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Preliminary Investigation of the Chemical Composition of Ballast Water and Tank Sediments of Selected Ships within the Lagos Harbour, Nigeria

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ABSTRACT.

Ballast water is important for safe and efficient operation of vessels, helping to maintain stability during voyage in seas and docking in harbours. However, ballast water can pose considerable environmental challenges because they are often laden with polluted sediments and invasive species. The Lagos Harbour, which houses in the largest port in West Africa, receives about five thousand vessels annually which discharge ballast water and tank sediments into the water with the potential to cause environmental pollution. In the Nigerian context there is high potential for pollution due to weak regulations, poor enforcement and limited research of this kind in order to understand their composition, fate and impacts. This study aims at characterizing the chemical composition (Heavy metals- Arsenic, Cadmium, Chromium, Copper, Lead & Zinc, as well as carbon and nitrogen content) of the ballast water and the tank sediments because of their positive correlation with the survival of invasive species in the ballast water and tank sediments. Water samples were collected from four ships (2 cargos and 2 tankers) within the Lagos Harbour; surface (1-5 cm) sediment samples were scooped from ship tanks using a specialized grab for sampling ballast sediments. The sediments were transferred in specialized sample containers (cool boxes) to the University of Portsmouth in United Kingdom for analysis. Total metal concentrations were analysed using X-ray fluorescence (XRF). They were subjected to two acid digestions: *Aqua regia* (AR) and 1 M hydrochloric acid (1 M HCl) following the procedures set out by the Canadian National Water Research Institute (NWRI) and the United States Environment Protection Agency (US-EPA Method 3050B). Total carbon and nitrogen contents were determined using an in-line Yanaco MT-5 CHN analyser. The results obtained were compared with established guidelines and subjected to correlation and Principal Component Analysis (PCA). The findings indicated high concentrations of Nickel, Lead, and Zinc in the sediments with values of 59.6 mg/kg, 33.75 mg/kg and 43,145.7 mg/kg respectively which exceeded NOAA and CSQGs permissible standards. Tanker vessels contained relatively higher concentrations of the pollutants than cargo vessels. The findings from this study provide useful baseline data which will guide a more intensive investigation of the chemical composition of ballast water and tank sediments for effective comparison with what is obtainable elsewhere in the world. The maritime industry needs to pay close attention to ballast as a potential source of marine pollution particularly in developing countries like Nigeria where there is limited regulation for management of coastal areas with respect to shipping activities. The IMO needs to direct further effort at investigating the non-biological components of ballast water and sediments in order to protect valuable biodiversity.

Keywords: Coastal Pollution, Ballast Water Management, Ships, Analytical Techniques

1.0: INTRODUCTION

Seas and other water bodies have for long connected human populations, serving as a route for transportation of people as well as merchandise. Today more than 90% of all worldwide trade goods are transported on the ocean (IMO, 2008). Shipping is essential to the global economy, providing the most cost-effective means of transporting bulk goods over great distances. Ships are specifically designed and built to move safely through the water while carrying cargo. The weight of the cargo ensures their stability, preventing them from toppling under the boisterous waves at sea (UNCTAD, 2018).

When cargo has been offloaded, the ship must take on additional weight on board (Ballast) to enable it operate effectively and safely. Ballast water is therefore bunkered to stabilize vessels and keep the ships from capsizing when not fully loaded or when cargo has been offloaded. If necessary, it is discharged into the waterway at long distances away from the source (UNCTAD, 2019).

Ships carry ballast water to aid in stability, trim (or balance), and structural integrity. An estimated 7,000 species are carried in ships' ballast tanks around the world (IMO, 2003). While most of them perish during the voyage, even a few survivors can be enough to establish a reproductive population when discharged into a waterway. Under certain conditions, non-native species can compete with native species and become pests in their new environment. Currently, ships entering U.S. waters with no ballast on board are exempt from some management requirements. However, even seemingly empty ballast tanks often contain residual water and sediments that can release non-native species to receiving waters when the ships take on and discharge water during a coastal or Great Lakes passage. Intercontinental voyages are not the only way to introduce non-native species through ballast water discharge. The spread of non-native species from one port to another within U.S. waters is of increasing concern on the East and West coasts. Unfortunately, the Coast Guard's jurisdiction is limited to vessels entering U.S. waters from outside the exclusive economic zone (EEZ) (IMO, 2003).

