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Harmful Algal Blooms (HABs) In Nigerian Inland and Coastal Waters

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Abstract: *Blooms of autotrophic algae and some heterotrophic protists are increasingly frequent in coastal and inland waters in Nigeria and around the world and are collectively grouped as harmful algal blooms (HABs). This paper reviewed the various impacts of HABs in inland and coastal water bodies in Nigeria. Literatures of relevant and previous studies on HABs in inland and coastal water bodies in Nigeria within Nigeria and outside Nigeria were reviewed. The impacts of these HABs are felt in many ways: human health is placed at risk; ecosystems are altered; marine mammals are injured or killed; and the fishing, aquaculture, and recreation industries suffer substantial economic losses. Understanding the causes of these phenomena, and preventing their consequences, should be major concerns to Nigerians and the rest of the world at large. Moreover, although it is generally acknowledged that occurrences of these phenomena are increasing throughout the world's oceans, the reasons for this apparent increase remain debated and include not only eutrophication, and climate change but increased observation efforts in coastal zones of the world. Algae are a natural component of the aquatic food chain and are typically not harmful to people. However, the overabundance of algae in a bloom can be aesthetically unappealing and harmful to the environment. If the types of algae that produce toxins reach high concentrations, then native aquatic organisms, and perhaps even people who come in contact with the toxins, can be affected.The public should be educated via various scientific outlets and outreaches on extreme environmental events such as HABs and their health effects on humans and aquatic ecosystems.*

Keywords: *Harmful algal blooms, causes, impacts, aquatic environment, Nigeria.*

INTRODUCTION

Algae are microscopic naturally occurring aquatic plants that are usually unicellular and lack true leaves, stems and roots (Bowman, Jensen and Bowman, 2010). They are diverse group of simple, mostly autotrophic organisms that range from unicellular to multicellular forms (Alphonse, 1997). They are natural fish food and its density to a greater extend determines the greenness of water bodies and primary productivity (Backer and McGillicuddy, 2006). Under conditions that are favourable, they experience abundant growth known as algal bloom (Anderson Gilbert and Burkholder, 2002). The term bloom in harmful algal bloom (HAB) simply means dangerous algae that occur in large numbers, in the range of several thousands to millions of cells.

Algal bloom is as a result of excessive nutrients, mainly phosphorus, which originates from fertilizers applied to land for recreational or agricultural purposes, detergents from industrial and residential areas which find their way into watersheds through run-off (Taylor, 1993).

Dinoflagellates are a major group of algae that constitute the basic source of energy in aquatic food webs. Zooplankton, shellfish and some fish benefit directly or indirectly from the nourishment provided by these dinoflagellates. Some dinoflagellates are harmful when they produce toxins that contaminate seafood, when their toxins intoxicate human consumers of seafood as well as kill other aquatic biota (Lu and Hodgkiss, 2004; Colin and Dam, 2005; Shumway, 1990). And also, they form obnoxious blooms (Roberts et al., 1983) that block gills of fish and shellfish and reduce the ecological integrity of water bodies (Boesch et al., 1997), consume most of the oxygen in the water with accompanying biota kills and increase shading effect to the disadvantage of benthic organisms (Gallegos and Bergstrom, 2005; Adesalu et al., 2016).

There is scanty information on the causes and effects of HABs on Nigerian water bodies as well as the preventive, control and mitigation measures of HABs in Nigerian inland and coastal waters. Some of the available literatures on HABs in Nigerian inland and coastal waters include works by (Odokuma and Isirima, 2007) in some aquatic environments in the Niger Delta (surface water - Sombreiro, Nun and New Calabar Rivers; (groundwater - Abonnema and Kiama; and pond water from Ogboro), (Davies, Abolude and Ugwumba, 2008) in Lower reaches of Okpoka Creek, Rivers State; (Chia et al., 2009) in aquatic ecosystems in Zaria, Northern Nigeria; (Davies and Ugwumba, 2013) in Upper reaches Okpoka Creek, Rivers State; (Davies, Ikenweiwe and Geroge, 2015) in Oya Lake, Bayelsa State; (Davies and Otene, 2013) in Amadi-Ama Creek,Rivers State; (Davies, Nwose and Teere, 2018) in Upper Reaches of Orashi River,Rivers State. This paper reviewed the various impacts of HABs on Nigerian Inland and Coastal Rivers.

