Analyzing the Effect of Physicochemical Processes of Calabar River on Coastal Hydraulic Structures: A Case Study of Calabar River

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ABSTRACT

The research study analyzes the effect of physicochemical processes of Calabar River on coastal hydraulic structures. The Calabar River holds ecological and economic importance, providing essential resources for irrigation, transportation, and fishing in Nigeria's. However, the discharge of industrial effluents, agricultural activities, domestic sewage and other human activities has resulted in significant alterations in the river's physicochemical properties, including changes in pH, temperature, salinity and concentration of chemical compounds. These changes have adverse effects on coastal hydraulic structures such as jetties, ports, sheet piles for coastal protection and offshore platforms, primarily due to accelerated corrosion rates induced by aggressive agents present in the river. The research employs a multi-disciplinary approach, combining materials science, structural engineering, and environmental analysis to assess the impact of Calabar River on hydraulic infrastructure. For comprehensive analysis, this study employed both field and laboratory methods. Field data collection involved measuring water quality parameters like pH, temperature, salinity, chloride, sulfate, and dissolved oxygen concentrations. Objectives of study included identifying potential impact of physicochemical processes on these structures, determining factors affecting their performance, proposing appropriate solutions for improvement, providing recommendations. It was observed that the presence of salt water on concrete reduces the compressive and flexural strength of concrete when compared to natural water. These findings will be invaluable for policymakers, engineers, and stakeholders involved in the management of coastal infrastructure in the region. It is recommended that further studies should be carried out using different blend proportions and concreting materials for hydraulic structures.

Keywords: pH, temperature, salinity, DO, flexural test, compressive test

INTRODUCTION

Background of Study

The Calabar River is one of the major rivers in Nigeria, located in the southeastern part of the country. It is approximately 150 km long and drains into the Atlantic Ocean. The river has significant ecological and economic importance, providing water for irrigation, transportation, and fishing for the local population. However, the discharge of various effluents from industries, agricultural activities, and domestic sewage into the river (see figure 1) has led to changes in its physicochemical properties, including changes in pH, temperature, salinity, and the concentration of various chemical compounds (Kanu and Achi, 2011). These changes in the physicochemical properties of the Calabar River can have a notable influence on the corrosion of coastal hydraulic structures, such as jetties, ports, and offshore platforms. Corrosion is a complex process influenced by several factors, including the chemical composition of the surrounding environment, the design and materials used in the structures, and the level of maintenance and inspection of the structures. The presence of aggressive agents, such as chlorides, sulfates, and dissolved oxygen, can accelerate corrosion rates and lead to premature failure of the structures (Bhandari et al., 2015). Several studies have investigated the effects of both physical and chemical processes particularly, on corrosion of structures in coastal areas. For instance, a study by (Ezuber et al., 2008) investigated the corrosion behavior of aluminum alloys in marine environments and found that the corrosion was influenced by the chloride content, pH, and temperature of the water. Hu et al., (2018) analyzed the corrosion of steel reinforcement reveal in concrete structures due to seawater and found that the corrosion

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was influenced by the pH, chloride content, and dissolved oxygen concentration of the surrounding environment. Despite the numerous studies on corrosion in coastal areas, there is still limited understanding of the effect of physicochemical processes of the Calabar River on the corrosion of coastal hydraulic structures. This study seeks to investigate the relationship between the physical and chemical properties of the Calabar River and the corrosion of coastal hydraulic structures, using a case study approach. The study aims at identifying the key factors contributing to corrosion in the region and to provide recommendations for the management and maintenance of coastal hydraulic structures. The study will use both field and laboratory methods to collect and analyze data on the physicochemical properties of the Calabar River and the corrosion rates of coastal hydraulic structures. The field data collection involved the measurement of water quality parameters such as pH, temperature, salinity, and the amount of chloride, sulfate, and dissolved oxygen. The laboratory analysis also involved the testing of the corrosion rates of metallic samples exposed to the river water using electrochemical techniques. The findings from this study was meant to benefit policymakers, engineers, and other stakeholders involved in the management of coastal infrastructures in the region.

Research Problem

The Calabar River is a major water body located in the southern part of Nigeria, and it is home to several coastal hydraulic structures. The physicochemical processes of the river, including the presence of salts, heavy metals, and pollutants, have been found to have significant impacts on the corrosion of these structures. Corrosion of these structures can give rise to structural failure, which can have severe economic, environmental, and social consequences. Therefore, it is imperative to analyze the effect of the physicochemical processes of Calabar River on the corrosion of coastal hydraulic structures to ensure their longevity and safe operation.