1.1: Pathways of Pollutants into the Coastal Environment/Harbours

Ballast water is one amongst several pathways of pollutants entry into coastal environment such as the Lagos Harbour as shown in Figure 1. Ballast is comprised of water, sediment and other biota (microorganisms, planktonic, benthic and fishes) as presented in Table 1.

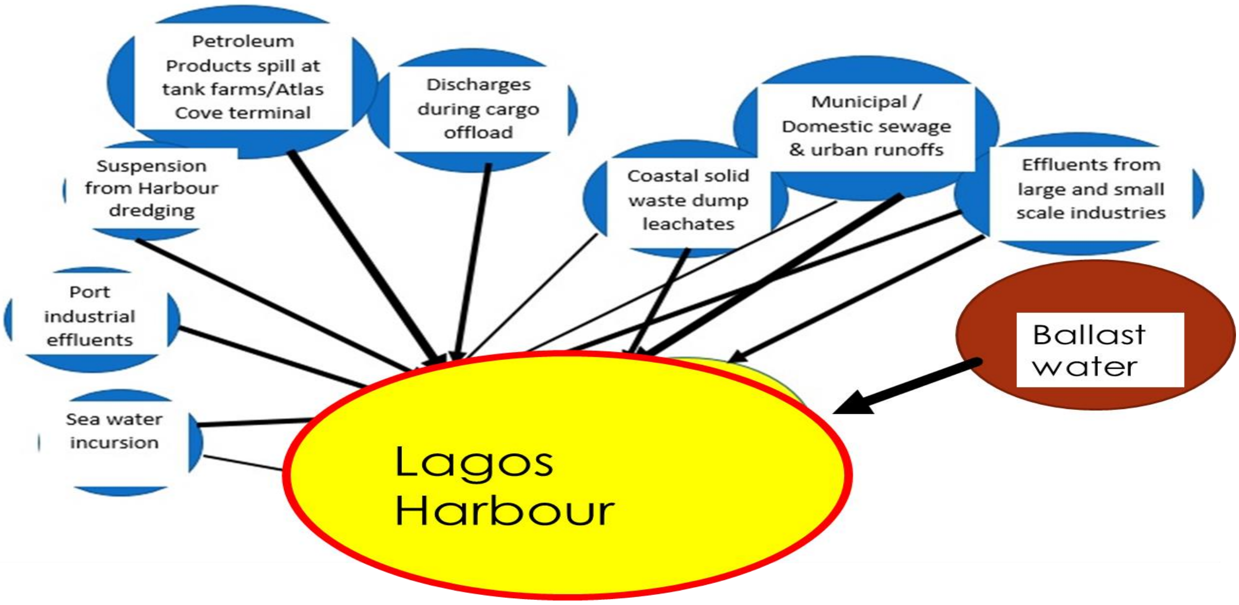

Figure 1: Pathway of pollutants into coastal environment

Table 1: Composition of the major components of Ship Ballast

Water	Sediment	Living organisms
Metals	Metals	Microorganisms/ Bacteria
Hydrocarbons	Hydrocarbons	Plankton
Nutrients	Nutrients	Benthic animals
Endocrine disruptors	Endocrine disruptors	Fishes

Source: Choudri and Baawain (2016).

1.2: Ballasting and De-Ballasting Operations

Ballast water is pumped into ballast tanks (ballasting) when a ship has delivered cargo and is departing with less or no cargo. However, ballast water is released (de-ballasting) upon loading a ship (Figure 2).

