentration of chemicals generated from industries, the domestic wastewater and their subsequent release to surrounding raise a wide spread and increasing public concern over the use of the surface water [15].

Water Quality Indices are useful tools, particularly for communicating water quality information to the public and stakeholders in water management who need to know whether the quality of water bodies is good enough for specified activities [16]. Standards are used by regulators in various types of permits (for example, industrial and municipal discharge permits) and set limits, based on applicable water quality standard [17].

Water pollution happens when a body of water receives excessive amounts of substances known as pollutants, which negatively affects the water's quality [18]. However, not much information is available on surface water quality parameters including dissolved oxygen (DO), biochemical oxygen demand (BOD_5), suspended solids (SS) and ammonia nitrogen (NH_3-N) in the upstream, midstream, and downstream of Ugwere-Boule, Khana Local Government Area of Rivers State. Therefore, having identified these gaps, this study focuses on the use of river pollution index (RPI) to determine surface water quality in Ugwere-Boule.

2. MATERIALS AND METHODS

Materials

The following supplies were utilized in the investigation: field notebook, life jacket, gloves, canoe, ice pack amber glass with Teflon line cover, sample bottles, ropes, preservatives, tapes and marker pens, sampler/sampling equipment, syringe and needles, coolers (sample storage/transit containers).

Sampling Design

In October 2023, water samples were taken in order to measure the parameters of surface water quality, such as dissolved oxygen (DO), suspended solids (SS), ammonia nitrogen (NH_3-N), and biochemical oxygen demand (BOD5), in specific areas of the Ugwere-Buole River that were upstream, midstream, and downstream of the sampling points. The sample points selected were designated upstream of Ugwere-Boule surface water (USW) to include A, B, and C, midstream of ugwere-Boule surface water (MSW) to include D, E, and F, and downstream of Ugwere-Boule surface water (SUD) to include G, H, and I . The sampling distance was at intervals of 10 m from each selected sampling points, and a total distance of 30 meter each the three of the study areas.

Description of Study Area

The study area is located in Ugwere-Boule in Khana Local Government Area of Rivers State. The geographical coordinates of the study area lie between latitude 4.6"71'72°N and longitude 7.3"43'98°E as shown in figure 1 below. The surface water crosses the entire community and its vegetation is mainly a high dense rain forest. Thus, the occupations of the people are mainly farming, fishing, and hunting.

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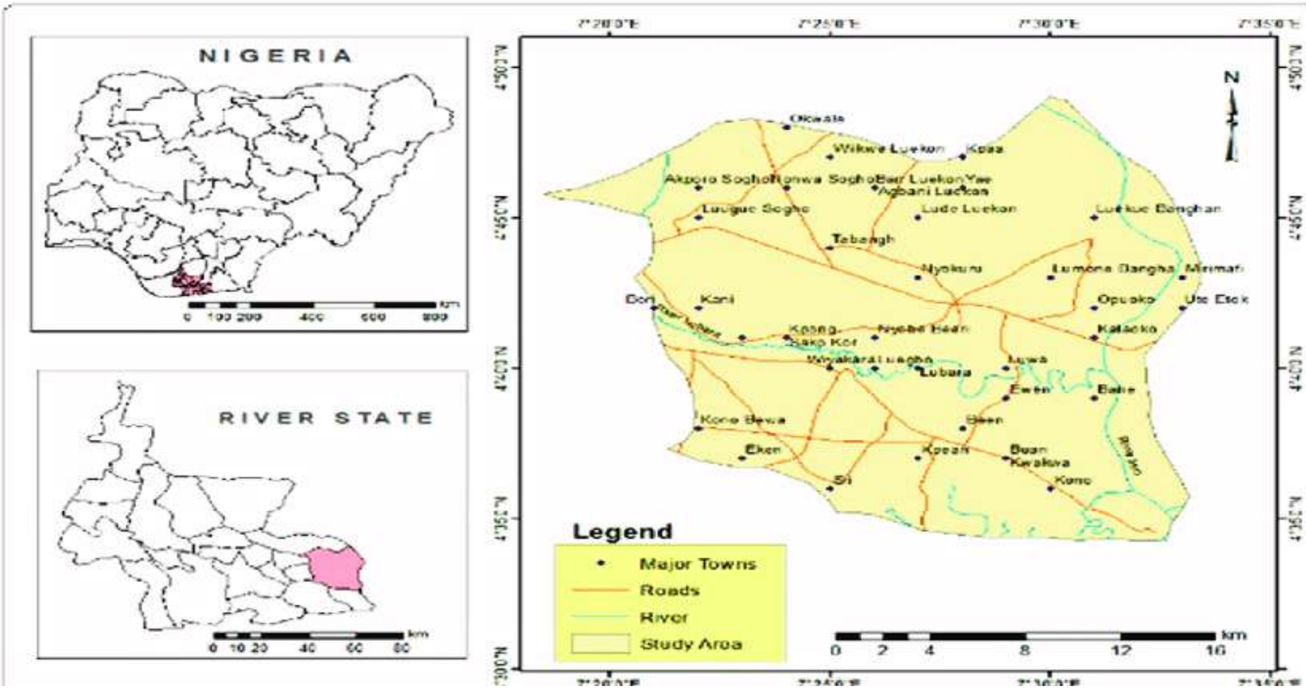

