ナイジェリアにおけるバラスト水管理の課題と提言に関する研究

Doctoral Dissertation

STUDY OF BALLAST WATER MANAGEMENT IN NIGERIA CHALLENGE AND RECOMMENDARION

March 2023

Graduate School of Marine Science and Technology
Tokyo University of Marine Science and Technology
Doctoral Course of Applied Marine Environmental Studies

THANKGOD IFEANYI NWIGWE

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I. DECLARATION

I hereby certify that this dissertation papers are the results obtained in the course of my doctorate studies and all the materials in this research that is not my work has been identified with references cited accordingly and that no materials have been included in this dissertation for which a degree has previously been conferred on.

Signature: ……………………………

Date: …………………………………

NWIGWE THANKGOD IFEANYI

ii. **ACKNOWLEDGEMENT**

The entire journey of my doctoral degree study has been a dream come true in my life and I feel excited at this point and grateful to all those that contributed towards the successful accomplishment my dream. Despite the several challenges encounter during this journey, I am happy for the beautify experience and I give all the thanks and praise to God Almighty, because at the end of the tunnel, he always brings out the light. At this point I would like to express my sincere thanks and gratitude to everyone that has contributed and made this light to shine and enabling me to complete my PhD. degree.

First and foremost, I give all thanks to the Almighty God and way maker, for his grace, passionate love, and mercy in my life, as without him nothing would be possible. The Almighty lord has always showed up at every moment in my life, when all hopes were gone, but he gave me strength, courage and hope to continue enduring till the end.

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Thirdly, I would like to express my gratitude to my thesis committee members, starting from my supervisor, **Prof. MINAMI KIYOKAZU** for his generosity, kind support, guidance, invaluable advice, patient and understanding. He is a good man with a cheerful heart and has always inspired and motivated me tirelessly towards my study and future dreams and career. Furthermore, I would like to express my appreciation to acknowledge all the members of my graduate thesis committee, **Dr. MITSUHIRO MATSUDA**, and **Dr. HITOI TAMARU** for their unfailingly patient and supportive effort to see me complete my study.

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ABSTRACT

The discharge of untreated ballast water into the marine coastal waters has often results to major environmental risks, as invasive species, sediments, and contaminant discharged along with ballast waters causes devastating effect on human health, the maritime ecosystem and economy of coastal states. This problem has attracted great attention in the maritime industry and many national authorities, the international maritime organization (IMO) has until date been responding in several ways towards solving this problem, particularly with the creation of the D2 ballast water performance standard, which will come into effect in September 2024. This study was focused on Nigeria maritime and coastal waters and examines the challenges facing the maritime shipping industry in the region towards implementation of the ballast water management convention, with the major objective of assessing the compliance status of shipping operators and the risks posed to the maritime coastal environment. An essential part of the research methodology employed is the analytic hierarchy process (AHP) for evaluating and ranking the various challenges and the analytical sampling and analysis of ballast water from selected ships for the investigating their physiochemical characteristics. The result obtained shows that technical challenges (TS's), environmental challenges (ENC's), economic challenges (ECC's), and other challenges (OC's) were the major factors contributing towards the poor compliance among the selected shipping operators that were sampled. The OC's, which includes both external and internal influences on ship operators, ship type, age, and trading route, obtained the highest rank (0.3666), followed by ECC's (0.3648) and TC's obtaining the third rank (0.1456), while the ENC's were regarded as the least concern (0.1223) for shipping operators' decision towards achieving compliance with the ballast water management convention. In terms of the risks of heavy metals composition and assessing the pollution status caused by the discharge of the ballast waters from our sampled ships, the investigated parameters include water temperature, salinity, total suspended solids, concentration of hydrogen ions, dissolved oxygen, and heavy metals. The result shows a complex correlation among the parameters and the presence of heavy metals among samples at different concentration levels in an increasing order from ship 4 > ship 3 > ship 2 > ship 1 (27.897 > 20.941 > 16.636 >16.586), based on their distance from the loading ports of ships. This study will be useful for policy makers and maritime regulators in prioritizing management measure based on the clear understanding of the various challenges faced by shipping operators, as well as the needs in monitoring the qualities of discharged ballast waters and taking decision to promote compliance and achieving a sustainable maritime environment.

KEYWORDS: Ballast water, BWM Convention, Invasive alien species, D-2 standard

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Supervisor 3: Prof. Hitoi Tamaru

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LIST OF ABBREVIATION

ABBR.	MEANING
G3 Guidelines	Guidelines for Ballast Water Management Equivalent Compliance (G3)
G7 Guidelines	Guidelines for Risk Assessment under Regulation A-4 of the BWMC
HAOP	Harmful aquatic organisms and pathogens.
MEPC	Marine Environment Protection Committee
NIS	Non-indigenous species.
RA	Risk assessment.
SRA	Same Risk Area.
TS	Target Species.
AGR	Apparent Growth Rate
ANS	Aquatic Nuisance Species
AHP	Analytical hierarchy process
BWMB	Ballast Water Management Book
BWMC	Ballast Water Management Convention.
BWMP	Ballast Water Management Plan
BT	Ballast Tank
COD	Chemical Oxygen Demand
DOM	Dissolve organic matters
EC	Electro chlorination
IMO	International Maritime Organization
MSA	Maritime Safety Administration
PSC	Port State Control
UV	Ultraviolent technique
TSS	Total suspended solid
PAH	polycyclic aromatic hydrocarbons

iv. LIST OF PUBLISHED PAPERS IN THIS STUDY

	MANUSCRIPT TITLE	JOURNAL NAME	STATUS
1.	Investigation of ballast water quality in the Onne harbor – Physiochemical Assessment	International journal of environmental science and technology (**IJEST**). (**Springers Journal**)	**Published**
2.	Challenges hindering the ballast water management compliance in Nigeria	Journal of international maritime safety, environmental affairs, and shipping **(JIMSEA**). (**Taylor & Francis**)	**Published**
3.	Study on ballast water management system technology – Review Study	Journal of maritime research **(JMR)** **(Spanish Society of Maritime research)**	**Under Review**

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CHAPER 1.

