

Water quality and environmental health indicators in the Andoni River estuary, Eastern Niger Delta of Nigeria

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Abstract Indicators of water quality in open coasts, estuaries, and inlets including nutrients, water clarity, and toxicants were investigated in the Andoni River estuary in the eastern Niger Delta of Nigeria using standard methods. DO was generally below 5 mg/L and 20 % of sampled sites had turbidity levels above standards recommended for estuarine ecosystems. The sampled sites also did not meet international standards for nitrate, heavy metals, and hydrocarbons, exceeding limits for natural resource preservation, coral reef conservation, and aquaculture by very wide margins. Nitrate ranges were between 0.6 and 1.5 mg/L; THC (4.6–52.6 mg/L) heavy metals (Fe 0.45–1.54 mg/L, Mn 0.004–0.19 mg/L, Ni 0.08–0.16 mg/L, Cd 0.02–0.5 mg/L, Pb 0.14–0.44 mg/L, and Zn 0.06–0.17 mg/L). A Water Quality Index calculated for the whole river system showed a declining capacity to support fish and aquatic grass habitats. This study, therefore, concludes that the estuary is suffering pollution from immediate hydrocarbon pollution sources and local pollution from eroded contaminated sediments, discharged domestic and human waste, and long distance river pollution. A comprehensive scientific investigation of estuarine conditions, source control measures for known pollutants, and

source conversion of fecal sludge in riverine communities are among recommendations.

Keywords Turbidity · Nutrients · Toxicants · Andoni River, Nigeria

Introduction

It has been estimated that up to 80 % of coastal and marine water quality impairment world-wide is caused by broad scale land-use activities. Land-based activities such as urban, industrial, and agricultural development can have significant detrimental effects on marine and estuarine environments by contributing suspended sediment, nutrients, pathogens, heavy metals, and other pollutants (UNEP 1995; Zann 1995). Some of the adverse effects of land use on the marine environment are manifest in excessive nutrients, sediments, and chemical pollutants which have severe impact on biological communities, declining water quality thereby impacting negatively on ecosystems, tourism, recreation, and commercial fishing (COA 2002).

Indicators of water quality in open coasts, estuaries, and inlets include nutrients, water clarity, and toxicants. These indicators which best describe the water quality are the fulcrum on which the estuarine and marine ecosystem health is hinged. Increased loads of nutrients, principally nitrogen (N) and phosphorus (P), and sediments from surrounding catchments remain the two key threats with the potential to cause degradation in nutrient status and water clarity at a regional scale; while toxicants are recognized to have a more localized influence on marine and estuarine environments, usually close to the mouths of rivers and creeks, or at point-source discharges (EPAV 2001).

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Although an estuary is a partially enclosed body of water along the coast where freshwater from rivers and streams meet and mixes with salt water from the ocean, estuarine environments may include open coasts, estuaries, and inlets (USEPA 2012). As fluvial rivers enter the sea, gradual transition in physical, chemical, and biological characteristics from fresh to sea water occur within the boundaries of the land (Wepener et al. 2006), thereby making estuaries to be among the most productive environments on Earth. They create more organic matter each year than comparably sized areas of forest, grassland, or agricultural land. The tidal, sheltered waters of estuaries also support unique communities of plants and animals especially adapted for life at the margin of the sea. Many different habitat types are found in and around estuaries, including shallow open waters, freshwater and salt marshes, swamps, sandy beaches, mud and sand flats, rocky shores, oyster reefs, mangrove forests, river deltas, tidal pools, and sea grasses (USEPA 2012).

The greatest threat to the benefits and services of the estuarine environment in the Niger Delta of Nigeria is oil pollution. Oil pollution from the exploration and exploitation activities of multinationals and currently the activities of oil thieves is destroying vast areas of the Niger Delta environment. Oil exploitation and exploration activities prevalent in the upper and lower reaches of the coastal ecosystem have caused untold environmental damage to the Niger Delta area leading to species extinction, biodiversity loss, and threat to very existence of man in the study area.

Pollutants from drilling fluids, oil waste water, spilled oil, and now waste from artisanal refining activities are freely and constantly being discharged into the environment of the study area. These discharged and spilled materials contain potentially dangerous pollutants such as persistent organic pollutants, heavy metals, and polycyclic aromatic hydrocarbons (PAHs) which ultimately find their way into the water and finally end up in the food chain and taken in by aquatic and marine organisms and ultimately by man (Opue 2005).

The Andoni River estuary is a receptacle of oil pollution that occur upstream (northwards) through a maze of creeks in the Ogu and the B3 Triangle of Ogoniland (B-Dere-Bodo-Bomu axis) and north-eastward through Andoni communities via the Oturuba River. It also receives oil-polluted discharges downstream from the Oputambi Creek where heavy artisanal refining activities are ongoing and inflows from the port and industrial towns of Onne, Okrika, Eleme, and Port Harcourt through the Bonny River estuary and another arm emanating south of Onne and the Ogu/Bolo areas (Fig. 1).

The Ogoni area has also been known for oil spillage both corporate (from multi nationals) and indigenous (from

locals through oil theft and artisanal refining). About a decade ago, the multinational Shell was forced to close down its operations in Ogoniland due to community disaffection and unabated oil pollution from its fields especially the Bomu oil field which lies north of the study area and abuts the Andoni River feeder creeks in B-Dere, K-Dere, Bodo, and Bomu (B3 Triangle) areas of Ogoniland. However, the pollution problem has worsened since after the exit of Shell as ruptured pipes and failed infrastructure from lack of maintenance continue to carry oil into these feeder creeks. Also oil theft from Shell pipelines and from the Trans-Niger Delta oil trunk line which has culminated in numerous oil spills and blowouts especially in the B3 Triangle and the deliberate discharge of artisanal oil refining waste into the creeks in Ogoniland, Ilotombi, and Oputambi areas of Andoni and Bonny, respectively, has turned the Andoni River into a big receptacle of both age-long (traditional) and the nouveau oil pollution.