Figure 1: Map of Khana, Local Government Area Rivers State

Method of Sampling

Water samples were taken in October 2023, three times within the same sampling point, to minimize error caused by non-uniform distribution of properties. The samples were taken at the distances of 0, 10, and 20 m for each sampling location along the discharge point on the water surface, assisted by a boat moving from upstream to downstream in the direction of water flow.

This was done according to [19] standard procedure.

Before being used, every plastic bottle that contained the water samples was thoroughly cleansed with distilled water and then rinsed with diluted nitric acid. The water sample bottles were refrigerated and kept out of the sun before being taken to the lab for analysis to determine the amount of petroleum hydrocarbon they contained.

Sample Analysis

To get an average concentration of the qualities of interest, surface water samples from three different sampling locations in Khana Local Government Area's Ugwere-Boule were tested in duplicate. Each sample was examined for the four most often used river water quality characteristics, which were then utilized to create the river water quality index (RPI) for the river under study. Dissolved oxygen (DO), ammonia nitrogen (NH_3-N), suspended solids (SS), and biochemical oxygen demand (BOD_5) are the parameters.

Determination of Surface Water Quality

The River Pollution Index (RPI) was used to determine the surface water quality. The formula for calculating an RPI can differ depending on the methodology and parameters used in a given index [20]. There isn't a single RPI formula that applies to all regions or organizations because different organizations and regions may develop their own indices that are customized to local conditions and regulatory requirements.

The "River Pollution Index," or "RPI" for short, is the complete index that the EPA now uses to evaluate the quality of river water. Four water quality parameters make up the RPI as shown in Table 1: Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD_5), Suspended Solids (SS) and Ammonia Nitrogen (NH_3^-N), which show the degree of pollution in river water and are computed to index integral value. Each of the four index scores was derived from the water quality variables that were used to calculate RPI (Si = 1, 3, 6, or 10) [21-24]. The following equation was used to calculate the River Pollution Index (RPI) [25].

$$RPI = \frac{1}{4}\sum_{i=1}^{4} Si \qquad (1)$$

Where: Si represents the index scores and the RPI value ranges from 1 to 10.

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Table 1: River Pollution Index (RPI) Chart [20], [25]

Water Quality / Item	Non/mildly-polluted	Lightly-polluted	Moderately-polluted	Severely-polluted
Dissolved Oxygen (DO) mg/L	DO ≧ 6.5	6.5 ＞ DO ≧ 4.6	4.5 ≧ DO ≧ 2.0	DO ＜ 2.0
Biochemical Oxygen Demand (BOD_5) mg/L	BOD_5 ≦ 3.0	3.0 ＜ BOD_5 ≦ 4.9	5.0 ≦ BOD_5 ≦ 15.0	BOD_5 ＞ 15.0
Suspended Solids (SS) mg/L	SS ≦ 20.0	20.0 ＜ SS ≦ 49.9	50.0 ≦ SS ≦ 100	SS ＞ 100
Ammonia Nitrogen (NH_3-N) mg/L	NH_3-N ≦ 0.50	0.50 ＜ NH_3-N ≦ 0.99	1.00 ≦ NH_3-N ≦ 3.00	NH_3-N ＞ 3.00
Point Scores	1	3	6	10
Pollution Index Integral Value (S)	S ≦ 2.0	2.0 ＜ S ≦ 3.0	3.1 ≦ S ≦ 6.0	S ＞ 6.0