STUDY INTRODUCTION

This section gives a brief background of the study and introduce ballast water management system and risks implication of invasive species spread and sediments transfer through ballast water. The study objectives, methodology to be followed in achieving it are also discussed. Also, the thesis structure and all terms and definitions stated in the study are explained in this session. Finally, the problem statement, study motivation, as well as research aims, and objectives are also discussed in this chapter.

1.1. BACKGROUND

The expansion of the global maritime trades has connected humanity at an unprecedented scale, as international shipping has become more important and the most reliable mode of transportation of heavy cargos over long distance (**GloMEEP, 2018; Raza, 2020**). It has been estimated that the shipping industry moves over 80% of the world's commodities (**UNCTAD, 2017**) and transfer approximately three to five billion tons of ballast water annually **(Lloyd's Register Maritime, 2017**). Until the advent of the recent corona outburst which resulted to a global lockdown in 2019, the average annual growth rate of maritime shipping has continuously increased at an average rate of approximately 2.1% per year, which surpasses the 10 billion tons of cargo transferred by globally when compared to 2015 (**Karam et al., 2020**). The Shipping industry depends on ballast water for maintaining the ships structural integrity, as well as stability for ensuring their safe navigation on sea, when additional cargo weights are added or removed, which may cause the ship to lower and sink below the ocean surface water level (**Apetroaei et al., 2018**). The ballast waters of ships can either be freshwater or seawater, depending on the ship's cargo loading or offloading destination (**Lv et al., 2022**) and ships sizes and configurations, always affect the volume of ballast waters contained in their ballast tanks. Ballast water uptake from one country and discharge into other countries are the major vectors for the spread of potential non-indigenous invasive species, that often put the various maritime ecosystems around the world at risk (**Wang et al., 2021**). These ballast waters carried onboard from the ship's cargo loading ports and discharge at its destination ports are often associated with heavy metals sediments and invasive species inside the ballast tanks of the transporting ships (**Carney et al., 2017**). The ballast water cycle in **Fig 1** shows the diagrammatical illustration of the transfer process.

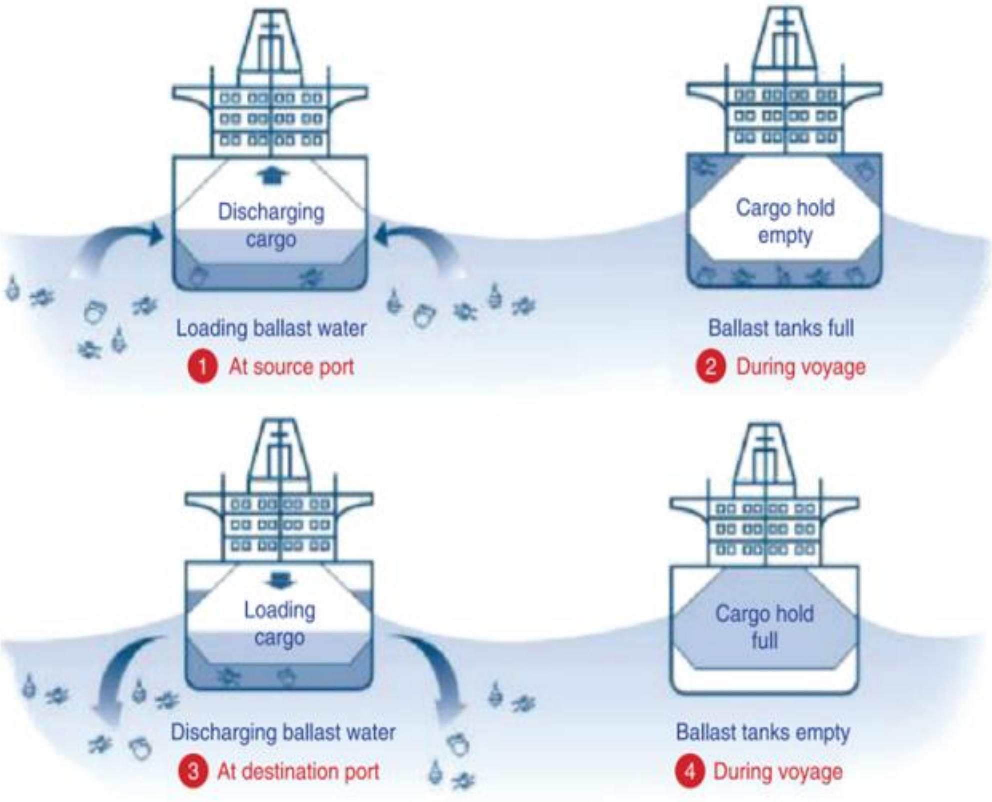

Figure 1: Ballast water cycle and transfer of invasive species
(Source: GloBallast Monograph Series No.18)

As a consequence of the transfer of untreated ballast waters, thousands of foreign species and marine microorganisms are transported by vessels each day into new environment, resulting to a wide range of both short and long term negative impacts on the coastal waters ecosystem (**Wan et al., 2016**). In addition, ballast water of ships also contains large quantity of sediments and contaminants such as heavy metals, toxins, or pharmaceutical components (**Lv et al., 2022; Valković and Obhođaš, 2020**), which often contaminate the coastal water quality and leading to the exposure of disease outbreaks in human and biotic homogenization to the biological diversity in the maritime coastal ecosystem. According to IMO, invasive species in ship ballast water are among the four largest global threats to the oceans waters (**GEF-UNDP-IMO, 2017; Nunes et al., 2014)** as they posed greater risks and endangered the local species populations, resulting to extinction of local organism, alteration in marine organism habitat, as well as shifts in their food webs and nutrient cycling when they are been transfer outside their natural past environment, (**Sala et al., 2000**). The typical example is the invading seaweed such as Japanese kelp, that can shade out native species by depriving them of light, oxygen and nutrients. The introduction of marine organism such as shrimp and sea squirts, could reproduced and often outnumbered their native counter parts, resulting to several damages to the marine ecosystem. The International Maritime Organization (**IMO**) have recently listed out the ten most unwanted marine species that are associated with ballast water operations, as seen in **Fig 2,**

