



Assessment of Water Quality in a Tidal River System using River Pollution Index (RPI)

A. Rim-Rukeh*

Department of Environmental Science, Federal University of Petroleum Resources, P.M.B. 1221, Effurun, Delta State, Warri, Nigeria.

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ABSTRACT

The water quality and tidal nature of Woji River have been experimentally studied. Experimental data monitored within the hours of 07:00 h and 19:00 h in the course of the study include tidal current river depth and width, suspended solids (SS), dissolved oxygen (DO), biochemical oxygen demand (BOD), and ammonia-nitrogen. The water quality of Woji River was evaluated using the River Pollution Index (RPI). Results indicate that tide peaks within the hours 11:00 h to 13:00 h and recede within the hours of 17:00. Maximum tide level was 1.80 m and the minimum value was 0.77 m. At the high tide, measured width varied between 110-121.8 m and at lower ebb, width of the river varied between 47.2 m and 51.2 m. At peak tide water flows at an average speed of 1.36 m/s in the South West direction and at ebb tide River flows in the reverse direction at a constant speed of 0.12 m/s. Physico-chemical characteristics showed DO values ranged between 2.00 and 3.55 with a mean of 2.75 mg/L. Suspended solids (SS) values ranged between 4,100-8,150 mg/L with a mean value of 6713.08 mg/L. Observed BOD levels at sampling point ranged between 9.50-17.60 mg/L with a mean of 13.33 mg/L. Ammonia-nitrogen levels at sampling point ranged between 1.90-5.60 mg/L with a mean value of 3.38 mg/L. River Pollution Index (RPI) of above 6.0 was obtained and hence water quality is classified as severely polluted. The water quality is severely polluted and unacceptable for drinking and domestic purposes and will require best management practice to improve the water quality.

1. Introduction

Tides are the periodic motion of the waters of the sea due to changes in the attractive forces of the Moon and Sun upon the rotating Earth [1]. It is the daily cycle's rhythm of the water flowing in and out as if it is retreating to some far off place. The complex flow of tidal streams is mainly influenced by interactions between river water and seawater. Thus, tidal streams are in constant flux as they adapt to river and climate conditions. The half-day tidal variation of the sea is the main driver of cyclic fluctuation in tidal streams [2]. Seasonal changes in flow conditions from estuaries determine water salinity [3].

Tides can either help or hinder a mariner. A high tide may provide enough depth to clear a bar, while a low tide may prevent entering or leaving a harbour. Tidal current may help progress or hinder it, may set the ship toward dangers or away from them. By understanding tides and making intelligent use of predictions published in tide and tidal current tables and descriptions in sailing directions, the navigator can plan an expeditious and safe passage through tidal waters.

Tidal rivers are very important features of the Coastal Zone because of their immense biological productivity and their proximity to centers of commerce and population. Most of the shellfish and much of the local finfish consumed by man are harvested from tidal rivers and estuaries. For example, within the vicinity of tidal Columbia River, large plant community consisting of 62 species of plants were reported [4]. Common plant species include Creeping spikerush (*Eleocharis palustris*), horsetail (*Equisetum sp.*), rice cutgrass (*Leersia oryzoides*), marsh seedbox (*Ludwigia palustris*), water milfoil (*Myriophyllum sp.*), and reed canary grass (*Phalaris arundinacea*) was secondary to *Salix sp.* In addition to the presence of large plant community, large number of varieties of fish species have also been reported [4]. Common fish species found are threespine stickleback (*Gasterosteus aculeatus*), peamouth chub (*Mylocheilus caurinus*), banded killifish (*Fundulus diaphanous*), and juvenile Chinook salmon (*Oncorhynchus tshawytscha*).

Globally, the pollution arising from urbanization, land run-off and industrial waste as well as agricultural activities has become increasingly serious concern of the functionality of tidal rivers ecosystem. The functionality of tidal rivers ecosystem are threatened by sewage, coastal settlement, land clearance and much more. Tidal rivers are affected by events far upstream and concentrate materials such as pollutants and sediments [5]. Effects of tidal pollution on fish stocks in the Amur River have also been reported [6].