The Nigerian Inland Waters

The Nigerian inland water is rated the second largest based on length of waterways in Africa, with a total of 8,600 kilometers (km) of inland waterways and also an extensive coastland estimated to be about 852 kilometers (Ndikom, 2008). The River Benueand River Niger are the major rivers making up the inland waterways and cuts across the country forming the cardinal north, east and west sections, the two Rivers meets at Lokoja (Fig 1), and empties into the Atlantic Ocean (Ndikom, 2008).

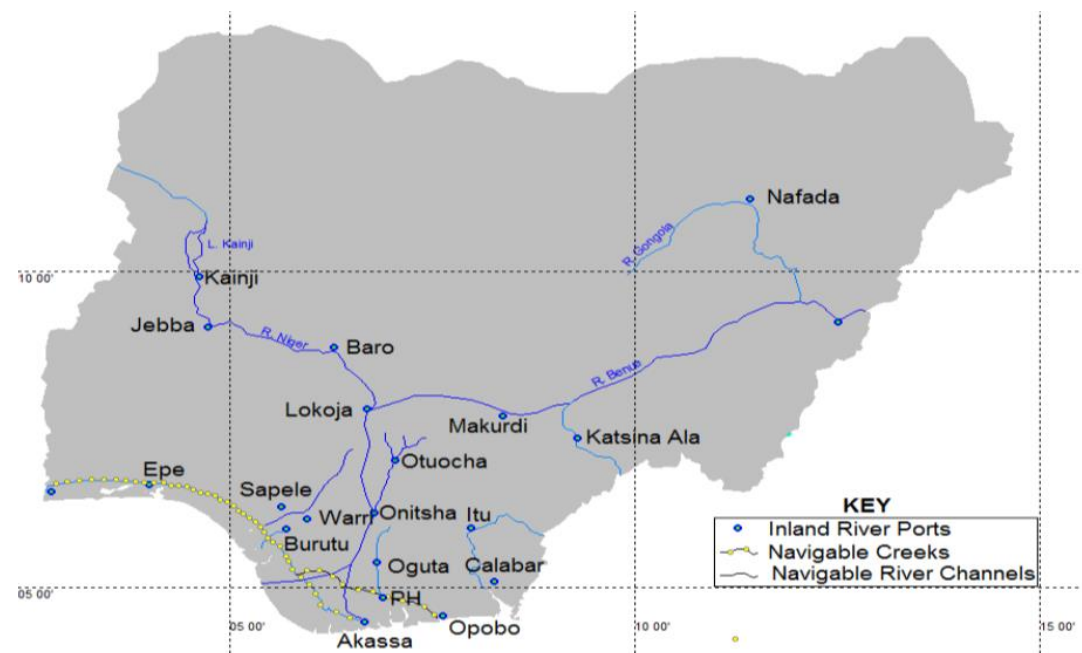

Fig. 1: Nigerian Inland Waterway, **Source**: (Chukwuma, 2014)

Nigerian Coastal Waters

The Nigerian marine and coastal area is a narrow strip of land bordered by the gulf of Guinea of the Central Eastern Atlantic in the south. The coastline is located within longitudes 3°24 and 8°19'E and latitudes 4°58' and 6°24'N and has a total length of about 850 km (Fig. 2). It is typified by the presence of lagoons and bays in the Southwest, and estuaries and creeks in the Niger Delta and Southeast (Nwankwo, 1997). The Zone lies within the Atlantic Ocean with its continental shelf, the exclusive economic zone and the coastal freshwater and brackish wetlands ramified by an atomizing network of rivers and creeks. The Nigerian coastal zone sprawls a total of nine coastal states out of the thirty-six state of the federation namely, AkwaIbom, Bayelsa, Cross River, Edo, Delta, Lagos, Ogun, Ondo and Rivers state. The coastal states are estimated to account for nearly 25% of the national population[1].