- Cholera Vibrio cholerae (various strains)
- Cladoceran Water Flea Cercopagispengoi
- Mitten Crab Eriocheirsinensis
- Toxic algae (red/brown/green tides) (various species)
- Round Goby Neogobiusmelanostomus
- North American Comb Jelly Mnemiopsisleidyi
- North Pacific Seastar Asteriasamurensis
- Zebra Mussel Dreissenapolymorpha
- Asian Kelp Undariapinnatifida
- European Green Crab Carcinusmaenas

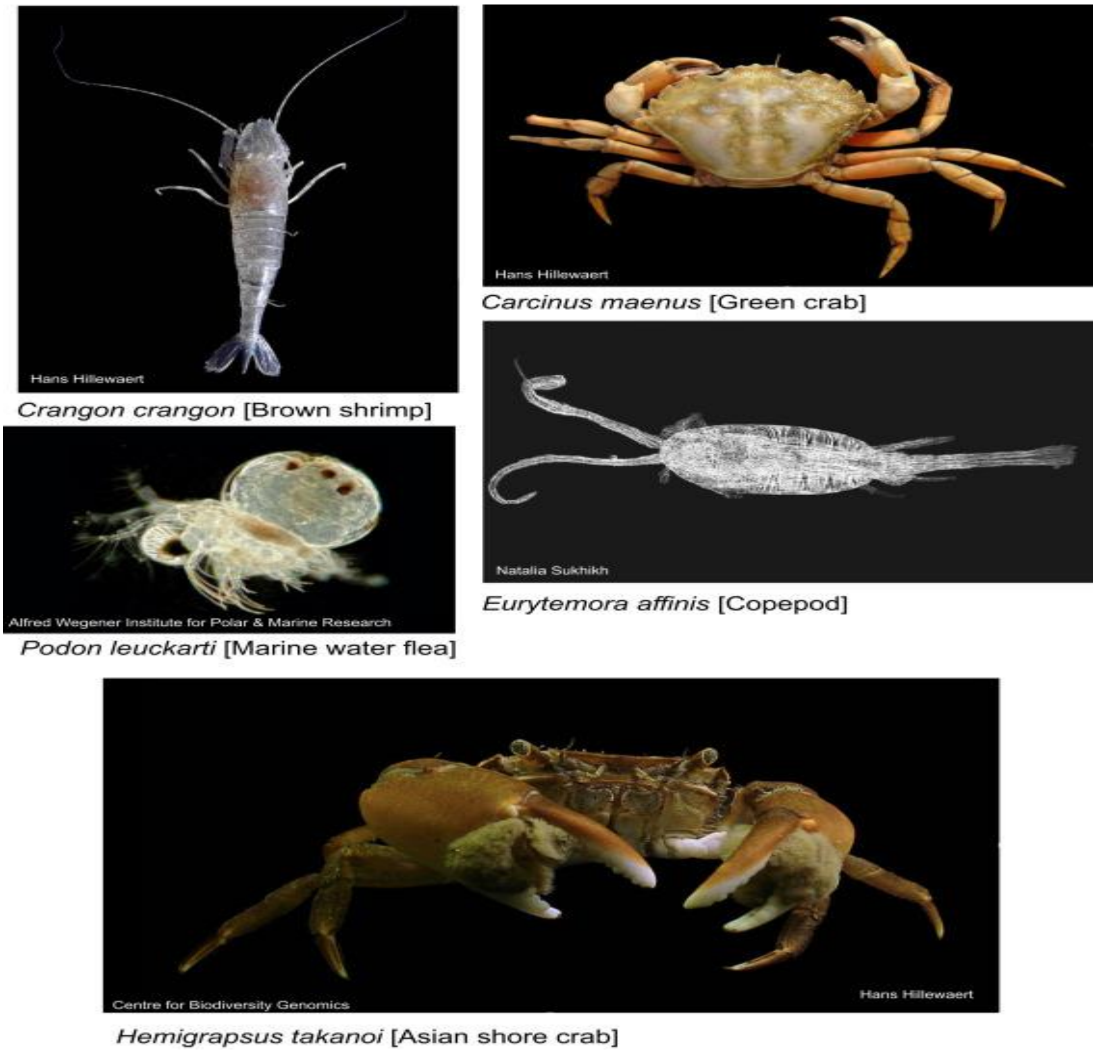

Figure 2: Typical invasive species transfer through ships ballast water.

The roles of ballast water as a vector for the transfer of aquatic invasions alien species in different parts of the world, resulting to significant environmental and economic damage to their coastal ecosystem cannot be over emphasis as this problem has already been experiencing in several parts of the world, including America, Europe, Africa, Caribbean's and Australia. The preliminary results from the Australian baseline studies on invasive species, identified over 200 introduced species and 100 cryptogenic species in the Australian maritime waters. The invasion of zebra mussels in the Northern America which infected over 40% of the inland waterways and blocking the water intake, resulting to the cost of more than 500 million united states dollars for the cleaning of the waterways is another typical problem recorded. Notwithstanding, several researchers and academy scholars have studied this problem to further understanding the problem, towards providing solutions in different parts of the world. Example, **Tavares and Melo (2004)** have analyzed the benthic samples from the Antarctic Peninsula research cruise had observed the presence of both female and male Majid spider crab Hyas Araneus has been spread around the globe over the years, but little has been known on the extent. The study carried out by **Delille &Delille (2000)**, had found the presence of enteric bacteria in Antarctic ice. It was observed that cholera outbreak completed its global cycle in Latin America during 1991, since its appearance in Indonesia during 1961. Also, in Southern Australia, New Zealand and the Mediterranean, there have been case of invasion of the Asian seagrass, which resulted in the changing of the local seabed community. The case of the invasion of the Heterocapsa circularisquama alien species in Northwest Indian Ocean, which was reportedly introduced by the discharge of ballast water from the western Pacific Ocean and resulting to the high mortality rate of bivalves in that region. The case in Maranhão coast in Brazil, where the invasion of phytoplankton species like Chaetoceros danicus, Planctonema lauterbornii, and Coscinodiscus cf. wailesii, transferred through ship ballast water where first recorded and resulted to tremendous damages (**Queiroz et al. 2021**). Based on this background and experience from other countries in the world, it is assumed that the increasing shipping activities in Nigeria, coupled with poor compliance of ballast water management in the region, will increase the potential of spread of successful ballast water-mediated invasive species and risks in the coastal water ecosystem in the region. Since the ratification of the Ballast water management convention and establishment of the various national legislation by the Nigerian states, in order to address the problems posed by the transfer of invasive species through ballast water of ship and minimizing the risks associated with the introduction of non-indigenous species through a preventative approach of ballast water management. However, despite all these efforts, there has been areas of weakness within the regulations that are still compromising their effectiveness. Furthermore, little studies have been focusing on assessing the compliance of ballast water management and the risks of transfer of alien species and sediments in the region.