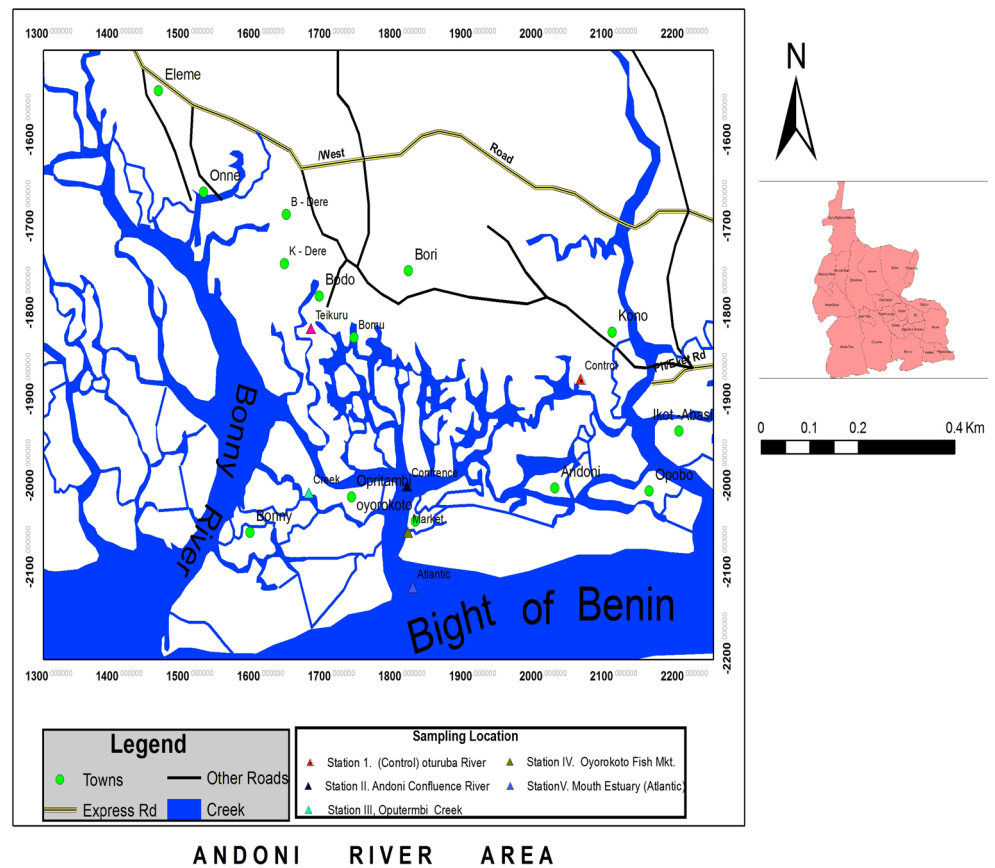
The Andoni River is therefore very contaminated river system by the time it joins the Atlantic Ocean. In view of these challenges, this study presents a general overview of ecosystem health in the Andoni River estuary as a baseline assessment against which future change can be measured. It is also an early warning of an ongoing and impending future change as the impacts of wanton oil and industrial pollution of the estuary is beginning to manifest in mangrove ecosystem destruction and reduction in fish catch; a major threat to biodiversity and the livelihoods of over a million local people.

Study area

The Andoni River is an off-shoot of several creeks flowing from Ogoniland especially the B3 Triangle and the Ogu/Bolo areas in the North. Two major arms flowing from the Bonny River south of the industrial town of Onne and eastwards from the Oturuba–Ilotombi–Uyeada axis of Andoniland also join the waters flowing down from the Ogoni axis to form the Andoni River estuary (Fig. 1).

It has a drainage length of over 42 km on the Bonny estuary axis, 23 km on the Uyeada–Opobo axis, and 25 km on the Ogoni axis, giving a drainage area of about 1500 km². The Andoni River estuary lies mainly below latitude 4°32' North of the equator and flows southwards to the Atlantic between the mega Bonny Island and Andoniland. It has a depth of over 12 m (17 fathoms—personal communication with field boat driver) in places and is wider than 1 km in its mouth toward the open sea. The Andoni River system developed through a maze of creeks and flows through an intractable mangrove ecosystem. In West Africa, mangrove ecosystems developed on the sheltered shores of deltas, alongside estuaries and in creeks

Fig. 1 Map of study area with sampling stations



where there is abundance of fine-grained sediments (silt, sand, and clay).

Vegetation

The mangrove vegetation thrives on coastal mud flats and continuous wetlands in the Niger Delta of Nigeria. They are particularly luxuriant and are a major feature of the rainforest especially in the brackish water environment where they have developed adaptations like breathing root systems and a tendency to germinate their seeds on the tree. The trees and roots provide rich habitats for a wide range of flora and fauna especially shell fish (Wikipedia 2013; UNEP 2007). In West Africa and Central Africa, there are three families of mangroves with three different species, including: *Avicenniaceae* (*Avicennia germinans*—referred to as white mangroves); *Combretaceae* (*Laguncularia racemosa*, *Conocarpus erectus*); and *Rhizophoraceae* (*Rhizophora harrisonii*, *Rhizophora mangle*, *Rhizophora racemosa*—usually called red mangroves). *Rhizophora racemosa* is very dominant in this region with characteristic long and straight poles in pure stands especially in tidal estuaries. While *R. harrosonii* and *R. mangle* are small trees and shrubs, respectively (WRM 2008).

The palm *Nypa fruticans* that was introduced from Asia has also become a major part of the hitherto mangrove ecosystem and has even overtaken the mangrove ecosystem in some places. The rich communities of oysters, crabs, invertebrates, and the great variety of fish sheltering and spawning in the mangroves sustain animal life including monkeys, African Manatee (*Trichechus senegalensis*), and turtles like the African soft-shell turtle (*Trionyx triunguis*). Birds include breeding water-birds such as Striated Heron and Reed Cormorant and large flocks of others during migration (Wikipedia 2013; UNEP 2007; USEPA 2013).

Soils

The area occupies a low-lying terrain of less than 5 m above sea level made up of intertidal mud flats. The soils around the river are light and dark organic peaty clays and mud usually inundated by brackish water. These muddy flats with high organic matter vary in thickness from place to place but are usually 3–5 m thick and are underlain by sands. The soil zones on the banks of the river are made up of fluvial deposits and/or mud banks which enhance the development of the mangrove vegetation (1995). Adedeji

et al. (2011) described the soils of the mangrove swamps of the Niger Delta as an ecosystem supported by saline soil.