The knowledge of tidal characteristics of rivers and estuaries are essential to the planning and execution of coastal projects for environmental impact monitoring and to the understanding of pollutants transport and distribution. In Nigeria, our knowledge of the processes governing these phenomena is limited and the measurements needed to improve our understanding are scarce [7]. Researches on tidal water bodies in Nigeria have focused on the definition and applicability of the term tidal river [7]. This study was in response to an increasing awareness of the importance and delicate ecological balance of tidal rivers' occasioned by excessive nutrient enrichment. The aim of this study is, therefore, to highlight the hydrodynamic processes involved in the tidal propagation along the Woji River system, based mainly on field measurements of tide currents, and water levels (tides). It is also aimed at assessing the water quality of the River for the purpose of highlighting the extent of pollution. The ultimate goal of the Woji River study is to generate data that are important to designing the management and conservation policies of the River. Further, the results obtained shall be used to propose a discussion on Woji River tidal classifications.

2. Experimental Methods

2.1 Description of the Study Site

The tidal river system used in this study is Woji River. It is an estuarine tidal water a tributary of the upper Bonny River located between longitudes 7°00' E and 7°15' N and latitudes 4°28' E and 4°40' N. It arises from the bifurcation to the left of the Okpoka River, which drains into Bonny River. The water body is tidal and gradually transits from fresh to salt water at the head. Woji River receives industrial effluent discharges from the Nigerian bottling company, Schlumberger, Halliburton and Rivers state vegetable oil company and transverses through several

*Corresponding Author

Email Address: arimrukeh@yahoo.co.uk (Akporfure Rim-Rukeh)

communities among which include Azuabie, Woji, Okuru-ama, Abuloma, Kalio-ama and Oba-ama. The Trans Amadi slaughter house and market generate wastes and faeces entering the River.

Woji River is located in the Trans Amadi Industrial area of Port Harcourt, Rivers State (Fig. 1). It separates Obio/Akpor Local Government Area (OBALGA) from Port Harcourt City Local Government Area (PHALGA) with a link (Trans Woji Link Bridge between Slaughter and Woji) across these local governments.

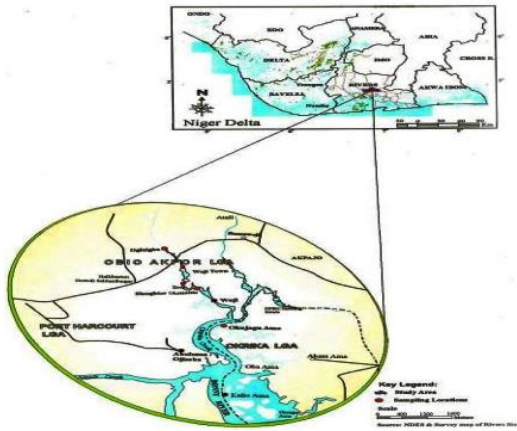


Fig. 1 Map of study area showing the Woji river system

Previous study of the meteorology of the area [8], reveals the average atmospheric temperature to be 25.50 °C in the rainy season and 30.00 °C in the dry season. The daily relative humidity values range from 55.50% in dry season to 96.00% in rainy season. Rainfall in the area averages 2500 mm annually. The rainfall pattern shows two identifiable seasons the rainy season (April to October) and the relatively short dry season (November to March).

2.2 Sampling Procedure

A sampling station with geographical coordinates of 4°53'57"N and 6°52'30"E was chosen for the study. The choice of the sampling station include the presence of the following activities: ship building activities, slaughter activities, industrial effluent discharge. Water samples for the study were collected in plastic containers pre-treated by washing them with 0.1 M dilute hydrochloric acid and sun-dried. At each of the sampling activity, the plastic containers were first of all rinsed with the water to be collected. One container at a time, with its lid closed was then dipped into the water body to a depth of about 5 cm from the surface where the lid was removed to fill the container with water. The lid was replaced immediately, and the container with the water sample taken out of the water body. (Replacing the lid of the container at the sampled depth excludes air and prevents contamination of the water sample with microorganisms from the environment). Samples for biochemical oxygen demand (BOD) were collected in Winklers bottles. All samples were stored in an ice-chest. All samples were conveyed in an ice-cooler and transported to the Anal Concept Laboratory, Port Harcourt for analysis.