1.2. THE IMPACTS OF BALLAST WATER DISCHARGE

Even though the ballast water is currently regarded as the most suitable solution for the maintenance of ship's integrity and stability during its operation and voyage at sea, it has also been stated clearly that many IAS transfer through ballast waters have led to major negative impact (**Wonham, 2004**). Some negative impacts of ballast water transfer into new environment includes changes of the ecosystem functions, human health and well-being, cultural impacts and economic impacts.

- **IMPACTS ON THE ECONOMIC OF COASTAL STATES**

This may arise due to the environmental pollution resulting from ballast sediments transfer, which can decrease the fishery population due to poisoning of the surrounding coastal water. The transfer of new species that attack native species, and the possibility of harmful algae that may be carried away during the ballast water disposal process often affect the local species in the region and reduce the economy (**Werschkun et al., 2014**). When this happens, the fishery products of the region can be reduced due to predators, habitat changes, competition, interference on marine culture by the spreading of algal blooms **(Jing et al, 2012)**. Also, coastal industry that depends on the use of ocean waters and other commercial activities and resources are sometimes disrupted by the invading species. Example is the impacts on tourism and recreational activities in coastal amenity areas that can diminish recreational activities, causing algal blooms and smothering in beaches, including severe odors from harmful algal blooms on beaches (**Tamelander et al., 2010**).

- **IMPACTS ON THE HUMAN HEALTH**

The introduction of ballast water can contaminate and affect the coastal water quality. There have been numerous reports of the spread of IAS through ballast waters of ships which causing negative impacts on the human health and wellbeing. Example is when toxic sediments and pathogens are discharged along with ballast water (**Strayer 2010**), resulting to potential human health illness and disease that can even lead to death in humans (**Carney et al., 2017; Imron et al., 2021**). Several researchers have reported cases of transportation of Vibrio cholerae, which is a disease-causing pathogen in humans that was carried by the exchange of ballast water entering the Chesapeake Bay (**Purwanti et al., 2020**). Other cases of the spread of Vibrio cholera; were the case reported in 1991 of the virulent strain of cholera from Asia which caused an epidemic in Peru and affected thousands of persons. There is also evidence of the cholera epidemic due to ballast water discharge which occurred in the Mobile Bay, Alabama on the United States coast of the Gulf of Mexico in 1992 (**Cohen et al., 2012**).

- **IMPACTS ON THE ECOLOGICAL OF THE REGION**

The ecological impacts of marine species carried by ballast water is a serious threat to the marine environment, and such impacts include the emergence of competition between native and alien species in foraging for food, resulting in the possibility of native species being preyed upon by newcomers (**Kumar, 2021; Kurniawan et al., 2020**; (**Queiroz et al., 2021**). During the processes of ships ballasting and de-ballasting at sea, thousands of marine species that are carried inside the ballast tanks often exchange with organisms in the new environment and becomes predators which may disrupt the balance of marine ecosystems (**Demann and Wegner, 2019; Jang et al., 2020**). The mixing of native organisms that have long inhabited an area with alien organisms, causes several changes to the marine ecosystem due to changes of water quality and nutrients content by IAS (**Saburova et al., 2022**). Example is the deposits of dead water hyacinth, which causes the lowering of the dissolved oxygen level and absorbs a lot of nutrients from the water, which often impacts of growth of aquatic organisms and inhibits the growth of native plants species (**Hess-Erga et al., 2019**). When the water hyacinth plants die, there deposits on the ocean bottom causes eutrophication because of the release of all the nutrients, which often declines the water qualities and leading to spread of diseases and changes all the proper ecosystem functioning (**Imron et al., 2019; Saburova et al., 2022**).

1.3. STUDY MOTIVATION

Nigeria is a developing country, located in a strategic geographical position, where oil exploration and rapid trade relationship with other countries, have helped witness a faster maritime growth, with the influx of various kinds of ships, accompanying with their ballast water exchanging operation into its maritime space. The issues of ballast waters transfer, and the impacts associated with the invasive species and heavy metals sediments concentration contained in the ballast tanks of ships, has become a major global concern and is currently a major issue facing the coastal waters regions in Nigeria; hence, this study has become necessary and important to understand the current problem in the study region. The major motivation behind this study is based on the assumption that, the coastal waters in the Nigeria are most like at greater risks and vulnerable to the problems associated with the ballast water transfer operations, due to the high shipping traffic, poor regulatory standard, lack of enforced IMO regulation, as well as the lack of financial and technical resource witness among local shipping companies in the region. Furthermore, as the Nigeria government have recently proposed the concept of ports with acceptable risks, at the MEPC 74 session, aimed at larger tankers calling at Nigerian ports to load crude oil, takes by taking advantage of the exemptions in BWM Convention regulation B-3. To the best of my knowledge, I strongly believe that this steps and proposition already taken, indicates a positive effort in the right direction which is aimed towards managing the problems posed by the ballast water operation and achieving the compliance of the ballast water management convention in the region. Hence, there is a greater need for more studies and research to be focus on the areas of ballast water, especially as we are fast approaching the IMO schedule deadline of September 2024, for all ships to meet up with the D2 ballast water performance standard.