Weather and climate

The Andoni river area lies within the rainforest belt of the eastern Niger delta of Nigeria. It is within the tropical wet (Af) climate classification of Koppen. The area is characterized by sustained high temperatures and rainfall. Average temperatures are usually greater than 18 °C. Annual precipitation is greater than 1500 mm. Precipitation occurs all year long although; there is a slight reduction in precipitation in month of august each year and between the months of December and February. Monthly temperature variations in this climate are less than 3 °C. Daily highs are about 32 °C while night time temperatures average 22 °C.

Economic activities

Around the river, the major economic activities are fishing, although there is limited farming, logging, and trading. Currently, the area is experiencing the menace of artisanal refining of petroleum products which is also endangering human and environmental health and threatening fishing as an occupation.

Materials and methods

For the purpose of this study, the Andoni river estuary is defined as the part of the Andoni River after the 3-arm confluence where the Uyeada–Oturuba–Opobo axis meets with the Bonny River estuary arm and the Ogoni arm (see Fig. 1). The estuary was sampled from the confluence downstream (estuary mouth/Atlantic). One control sample was collected from the sheltered arm of the Oturuba Creek.

Sample stations

Five sample station where purposefully selected for this study and accessed by motor boat.

Station 1 (C1: N04°28'682"/E007°21'518") is the Oturuba River (creek) flowing from the Opobo–Andoniland area. This area is sheltered from direct discharge from the Port Harcourt and Onne industrial areas and from the artisanal refining waste and oil spillages from the Ogoni and Oputambi areas (see Fig. 1). This area is chosen more as a sort of control as it is not within the Andoni River.

Station 2 (A1: N04°29'364"/E007°20'261"): The Andoni River triple confluence is about 2.73 km from station C1 on the Oturuba Creek. This station is downstream of the Andoni River Triple confluence where the bonny, Ogoni/Onne, and the Andoni arm of the River met.

This station therefore represents the quality of the river and impacts from the Port Harcourt, Onne, Ogoni, and Andoni axis and helps us to measure the local impacts from artisanal oil refining activities downstream of this point.

Station 3 (A2: N04°28'354"/E007°19'116"): The Oputambi Creek junction of the Andoni River. This point is about 2.8 km from the confluence (Station 2). This is a zone with a high concentration of artisanal refineries. Oil slicks can be seen flowing down the river from the Oputambi Creek.

Station 4 (A3: N04°27'004"/E007°19'061"): The Oyorokoto Fish Market. This point is originally known for its regional fish market, however, in recent years, the reduction in fish catch has reduced to nothing the fish market influence of this settlement. This sampling point is about 3.1 km downstream from the Oputambi junction.

Station 5 (A4: N04°26'423"/E007°19'480"): Estuary Mouth. This point is about 1 km from the Oyorokoto sampling point and abuts the open sea.

Method of data collection

Several methods of data collection were employed in this study. They include water sampling, global position (GPS) measurements, on-the-spot interview, and photography.

Water sampling

Water sampling, preservation and analysis followed standard methods (Rainwater and Thatcher 1960; Brown et al. 1970; APHA 2005). Sampling was carried out in May 27th 2013. Three samples of water were taken at each sampling point. For physico-chemical analysis, samples were collected with new 1 L plastic containers pre-rinsed with dilute nitric acid and rinsed three to four times with the water sample before filling it to capacity and then labeled accordingly. The samples were stored in coolers with ice packs at a temperature below 4 °C prior to analysis in the laboratory. Samples for heavy metal analysis were collected in 100 mL plastic containers and treated with 2 mL nitric acid (assaying 100 %, trace metal grade, Fischer Scientific) prior to storage. This was done to stabilize the oxidization states of the metals. All the samples were placed in coolers before transferring them to the laboratories.

Methods of data analysis

The methods described below were used in obtaining the results for this study. Methods previously described by Ezekwe et al. (2013) were used in water analysis.

Measurement for pH, temperature, conductivity, turbidity, Eh, and salinity were done in situ, using Horiba Water Checker (model U-10) after calibrating the

instrument with the standard Horiba solution in °C, µs/cm, NTU and ‰; respectively. Total dissolved solids (TDS), ORP, DO, and resistivity were measured in situ with an EC 900 AMTAST Meter in mg/L, mV, and mg/L and in Ohms, respectively. Alkalinity, hardness, chloride, and calcium were determined by titration method, while magnesium concentration was determined by calculation. Sulfate, phosphate, and nitrate were determined by the turbidimetric, stannous chloride and Brucine methods, respectively using Standard Methods for the Examination of Water and Wastewater (APHA 2005). Also, water samples previously acid treated and pre-concentrated were subsampled for the determination of metal content by Atomic Absorption Spectrophotometry using Buck Scientific Model 200A Spectrophotometer. All manipulations were done under controlled conditions to avoid contamination.

Samples for THC were collected in 250 mL glass bottles and preserved by adding 1 mL HCl (analytical grade). Two hundred milli liter of sample water was batch extracted with 20 mL chloroform in 5 mL replicates using a 250 mL glass separator funnel. After complete phase separation, the lower organic phase was removed for absorbance determination and total hydrocarbon content determined spectrophotometrically at 420 nm wave length using HACH DR 890 (API RP 45 1998).

Water Quality Index (WQI)

The Environment Protection Authority Victoria of Australia (EPAV 2001) in their water quality objectives for marine and estuarine waters and ecosystem protection stated that increased loads of nutrients and sediments from activities in catchments are the two key threats to marine and estuarine water quality. While pH, temperature, and total dissolved solids (surrogate measure of salinity) are not considered major threats to the water quality of marine and estuarine systems as a whole, they are considered to be only important modifying factors that alter the bioavailability of nutrients and toxicants. Therefore, they recommended indicators that are biologically meaningful and readily collected and interpretable in relation to ecological conditions. Six indicators of nutrients were, therefore, recommended for assessing the status of marine and estuarine waters; including dissolved inorganic nitrogen (DIN), total nitrogen (TN), dissolved inorganic phosphorus (DIP), total phosphorus (TP), chlorophyll *a* (Chl, *a*), and dissolved oxygen (DO). Of the six indicators, TN provides a better indication of the nitrogen cycling through the algal community and how much is dissolved in the water. TN is the sum concentration of bioavailable (dissolved) and particulate forms of inorganic and organic nitrogen; while TP provides a better indication of the phosphorus cycling through the algal community and how much is dissolved in

the water. TP is the sum concentration of dissolved and particulate forms of inorganic and organic phosphorus. Also Chl, *a* which is a crude measure of phytoplankton biomass is often used as an integrated, surrogate measure of nutrient status while DO, the net balance of the amount of oxygen produced by photosynthesis, relative to that consumed by respiration and other forms of biological and chemical oxygen demand is a better measure of low DO (hypoxia) that may arise following blooms of phytoplankton stimulated by nutrient enrichment. Turbidity, a measure of light absorption, was also recommended because it is an easy to measure indicator of general water clarity while toxicity is better measured on individual basis and concentrations.