River pollution index (RPI) published by Environment Analysis Laboratory

Biochemical Oxygen Demand (BOD_5)

Biochemical oxygen demand (BOD_5) was determined by conventional methods according to Association of Official Analytical Chemists [26]. A sample of the solution (50ml) was placed in a 500 ml BOD bottle and filled to the mark with previously prepared dilution water. A blank solution of the dilution water similarly prepared and placed in two BOD bottles.

A control solution without dilution water is also prepared and placed in a BOD bottle. The bottles are stoppered, sealed and incubated for five days at room temperature. BOD is calculated from the relation:

$$\mathrm{BOD} = (\mathrm{D1} - \mathrm{D2})/\mathrm{P}, \quad (2)$$

Where;

D_1= dissolved oxygen 15 minutes after preparation,

D_2= dissolved oxygen in diluted sample after incubation, and

P= amount of sample used

Dissolved Oxygen Modeling

Using the widely used established model, the dissolved oxygen (DO) in the creeks was predicted by [27]. The concentration of DO, according to Streeter and Phelps, was dependent on two opposing processes: reoxygenation and deoxygenation.

Case I: Deoxygenation

The amount of BOD that is eliminated during deoxygenation determines how quickly oxygen is consumed; this can be stated as:

$$r_1 = \frac{dL}{dT} = -K_1 L \quad (3)$$

Where:

r_1 = Rate of deoxygenation (mg/l.day)

K_1 = First order rate coefficient (day^{-1})

L = Remaining BOD in water (mg/l)

t = Time of deoxygenation (day)

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Upon integration of equation (3) and simplifications, we obtained as follows:

$$\int_{L_0}^{L} \frac{dL}{L} = K_1 \int_0^t dt \qquad (4)$$

$$L = L_0 e^{-K_1 t} \qquad (5)$$

Where:

L_0= Ultimate BOD or initial concentration of BOD (mg/l)

Substituting equation (5) into equation (3) gives:

$$r_1 = \frac{dL}{dT} = -K_1 L_0 e^{-K_1 t} \qquad (6)$$

Case II: Reoxygenation

The reaeration rate coefficient and DO deficit determine the oxygen replenishment rate during reoxygenation, which can be expressed as follows:

$$r_2 = K_2(C_s - C) = K_2 D \qquad (7)$$

Where:

r_2 = Rate of reaeration (mg/l.day)

K_2 = reaeration rate coefficient (day^{-1})

C_s = DO saturation (mg/l)

C = Actual DO concentration (mg/l)

D = DO deficit (mg/l)

However, the time rate of DO deficit was expressed according to [27] Streeter and Phelps (1925) as:

$$\frac{dD}{dt} = K_1 L + K_2 D \qquad (8)$$

But the concentration of actual dissolved oxygen was generally expressed as:

$$\frac{dC}{dt} = -K_1 L + K_2 D \qquad (9)$$

If the rate of reaeration is constant, then, equation (7) becomes:

$$D = C_s - C \qquad (10)$$

And upon differentiating equation (10) at constant C_s gives:

$$\frac{dC}{dt} = -\frac{dC}{dt} \qquad (11)$$

Combining equations (5), (8) and (11) gives:

$$\frac{dC}{dt} = -\frac{dC}{dt} = K_1 L_0 e^{-K_1 t} - K_2 D \qquad (12)$$

Therefore, on re-arrangement, we have:

$$\frac{dC}{dt} + K_2 D \;= K_1 L_0 e^{-K_1 t} \qquad (13)$$

Equation (11) is a non-linear ordinary differential equation, and its solution given as:

$$D_{(t)} = \frac{K_1 L_0}{K_2 - K_1}\left(e^{-K_1 t} - e^{-K_2 t}\right) + D_0 e^{-K_1 t} \quad (14)$$