1.4. PROPLEM STATEMENT

The shipping industry is currently facing the problem caused by the discharge of ballast water along with the introduction of invasive species and physio-chemical parameters, which poses serious environmental risks to the marine ecosystem. There has been constant international pressure to all member states to comply with the stringent IMO ballast water management regulatory framework and manage the ships ballast water problem. Nevertheless, ship owners are challenged by the difficult task of selecting the most suitable solutions on board their ships, due to several hindrance factors. Therefore, there is a need to improve on similar studies and understanding the hindrance faced shipping operators towards compliance and effectively management of the problem of invasive species spread as this will help decision-makers achieve their goals towards achieving a sustainable maritime environment in the near future. Hence, I have undertaken both quantitative and qualitative research approach to understand the problem of ballast water in Nigeria, with the aim of contributing towards achieving solution or minimizing the problems. The main problems researched in this study is to understand the risks posed by ballast water in the region and the major challenges contributing to the non-compliance of ballast water among shipping operators in the region. The understanding of these problems will contribute towards achieving compliance and a lasting solution with the ballast water management convention for minimizing the spread of invasive species in Nigeria.

1.5. STUDY AIM AND OBJECTIVES

This study is aimed to surveys the existing ballast water management problem in Nigeria and assess the compliance of shipping operators in the region, as well as the risks posed by the discharge of ballast water in the marine ecosystem. In addressing this problem, a literature review has been carried out current ballast water treatment technologies and also the ballast water management. To understand the response of the local shipping operators and their response with the requirement of BWMC, an in-depth expert interviews was also conducted. The actual situation of ballast water management is investigated, under the current existing international and national legal framework, to present the various challenges hindering compliance in the region, using qualitative approach. In applying the qualitative approach of this study, the researcher visited the targeted study location for collecting original data collection and field inspection from shipping operators and targeted port authorities. The risks of introduction of sediments heavy metals through ships ballast water is assessed using established sample collection and laboratory analytical tests method, to check for the presence of heavy metals concentration to understanding the compliance level of ballast water management. Finally, this study will propose recommendations on how to address the current issue and achieve compliance of the ballast water management, in order to minimize the spread of non-invasive species and sediments through ballast water in the region. It is therefore believed that the output of this study will contribute to the already existing literature and provide useful information's that will contribute towards the better understanding of the problems, as well as providing useful insights to decision makers on the development of a more efficient management strategy in solving the problems accompanying ballast water.

1.6. STRUCTURE OF THE THESIS

The thesis is structured in the form of researched manuscripts, with each session having its own abstracts and respective results and conclusions. Furthermore, the PhD thesis have been divided into five separate chapters, to enable me to cover the research scope and objectives.

- **Chapter one**

This chapter presents the study background and gives a general introduction of ballast water management system, the problems and associated risks and implication of invasive species spread, and sediments transfer on the maritime ecosystem. The study objectives, methodology to be followed in achieving it are also discussed. Also, the thesis structure and all terms and definitions stated in the study are explained in this session. Finally, the problem statement, study motivation, as well as research aims, and objectives are also discussed in detail in this session of the thesis.

- **Chapter two**

This chapter explain the ballast water management convention and described describes the ballast water management convention explains important features of the international convention for the control and management of ship´s ballast water and sediments, and efforts are made in reviewing the various ballast water treatment technologies and assessing for their efficiency and possible limitations.

- **Chapter three**

This chapter, studies the ballast water compliance in Nigeria, using field investigation from selected shipping operators and expert knowledge from shipping experts in the region, in order to provide understanding and identify the various challenges hindering the ballast water compliance in Nigeria. The AHP multicriterial analysis method is used in prioritizing the various barriers hindering the BWMS compliance of the shipping operator, as this will assist policy makers in understanding areas for consideration in decision making process.

- **Chapter four**

In this chapter, the analytical method is applied to assess the physiochemical properties of the ballast water samples in order to assess the risks status posed by ballast water and further confirm the compliance status in the region.

- **Chapter five**

This chapter presents the overall conclusion of the study and present some possible recommendations towards improving the compliance of the BWMS in Nigeria.

Shipping industry can be seen a global as well as a regional industry, and in solving the problems and challenges associated with the shipping industry, more considerations must be giving from both the global and regional perspective..

海運業はグローバルな産業であると同時に地域的な産業でもあり、海運業が抱える問題や課題を解決するためには、グローバルな視点と地域的な視点の両方からより多くの考慮が必要です。。

CHAPTER 2.

STUDY OF BALLAST WATER MANAGEMENT SYSTEM

This section describes the international convention for the control and management of ship´s ballast water and sediments, its generalities, and key drivers. Also, the review study of the various ballast water treatment technologies is presented in this chapter to assess their efficiency and possible limitations.

2.1. BACKGROUND

The risks of invasive species spread through ballast water transfer has become a priority concern in the global maritime industry, leading to the search for an appropriate and efficient ballast water management strategy and treatment system for solution (**Outinen et al., 2021**). In response to managing this problem, the international maritime organization, had already adopted the international convention for the control and management of ship's ballast water and sediments on the 16th of February 2004, which entered into force on 8 September 2017 (**Gollasch et al., 2007; Chen et al., 2021**), with the main objective of limit the transfer of invasive species. In achieving the objectives of the ballast water conventions, the D-1 and D-2 ballast water discharge standards have been design for both new and existing ships (**Saebi et al., 2020; Lakshmi et al., 2021**). In addition, guidelines for sampling system and analyzing methods of ballast water (**IMO, 2015, 2008a**), and the requirements for risk assessments and information about safety issues have been introduced (**IMO, 2017, 2008b**). The regulation D-1 standard of the BWM convention involves the exchange of ships ballast water around 200 nautical miles from the coast and specifies that "ships performing ballast water exchange shall conduct such operation with an efficiency of a minimum 95% volumetric exchange of their ballast water (**IMO, 2004**). The regulation D-2 standard involves the use of onboard ballast water treatment system and specifies the maximum concentration of viable organisms allowed in the discharged ballast water and specified indicator microbes harmful to human health as presented in **table 3**. Furthermore, it is expected that all existing ships will have to meet the ballast water convention's regulation D-2 standard from the date of the ship's international oil pollution prevention certificate (**IOPPC**) renewal survey, which must be undertaken at least every five years until September 2024, based on the IMO implementation time-table schedule as seen in **Fig 3**, (**Wang et al., 2021; Saebi et al., 2020b**; **Jang et al., 2020;**)

1.	< 10 viable cells per m^3 for plankton smaller than 50 µm
2.	< 10 viable cells per mL for plankton between 10-50 µm
3.	< 10 Colony Forming Unit per 100 mL for Toxicogenic Vibrio Cholerae
4.	< 250 Colony Forming Unit per 100 mL for Escherichia Coli
5.	< 100 Colony Forming Unit per 100 mL for Intestinal Enterococci