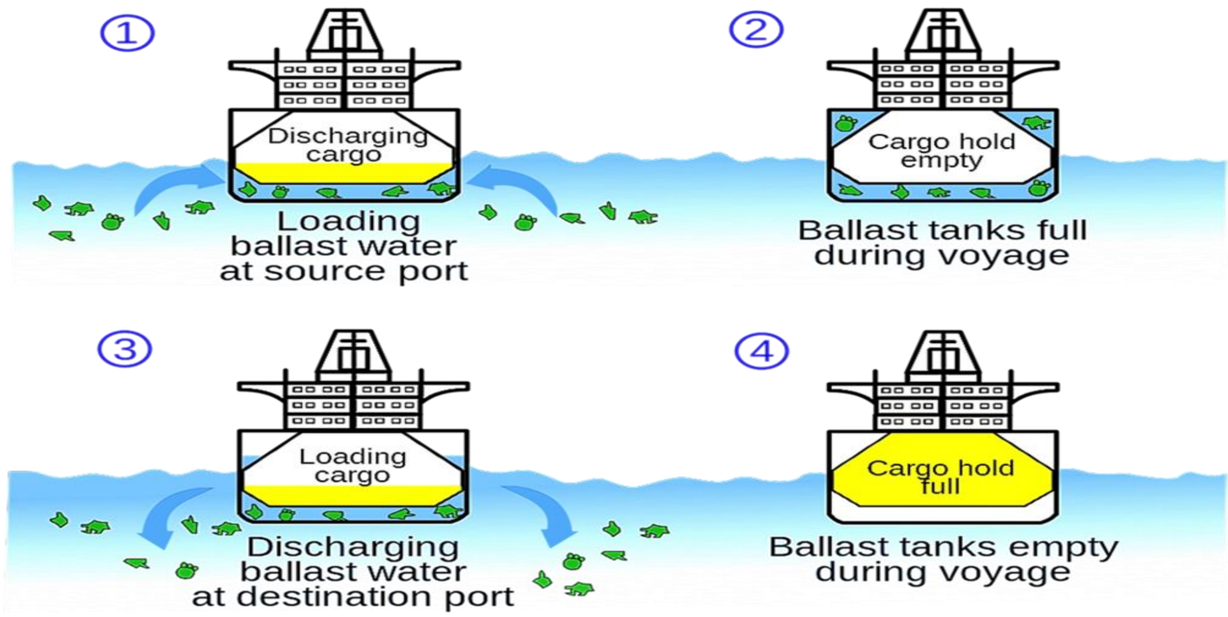

Figure 2: Ballasting/de-ballasting procedures for a bulk carrier

Source: GloBallast, International Maritime Organization (2017).

Lloyd's Register Maritime, (2017) reported that on a global scale, shipping is estimated to transfer three to five billion tons of ballast water annually. However, due to increasing marine transport from the last two years, it is now estimated that over 12 billion tons of ballast water is moved across vast coastal and oceanic domains annually (Ahmad, 2019).The problem associated with ballast water - facilitates global spread of invasive species and one major source of environmental pollutants into the Lagos Harbour. Generally, the focus has been on the ballast water and its invasive species burden with limited or no attention paid to the sediments and its pollution loads. The sediment contributes to pollutants and conditions under which the invasive species thrive. Thus, diverse pollutants can accumulate in the sediments and they become more important repositories of pollutants than the ballast water which is commonly analysed. Hence, the focus of this study is to draw attention to ballast tank sediment.

2.0: MATERIALS AND METHODS

2.1: Study area

Nigeria hosts a number of ports with large cargo traffic annually, recording cargo throughput of over 50,000,000 metric tons of cargos per annum. This result in large scale ship movement and the attendant discharge of ballast into water. Currently discharges occur in the harbour together with sediments. Plans are on the way for designation of exchange area at sea based on D-1 regulation of the BWMC (2017). The Lagos Harbour is a semi closed system, thus substances dumped into the harbour eventually settle at the bottom of the water in the sediments (Amaeze, 2014). These contaminants accumulate in sediments and subsequently pollute the water column upon resuspension, thereby negatively impacting the benthic and pelagic flora and fauna of the marine environment.

2.2: Environmental Setting– General, Features of the Study Area

Lagos Harbour is the main water inlet from the Atlantic Ocean to the seaports (James and Adejare, 2010). It is a section of the Lagos Lagoon system characterized by intense shipping activities. Lagos Lagoon, situated in the western coast of Nigeria, is the largest of the four lagoon systems of the Gulf of Guinea (Onyema, 2013).The Lagos Harbour and its adjoining Lagoon is shown in Figure 3. The vessel traffic at the Apapa terminal was documented by the Nigerian Maritime Administration and Safety Agency (NIMASA) for two years (2013 – 2014) as shown in Table 2.