Water samples for the study were collected on an hourly basis within the hours of 07:00 h to 19:00 h on the 27th of July, 2015. The sampling, handling and analysis of water samples were carried out as recommended [9-11].

2.3 Measured Parameters

Parameters analyzed for in all samples collected were biochemical oxygen demand (BOD), dissolved oxygen (DO), suspended solids (SS) and ammonium (NH₄). These parameters are good environmental impact indicators for River Pollution Index (RPI) [12].

Within the sampling period of 07:00 h to 19:00 h, hydrodynamic characteristics such as, tidal current, tides and width of the water body at the sampling station were also determined. Tidal current was determined using model 106 light weight current meter. Water depth and width was measured using a calibrated stick. Velocity of the water body was also determined using the float method.

2.4 Laboratory Analysis

Fast changing parameters such as dissolved oxygen (DO) was measured *in-situ* using a multi-parameter water quality (model 600 UPG). Biochemical oxygen demand (BOD) of the water samples was determined using the Winkler Titration Method [11]. Suspended solids (SS) was determined using the mass loss technique (APHA 209D-Total Non-filtrate

Residual Dried at 103-105 °C. Ammonium (NH₄) was determined using Brucine colourimeter method. All methods of analysis are consistent with those reported [9-11].

2.5 River Pollution Index

The conventionally adopted classification system for monitoring water quality is the River Pollution Index (RPI) [12] that includes four variables: dissolved oxygen (DO), biochemical oxygen demand (BOD₅), suspended solids (SS), and ammonia nitrogen (NH₃-N). Each variable of water quality used to determine RPI is converted to one of four index scores (S_i = 1, 3, 6, or 10). Notably, RPI refers to the arithmetic average of these index scores with respect to the water quality:

$$RPI = \frac{1}{4} \sum_{i=1}^4 S_i \tag{1}$$

where S_i represents the index scores based on Table 1 and the RPI value ranges from 1 to 10. According to the river pollution index listed in Table 1, the four classifications of pollution are unpolluted, negligibly polluted, moderately polluted, and severely polluted.

Table 1 Definition of river pollution index (RPI)

Items	Ranks			
	Unpolluted	Negligibly polluted	Moderately polluted	Severely polluted
DO (mg/L)	Above 6.5	4.6-6.5	2.0-4.5	Under 2.0
BOD ₅ (mg/L)	Under 3.0	3.0-4.9	5.0-15	Above 15
SS (mg/L)	Under 20	20-49	50-100	Above 100
NH ₃ -N (mg/L)	Under 0.5	0.5-0.99	1.0-3.0	Above 3.0
Index Scores (S _i)	1	3	6	10
RPI	Under 2	2.0-3.0	3.1-6.0	Above 6.0

Table 2 Hydrodynamics characteristics of tidal Woji river

Sampling Time (h)	Tide (m)	Width (m)	Tidal current (m/s)
07:00	0.77	47.2	0.12
08:00	1.16	51.4	0.24
09:00	1.46	69.1	0.27
10:00	1.65	82.7	0.76
11:00	1.76	110.0	1.36
12:00	1.80	134.6	1.50
13:00	1.76	121.8	1.15
14:00	1.64	107.3	0.84
15:00	1.45	89.2	0.70
16:00	1.18	79.5	0.64
17:00	0.91	73.3	0.24
18:00	0.81	66.4	0.22
19:00	0.92	51.2	0.19
Mean	1.33	83.36	0.63