Fig. 2: The Nigerian coastal stretch showing some major population centers[2],

Importance of Nigerian Inland and Coastal Waters

The movement of people, goods and services along the inland waterways is said to be one of the oldest means of transporting goods and services from one point to another (Fellinda, 2006). The inland water transport (IWT) offers the most economical, environmental friendly and energy efficient means of transporting most cargo from one place to place (Ojile, 2006). It also offers safer and cheaper rates in areas where water abounds naturally. This facilitates commerce, poverty alleviation, promotes wealth creation,and creates job opportunities for young people within such regions. The boat building industry also generates employment through active engagement of the youths in welding and fabrication process (Gray, 2004).

The coastal area provides goods and services for economic growth and the general well-being of its indigenous populace. In most coastal areas, most of the poor people live in these areas and earn their livelihood from the available resources[3]. Economic activities in the coastal zone include oil and gas exploration and production, fishing industries, shipping, agriculture and tourism.

Characteristics of the Nigerian Inland waters

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[1] https://www.pub.iaea.org/mtcd/publications/pdf/cnpp2013_cd/countryprofiles/Nigeria/Nigeria.htm (Retrieved on 10 March 2019)

[2] **Source:** ibid

[3] ibid

The Nigeria inland waters are characterized by navigable rivers, lakes, coastal creeks, lagoons, and canal (Aderemo and Mogaji, 2010). The inland waters transverse 20 out the 36 state within the nation and the areas adjacent to the navigable rivers which represents the nation's most agricultural and minig regions (Ezenwaji, 2010).

Characteristics of Nigerian Coastal Waters

Nigeria coastline is characterized by dense evergreen forest cover, which runs from Lagos State in the Southwest, and passing through Warri and Port Harcourt (the Niger Delta) to Calabar in the Southeast (Ajuzie and Houvenaghel, 2009). The coastal sea is influenced by the Guinea and Equatorial Counter Currents, as well as heavy rains that normally last from April to October[4]. The biological activity of the coastal zone ensures stable pH; a notable features of the marine environment, whereby conditions are remarkably constant over certain areas. Consequently, marine plants and animals have correspondingly wide distribution. The marine life has therefore evolved in great diversity. Mangrove swamps are the predominant vegetation in the Niger Delta. The red mangrove*Rhizophoraracemosa*makes up about 90% of the vegetation of the mangrove ecosystem. The other species of red mangrove are *R. harrisonii*, *R. mangle* and white mangrove, *Avecennia nitidae*[5].

Composition, abundance and distribution of Harmful Algal Blooms in Nigerian Inland and Coastal Waters

Table 1 and Table 2 is a review of previous data on HABs species in some aquatic environments in Nigeria. New Calabar river water recorded the highest average cyanobacterial counts per 100 ml (23.4) while the least (11.3) was recorded in pond water from Ogboro. From Table 2, the highest harmful algal bloom-forming genera in some aquatic environments in Rivers and Bayelsa States indicated that 4 genera were recorded in Lower reaches of Okpoka Creek, Rivers State, Elechi Creek, Rivers State and Upper reaches Okpoka Creek, Rivers State while 2 genera was recorded in Upper Reaches of Orashi River, Rivers State.

Table 1: HABS Species in the surface and ground waters of Rivers and Bayelsa States (**Source: Odokuma and Isirima, 2007)**

Sample	Cyanobacteria	Average cyanobacterial counts per 100 ml
SRNC	*Microcystis* sp.	23.4
	Nodularia sp.	13.2
	Cylindrospemopsis sp.	11.4
SRN	*Anabaena* sp.	13.2
	Microcystis sp.	16.6
GWK	*Anabaena* sp.	13.2
	Cylindrospemopsis sp.	11.4
SPD	*Anabaena* sp.	16.2
	Microcystis sp.	11.2
GWA	*Cylindrospemopsis* sp.	13.2
	Anabaena sp.	11.4
SRS	*Anabaena* sp.	16.4
	Lyngbya sp.	13.2