Table 1 . Ballast water D-2 regulation standards

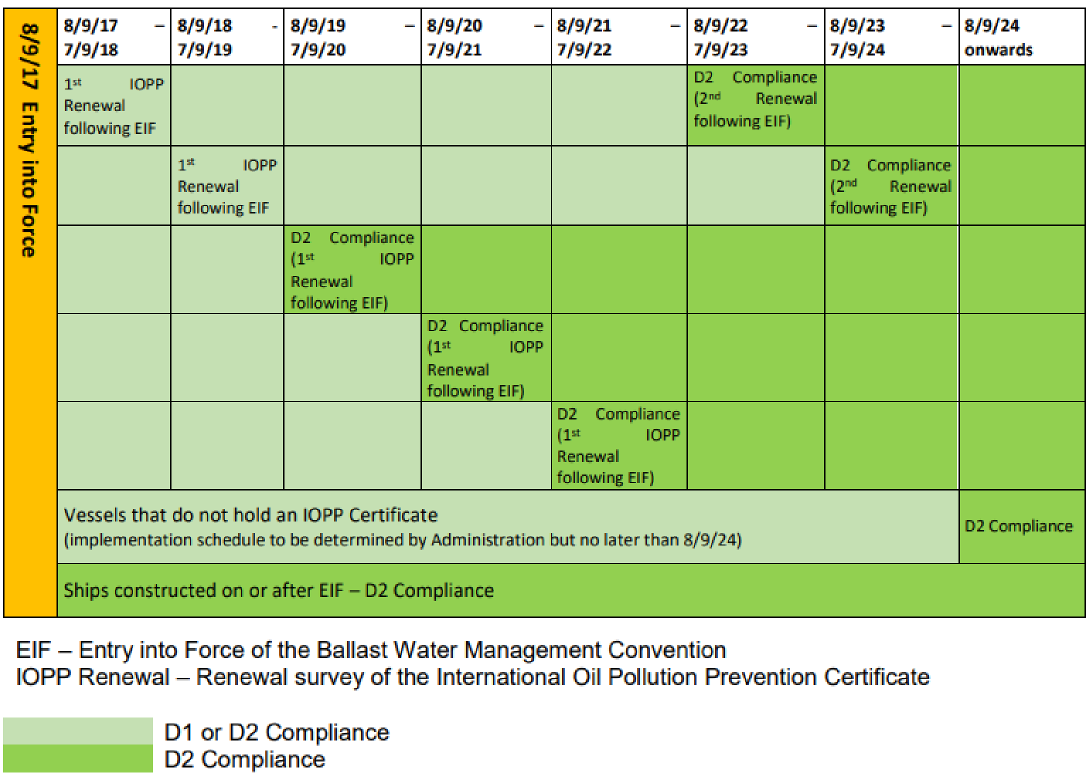

Fig 3. Ballast water management implementation time schedule

2.2. BALLAST WATER EXCHANGE

According to the requirements of the IMO Ballast water convention, ballast water exchange must take place at least within 200 nautical miles from the nearest land and in seawater of at least 200 meters in depth, or in the case, where this is not possible, the ballast water exchange should occur at least, within 50 nautical miles from the nearest land. The ballast water exchange process is currently being considered as a transitional and short-term management measures for the ballast water problem, since its requirements are not for new ships constructed in or after 2009 with a ballast water capacity of 5000 cubic meters (**IMO, 2004**). This method will be allowed until 2024, even though ships constructed before 2009 are required to install BWMS for meeting standards set by the Ballast Water convention **(IMO, 2004**). This management approach is based on the facts that, certain organisms from coastal waters are unable to survive in open ocean waters where the sea water characteristics like salinity, temperature and nutrients concentration differs from the waters in their original source. Similarly, marine organisms from oceanic waters far from shore will not survive when released into coastal waters, estuaries or rivers. Ballast water exchange involves the ship releasing lower-salinity coastal water they brought aboard and replace it with high salinity open-ocean water on their next port of call. However, most organisms with a wide tolerance rate for differing salinities may survive ballast water exchange, especially any such organisms that may reside in the unpumpable residual water and sediment remaining in the tanks during any ballast water exchange. Studies have indicated that the probability of finding live planktons and microorganisms are more in short voyages than in longer voyages. For example, exchange trials showed that even thou the ballast water exchange is correctly performed, it is expected that an approximate of 5% of the original ballast water will remain inside the tanks after exchanging three tank volumes and might be sufficient for transferring of alien species. Thus, ballast water exchange process cannot be considered an effective method for eliminating the risks of biological invasions since the probability of survival for the organisms present in ballast water will always exist. Furthermore, there are various safety issues, associated during the ballast water exchange processes, which may result to the capsize of the vessels. The efficiency of mid ocean ballast water exchange depends on several factors like the nature and behavior of organisms inside the ballast tank, the design and structural configurations of tanks, mixing within the tanks, the type and behavior of sediments, depth of ocean water, season and the method of exchange (**Rigby & Taylor, 2001; Galil and Hulsmann, 2002**). Hence, in order to conduct the BWE safely; weather and sea surface conditions, has to be optimum during operation (**Shapoori et al. 2014**) and safety aspects like stability, longitudinal stress, wave induced hull vibrations, forward and aft droughts and bridge visibility have to be considered while performing mid-sea exchange (**IMO, 2006c**). The different methods of BWE are presented graphically in **Fig 4**.