Several studies have pondered on the outcome of corrosion on various types of hydraulic structures. For instance, Davis (2000)] studied the corrosion of steel reinforcement in concrete structures exposed to seawater and found that corrosion can lead to reduced structural integrity and eventual collapse. Similarly, Omotoso (2011) evaluated the corrosion resistance of offshore steel structures in the Niger Delta region and found that corrosion can result in significant material loss and reduced service life of the structures. These studies highlight the need to understand the corrosion behavior of hydraulic structures and to implement corrosion protection measures.

In addition, heavy metal contamination is a significant environmental issue in the Calabar River, which can exacerbate corrosion of hydraulic structures. Ewa et al., (2013) conducted a review of heavy metals contamination in Calabar River and found that lead was present in the river at levels that exceed recommended limits. These heavy metals can cause accelerated corrosion of hydraulic structures, leading to increased maintenance costs and potential environmental hazards. Therefore, understanding the interplay between heavy metal contamination and corrosion of hydraulic structures is crucial for developing effective corrosion mitigation strategies.

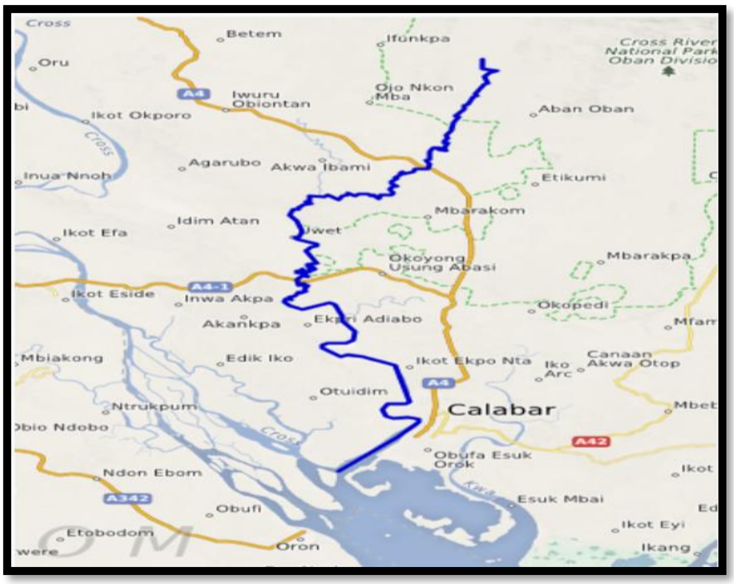

Fig.1. Map of the Calabar River

Furthermore, the marine environment is a complicated system that presents numerous challenges to the operation and maintenance of hydraulic structures. Factors such as tidal currents, waves, temperature, and salinity can all contribute to the defacing and distorting of these structures. A study by Morris et al., (2002) investigated the corrosion behavior of reinforced concrete structures in a coastal environment and found that exposure to high chloride concentrations, high temperatures, and high humidity led to significant corrosion of the steel reinforcements. Understanding the complex interactions between the marine environment and hydraulic structures is essential to develop effective corrosion prevention and mitigation strategies.

In conclusion, the statement of the problem for this research topic is to analyze the effect of physicochemical processes, including heavy metal contamination, on the corrosion of coastal hydraulic structures in the Calabar River. The study provided immerse detail into the corrosion behavior of hydraulic structures, identified the factors that influence corrosion, and developed effective corrosion mitigation strategies. This research was essential, for ensuring the safe and sustainable operation of hydraulic structures in the Calabar River and other marine environments.

Aim and Objectives

Aim

Analyzing the effect of physicochemical processes of Calabar River on coastal hydraulic structures: a case study of Calabar River.

Objectives

The following objectives will guide the research study to achieve a comprehensive analysis of the effect of physicochemical processes of Calabar River on coastal hydraulic structures in Calabar, Cross River State, Nigeria.

a) To assess the physical and chemical properties of Calabar River including temperature, pH, dissolved oxygen, turbidity, and salinity.
b) To investigate the hydraulic structures along the coast of Calabar and their functionality.
c) To identify the potential impact of physicochemical processes of Calabar River on coastal hydraulic structures.
d) To determine the factors affecting the performance of the hydraulic structures.
e) To propose appropriate solutions for improving the performance of the hydraulic structures.
f) To provide recommendations for the sustainable management and development of coastal resources in Calabar, Cross River State, Nigeria.
g) To determine the sediment transport of the flowing river and the abrasive nature of some of these particles on the structure.