Code for water samples: SRNC - (New Calabar Rivers water), SRN - (River Nun), SRS - (River Sombreiro), SPD - (Pond water from Ogboro), GWA - Ground water from Abonnema), GWK - (Ground water from Kiama)

[4] ibid

[5] ibid

Table 2: Major harmful algal bloom-forming genera in some aquatic environments in Rivers and Bayelsa States

Water body	Observed CyanoHAB genera	Observed BacillarioHAB genera	Observed DinoHAB genera	Observed ChrysoHAB genera	Reference
Lower reaches of Okpoka Creek, Rivers State	*Microcystis,Anabeana, Lyngbya, Oscillatoria*	*Melosira, Nitzschia, Navicula, Melosira, Cyclotella, Synedra, Coscinodiscus, Cymbella, Biddulphia*	*Ceratium*	*Dinobryon*	(Davies, Abolude and Ugwumba, 2008)
Elechi Creek, Rivers State	*Microcystis, Anabeana, Lyngbya, Oscillatoria*	*Melosira, Navicula, Nitzschia, Cymbella, Cyclotella, Coscinodiscus, Synedra, Biddulphia*	*Ceratium*		(Davies, Abowei and Tawari, 2009)
Minichinda Stream, Rivers State	*Anabaena, Oscillatoria, Lyngbya,*	*Melosira, Cyclotella, Nitzschia, Navicula, Synedra*		*Dinobryon*	(Davies, Abowei, and Otene, 2009)
Upper reaches Okpoka Creek, Rivers State	*Microcystis,Anabeana, Lyngbya, Oscillatoria*	*Melosira, Nitzschia, Navicula, Melosira, Cyclotella, Synedra, Coscinodiscus, Cymbella, Biddulphia*	*Ceratium*	*Dinobryon, Phyllosiphon*	(Davies, and Ugwumba, 2013)
Oya Lake, Bayelsa State	-	*Melosira*	-	-	(Davies, Ikenweiwe and Geroge,2015)
Amadi-AmaCreek,Rivers State	*Microcystis,Anabeana, Oscillatoria*	*Cyclotella, Melosira, Navicula,Nitzschia, Synedra,*	-	-	(Davies, and Otene, 2013)
Upper Reaches of OrashiRiver,Rivers State	*Microcystis,Oscillatoria*	*Cyclotella, Melosira, Coscinodiscus, Cymbella, Synedra*	-	-	(Davies, Nwose and Teere, 2018)

Table 3 presents the distribution of the dinoflagellates in Nigerian coastal waters and their potential harmful effects. At Bar Beach (BB); James Town (JT) and Lagos Area (LA), the bloom of the dinoflagellates, *Ceratium furca* have been reported to cause biota kills while the bloom of the dinoflagellates, *Gonyaulax diegenesis* and *G. Scrippsae* were reported to deplete oxygen in Lagos Area waters.

Table 3: Distribution of the dinoflagellates in Nigerian coastal waters and their potential harmful effects

Species (Distribution)	Harmful effects (References)
Ceratiumfurca (BB, TB in LA)	Biota kills (Matthews and Pitcher,1996)
C. fusus (BB in LA &Forc. In WA)	Biota kills (Taylor, Fukuyo and Larsen, 1995)
C. tripos (BB in LA)	Oxygen depletion (Taylor, Fukuyo and Larsen, 1995)