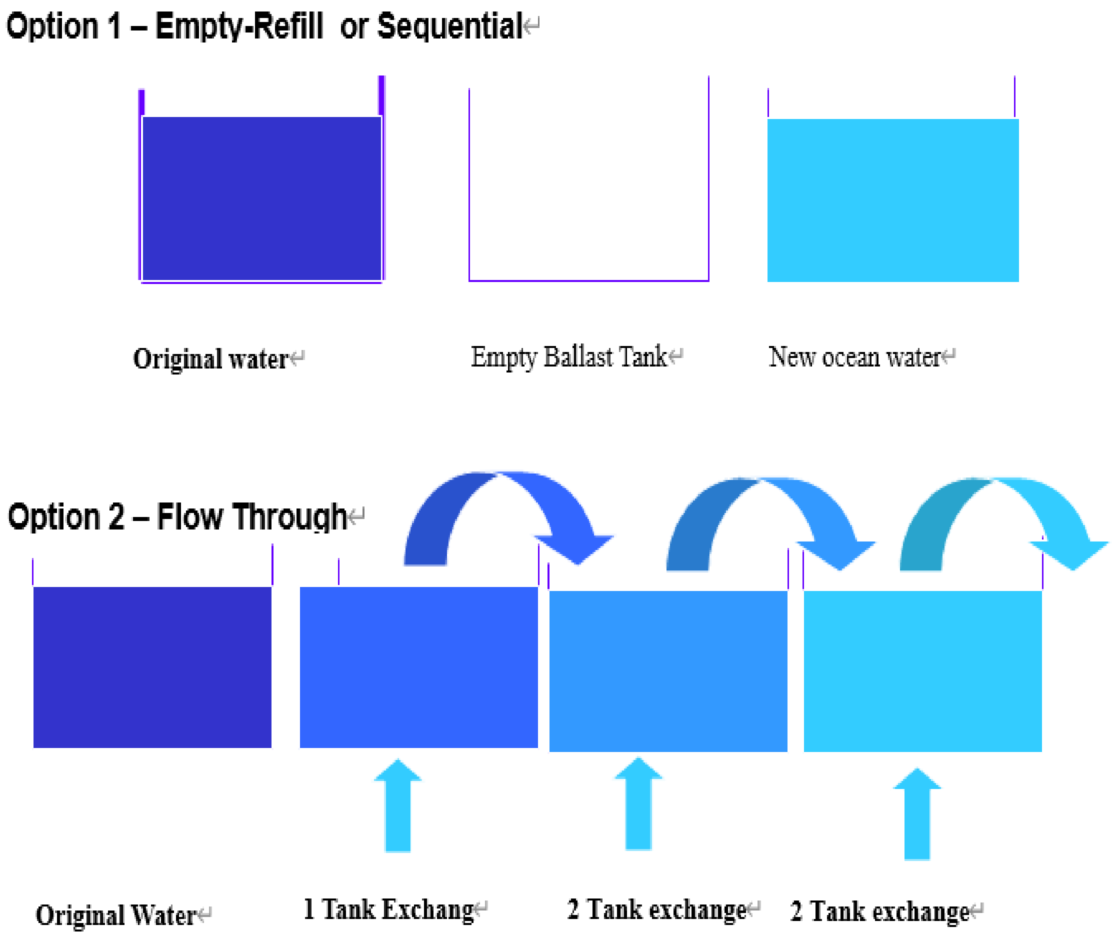

Fig. 4. Ballast water Exchange system

- **The Sequential method**

This method entails emptying ballast tanks completely and refilling with open-ocean water. In this method the ballast tanks are emptied until the ballast pumps lose suction in the ballast tanks. During the sequential ballast water exchange method, there may be times when, for a transitory period, the criteria for propeller immersion, minimum draught or bridge visibility cannot be met. It also suggested that during full tank ballasting procedures, large changes in loading conditions may lead to major reduction of stability, higher stresses, high sloshing pressures and increased probability of bow slamming and refilling tanks will not remove all the sediments and organisms at the bottom of the ballast tanks.

- **Flow-through method**

This method involves the replacement of ballast water by pumping open-ocean water into a full ballast tank and allowing it to overflow through the air vent or dedicated overflow vents. In order to effectively eliminate aquatic organism, ballast equal to approximately three times the volume of the tank capacity is pumped through the tank to achieve 95% efficiency of exchange. **CEPA, 2002** studied the effectiveness of these methods and found that flow through method is able to remove 95% of organisms in the ballast tank. The flow through method does not alter the stability, stress, and ship attitude.

- **Dilution method**

In this method the tank has two openings; water is pumped in from one opening and flows out through the other. a process by which replacement ballast water is filled through the top of the ballast tank intended for the carriage of ballast water with simultaneous discharge from the bottom at the same flow rate and maintaining a constant level in the tank throughout the ballast exchange operation. **Michael Taylor and Elizabeth Bruce (1999)** has studied the dilution efficiency of ballast water exchange using tracer dye Rhodamine WT between two ships with different carrying capacity for ballast water tank. The study concluded that 90% efficiency was observed for ship with tank capacity of 114 cubic meters and 99% efficiency for ships having tank capacity 1435 cubic meters. Based on the result of their studies, it can be concluded that efficiency of dilution method in the ballast water exchange in diluting the pollutants, salinity, phytoplankton and zooplankton increases with increase in ballast water tank capacity and increase in the number of times exchange is being done.

- **Port-Based treatment approach**.

The IMO regulation B-3 provided an alternative measure that requires the transferred ballast water to an onshore or barge-based treatment facility and the necessary treatment can be carried out. The size of the treatment facility may depend on several factors, like frequency, timing, and type of ships leaving or entering the port terminal system. While in some ports, there may be enough space to establish a large-scale, shore-based treatment facility for ballast water, others may not have enough space and may employ barge-based treatment facility. Since IMO does not promote regional based port treatment systems, only concerns and interested countries may invest in this kind of treatment method as the ports are required to maintain the treatment equipment and operations to meet the port quarantine standards and local environmental protections laws in the region. A typical example of the port-based treatment facility can be seen in Valdez Marine Terminal Alaska as shown in **Fig 6** below. This facility employs series of techniques such as gravity separation, dissolved air floatation, and biological treatment in the removal of residual hydrocarbons like oily waste from dirty ballast water and it is designed to handle around 33 million gallons of ballast water per day.