Table 3 Physico-chemical characteristics of tidal Woji river

Sampling Time (h)	Tide (m)	SS (mg/L)	DO (mg/L)	BOD (mg/L)	NH ₃ -N (mg/L)
07:00	0.77	7,800	2.50	9.50	1.90
08:00	1.16	8,000	2.40	9.89	2.04
09:00	1.46	8,150	2.50	10.70	2.20
10:00	1.65	7,520	2.60	11.30	2.90
11:00	1.76	6,800	3.30	12.80	3.70
12:00	1.80	5,800	3.28	14.20	4.27
13:00	1.76	4,900	3.55	15.50	4.95
14:00	1.64	4,100	3.20	17.60	5.60
15:00	1.45	5,600	3.26	16.90	4.32
16:00	1.18	6,300	2.86	15.40	3.70
17:00	0.91	7,100	2.10	13.10	2.85
18:00	0.81	7,500	2.00	12.20	2.10
19:00	0.92	7,700	2.20	14.10	3.40
Mean	1.27	6713.08	2.75	13.33	3.38

3. Results and Discussion

Results indicating the hydrodynamic and physico-chemical characteristics of tidal Woji River monitored between the hours of 7:00 h and 19:00 h at the determined sampling station are presented in Tables 2 and 3 respectively.

Fig. 2 is a graphical representation of the rise and fall of the tide during the 13 h study period. Tidal peaks were observed within the hours 11:00

h to 13:00 h and begin to recede within the hours of 17:00. Similar tidal fluctuations have been reported [13, 14]. The curve has the general form of a variable sine curve. In this study, the maximum tide level obtained during the daylight field measurement was 1.80 m and the minimum value was 0.77 m.

Like in most places, tidal change occurs twice daily and when there are two high and two low waters each tidal day, with relatively small differences in the respective highs and lows, the tidal form is called semi-diurnal. Observation of tidal Woji River shows that the tides were found to be largely semi-diurnal in nature. This observation is consistent with tides on Boston Harbour of the United States [15].

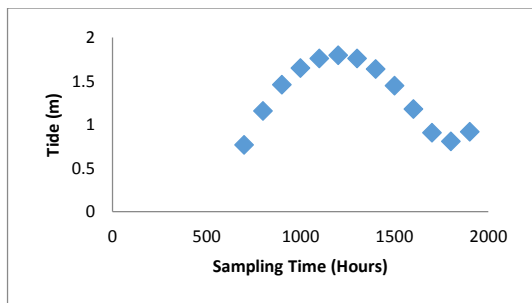


Fig. 2 Variation of tide (m) against sampling time (h)

Field measurement of tidal Woji River, shows that the width of the river varies with the observed tides (Fig. 3). At the high tide which occurred between 11:00-13:00 h, measured width varied between 110-121.8 m. At the lower ebb which occurred at 07:00 h and 19:00 h, width of the river varied between 47.2 m and 51.2 m.



Fig. 3 Variation of width of Woji river against sampling time (h)

Tidal current is the periodic horizontal flow of water accompanying the rise and fall of the tide. Since the River depth range within the channel under investigation do not exceed 10 m, only surface current was considered and measured [16]. Field measurement shows that the speed of tidal Woji River varies throughout the tidal cycle, passing through two maximums in approximately opposite directions, and two minimums about halfway between the maximums in time and direction. Field measurements indicated that at peak tide water flows at an average speed of 1.36 m/s in the South West direction and at ebb tide River flows in the reverse direction at a constant speed of 0.12 m/s. Observed tidal currents are semi-diurnal in nature (Fig. 4) since it corresponds to a considerable degree to the type of tide at the place.