Also, the United States Environmental Protection Agency (2008) also recommended the use of five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen for estuarine water quality indices. This Water Quality Index was used in the 2001 and 2002 NCA survey for the coastal waters of the Gulf Coast region and the results were found to be comparable to NOAA's (National Oceanic and Atmospheric Administration) Estuarine Eutrophication Survey of 1999.

The Water Quality Index applied in this study is that used by Carruthers and Wazniak (2004) in the Maryland's Coastal Bays: Ecosystem Health Assessment excluding data on chlorophyll *a* which is not available. This approach summarizes compliance of water quality variables with threshold values and has previously been used in a study of the United States mid-Atlantic estuaries and tributaries within the Chesapeake Bay (Kidson et al. 2003; Jones et al. 2003). The Water Quality Index was designed to synthesize the status of chlorophyll *a*, total nitrogen, total phosphorus, and dissolved oxygen into a single parameter. Parameters are compared to criteria based on ecosystem function, such as maintaining fisheries (DO threshold) and the maintaining of submerged aquatic grasses (Chl *a*, TN, and TP threshold). The Index is unitless and is scaled between zero and one, such that a WQI of one indicates habitat suitable for fish and aquatic grass survival, while a value of zero indicates relatively unsuitable habitat for either fish or aquatic grasses. Intermediate values indicate a system in flux, where it might be expected that some ecosystem functions (grass beds or fish) may be present some of the time.

Results and discussion

Results

Water quality parameters in water from this study are shown in Table 1, while Table 2 is a summary of water

Table 1 Quality parameters in sampled water

S/no	Parameters	A1 Confluence	A2 Oputambi	A3 Oyorokoto	A4 Atlantic	C1-CONTROL
1	GPS	N04°29'364" E007°20'261"	N04°28'354" E007°19'116"	N04°27'004" E007°19'061"	N04°26'423" E007°19'480"	N04°28'682" E007°21'518"
2	Temp °C	27.7	27.7	28.7	28.3	26.2
3	Turb. (JTU)	25	10	5	10	2.25
4	pH	8.1	7.85	8.22	8.21	7.77
5	Cond. (µS/cm)	18,490	26,800	35,150	43,500	16,460
6	TDS (mg/L)	16,800	27,800	22,489	27,840	14,900
7	Sal (mg/L)	11,094	16,080	21,090	27,100	10,534.4
8	DO (mg/L)	5.30	4.51	4.23	4.02	6.6
9	ORP (mV)	−3	−3	−12	−14	29
10	∑Hardness (mg/L as CaCO ₃)	4023.6	4023.6	4790	4598.4	3065.6
11	NO ₃ [−] (mg/L)	0.7	1.5	1.2	0.6	1.3
12	PO ₄ ^{3−} (mg/L)	<0.05	<0.05	<0.05	<0.05	<0.05
13	SO ₄ ^{2−} (mg/L)	633.3	726.5	815.9	781.7	658.6
14	Cl [−] (mg/L)	12,448.8	16,499.6	19,266	16,598.4	12,745.2
15	∑Alk (mg/L as CaCO ₃)	44	40	20	40	32
16	Ca ²⁺ (mg/L)	460.0	383.3	383.3	383.3	230
17	Mg ²⁺ (mg/L)	699.8	746.4	933.0	886.4	642.2
18	THC (mg/L)	19.0	56.2	43.3	12.20	4.6
19	Fe (mg/L)	0.45	0.61	1.54	0.46	0.45
20	Cr (mg/L)	<0.02	<0.02	<0.02	<0.02	<0.02
21	Mn (mg/L)	0.16	0.15	0.15	0.04	0.08
22	Ni (mg/L)	0.09	0.08	0.08	0.11	0.10
23	Cd (mg/L)	0.05	0.03	0.05	0.5	0.02
24	Pb (mg/L)	0.44	0.25	0.36	0.30	0.14
25	Zn (mg/L)	0.17	0.08	0.08	0.08	0.06

quality standards/criteria relevant to marine water aquaculture used to compare the results in Table 1.

Alkalinity, dissolved oxygen, temperature, turbidity and pH

According to the PHILMINAQ (PHILMINAQ, 2008), the pH of natural waters range between 5.0 and 10.0 while seawater is near pH 8.3. The pH of all the sampled sites falls within the desirable limit (6.5–9.0) for fish (Lawson 1995; Tarazona and Munoz 1995). Sampling site figures are between 7.77 and 8.22 (Fig. 2a) which are well within the water quality standards for estuarine ecosystems for Tropical Australia (Queensland Government 2012).

While all sampling sites fall within acceptable limits for temperature and alkalinity, average DO downstream from the Oputambi site is 4.25 mg/L. Dissolved oxygen is needed by fish to respire and perform metabolic activities. Thus low levels of dissolved oxygen are often linked to fish kill incidents. In general, a saturation level of at least 5 mg/L is

required. Values lower than this can put undue stress on the fish, and levels reaching less than 2 mg/L may result to death (Chapman 1997; Mitchell and Stapp 1992). DO found around and downstream of Oputambi is below 5 mg/L, in fact, average DO downstream from the Oputambi site is 4.25 mg/L and these are parts of the Andoni River estuary that suffer from the direct effect of artisanal refining activities.

Oil slicks and sheens were found commonly floating in the surface of the estuary during the fieldwork. On the spot interview of seven fishermen encountered during the fieldwork for this study revealed a reduction in fish catch by 70 % over a 2-year period. This they attributed to oil pollution from artisanal refining activities.