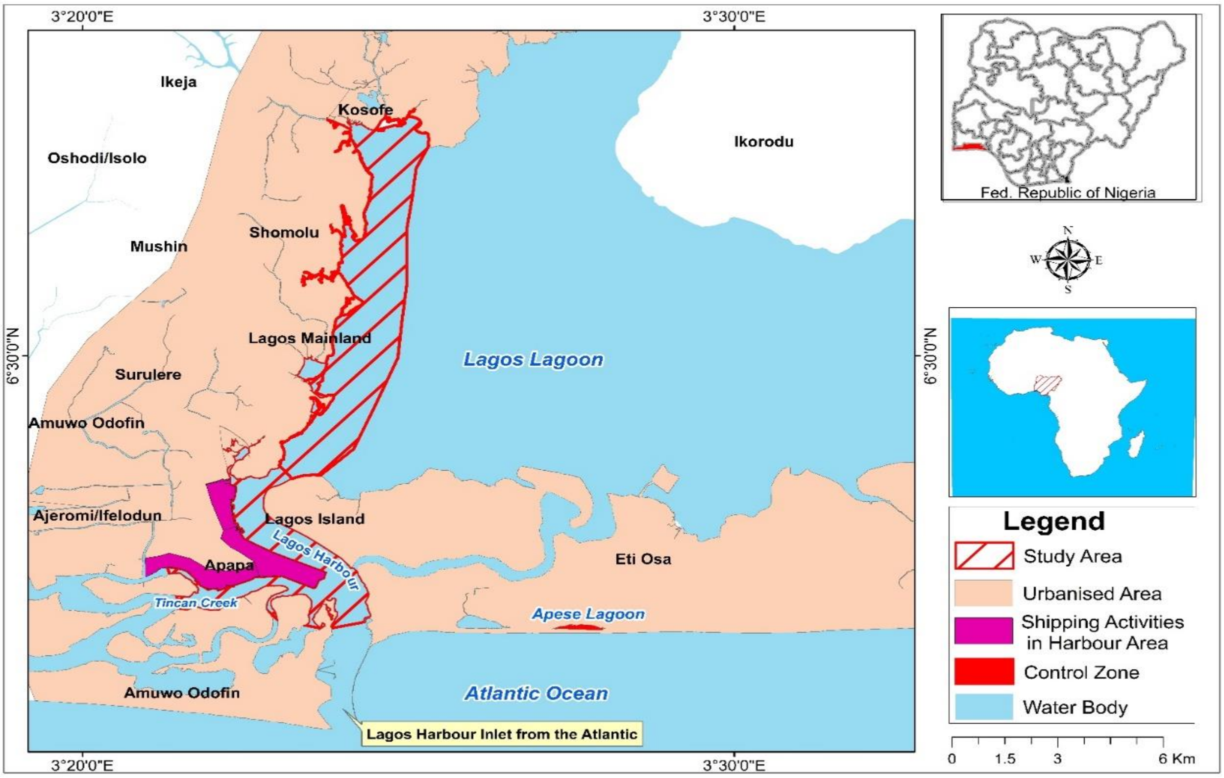

Figure 3: The Lagos Harbour and the adjourning Lagoon

Table 2: Vessel Traffic at Apapa Terminal, Lagos between 2013-2014

PORT / TERMINAL	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEPT		OCT		NOV		DEC		TOTAL	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
ABTL	14	8	7	11	9	12	10	14	12	15	7	9	14	15	15	13	11	15	14	10	14	9	11	11	138	142
ENL	23	18	16	16	24	23	22	27	34	17	19	14	28	17	29	28	26	22	25	25	18	20	25	23	289	250
APMT	39	43	33	45	39	43	38	42	38	43	35	39	43	47	40	50	44	47	44	44	48	39	47	46	488	528
GDNL	10	8	9	6	7	7	6	8	10	7	3	5	6	6	7	4	3	8	9	5	6	11	11	6	87	81
PETROLEUM JETTY	45	35	40	37	47	51	39	40	41	45	44	38	41	42	45	42	43	40	39	43	37	41	47	48	508	502
TOTAL	131	112	105	115	126	136	115	131	135	127	108	105	132	127	136	137	127	132	131	127	123	120	141	134	1,510	1,503

2.3: Conceptualised methodology

The conceptualised methodology is subdivided into two (2) parts: Field and analytical works as shown in Figure 4.