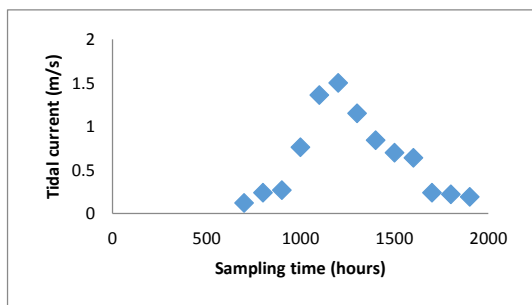


Fig. 4 Variation of tidal current against sampling time (h)

At many places where current and tide are both semi-diurnal, there is a definite relationship between times of current and times of high and low water in the locality. Current atlases and notes on nautical charts often make use of this relationship by presenting for particular locations, the

direction and speed of the current at each succeeding hour after high and low water, at a place for which tide predictions are available.

Table 3 represents the physico-chemical characteristics of the Woji River system monitored during the 13 h study period. Dissolved oxygen is required by all aquatic organisms. Low dissolved oxygen levels (hypoxia) can impair animal growth or reproduction, and the complete lack of oxygen (anoxia) will kill aquatic organisms. Aquatic organisms with limited mobility such as oysters and clams are particularly vulnerable to hypoxic or anoxic conditions. Even fast swimmers such as fish can become trapped in areas with low oxygen or no oxygen. Dissolved oxygen levels are affected by a number of factors, including water temperature, water mixing characteristics, how much oxygen is being produced by biological processes (such as photosynthesis by plants, and how much oxygen is being used up by abiotic and biological processes (e.g. respiration or the decomposition of organic matter such as dead phytoplankton) in the water column or in the sediments and, at the sediment-water interface [17].

The observed DO levels at sampling point were generally low and ranged between 2.00 and 3.55. However, higher values of DO were recorded during the high tidal period, which may be due to the dissolution factor resulting from the tidal action. The low level of DO measured may have resulted from the palpable presence of decomposing organic matter [17, 18]. The normal saturation DO value for fresh water depends upon the temperature, and its value varies from 14.62 mg/L at 0 °C to 7.63 mg/L at 30 °C (at normal atmospheric pressure). DO levels below 5.0 mg/L, aquatic life is put under stress and could result in large fish kills if sustained for a few hours [17]. The water body in the study area especially at some sampling station provides a poor condition for the survival for aquatic life [17].

Suspended solids (SS) consists of an inorganic fraction (silts, clays, etc) and an organic fraction (algae, zooplankton, bacteria, and detritus) that are carried along by water as it runs off the land and these contribute to the turbidity or cloudiness of a water body [19]. Suspended solids can clog fish gills, resulting in either fish death or reduction in growth rate. They also reduce light penetration, thereby reducing the ability of algae to produce food and oxygen. A positive effect of the presence of suspended solids in water is that toxic chemicals such as pesticides and metals tend to adsorb to them or become complexes with them thereby making the toxics less available for absorption by living organisms. In a study in which TSS was increased to 80 mg/L, the macro invertebrate population was decreased by 60% [19].

The observed SS levels at sampling point were very high and ranged between 4,100-8,150 mg/L. The obtained levels of SS may have resulted from presence of silt and other suspended materials observed on the surface of the water body.

Biochemical oxygen demand (BOD) is the amount of oxygen required by microorganisms to stabilize decomposable organic matter at a particular time and temperature. BOD test is widely used to determine the pollutional strength of domestic and industrial wastes in terms of the oxygen that they require to deliver end products as CO₂ and H₂O. The most widely used parameter of organic pollution applied to both wastewater and surface water is the 5 day BOD (BOD₅) at 20 °C. BOD is used in water quality measurement and assessment, ecology and environmental science. It is an indication of the quality of a water source. Most pristine rivers will have a 5-day BOD below 1 mg/L. Moderately polluted rivers may have a BOD value in the range of 2 to 8 mg/L. Municipal sewage that is efficiently treated by a three stage process would have a value of about 20 mg/L. Untreated sewage varies, but averages around 600 mg/L in Europe and as low as 200 mg/L in the United State, or where there is severe groundwater or surface water infiltration [11].

The observed BOD levels at sampling point ranged between 9.50-17.60 mg/L. The relatively high levels of BOD can be attributed to the presence of decaying organic matter especially. Using the BOD values as standard for evaluation, the tidal Woji River may be classified as heavily polluted [11].