Dinophysisacuta (BB in LA)	Toxic (Johansson et al., 1996)
D. caudate (BB in LA & JT in CA)	Toxic (Karunasagar, Segar and Karunasagar, 1989)
D. rotundata (BB in LA)	Toxic (Lee et al., 1989)
D. tripos (BB in LA)	Toxic (Lee et al., 1989)
Dinophysis sp. (BB in LA)	Potentially toxic (Taylor, Fukuyo and Larsen, 1995)
Gonyaulaxdiegenesis (Ijora in LA)	Oxygen depletion (Taylor, Fukuyo and Larsen, 1995)
G. scrippsae (BB in LA)	Oxygen depletion (Taylor, Fukuyo and Larsen, 1995)
G. spinfera (JT in CA)	Oxygen depletion (Taylor, Fukuyo and Larsen, 1995)
Gymnodiniumsp (BB in LA)	Potentially toxic (Taylor, Fukuyo and Larsen, 1995)
Lingulodiniumpolyedrum (JT in CA)	Toxic (Tubaro et al., 1998)
Prorocentrum lima (Ijora in LA)	Toxic (Jackson, Marr and Mclachlan, 1993)
P. micans (BB in LA & JT in CA)	Biota kills (Matthews and Pitcher, 1996)
P. minimum (TB, Ij., Maj. In LA &Forc. in WA)	Toxic (Tseng, Zhou and Zou, 1993)
P. sigmoides (BB in LA)	Oxygen depletion (Lam and Ho, 1989)
Scrippsiellatrochoidea (TB, Ij., Maj. In LA)	Oxygen depletion (Hallegraeff, 1991)

Note: (BB) Bar Beach; (JT) James Town; (TB) Takawa Bay; (Forc.) Forcados; (Ij.) Ijora; (Maj.) Majidun; (CA)Calabar Area; (LA) Lagos Area; [6]

Causes of Harmful Algal Blooms

Previous studies suggests that climate change impacts and other sources may facilitate the dominance and growth of harmful algal through a diverse mechanisms including changes in salinity, temperature, increases in atmospheric carbon dioxide concentrations, coastal upwelling, changes in rainfall patterns, light stable condition and turbidity, sea level rise high and nutrient loads (Hallegraeff, 1991).

Effects of HABs in Nigerian Inland and Coastal waters

Previous studies pointed out that HABs have different effect on the environment including aquatic lives, man and also his livelihood[7]. These effects are discussed below.

Effects on Ecology

Harmful algal blooms negatively impact the food web by decreasing the amount of nutritious, edible phytoplankton that zooplankton and other primary consumers need to survive. These organisms may then starve, leading to decreased food for secondary and higher order consumers. Increased cell concentration can block sunlight from primary producers under the water's surface as well, leading to decreased food and oxygen levels. When the cells in the bloom begin to die, it can also lead to decreased dissolved oxygen levels that can be lethal to other aquatic organisms and cause fish kills. Low dissolved oxygen can be made worse by overcast days and warmer temperatures (Bushaw-Newton and Sellner, 1999). Decreased recreational use and poor aesthetical value of waters due to toxicity, mats of algae, offensive odor and tastes, and large fluctuation of pH when their cells begin to die, are some of the problems associated with harmful algal blooms. In addition, HABs death and decomposition create dead zones in the water (Bushaw-Newton and Sellner, 1999).

Effects on Human and Animal

HABs have been implicated for man and animal health, Cyanobacterial blooms can contaminate drinking water with taste, odor, or toxic compounds (NOAA, 2001). The toxins produced during blooms are possible carcinogens to humans. Harmful algal blooms have been known to poisoning of man who drinks or baths in ponds with algal bloom, also waterfowl, livestock and dogs have died after eating mats of cyanobacteria or

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[6] Source: ibid

[7] ibid

licking their fur after swimming in bloom infested waters. Harmful algal blooms can also produce extremely dangerous toxins that can sicken or kill people and animals (NOAA, 2001).

Effect on Socio-economics

There are social and economic costs to HAB events, ranging from short-term to long term, which must be taken into consideration by policy and decision makers. These effects are as follows:

1. Closure of a body of water or beach due to HAB-related fish kills and toxic aerosols can have substantial effects on tourism and fishing.
2. In some cases, the negative public reaction to HAB events can be severe and prolonged, and misinformation can cause scares unnecessarily, creating heavy pressures on management agencies and increasing economic losses.
3. Some of the costs are direct, such as those related to health issues and agency monitoring programs, and lost sales of fish and shellfish products. For example in the past decades, U.S has spent more than $1 billion on harmful algal blooms (Bushaw-Newton and Sellner, 1999).
4. Others may be indirect and harder to quantify, such as negative investment decisions in coastal aquaculture due to the threat of HAB events or lost recreational opportunities (Bushaw-Newton and Sellner, 1999).
5. The treatment costs for drinking water for industries that depend on clean water only is a major socio-economic effect (NOAA, 2001).