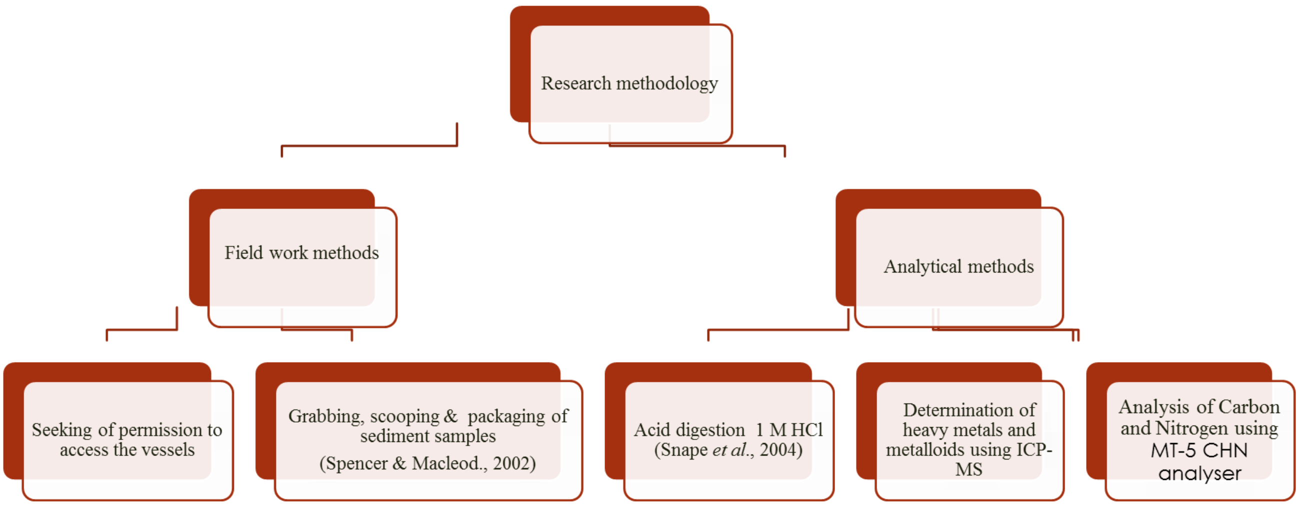

Figure 4: Conceptualised framework of the methodology

Sample collection

Sediments from four foreign ships arriving the Lagos Harbour were sampled using specialized grabs. This includes 2 cargo and two petroleum products tanker vessels shown in Figure 5.

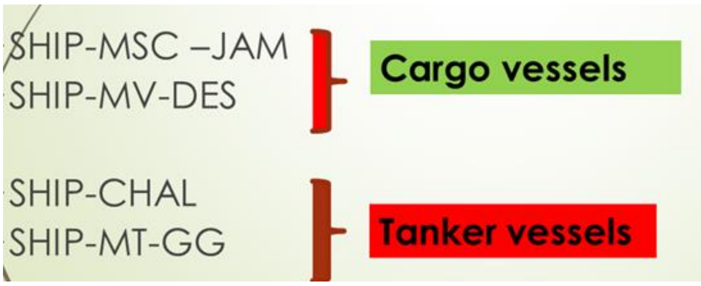

Figure 5: Samples collection from two types of vessels

Collected sediments were stored in specialized coolers and transported to the University of Portsmouth, UK for analysis. Bioavailable metals in the sediment were determined using a 1 M HCl extraction and ICPMS analysis, as described by Snape et al. (2004). Approximately 0.5g sediment samples were weighed accurately (to four decimal places) and placed into a 15 mL centrifuge tube 0.5 g. A triplicate of the acid blank labelled a 15mL centrifuge tube “Blank1M” was used. In the fume cupboard – to each of the 15 mL centrifuge tubes 10mL of 1M hydrochloric acid was added and mixed thoroughly. The lids were secured with the use of Parafilm to prevent leakages. The tubes were loaded in the rotating rack for 4h. Samples were filtered through an acid washed pore size filter using a Swinnex filter housing and syringe and collected the sample in a labelled 3 M Sterile tube. The samples were prepared to a 10 times dilution.

Figure 6a shows the ballast sediment sample from the ship and Figure 6b shows the laboratory technique applied using ICP-MS Agielnt 7500 to analyse the samples.