Nitrogen is an essential nutrient that is required by all plants and animals for the formation of amino acids. In its molecular form, nitrogen cannot be used by most aquatic plants, therefore it must be converted to another form. One such form is ammonia-nitrogen (NH₃-N). The term ammonia refers to two chemical species which are in equilibrium in water (NH₃, un-ionized and NH₄⁺, ionized). Tests for ammonia usually measure total ammonia (NH₃ plus NH₄⁺). The toxicity to ammonia is primarily attributable to the un-ionized form (NH₃), as opposed to the ionized form (NH₄⁺). When dissolved in water, normal ammonia (NH₃) reacts to form an ionized species called ammonium (NH₄⁺). NH₃ is the principal form of toxic ammonia. It has been reported toxic to freshwater organisms at concentrations ranging from 0.53 to 22.8 mg/L. Toxic levels are both pH and temperature dependent. Toxicity increases as pH decreases and as temperature decreases. Plants are more tolerant of ammonia than animals, and invertebrates are more tolerant than fish. Hatching and

growth rates of fishes may be affected. In the structural development, changes in tissues of gills, liver, and kidneys may also occur. Toxic concentrations of ammonia in humans may cause loss of equilibrium, convulsions, coma, and death. Ammonia levels in excess of the recommended limits may harm aquatic life. Fish may suffer a loss of equilibrium, hyperexcitability, increased respiratory activity and oxygen uptake, and increased heart rate. At extreme ammonia levels, fish may experience convulsions, coma, and death. Experiments have shown that the lethal concentration for a variety of fish species ranges from 0.2 to 2.0 mg/L. Trout appear to be most susceptible of these fish and carp the least susceptible [20]. The observed ammonia-nitrogen levels at sampling point ranged between 1.90-5.60 mg/L which far above regulatory limits of 0.5 mg/L [21]. The relatively high levels of ammonia-nitrogen can be attributed to the direct discharge of slaughter waste, livestock waste and industrial wastes into the water body. Using the ammonia-nitrogen values as standard for evaluation, the tidal Woji River may be classified as severely polluted [12].

This study also evaluated the pollution status of Woji River using the River Pollution Index (RPI). During the study, four values of water quality obtained from the sampling station were assigned to the corresponding points; the RPIs at various time intervals were calculated for each sampling station. Based on Table 1, water quality is classified as unpolluted for the integral of RPI under 2.0 negligibly polluted refers to the integral of RPI between 2.0 and 3.0 moderately polluted indicates water quality above 3.0 but under 6.0. For the integral of RPI above 6.0, water quality is classified as severely polluted.

In this study the Dissolved Oxygen (DO) 3 mg/L, Biochemical Oxygen Demand (BOD5) 2.2 mg/L, Suspended Solids (SS) 13.6 mg/L, and Ammonia Nitrogen (NH₃-N) 1.54 mg/L. The scores are obtained as following (Table 4):

Table 4 Water quality parameter index score

Water Quality/Item	Monitoring Data	Index scores
Dissolved Oxygen (DO)mg/L	2.75	6
Biochemical Oxygen Demand (BOD5)mg/L	13.33	6
Suspended Solids (SS) mg/L	6713.08	10
Ammonia Nitrogen (NH ₃ -N)mg/L	3.38	10
Total Point Score		32

The total point score is then divided by the number of items for determining water quality, i.e. $32/4 = 8$. The obtained value 8 was then compared to the above "Pollution Index Integral Value", which was above 6.0, and therefore is determined as severely polluted.

4. Conclusion

Woji River is a tidal water body that peaks (high tide) between 11:00 and 13:00 h and recede (low tide) between 7:00 h and 8:00 h. Tidal Woji River is semi-diurnal in nature. River Pollution Index (RPI) of the tidal Woji River showed that water quality is severely polluted and

unacceptable for domestics' purposes and will require best management practice to improve the water quality.

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