Significance of the Study

The research topic "Analyzing of the effect of physicochemical processes of Calabar River on Coastal hydraulic structures: A case study of Calabar, Cross River State, Nigeria" is significant as it will contribute to environmental protection, sustainable development, disaster prevention, economic benefit, and the expansion of knowledge in the area of environmental management and engineering.

METHODS

Water is one of the earth's most important, renewable and widely distributed resources. Comprising of 70 percent of the entire earth mass [2]. Due to rapid growth of population, industrialization and urbanization, there has been intense human activities and interference with nature leading to an over exploitation and severe pollution of natural water bodies. Samples from the Calabar River, Calabar, Cross River State, Nigeria where human activities capable of polluting the river takes place were analyzed. Parameters being measured include specific conductance, pH, water temperature, dissolved oxygen and turbidity. In addition, periodic water samples were

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collected manually and analyzed for selected constituents, including alkalinity, dissolved solids, chloride, sulfate, fecal coliform bacteria etc. Refer to Fig. 1 of this work to get the map of the Calabar River.

Sample Collection

Samples were collected from strategic location in the Calabar River where human activities which lead to pollution were more likely to occur. Samples were measured for physical properties such as temperature, dissolved oxygen, specific conductance, and pH including turbidity. A clean sterile bottles were used to collect the water samples, without allowing the bottle head make contact with the top nozzle to prevent possible contamination.

Sampling Method and Procedure

The samples collected were properly stored inside a cooler to maintain same temperature and transported immediately to the laboratory for analysis. The samples were analyzed for total coliform, fecal coliform, biochemical oxygen demand (BOD), total suspended solids (TSS), chemical oxygen demand (COD), total volatile solids (TVS), nitrate (NO_3), sulphate (SO_4), chloride (Cl), heavy metals, alkalinity and turbidity. All water samples analysis were done using the standard analytical techniques.

Laboratory Analysis

These involves testing and analyzing the collected sample to check for the presence of certain substances. Test for Nitrogen in water was typically discovered in the form of nitrates and as a negatively charge nitrate ion in water soluble salt. However, the diphenylamine test was the easiest test in acknowledging the existence of nitrates.

Test for Coliform involved Multiple Tube Fermentation Techniques. For this technique, the procedure involves three main phases that include: Presumptive stage, confirmed state and completed test For presumptive stage, where lauryl trypsone broth was used being a growth medium for coliform analysis. Different measured quantities of the water sample were inoculated into the fermentation tubes and the tubes incubated for 24 and 48 hours at a temperature of 35^0C and checks was carried out for gas formation in 24hrs. The presumptive test was observed during the gas formation when bubbles were noticed inside the tubes. For the confirmed state, only the sample marked as positive from the presumptive stage was consider for the test using brilliant green lactose bile broth fermentation tube. The tubes were inoculated for a period of 48hrs under a temperature of 35^0C. However, gas formation during this phase was an acknowledgement of positive confirmed test. Finally for completed test, phase requirement involved samples with positive confirmed test, incubator, nutrient agar lauryl tryptose broth fermentation tube and eosin methylene blue plate. The plate was incubated for a period of 24hrs under a temperature of 35^0C. A colony of bacteria was obtained from the plate and was then moved into fermentation tubes medium including the agar slant. Then the agar and the fermentation tubes where incubated for 24 and 48hrs under a temperature of35^0C. In order to observe the sample under microscope, gram staining was required whereas for the fermentation tube, the presence of gas was required. The presence of gas was the indication of bacteria presence and was concluded as a complete test.

Test for E-coli was carried out using microscope to view E.coli coliform in sea water. Here, microscopy was used to sight bacteria colonies or individual bacterial cells count. The apparatus used included, a low power microscope, membrane filter, a pair of forceps, sample of water from Calabar River and a prepared agar. The sample was now poured into a sample membrane placed in between the apparatus and funnel. The membrane was carefully removed and then placed on agar plate. The plate was covered with a stopper and incubated for 2hrs under a temperature of 35^0 C. Hence, using a microscope, coliform colonies were observed on the plate and the number of individual colonies was counted on the filter media.

Sulphur test was a simple one. The apparatus used included, a multi-cell adapter, test tube and a stop watch. The square sample cell was filled with 10ml water sample obtained from the Calabar River. One sulfaver 4 reagent powder pillow content was added to the sample. This was then swirled to properly dissolve the powder. However, white turbidity appeared indicating the presence of sulfate within five minutes.