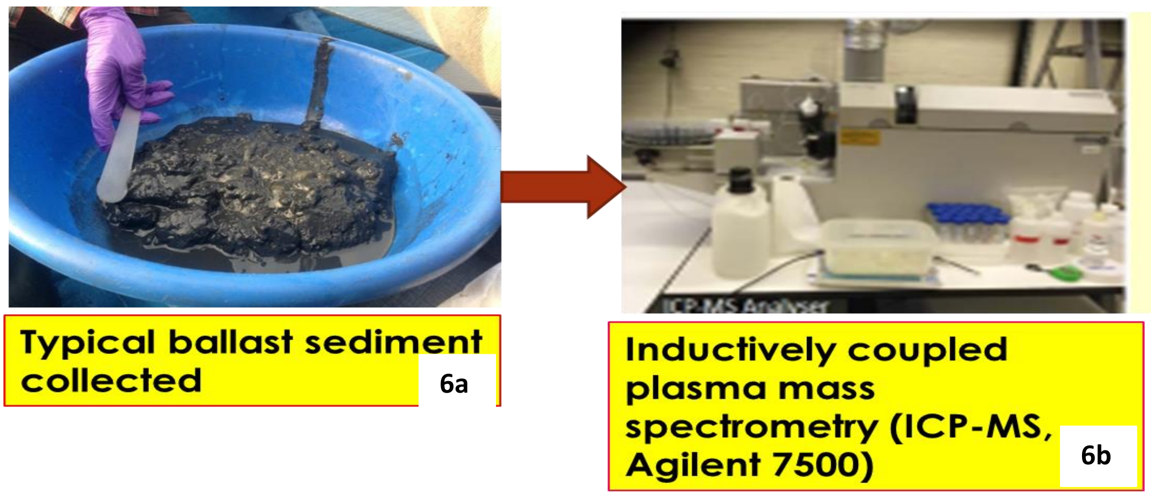

Figure 6: (a) Ballast sediment sample and (b) Laboratory equipment for analysing the samples

The Total carbon and nitrogen contents were determined using an in-line Yanaco MT-5 CHN analyser. Samples for carbon preparation were adopted using Salville *et al.* (2011) as presented in Figure 7.

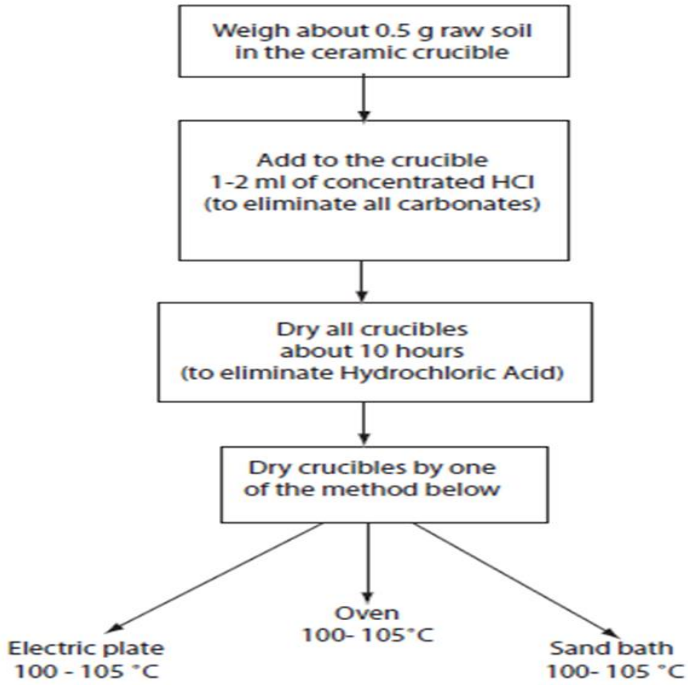

Figure 7: Schematic diagram for sediment preparation for Carbon analysis

Source: Salville *et al*.(2011)

2.4: Statistical Analysis

The results obtained were presented as mean ± standard error (S.E). The mean concentrations were subjected to Pearson correlation coefficients and compared with standards. Data was converted to Log equivalent for comparative purposes due to the large differences in the range of the metal concentrations.