Turbidity above 20 NTU (JTU equivalent) is above the water quality standards for estuarine ecosystems for Tropical Australia. All the sampling sites fall within limits apart from the confluence which has a value of 25 JTU. This can be accounted for by the mixing of water from 3–4 different sources. High water turbidity, reduce photosynthetic activity, and increase the water temperature (PHILMINAQ 2008).

Table 2 Summary of water quality standards/criteria relevant to marine water aquaculture (PHILMINAQ 2008)

Parameter	Unit	Australia	ASEAN	Hong Kong	India	Kenya	Malaysia	New Zealand	Norway	Philippines	Southern Australia	United States	Desirable for fish production
pH		6.0–9.0			6.5–8.5		6.5–9.0	6.0–9.0		6.5–8.5			6.5–9.0
DO	mg/L	>5.0	4.0	>4.0	5.0		3.0–7.0	>5.0		5.0	>6.0		>5.0–6.0
TAN	mg/L						0.3						<0.01
NH4	mg/L	<1.0						<1.0			0.2		
NH3	mg/L	<0.01		<0.021				<0.01			0.05		
NO3	mg/L	<100	0.07					<100					
NO2	mg/L	<0.10	0.055					<0.10					
P	mg/L		0.015					<0.025					
PO4	mg/L	<0.05						<0.05		Nil			
TSS	mg/L	<10	10 %			30		<10		<30 % (increase)	10		
TDS	mg/L					1,200							
Fecal coliform													
Total coliform													
Mercury (Hg)	µg/L	<1.0	0.16		1.0	5.0		<1.0		2.0		1.8	
Lead (Pb)	µg/L	<1–7.0	8.5		1.0	10		<1–7.0		50		210	<5.6
Cadmium (Cd)	µg/L	<0.5–5	10		1.0	10		<0.5–5		10		42	<9.3
Nickel (Ni)	µg/L	<100				300		<100				74	
Aldrin	µg/L	ND						ND		1.0		1.3	0.003
Chlordane	µg/L	0.004						0.004		50		0.09	0.004
DDT	µg/L	ND						ND		1.0		0.13	0.0019
Dieldrin	µg/L	ND						ND		Nil		0.71	0.004
Endrin	µg/L	ND						ND		Nil		0.0023	0.0036
Heptachlor	µg/L	ND						ND		Nil		0.037	0.005
Toxaphene	µg/L	ND						ND		5.0		0.053	0.0002

N.D not detected

Conductivity, TDS, salinity, hardness, and chloride

Acceptable TDS values for marine environment in Kenya must fall below 1200 mg/L (PHILMINAQ 2008), however TDS ranged between 14,900 mg/L in the control site at Oturuba river to 27,840 mg/L in the estuary mouth (Fig. 2b). High concentrations of dissolved solids in marine water can result to damage in organism’s cell (Mitchell and Stapp 1992). Factors affecting the level of dissolved solid in water body are urban and fertilizer run-off, wastewater and septic effluent, soil erosion, decaying plants and animals, and geological features in the area. The water quality standards for estuarine ecosystems for Tropical Australia (Queensland Government 2012) stipulate a value of 37,000 mg/L for salt water aquaculture, and sites fall within this limit and by extension, same applies to hardness, chloride, and conductivity.

Nutrients

The water quality standards for estuarine ecosystems for Tropical Australia (Queensland Government 2012) stipulate a value of 0.25 mg/L for nitrates in estuarine systems and 0.1 mg/L for marine inshore zones. All the sites, however, exceeded the stipulated standard as values ranged between 0.6 in the estuary mouth to 1.5 mg/L at Oputambi junction (Table 1).

Hydrocarbons and heavy metals

The Indian Government standard for Oil and Grease (including Petroleum Products) for salt pans, shell fishing, mariculture, and ecologically sensitive zone is 0.1 mg/L. This recommendation derives from the fact that above this concentration levels, the survival of larvae and fish eggs is jeopardized (MPCB 2012). While the Thai Government (Thailand National Environment Board (2000) on the other hand stipulates the following limits for petroleum hydrocarbons in marine waters; 0.5 mg/L for natural resource preservation, coral reef conservation, and aquaculture; <1 mg/L for recreation and <5 mg/L for residential district areas.

However, all the sites show high levels of hydrocarbon pollution exceeding the stated limits by very wide margins (Fig. 3). Only the control point at Oturuba River fall within limits for residential district areas. The Andoni River estuary, therefore, does not meet the standards for natural resource preservation, coral reef conservation, and aquaculture for petroleum hydrocarbons.

Heavy metal concentrations in the estuary are also high (Fig. 4) and does not meet international standards for heavy metals in estuarine settings. For instance, the water quality standards for estuarine ecosystems for Tropical Australia (Queensland Government 2012) stipulate a value of