For Chloride test, filled a cell was with 10 ml of sample water from the river. Also, filled another sample cell with 10 ml of deionized water. A 0.8ml of Mercuric Thiocynate solution were poured into each sample cells. Note: Use 1.0 mI with Dr. 5000. The mix was swirled properly for uniform mixing, an orange color was observed indicating that chloride was present and results were in mg/l Cl.

Workability of Concrete (Slump Test).

Sieve analysis was carried out for the fine aggregates in determining the slump test of concrete. The sun-dried soil (fine aggregate) sample was weighed to 0.1% of the total mass.

The sieves were brushed/cleaned and then assembled in the order of their sieve sizes. The pan was placed below the last sieve. The fine aggregate (sand) sample was precisely streamed into the top sieve and then covered by its cap/lid. The sieve stack was placed on the mechanical shaker and then vibrated for 10 minutes. The stack was removed from the mechanical shaker and carefully weighed to record the exact weight of each sieve with its retained soil. In addition, the bottom pan with its retained fine aggregate was weighed and recorded. The internal surface of the frustum cone was thoroughly cleaned with water.

The cone was placed on a smooth, horizontal and absorbent surface and then filled in three layers with freshly proportion of mixed concrete, each approximately to one-third of the height of the cone. Each layer was tampered/compacted 25 times by a tamping rod evenly around the cross-section

Fig. 2: Workability of concrete (Slump Test)

Left over of the freshly mixed concrete at the top layer of the cone was struck off to level with the cone to give a flat surface using a trowel and the tamping rod. The cone was removed immediately from the cone by raising it slowly in the vertical direction.

The difference in height between the height of the frustum cone and that of the subsided freshly mixed concrete was measured and recorded as could be seen in Fig.2 of this work. The height difference in mm was the slump value of the concrete.

Aggregate Impact Value Test, the test procedure shows that the materials were sieved using sieve size 37.5mm, the aggregate passing through 37.5mm sieve and retained in 19mm sieve comprised of the test materials.

i. The mould (cylindrical) was weighed, $M_{1.}$

ii. The mould was filled with coarse aggregate subjected to 25 blows using tamping rod.

iii. The excess aggregates were struck off.

iv. The mould plus sample was weighed, $M_{2.}$

v. The impact value machine was brought to rest without wedging or packing up on the level plate, so that it was rigid and the hammer guided by the columns vertically.

vi. The cup was positioned firmly on the base of the machine and the whole sample was placed in it and compacted with 25 gentle strikes with the tamping rod.

vii. The hammer was raised until its lower face was 380mm above the surface of the aggregate sample in the cup and allowed to freely fall on the sample aggregate. Then 15 blows were given at a space of not less than one second between consecutive falls.

viii. The crushed aggregates were removed from the cup and sieved through BS sieves until no further significant amount passes in one minute. The tiny part passing the sieves was weighed to an accuracy of 1g (W_2). Also, the tiny part retained in the sieves was weighed.

ix. The observations in the performance were noted and the 'Aggregates Impacts Value' computed.

Compressive Strength of Concrete Test

Test Procedure shows that, the materials required for preparation of concrete of given proportions were measured. The materials were also mixed thoroughly until a uniform color of concrete was obtained.

The concrete was poured into lightly greased cube moulds of 150mm x 150mm x 150mm in size. And the concrete was filled in two layers, each approximately 75mm and rammed 35 blows evenly over the surface layers.

Proper identification marks were given to the specimens and then removed from the moulds after 24hrs and cured in water.

The specimens were removed from the curing tank after stated curing time, and the excess water on them were wiped from the surface and dried. The surface bearing of the testing machine was cleaned. The orientation of the specimen on the machine was in a manner that, the load can be introduced on the cast cubes in the opposite sides.

The specimen was centrally aligned on the base plate of the machine and the movable portion of the machine gently rotated by hand so that the specimen top surface is touched.

The compressive strength machine was turned on and the crushing commenced.

The maximum load was recorded. Load at failure divided by area of the specimen gives the compressive strength of concrete.

Flexural Strength Test

The test specimen was moulded concrete beams and they were cured after 24hrs of casting for 28 days in accordance with relevant parts of this standard. The size of the concrete beam was 100 mm x 100 mm x 500 mm long. The bearing surfaces of the supporting and loading were wiped clean. Also, water was wiped off the surface of the specimen. The test specimen was placed in the machine, correctly centered with the longitudinal axis of the specimen at right angles to the rollers. A sawn specimen was placed in the machine so that the original finished surface was in tension. Load was applied when all loading and supporting rollers were in even contact with the test specimen. The loading rate was maintained until failure occurred. The maximum load read on the scale as the breaking load was recorded.