3.0: RESULTS AND DISCUSSION

The mean concentration and relative concentrations of metals and metalloids in the ballast sediment compared with standards from the Lagos Harbour is presented in Table 3 and Figure 8. Ni, Pb and Zn exceeded the permissible limits of NOAA and CSQGs. The level of Ni in the ballast sediment is 4 fold higher, and Zn is 348 fold higher than the standards.

Table 3: Mean concentrations of metals in the ballast sediment samples and Limits of sediment concentrations (international guidelines/standards (mg/kg).

Metals/metalloids	As	Cr	Mn	Fe	Ni	Cu	Pb	Zn	Cd
Concentration	2.9	21.9	728.3	20571.1	**59.6**	605.2	**33.75**	**43145.7**	0.15
NOAA	7.2	52.3	0.68	-	**15.9**	18.7	**30.4**	**124**	**-**
CSQGs	7.24	52.3	0.7	-	**-**	18.7	30.2	124	-

Canadian sediment quality guideline (CSQGs)
National Oceanic and Atmospheric Administration (NOAA).

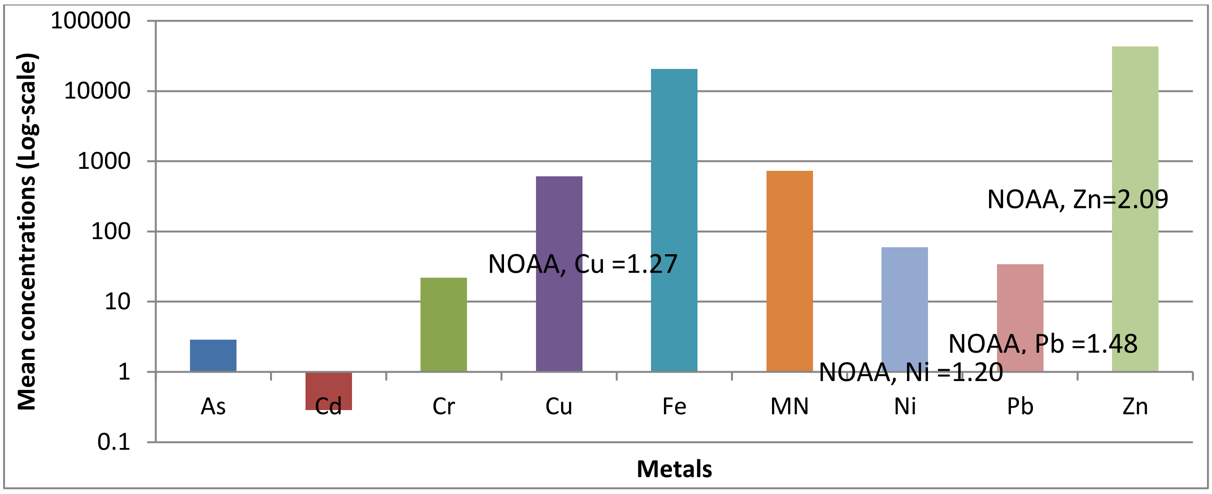

Figure 8: Relative concentrations of the metals and metalloids in the ballast sediments compared to the Canadian sediment quality guideline (CSQGs) and National Oceanic and Atmospheric Administration (NOAA). NB: Values are in Log scale in other to show comparison in a slide

Table 4: Mean Concentrations of Total Carbon and Nitrogen observed in the ballast sediments

Parameters	Concentrations Observed
Mean Total Carbon (g/g)	17.833
Mean Total Nitrogen (mg/g)	1.987
Mean Carbon Nitrogen ratio	**8.97 : 1.00**

Table 4 showed mean concentrations of total carbon and nitrogen in ballast sediment. The observed carbon nitrogen ratio of 8.97 to 1 indicates that the ballast sediments examined in this study do not contain enough carbon to make the microorganisms outcompete plants. Thus, the ballast may be able to sustain invasive plant until they are discharged in the harbour.

It is recommended that the Carbon to Nitrogen Ratio be below 20 to 1. If the Carbon to Nitrogen ratio exceeds 20 to 1, soil microorganisms outcompete plant roots, resulting in reduced plant growth (Hamad and Omran, 2016). The C: N ratio can be attributed to being from nutrient rich waters that could be from municipal canals, dumpsites and inland rivers and creeks. This also could suggest that the ballast water may be impacted with agricultural runoffs, as well as high nitrogenous material.