Where:

$D_{(t)}$ = O_2 deficit with time = $C_s - C_t$ − (mg/l)

D_0= Initial O_2 deficit (mg/l)

Therefore, from equations (11) and (14), the actual DO oxygen concentration is given as:

$$C = C_s - \left[\frac{K_1 L_0}{K_2 - K_1}\left(e^{-K_1 t} - e^{-K_2 t}\right) + D_0 e^{-K_1 t}\right] \quad (15)$$

Where:

C = Actual

From [28], at 20 ºC and 40 ºC, DO saturation was given as 9.0 mg/l and 6.0 mg/l, respectively. Hence, at average creek temperature of 28 ºC, the DO saturation can be interpolated as:

$$C_{s(28\,^{\circ}\mathrm{C})} = C_{s(20\,^{\circ}\mathrm{C})} + \left(\frac{28-20}{40-20}\right) \times \left(C_{s(40\,^{\circ}\mathrm{C})} - C_{s(20\,^{\circ}\mathrm{C})}\right) \quad (16)$$

Therefore, DO saturation at average temperature of 28 ºC is calculated as:

$$C_{s(28\,^{\circ}\mathrm{C})} = 6 + \left(\frac{8}{20}\right) \times 3 = 7.2 \quad (17)$$

The values of the constants1k and 2k were obtained from [28] as 0.34 and 0.20 day^{-1} respectively. In order to verify the model's goodness of fit, the experimental findings of the surface water in Ugwere-Boule throughout the study period were simulated into the equation. Additionally, the coefficient of determination (r^2) was used.

3. RESULTS AND DISCUSSION

Concentration of Selected Surface Water Quality Parameters of Upstream, Midstream, and Downstream of Ugwere-Buole River

Dissolved Oxygen (DO)

Figure 2 shows the plot of dissolved oxygen in the surface water samples upstream, midstream, and downstream. The corresponding DOs for samples A, B, C, D, E, F, G, H, and I were 6.225, 5.505, 5.105, 4.835, 4.205, 3.725, 1.57, and 1.08 mg/l. The DO of river water continuously decreases from upstream to downstream in accordance with the river's flow. This indicates the presence of microbes and other species in the samples, maybe due to their high nutritional content. With the exception of samples I and J, which were under the WHO-permitted level, all of the samples had DO concentrations higher than the WHO's [17] allowed limit.

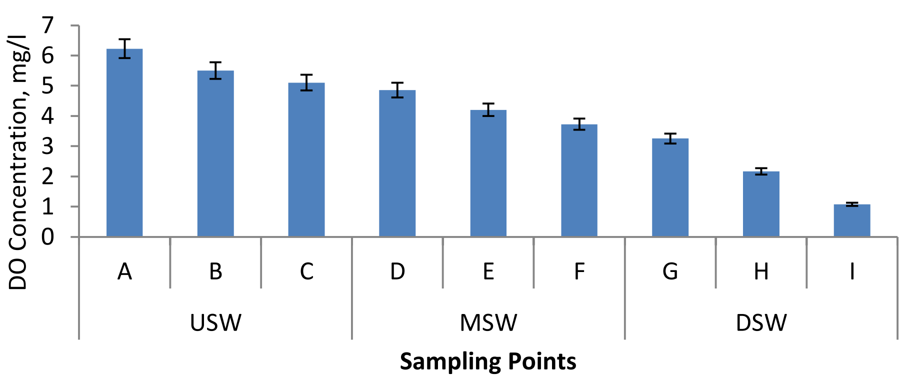

Figure 2: DO of the River Water Sample

Biological Oxygen Demand (BOD_5)

The surface water samples from the upstream, midstream, and downstream of the Ugwere-Buole surface water are plotted for biological oxygen demand (BOD5) in Figure 3. According to the samples, the BOD5 values were 17.65, 16.415, 15.015, 13.505, 12.65, 10.915, 8.005 mg/l for samples A, B, C, D, E, F, G, H, and I. Downstream flow of the river results in a decrease in BOD5 due to water dispersion. This indicates that bacteria and other organisms that consume oxygen were present in the samples. This may account for the favorable conditions for aerobic exercise produced by adequate oxygenation over the duration. The BOD5 amounts in every sample were below the threshold set by WHO [17].