Flexural strength values were computed using:

$$\sigma = \frac{3fl}{2bd^2} \qquad (1)$$

Where: f is the breaking load (in N), b is the width of beam in (in mm), and d is the depth of the cross-section (in mm), *l* is the distance between the supporting rollers (in mm).

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RESULTS AND DISCUSSION

The data and results obtained from the various laboratories and experiments for properties of concrete materials and concrete (Fresh and Hardened) itself during the research work are presented and analyzed in charts shown in table 1. Tests on salt water (gotten from the marina Beach of Calabar River) were conducted in the chemistry laboratory of University of Cross River State, Calabar. All preparations and tests for concrete was done in the Strength of Materials Laboratory in the university. A constant mix ratio of 1:2:3:0.4 was used in the production of concrete samples using natural water while a mix ratio of 1:2:3:0.6 was used in the production of concrete samples using salt water. Curing of samples were done in a plastic tank filled with water and at normal room temperature until the age for each sample to be tested reached.

Table 1: Water Quality Parameters

WATER QUALITY PARAMETERS	CONCENTRATIONS	NSDWQ
pH	6.36	6.5 – 8.5
ELECTRICAL CONDUCTIVITY (µS/Cm)	105.00	1000
TDS (mg/l)	4.95	500
TSS (mg/l)	103.00	10
TOTAL HARDNESS (mg/l)	56.20	500
TOTAL ACIDITY (mg/l)	16.00	4.5 - 8.2
TOTAL ALKALINITY (mg/l)	15.00	100 - 200
CHLORIDE (mg/l)	32.99	250
SULPHATE (mg/l)	2.23	1000
SALINITY (%)	57.75	0.5

*NSDWQ National Standard for Drinking Water Quality

From the water quality parameters, it is observed that the total dissolved solids (TDS) is below the standard suitable for drinking as recommended by the National Standard for Drinking Water Quality (see table 1). TDS for the Calabar River ranges from 85-101ppm according to (Akpan et al., 2017). The water pH (6.36) is a little below the average of 6.5 to 8.5 for domestic use and agrees with (Akpan and Edem, 2015) that pH of Calabar River Ranges from 6.5-7.5. A pH value below 7 is acidic and can corrode or dissolve metals (APHA, 2005). Water from the Calabar River is considered to be moderately hard as it has a total hardness value of 56.20mg/L.

Physical Properties of Concrete Materials

Specific Gravity

Table 2: Specific Gravity Table

S/No	Description	Fine Aggregate (g)		Coarse Aggregate (g)	
		A	B	A	B
1	Weight of empty bottle (M_1)	388	366	405	402
2	Weight of empty bottle + sample (M_2)	740	719	713	650

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3	Weight of empty bottle + sample + water (M_3)	1279	1221	1257	1288
4	Weight of bottle full of water (M_4)	1082	1008	1070	1047
5	Mass of water used ($M_3 - M_2$)	539	502	544	638
6	Mass of sample used ($M_2 - M_1$)	352	353	308	248
7	Specific gravity Gs = $\frac{M2 - M1}{(M4 - M1) - (M3 - M2)}$	2.270	2.512	3.347	2.343
	Average	2.39		3.39	

Aggregate Impact Value Test (AIV):

With an AIV value of 9.30% from table 3, the gavel (coarse aggregate) used for the purpose of this research work is considered to be strong and suitable for road constructions as well as concrete works.

Table 3: Aggregate Impact Value Table

S/NO	Description	Test Value
1	Mass of empty mould (M_1)	1666g
2	Mass of empty mould + sample before impact (M_2)	2182g
3	Mass of empty mould + sample after impact	2182g
4	Mass of sample only (A)	516g
5	Mass of sample passing sieve 2.36mm (B)	48g
6	AIV =B/A × 100	9.30%

The AIV value proves that this aggregate is exceptionally strong and suitable for road constructions and concrete works as it falls within the range of 0-10% (ASTM)

Particle Size Distribution (Sieve Analysis)

Table 4. Sieve analysis of Fine Aggregate (Sand)

Sieve sizes	Mass Retained	% Retained	Cumulative % Retained	% Passing
6.3mm	0	0	0	0
4.75mm	0	0	0	0
2.36mm	2	0.2	0.2	99.8
1.18mm	160	16	16.2	83.8
600µm	394	39.4	55.6	44.4
300µm	406	40.6	96.2	3.8