Fig. 2 Physico-chemical parameters in water

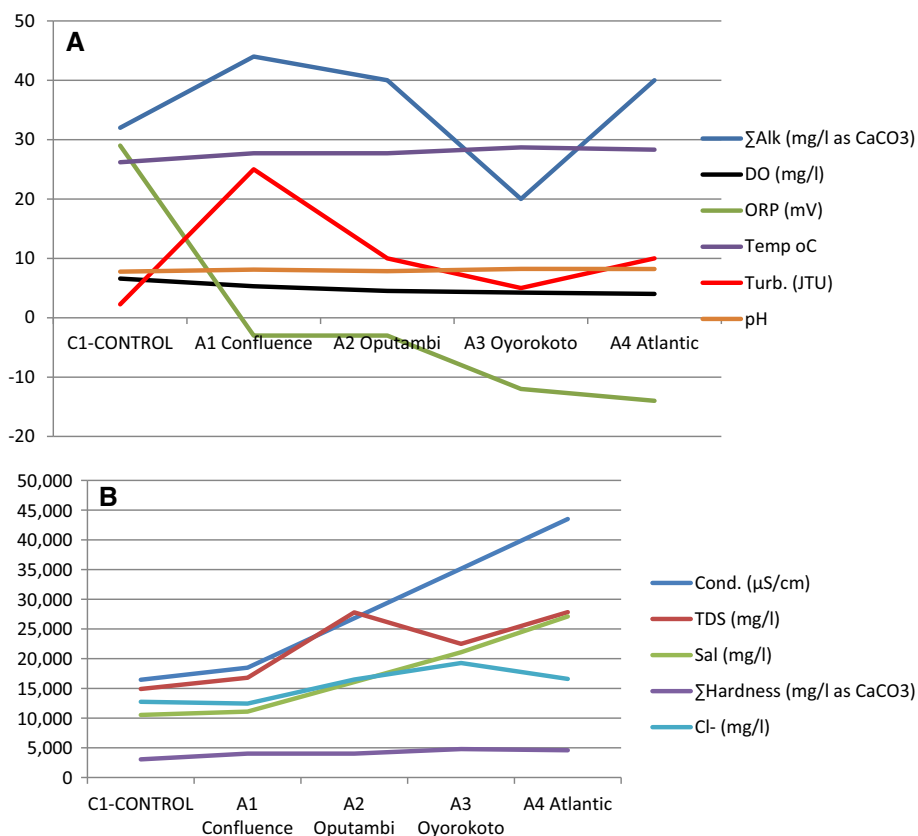


Fig. 3 Total hydrocarbons in water

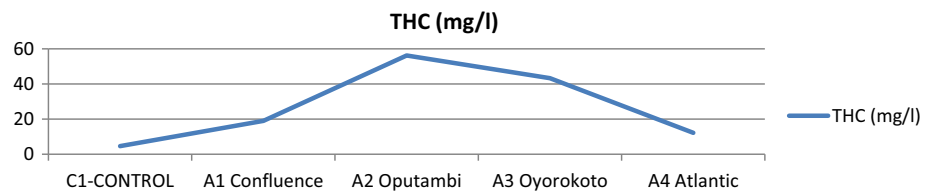
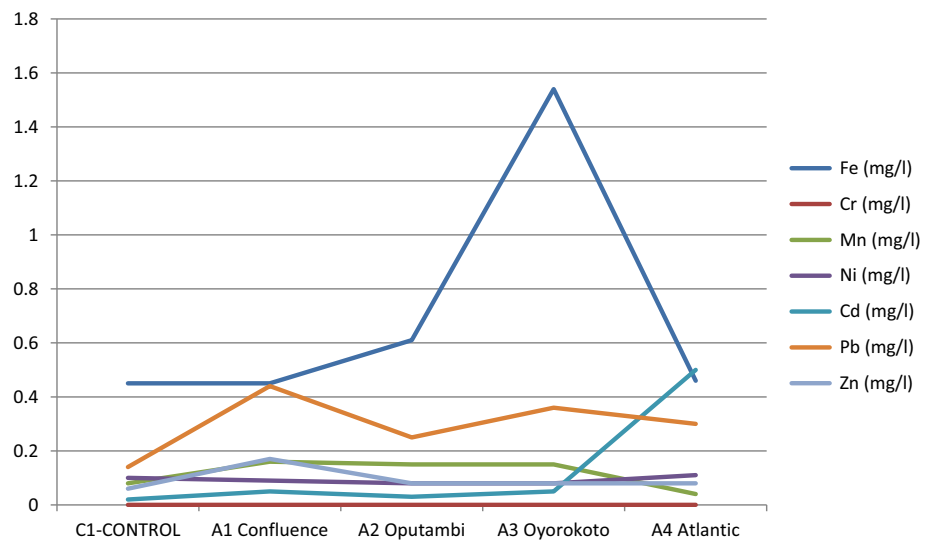


Fig. 4 Heavy metals in water



0.01 mg/L for iron for saltwater aquaculture. All the sampling sites exceeded this recommendation with the Oyorokoto market having the highest concentration of 1.54 mg/L Table 1.

The international standards (Table 2) for lead in marine water include <0.007 mg/L for Australia; Hong Kong (0.001 mg/L), India (0.001 mg/L), Philippines (0.05 mg/L) and USA (0.021 mg/L). However, recommended desirable limit for fish production is <0.0056 mg/L (PHILMINAQ 2008). Lead concentrations in the sampled sites ranged from 0.14 to 0.44 mg/L thereby exceeding international limits. Highest lead concentrations were found at the confluence sampling station (Table 1).

Allowable ranges for cadmium in the referred countries ranged between <0.0005 and 0.042 mg/L with recommended desirable limit for fish production at <0.0093 mg/L. Cadmium in the sampling sites, however, ranged between 0.02 and 0.5 mg/L with highest concentration at the estuary mouth (Table 1). Internationally acceptable ranges for nickel are between 0.074 and 0.3 mg/L (Table 2), however, concentrations of nickel in sampled sites ranged between 0.08 and 0.11 mg/L with highest concentration at the estuary mouth. The Thai standard for chromium and manganese is 0.01 mg/L Thailand National Environment Board (2000). However, the ranges of concentration for chromium were below 0.02 mg/L, while that of manganese ranged between 0.16 and 0.04 mg/L,

Also based on a report by the British Columbia Ministry of Environment, Lands, and Parks for the Canadian Council of Ministers of the Environment (CCME 1999), the standard recommendation for zinc in marine waters is 0.001 mg/L. Concentrations of zinc in Andoni River estuary ranged from 0.06 and 0.17 mg/L. Highest concentrations were found at the river confluence.

Discussions

Marine ecosystem health indicators

Water Quality Index

In applying the water quality index of Carruthers and Wazniak (2004) to this study, the variables and threshold values shown in Table 3 were used. From the calculations, the river confluence site (A1), the control site (C1), and the Atlantic Ocean front (A4) yielded an indices of 0.67, while sites A3 and A2 (Oputambi Creek mouth and the Oyorokoto Market downstream) yielded an indices of 0.33, indicating that these sites are highly polluted and cannot support the survival of fish and aquatic grass. Please note that TP (total phosphorus concentrations were below detectable limit of <0.05 mg/L concentration and to achieve a fair calculation, the

Table 3 Variables and threshold values used in the calculation of the Water Quality Index for the ANDONI River estuary (after, Carruthers and Wazniak 2004)

Variable WQI	Threshold value	Reference
Total nitrogen	<0.65 mg/L (46 µM) 4	Stevenson et al. (1993)
Total phosphorus	<0.037 mg/L (1.2 µM) 4	Stevenson et al. (1993)
Dissolved oxygen	>5 mg/L 3	USEPA 2003

concentration was divided by two yielding an average concentration of 0.025.