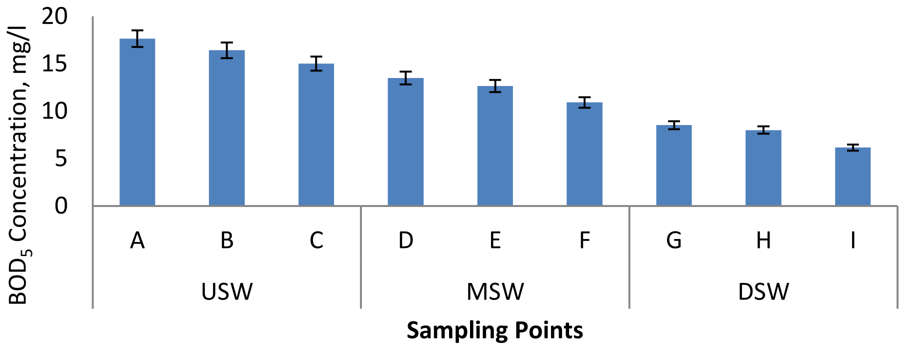

Figure 3: BOD$_5$ of the River Water Sample

Suspended Solid (SS)

The results of the Suspended Solid (SS) measurement of the river water are summarized in Table 2, and Figure 4 shows the graphical depiction of SS in the upstream, midstream, and downstream of Ugwere-Boule surface water. These values varied from 8.99, 8.005, 6.705, 5.77, 5.065, 4.55, 4.105, and 2.555 mg/l for A, B, C, D, E, F, G, H, and I, respectively. The WHO recommended amount was significantly below, according to the results. This shows that aquatic life can flourish in the river dependent on the SS levels of the wastewater discharge.

Table 2: Selected Water Parameters

Location	Sampling Point	Parameters (mg/l)			
		BOD	DO	SS	NH_4-N
USW	A	17.65	6.225	8.99	2.49
	B	16.415	5.505	8.005	2.255
	C	15.015	5.105	6.705	2.06
MSW	D	13.505	4.855	6.005	1.945
	E	12.65	4.205	5.77	1.755
	F	10.915	3.725	5.065	1.665
DSW	G	8.515	3.255	4.55	1.335
	H	8.005	2.165	4.105	1.105
	I	6.155	1.08	2.555	0.765

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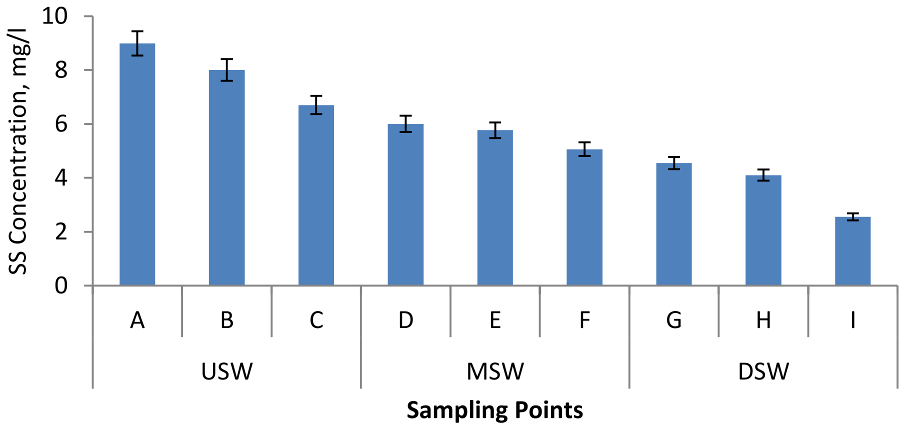

Figure 4: SS of the Surface Water Sample

Ammonia-Nitrogen (NH_3-N)

Figure 5 depicts the NH3-N in the surface water of Ugwere-Buole upstream, midstream, and downstream. The NH3-N experimental results for samples A, B, C, D, E, F, G, H, and I are 2.49, 2.255, 2.06, 1.945, 1.755, 1.665, 1.335, 1.105, and 0.765 mg/l, in that order. These findings indicate that the water flows in the direction of NH3-N decrease. This might be caused by the genesis of NH4-N formation and the spread of contaminants. For samples A through F, the NH3-N level was over the WHO permitted range, but for samples G through I, it was within the permissible limit.