150µm	27	2.7	98.9	1.1
Pan	9	0.9	99.8	0.2
Total	998	-	-	-

Table 5: Sieve Analysis of Coarse Aggregate (Gravel)

Sieve sizes	Mass Retained	% Retained	Cumulative % Retained	% Passing
37.5mm	0	0	0	100
25.00mm	18	1.8	1.8	98.2
19.00mm	346	34.6	36.4	63.6
13.20mm	505	50.5	86.9	13.1
12.30mm	115	11.5	98.4	1.6
4.75mm	12	1.2	99.6	0.4
3.55mm	0	0	99.6	0.4
2.36mm	0	0	99.6	0.4
1.18mm	0	0	99.6	0.4
Pan	2	0.2	99.8	0.2
Total	998	-	-	-

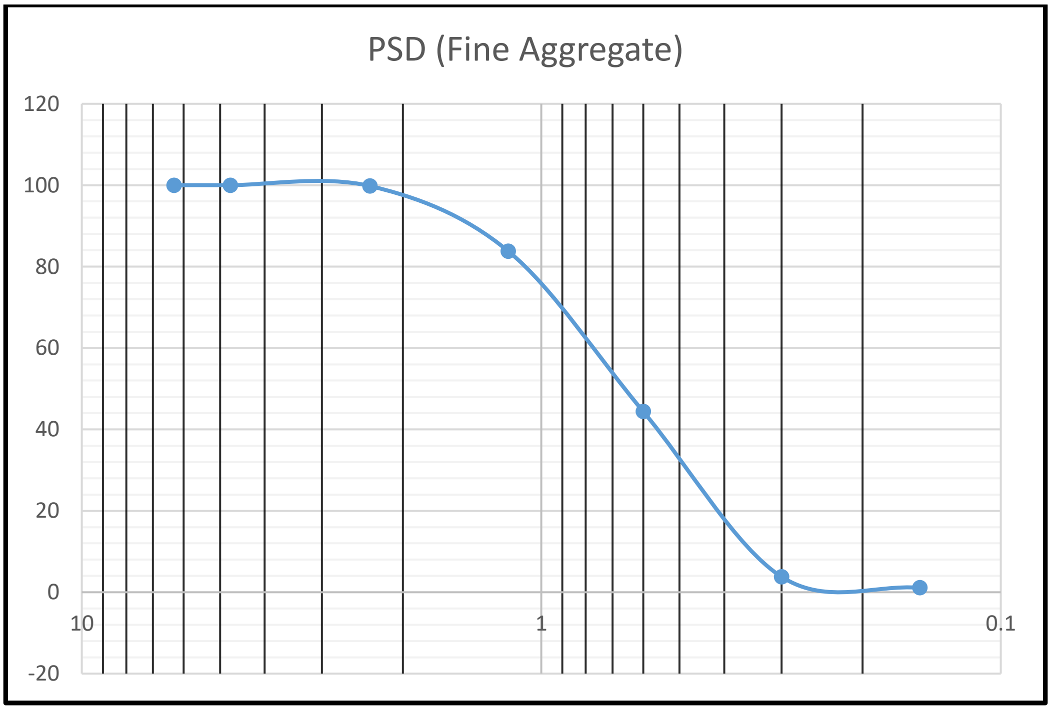

Fig. 2: Particle Size Distribution (Fine Aggregate)