Table 5 shows the correlation coefficients of heavy metals with total Nitrogen and total Carbon. There were negative significant correlation of As (metalloid) with total nitrogen ($p<0.05$, r = -0.67*), Cd with total nitrogen ($p<0.05$, r = -0.68*), Cu with total nitrogen ($p<0.05$, r = -0.69*) and Zn with total nitrogen ($p<0.05$, r = -0.69*). Significant correlations were observed between most heavy metals and total nitrogen content of the ballast. This implies that the heavy metals together with the nutrients create suitable conditions for invasive species to survive long enough to get to their destination harbours.

Table 5: Correlation coefficients of the heavy metals with total nitrogen and total carbon

	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn	TN	TC
As	1										
Cd	0.97**	1									
Cr	0.92**	0.94**	1								
Cu	0.93**	0.97**	0.92**	1							
Fe	0.91**	0.9**	0.97**	0.86**	1						
Mn	-0.14	-0.3	-0.24	-0.42	-0.03	1					
Ni	0.9**	0.94**	0.97**	0.93**	0.95**	-0.28	1				
Pb	0.83**	0.79**	0.93**	0.75**	0.91**	-0.1	0.84**	1			
Zn	0.93**	0.98**	0.92**	0.99**	0.86**	-0.43	0.94**	0.74**	1		
TN	-0.67*	-0.68*	-0.8**	-0.69*	-0.83**	0.14	-0.83**	-0.8**	-0.69*	1	
TC	-0.24	-0.26	-0.41	-0.31	-0.52	-0.26	-0.42	-0.34	-0.28	0.53	1

*****Correlation is significant at the 0.01 level (2-tailed)***

****Correlation is significant at the 0.05 level (2-tailed)***

This finding indicates that the ballasts originated from locations with considerable input of nutrients perhaps from sewage with high nitrogenous material being discharged at the coastline. This has the implication of creating conditions suitable for survival of invasive biota which includes phytoplankton and micro-organisms in the ballast sediment. Once in a new environment after the ballast discharge, the invasive organisms can outcompete native species creating far reaching ecological and economic consequences.

This study has steered the focus with respect to ballast management away from just routine invasive species and physicochemical parameters assessment to the status of the ballast sediment. Ballast sediment, is a store of pollutants, a habitat for invasive species and provides ambient conditions for invasive species to thrive.

4.0: CONCLUSION

This study has provided baseline data upon which further research can be built ~~on~~, especially with respect to other chemical components of the ballast sediment which hitherto has evaded regulatory actions. The outcome of this study can contribute in the development of guidelines for monitoring marine pollution and determining appropriate locations to source ballast. It will also aid in ballast risk assessment as well as making general health and safety decisions.

This study has highlighted the status of ballast sediments in ships discharging in the Lagos Harbour. It has noted that ballast is source of chemical pollutants such as heavy metals and algal bloom inducing nutrients into harbours. It should be noted therefore that the continued discharge of ballast sediment alongside the ballast water into Harbours' poses pollution threat to coastal ecosystems which hitherto has been subsumed by the focus on Invasive Species. Focus on conditions enhancing survival of organisms in ballast sediment is germaine.

Management of ballast sediment should be prioritized because it contains higher levels of pollutants than the water. Development of ballast water and sediment management systems must bear in mind the uniqueness of the ballast tank compared to the natural environment which is characterized by wave action, tides, etc. The findings from this study provide opportunity for development of treatment technologies for ballast sediments.

4.1: RECOMMENDATIONS

The findings from the study present an opportunity for industry to consider developing technologies which would be capable of managing sediment chemical pollution load and creating conditions difficult for invasive species to thrive.

As the IMO moves away from the d-Regulation (involving ballast water exchange) there is need to develop technologies which monitor and perhaps treat the ballast and its sediments before discharge. Consideration should be given to locations appropriate for sourcing ballast-alternatives to harbour sourcing especially in countries with limited sewage management regulations.

More so, ballast sediment should be buried onshore in designated locations or used for other purposes rather than being discharged in coastal areas. It appears that the discovery of liquid ballast has resulted in the end of research into technologies to ensure vessel stability. This should not be so, there should be continued research into more environmentally sustainable alternatives to the use of water as ballast.

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