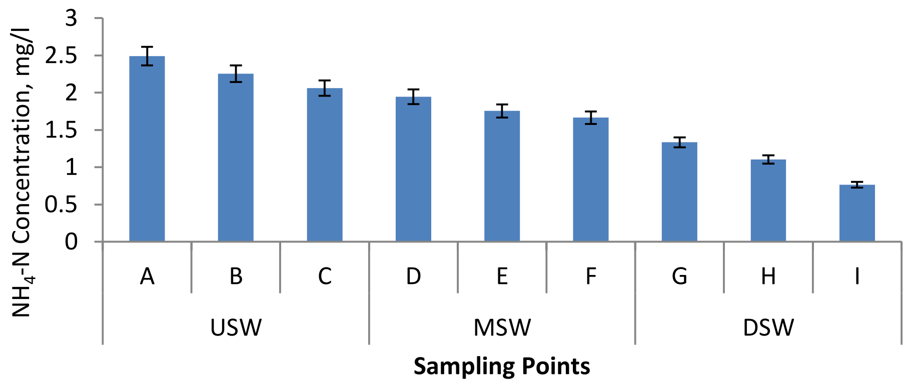

Figure 5: HN_3-N of the Surface Water Sample

Surface Water Quality using River Pollution Index (RPI)

The water quality was determined using RPI, which classifies water quality according to the degree of purity using four measured water quality variables: DO, SS, BOD_5, and NH_3-N. The pollution status is calculated using four states for each parameter. The current study compared the levels of DO, BOD_5, SS, and NH_3-N with those reported in the RPI table (Tables 1 and 3) in order to assess the status of particular water variables. Table 2 revealed the RPI for the variables in the Ugwere-Buole surface water upstream, midstream, and downstream. It was discovered that the DO range in the sample locations was 0.27 to 1.55625 mg/l. Comparing the sample locations to RPI, all of them showed significant pollution, with values of DO ranging from 0.27 to 1.55625 mg/l, which was less than 2.0 mg/l.

The BOD_5 concentrations at the sample locations ranged from 1.53875 to 4.4125 mg/l. The findings show that the BOD5 concentrations in sample locations A through E ranged from 3.0 to less than 4.9 mg/l, indicating a mildly contaminated water source. BOD_5 values less than 3.0 mg/l at sample locations F through I indicated that the water met RPI requirements for non- or mildly-polluted status only. Less than 20 mg/l of SS was found in all sample locations (A–I), suggesting that the water was neither non- nor mildly contaminated.

The NH_3-N concentrations in sample locations A through C range from 0.19125 to 0.6225 mg/l, suggesting that the water in those places is slightly contaminated when compared to RPI. In comparison to RPI, sample locations D through I with NH_3-N contents less than 0.50 mg/l show that the water is not or is only weakly contaminated. Similarly, Sample Locations D to I had NH_3-N concentrations of less than 0.50 mg/l, suggesting that the water is either completely unpolluted or relatively mildly contaminated. Sample locations A through E were found to be extremely contaminated, as were sample F through I, with less than 3.1 mg/l and less than 6.0, according to the pollution integral value data.

This indicated that, in relation to the pollution index integral value (S), the samples were moderately polluted. The water at sample location I has a S value of less than 2.0, meaning that it is just slightly or non-polluted. Sample location I's S values, which are less than 2.0 mg/l, suggest that the local water is either completely clean or only marginally contaminated.