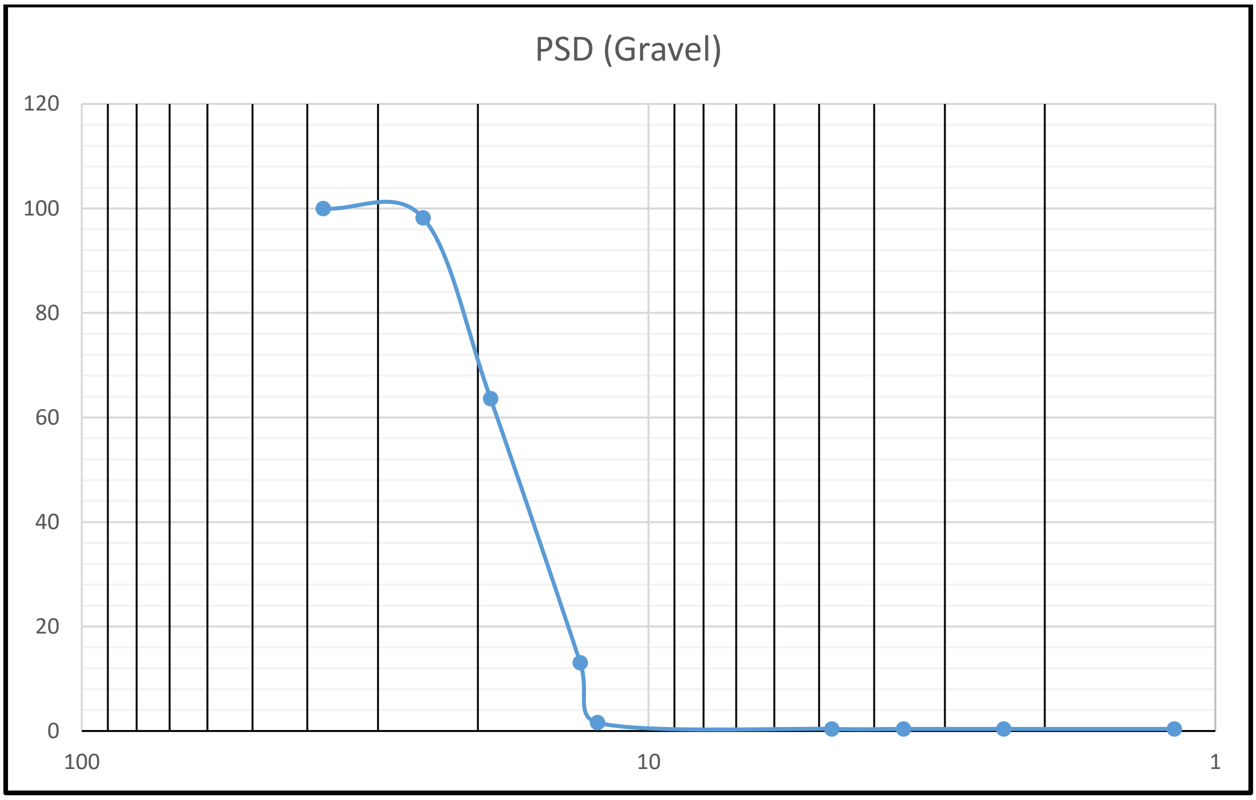

Fig. 3: Particle Size Distribution (Coarse Aggregate)

Properties of Fresh and Hard Concrete

Slump (Workability of Concrete) Test

The results for the concrete workability for a constant mix ratio of 1:2:3 using slump test were true slump measuring 30mm and 12mm for natural water and salt water respectively. A constant water to cement ratio was used throughout the mix process. For natural water, w/c ratio was 0.4 while that of salt water was 0.6. This shows that concrete made from both natural and salt water is suitable for work. The increase in water to cement ratio for salt water could be due to the presence salt and hardness of water. Images of slump tests are found in the appendix of this work.

Compressive Strength Test

A concrete mix ratio of 1:2:3:0.4 was used for the manufacture of concrete using natural water and 1:2:3:0.6 for salt water for different ages. Concrete cubes measuring 100mm x 100mm x 100mm were produced using wooden cube moulds. Concrete was mixed in room temperature and turned into the wooden moulds in three layers and vibrated with the metal hammer 25 times per layer. The 3rd, 7th, 14th and 28th day results of the compressive strength carried out on concrete cube samples are summarized and presented in table 6 and figure 4 below. WS represents samples made and cured with salt water while WG represents samples made and cured with natural water.

Table 6. Compressive Strength Table

Water Type	Age (Days)				
	3	7	14	21	28
WS	17.93	17.21	17.25	17.18	16.43
WG	25.28	28.38	21.79	19.06	21.53