In the water quality criteria, a value of 1 indicates habitat suitable for fish and aquatic grass survival, while a value of 0 indicates relatively unsuitable habitat for either fish or aquatic grasses. Intermediate values indicate a system in flux and the management objective of the index which is to maintain a suitable fisheries, and sea-grass habitat specifies a draft Indicator Water Quality Index of >0.6 (EPAV 2001). On this basis therefore, we can conclude that pollution from the Port Harcourt, Onne, and Ogoni axis of the river are localized and attenuated before the triple arm confluence of the river while pollution from artisanal refining activities are localized within between the mouth of the Oputambi Creek and the Oyorokoto market.

However, calculating an average index for the whole river system and considering the fact that a blanket figure was taken for phosphorus as a TP value of <0.05 (below detectable limit) may be more or less than the threshold figure of <0.037 mg/L, we arrived at an average Water Quality Index of 0.5 which is far lesser than the recommended >0.6 value suitable for the maintaining of a fisheries and sea-grass habitat.

Water quality parameters and criteria for marine water aquaculture

It was earlier stated that indicators of water quality in open coasts, estuaries and inlets include nutrients, water clarity, and toxicants. EPAV (2001) recognized that increased loads of nutrients, principally nitrogen (N) and phosphorus (P), and sediments from surrounding catchments remain the two key threats with the potential to cause degradation in nutrient status and water clarity at a regional scale; while toxicants are recognized to have a more localized influence on marine and estuarine environments.

Nutrients

This study showed a very high level of nutrient loading into the estuarine environment especially for nitrates (Fig. 5) indicating high sewage discharge from anthropogenic sources and industrial discharges that contain corrosion inhibitors (USEPA 2012). Since there is very limited use of fertilizers for agriculture in this environment, erosion of

contaminated sediments and direct discharge of fecal and household waste into the estuarine system is indicated. This study also reveals that inland waters or creeks which are sheltered by vegetation and protected from open interaction with the sea tend to have more nitrate concentrations. Figure 5 shows a higher concentration of nitrates in the Oturuba River which was supposed to be a control and also the Oputambi outlet into the estuary. Nitrate concentration declines toward the sea. This is in line with the discovery of Robinson et al. (1998) in the River Coine estuary in Essex, UK. Mixing and aeration in estuarine environments may, therefore, be very important in the concentration of nitrates in estuarine systems.

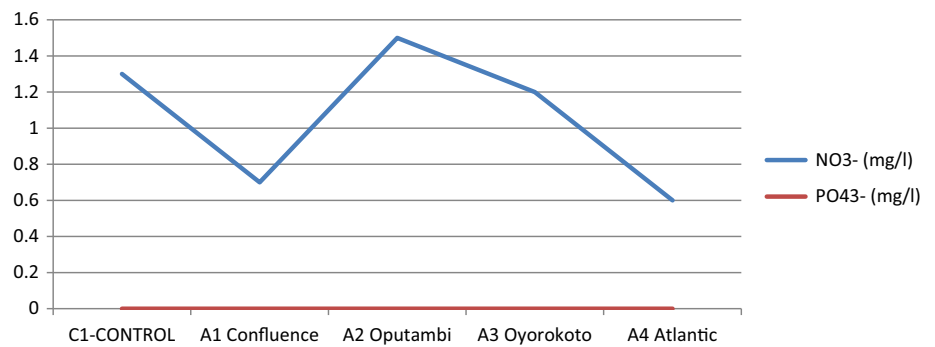
The USEPA (2012), states that nitrates in conjunction with phosphorus in excess amounts can accelerate eutrophication, causing dramatic increases in aquatic plant growth and changes in the types of plants and animals that live in a stream. This, in turn, affects dissolved oxygen, temperature, and other indicators. Excess nitrates can cause hypoxia (low levels of dissolved oxygen) and can become toxic to warm-blooded animals at higher concentrations 10 mg/L or higher under certain conditions. The natural level of ammonia or nitrate in surface water is typically low (less than 1 mg/L).

According to the Ecological Society of America (2000), nutrient over-enrichment which leads to hypoxia and anoxia (periods of oxygen depletion) has a range of effects on coastal systems, leading mainly to biological diversity loss. Hypoxia and anoxia alters the structure of ecological communities by killing off more sensitive or less mobile organisms, reducing suitable habitat for others, and truncating trophic interactions especially between predators and their prey. For instance, recurring periods of low oxygen tend to shift the dominance in the seafloor community away from large, long-lived species such as clams to smaller, opportunistic, and short-lived species such as polychaete worms that can colonize and complete their life cycles quickly between the periods of hypoxia.

Water clarity

The USEPA (2012) stated that turbidity can affect the color of the water and high turbidity increases water temperatures because suspended particles absorb more heat. This, in turn, reduces the concentration of dissolved oxygen

Fig. 5 Nutrients in water



(DO) because warm water holds less DO than cold. Higher turbidity also reduces the amount of light penetrating the water, which reduces photosynthesis and the production of DO. Suspended materials can clog fish gills, reducing resistance to disease in fish, lowering growth rates, and affecting egg and larval development. As the particles settle, they can blanket the stream bottom, especially in slower waters, and smother fish eggs and benthic macro-invertebrates. They further stated that possible sources of turbidity include: soil erosion, waste discharge, urban runoff, eroding stream banks, large numbers of bottom feeders (such as carp), which stir up bottom sediments and excessive algal growth.

In the case of the Andoni River estuary, we conclude that erosion of contaminated surficial sediments from peaty soils around the estuary, waste discharge, urban run-off from upstream sources, and a self-reinforcing algal growth in the ecosystem is causing a major water clarity challenge with great regional implications which is already manifesting in reduced fish catch, thereby threatening the livelihoods of fishing communities like Oyorokoto that has lost their status as fishing settlements and now serve as trading outposts for fish caught deep sea or in other areas.