Public Health Impacts

Human sickness and death from eating tainted seafood result in lost wages and work days. Costs of medical treatment and investigation also are an important part of the public health impact caused by such events. Cases of sickness and death from shellfish toxins are probably the most clearly documented among the different types of HAB impacts (Anderson, Gilbert and Burkholder, 2002).

Recreational and Tourism

Although many experts argue that the impacts of HABs on recreation and tourism are important and potentially large, there are few available data describing the size of the impacts (WHOI, 2000). Efforts to measure recreation and tourism impacts must be undertaken at the local level because local environmental and socioeconomic conditions are critical determinants of changes in recreational benefits (WHOI, 2000).

Commercial Fishery Impacts

Commercial fishery impacts from HABs include wild harvest and aquaculture losses of fish and shellfish resources. The estimation of commercial fishery impacts is complicated further by the transfer of shell fishing effort from closed areas to areas that remained open and by fishermen switching toother fishing activities. In addition, the net worth of wild fish kills or of lost opportunities for harvesting some untapped shellfish resources have great economic implications (WHOI, 2000).

Monitoring and Management

The case of water monitoring tasks, including shellfish testing for HABs are spread across different divisions of state government in many countries where harmful algal blooms due occur, making it difficult to collect data on costs (WHOI, 2000).

Preventive Measures

For proper prevention of HABs the following should be put into consideration.

1. Ensure a safe and sustainable seafood supply by developing fisheries and aquaculture management strategies to minimize the impacts of HABs (NOAA, 2001).
2. Ensure that the public can use and enjoy coastal waters safely, free from exposure to HABs, thereby protecting public health and economic vitality.
3. Provide information and tools so that coastal managers and policy makers can consider HABs in their decision – making process at local and regional levels (NOAA, 2001).

4. Prevent the spread or enhancement of HABs from human activities (NOAA, 2001).

Control Measures of HABs

Biological, physical and chemical control measures have been used in fresh water systems for small and large-scale control of HABs due to their significant public health, economic, and ecosystem impacts (Chorus and Bartram, 1999). Given that HABs in the ocean have similar impacts, these phenomena would appear to be legitimate targets for control efforts. Approaches to direct bloom intervention can be grouped into three categories: mechanical, physical/chemical, and biological control.

i) **Biological Control**

This involves the use of organisms or pathogens (e.g., viruses, bacteria, parasites, zooplankton and shellfish) that can kill, or remove HAB cells.

ii) **Mechanical/Physical Control**

Mechanical/Physical control involves the use of filters, pumps, and barriers (e.g., curtains, floating booms) to remove or exclude HAB cells, dead fish, or other bloom-related materials from impacted waters (Bushaw-Newton, and Sellner, 1999).

iii) **Chemical Control**

This involves the use of chemical or mineral compounds to kill, inhibit, or remove HAB cells in the water body (Bushaw-Newton, and Sellner, 1999).

Mitigation Measures

Mitigation measures involves minimizing HAB impacts on human health, living resources, and coastal economies when they do occur or by control actions that directly reduce or contain the bloom population such as, checking for warning and closures before harvesting and eating shellfish, Exercise caution when eating fish caught during HABs, removing the viscera is strongly recommended (NOAA, 2001).

Conclusion and Recommendations

Algae are a natural component of the aquatic food chain and are typically not harmful to people. However, the overabundance of algae in a bloom can be aesthetically unappealing and harmful to the environment. If the types of algae that produce toxins reach high concentrations, then native aquatic organisms, and perhaps even people who come in contact with the toxins, can be affected. The public should be educated via various scientific outlets and outreaches on extreme environmental events such as HABs and their health effects on humans and aquatic ecosystems.

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