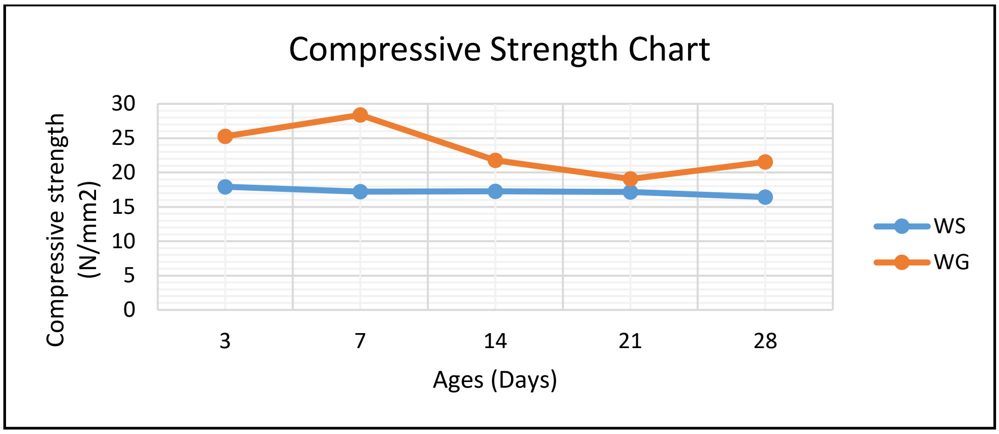

Fig. 4. Compressive strength with increasing age

From the table 6 and fig. 4 above, it was observed that the highest strength of concrete using natural water was highest on the 7th day. Concrete made with natural water had a higher compressive strength when compared with concrete made from salt water. There was an observed decrease in compressive strength of samples made from salt water as the age increased while natural water had an initial increase from the third day to the fourteenth day and then a decline in strength on the fourteenth and twenty first day.

Flexural Strength Test

100mm x 100mm x 500mm long concrete beams made from wooden molds were used in this experiment. The same mix ratio used in the production of concrete cubes for compressive strength was adopted for natural and salt water respectively. A summary of the flexural strength is given in table 7 and figure 5 below. WS represents samples made and cured with salt water while WG represents samples made and cured with natural water.

Table 7. Flexural Strength Table

Water Type	Age (Days)				
	3	7	14	21	28
WS	4.15	4.05	5.17	3.84	4.64
WG	3.99	5.18	5.73	4.66	5.78

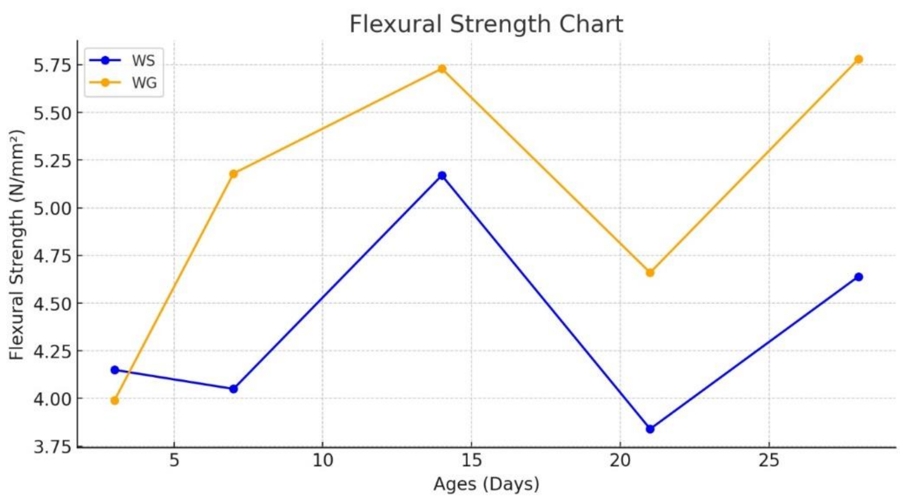

Fig 5. Flexural Strength chart with respect to age.

Flexural strength was maximum for natural water on the 28th day for natural water when compared with salt

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water. Flexural strength increases from age three days to the fourteenth day but reduces on the twenty first day and then increases on the twenty eight day for samples made from both salt and natural water.

CONCLUSIONS

From results and observations gotten from this research work, the following conclusions can be made:

(a) Both concrete samples made from natural and salt water have densities above 2.4Kg/m^3 indicating that they are within the range for normal weight concrete.

(b) Salt water reduces the compressive and flexural strength of concrete.

(c) The moderately low pH and presence of chloride in the Calabar River will corrode metals with time.

RECOMMENDATIONS

(a) More studies should be carried out using different mix ratios and concrete conditions to understand the properties of concrete influenced by salt water.

(b) Further studies should be done to discover new materials that would be used in the production of concrete used around coastal and riverine areas.

(c) Coastal hydraulic structures should be evaluated/tested frequently to understand their strength/durability as corrosion increases with time.

(d) Water pollution increases the presence of acids, salts and organic compounds that are capable of accelerating water pollution. Hence, proper environmental care strategies should be taken in order to curtail water pollution of hydraulic structures around coastal regions including the Calabar River.

(e) Protective coatings should be applied on the surface of metals to provide a barrier between the metal and the corrosive environment.

Abbreviations

ASTM American society for Testing and Materials.

APHA American Public Health Association.

WS Samples made and cured with salt water.

WG Samples made and cured with natural/potable water.

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Authors' contributions

Not application.

Authors' information

Not Applicable.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on

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request.

Declarations

Competing interests

The author declare that there are no competing interests.

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