Table 3: Computed River Pollution Index (RPI)

Location	Sampling Point	Parameters (mg/l)				
		BOD	DO	SS	NH_3-N	S
USW	A	1.55625	4.4125	2.2475	0.6225	8.83875
	B	1.37625	4.10375	2.00125	0.56375	8.045
	C	1.27625	3.75375	1.67625	0.515	7.22125
MSW	D	1.21375	3.37625	1.50125	0.48625	6.5775
	E	1.05125	3.1625	1.4425	0.43875	6.095
	F	0.93125	2.72875	1.26625	0.41625	5.3425
DSW	G	0.81375	2.12875	1.1375	0.33375	4.41375
	H	0.54125	2.00125	1.02625	0.27625	3.845
	I	0.27	1.53875	0.63875	0.19125	2.63875

Dissolved Oxygen Model

The predictions and validation of a generated model for a given situation determine its true nature. The findings of several measured data sets were substituted into the created dissolved oxygen model to obtain the results for Ugwere-Boule surface water throughout the examined period. To determine the model's predictability, these were compared. Table 4 displayed the anticipated findings for the surface water's dissolved oxygen during the study period.

The graphical relationship between the dissolved oxygen values as predicted by regular operating procedures and the measured values is displayed in Figure 6. A coefficient of determination (r2) value of 0.9705 was found to indicate a strong correlation between the model and surface water collected data over the study period. This demonstrated that the model can accurately represent the outcomes of the experiments.

Table 4: Predicted Disolved Oxygen in the Ugwere-Buole Surface Water

Sampling Points	Measured DO, mg/l	Predicted DO, mg/l
0	6.225	6.321
10	5.505	4.961
20	5.105	4.323
30	4.855	4.261
40	4.205	3.985
50	3.725	3.658
60	3.255	3.013
70	2.165	1.982
80	1.08	0.989

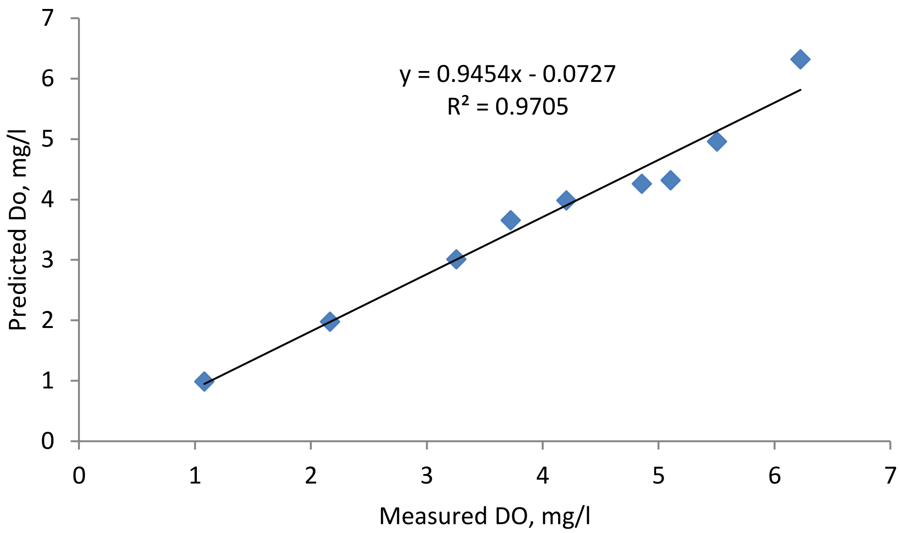

Figure 6: Measured and Predicted DO for Ugwere-Buole Surface Water

4. CONCLUSION

Research has been conducted on the quality of the surface water in Khana Loval Government Area's Ugwere-Boule. The following claim is corroborated by the test results analysis:

1. The BOD_5, and SS value in the studied upstream, midstream, and downstream of Ugwere-Boule surface water were within the permissible limit including samples I for DO, in samples G, H, and I for NH_3-N except DO for A, B, C, D, E, F, and NH_3-N for A, B, C, D, E, and F above WHO permissive limit.
2. The study revealed that using RPI and S proved that the surface water was polluted except sampling point I that was non/mildly-polluted.
3. Model prediction achieved in this study can be categorized as almost good for high coefficient of determination (r^2). These show the potential of the model to predict DO in Ugwere-Boule surface water.

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