Toxicants

Toxicants considered in this study include heavy metals and hydrocarbon pollutants. Studies have confirmed that zinc, cadmium and lead are present at high levels in the water and sediments of estuaries and these correlates with heavy metals found in fish (Plataforma SINC 2009; Opuene 2005). According to Jean-Paul (2013) chemicals like cadmium, bis-phenolic compounds; dioxin, endosulfan, vinclozolin, fenarimol and other fungicides; endosulfan, benzidine-based dyes among others released to the estuarine environment from industrial discharges can disrupt the endocrine systems of a wide range of wildlife species. The reproductive hormone-receptor systems appear to be especially vulnerable. Indeed, changes in sperm counts, genital tract malformations, infertility, an increased frequency of mammary, prostate and testicular tumors,

feminisation of male individuals of diverse vertebrate species, and altered reproductive behaviors, have all been reported.

Jean-Paul (2013) reported that heavy metals are dangerous to living organisms in the form of cations when bonded to short chains of atom carbon. In particular, cations have a strong affinity for sulfur, and especially the sulfhydryl groups in enzymes easily attach themselves to cations or molecules and so the enzyme is blocked. They are a problem in the marine environment because they bioaccumulate in marine organisms and despite measures taken to combat pollution, they are still concentrating year after year. Pollution above background levels in the environment can cause serious effects (Opuene and Agbozu 2008; Ezekwe et al. 2012). For instance, copper is a useful oligo-element but in excess can negatively affect trophic levels.

Hydrocarbons and their derivatives in all forms are dangerous to the environment. Apart from physical impairment and immobilization of marine animals during oil spills, hydrocarbons also affect the survival of larvae and fish eggs (MPCB 2012). Fish can also be affected directly by oil spills through ingestion of oil or oiled prey, through uptake by the gills, or through changes in the ecosystem that support the fish. Oil and grease in water can also present both physical and physiological hazards to benthic invertebrates. Sessile species such as barnacles are vulnerable to smothering by heavy oils, and even the more mobile invertebrates may come immobilized by toxic effects of the hydrocarbons. Birds are also affected especially, wading birds, waterfowl, shorebirds, bulls, and rails. Problems for these species include direct contact resulting in oil-covered feathers and loss of food sources. Oil may also affect birds by impacting their plumage, clogging the fine structure of its feathers, thereby compromising their ability to maintain water-repellence and heat insulation (University of Delaware Sea Grant Program 2004).

Correlation and factor analysis

The multivariate statistical methods used by Ezekwe et al. (2012) were also applied in this study. According to

Table 4 Proximity matrix for sampling sites

	A1	A2	A3	A3	Control-Oturuba Creek
<i>Proximity matrix</i>					
Correlation between vectors of values					
A1 confluence	1	0.992	0.985	0.988	0.971
A2 Oputambi	0.992	1	0.997	0.997	0.991
A3 Oyorokoto	0.985	0.997	1	0.999	0.993
A4 Estuary mouth	0.988	0.997	0.999	1	0.993
Control-Oturuba Creek	0.971	0.991	0.993	0.993	1
This is a similarity matrix					
Euclidean distance					
A1 Confluence	0	135.525	308.641	251.268	242.395
A2 Oputambi	135.525	0	208.534	157.181	206.848
A3 Oyorokoto	308.641	208.534	0	68.843	368.988
A4 Estuary mouth	251.268	157.181	68.843	0	316.751
Control-Oturuba Creek	242.395	206.848	3368.988	316.751	0
This is a dissimilarity matrix					

Ezekwe et al. (2012) multivariate methods used in analyzing environmental data constitute an increasingly important part of statistics, because they allow an easier interpretation of the results (Narváez et al. 2007). Factor analysis is a multivariate statistical method that allows data reduction (simplification) by extracting eigenvalues and eigenvectors from a covariance or a correlation matrix (Davis 2002). The procedure of multivariate analysis is based on the observations obtained in relation to several variables for a number of samples (also called eigenvectors).

Table 4 reveals that while the whole sites are quite similar to each other, the confluence of the Andoni River estuary is most similar to the Oturuba Creek while the greatest dissimilarity occurs between the Oturuba and Oyorokoto that receives serious polluted discharge from the upstream and the estuary mouth at the Bight of Bonny.

Proximity matrix and covariances of variables based on correlation between vectors of values showed that all the variables have very negative impact on redox conditions of the estuary apart from alkalinity, dissolved oxygen, and importantly chromium (−0) and nickel (0.006) which have near neutral charges. Turbidity or water clarity is affected mainly by natural sea water and industrial sources (cadmium) while dissolved oxygen is being affected by oil pollution (THC, 0.27). Hydrocarbon pollution also affects alkalinity and is the major source of heavy metal pollutants especially lead, nickel, and cadmium. Industrial sources (Cd) and petroleum pollution are also affecting nutrient levels (nitrate) through untreated discharge from upstream sources and downstream from Oputambi and Ilotombi/Oturuba channels.

Summary, recommendations, and conclusion

The Andoni River estuary is a receptacle of all the oil pollution that occur upstream (northwards) through a maze of creeks. This study showed a very high level of nutrient loading into the estuarine environment especially for nitrates indicating high sewage discharge from anthropogenic sources, industrial discharges that contain corrosion inhibitors and erosion of contaminated soil.

Water Quality Index calculated for the whole river system showed a declining capacity to support fish and aquatic grass habitats with sites A3 and A2 (Oputambi Creek mouth and the Oyorokoto Market downstream) being the worst affected sites.

All the sites show high levels of hydrocarbon pollution exceeding the stated limits by very wide margins and therefore does not meet the standards for natural resource preservation, coral reef conservation, and aquaculture for petroleum hydrocarbons. Also international standards for heavy metals tested were surpassed, sometimes by up to 10^3 magnitudes.

We also conclude that oil pollution, waste discharge, urban run-off from upstream sources, and self-reinforcing algal growth in the ecosystem are causing a major water clarity challenge with great regional implications.

It can, therefore, be concluded that the estuary is suffering pollution from immediate hydrocarbon pollution sources, local pollution from domestic and human waste, and erosion of contaminated soil and long-drift river-polluted discharge. The implementation of source control measures for known pollutants in industrial and agricultural facilities and findings ways to curb the menace of

illegal oil bunkering and the activities of artisanal oil refining has become expedient.

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