Fig 5. Aerial-view of VMT Alaska BWT facility (**Source; Alyeska Pipeline service**)

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2.3. REVIEW STUDY OF BALLAST WATER TREATMENT SYSTEM TECHNOLOGIES

ABSTRACT

The transfer of ballast water is considered the major global pathway for spread of invasive spices and sediments in the aquatic environment, resulting to devastating impact in the coastal waters. There have been various technologies and studies been conducted to provide solutions on the problems caused by the ballast water. This review study discusses the various ballast water treatment system techniques and their applications been applied in the maritime industry. The physical treatment is most simple, sustainable, cost effective, and environmental-friendly technique among all others, and chemical methods always generates its relevant disinfection by-product, while treatment system employing both heating and electric field technology, are more expensive but their effectiveness is not affected by the ballast water composition, salinity, or temperature level of their surrounding waters. As each treatment technology has its strength and weaknesses, it can be concluded that no particular treatment technology has total efficiency in managing the microorganism, but the combination of various treatment techniques will be highly effective and efficient. There is a need for further research, and practical implementation towards improving the existing technology and obtaining a sustainable maritime ecosystem.

Keywords; BWMS, Mechanical BWTS, Physical BWTS, Chemical BWTS

2.3.1. INTRODUCTION

The uptake of ballast water from one country and discharge into a new country have been identify as a major pathway for the transfer of invasive species and introductions of pollutant sediments (**Wang et al., 2021; Outinen et al., 2021)**. Around 84% of global ecosystems are affected by invasive species discharge through ballast water transfer (**Molnar et al. 2008 ; Gollasch et al., 2007**). The impacts of the spread of non-invasive species through ballast waters of ships include predation, water quality alteration, and spread of diseases like paralytic poisoning, cholera outbreak on human health and marine ecosystem (**Strayer 2010**; **Gollasch and David, 2018**). In managing this problem, IMO has adopted the international convention for control and management of ships' ballast water and sediments (**Sukizaki et al., 2013; Jang et al., 2020**). The convention was designed along with management standards such as the D-1 and D-2 discharge standards for both new and existing ships, with the aim of managing the spread of non-indigenous invasive species in the maritime ecosystem (**Saebi et al., 2020; Lakshmi et al., 2021**). While the D-2 regulation standard envisaged the long-term management solution which involves, the installation of ballast water treatment system, for the management and control of the spread of invasive species (**Herdzik, 2018; Chen et al., 2021**). In response, different vendors are rapidly pursuing extensive development of ballast water treatment system and research employing variety of techniques in the removal of microorganisms inside ballast water are being proposed constantly (**Summerson et al., 2019**; **Apetroaei et al., 2018**). As of February 15, 2022, a total of ninety-six ballast water management systems, involving mechanical methods (e.g., include filtration and separation), physical methods (e.g., includes ultraviolet light, ozone, heat, ultrasound), and chemical methods (using biocides) has been granted final approval by IMO has been published by ClassNK as approved ballast water management system in the market, (**Class NK 2022**). The various treatment technology, principles and disadvantage are presented in **Table 1** below. However, there are still some challenges with the current ballast water treatment technologies, affecting their efficiency in the treatment of ballast water qualities and resulting to environmental risk. In-line with this background, this study discusses the various ballast water treatment methods, examining their principles, system requirements, system advantages, technical challenges as well as assessing their efficiency.

2.3.2. TECHNOLOGIES APPLIED FOR BALLAST WATER TREATMENT

- **FILTRATION TECHNIQUE**

Filtration is the process of passing the ballast water through disc or screen filters to remove organism and suspended solid particles settling in the ballast water. The filtration technique is mostly affected by the drops in pressure and reduced flow rate of the ballast water system due to the resistance in the filter elements during self-cleaning process. (**ABS 2011**). Several studies have investigated the efficiency and problems involve in the filtration technique. **Matheickal and Holmes, 2003** have combines filtration with gravity separation to remove large organisms and sediments from the ballast water. **Parsons and Harkins (2002)** had compared the performances of three different filtration techniques by using a 50 μm screen-type surface automatic backwash filter, a 100 μm disk-type depth automatic backwash filter, and a 100 μm rated cyclonic separation device. There results showed that both screen-type and disk-type automatic backwash filters demonstrated high particle removal efficiency of over 90%, while hydro cyclonic separation attained only around 30% particle removal efficiency. While these techniques have been proven to be efficient, other studies has also discovered their limitations. Studies by **Waite and Kazumi, 2003** also confirm the effects of water salinity, temperature, turbidity, organics, vibration, and other variables on the efficiency of filtration technique in the ballast water treatment system. In further work by **Tang et al. (2006a)**, the crumb rubber filters made from waste tires was utilized with the aim of the elimination of turbidity, phytoplankton, and zooplankton from ballast water. They investigated various parameters affecting filtration performance, such as filter depth, media size, filtration rate, temperature, turbidity, and process time. It was observed that when the filter depth, filtration rate, and media size were selected as 0.9 m, 24.4 m3/h.m2, and 0.5–1.2 mm respectively, removal efficiencies of 69.1% for phytoplankton and 66.0% for zooplankton were obtained. In addition to these parameters, the study also investigated the effects of coagulation, pressure filtration, and dual-media (gravity) filtration on filtration performance. It was observed that more than 70% of phytoplankton and 90% of zooplanktons were removed from a crumb rubber/sand dual-media filtration system. It can be concluded that filters are prone to blockages and require regular replacement and back flushing. The effectiveness of filtration will not be influenced by the salinity of the water. As long as no ice is formed, it is unlikely that the performance of screen or disc filters will be affected by the water temperature. Crumb rubber filters might be more sensitive to arctic conditions as it can be expected that low temperatures will reduce the flexibility of the filtering material.

- **HYDROCLONE TECHNIQUE**

Hydrocyclones were considered a viable method for removing large organisms from ballast water due to the ease of use, operation, and maintenance(**Taylor and Rigby, 2001**). They employ centrifugal forces for the separation of particles with specific gravity greater than water, but their efficiencies are much lower than the filtration. There have been several developments aimed at improving these techniques, resulting to the design and application of a variety of filtration and hydrocyclone techniques, such as slow and rapid sand filtration, screen filtration, cloth screens/filters, pre-coat filtration, disk filtration, crumb rubber filtration, membrane filtration, well filtration, and cyclonic separation are integrated into the treatment systems (**Gregg et al., 2009; Kumar et al., 2021**). The Hydro clone treatment technique could be considered to be an effective cost alternative to filtration in the treatment of ballast water. However, they can be said to be less effective than simple self-cleaning filtration techniques. Furthermore, since the hydro cyclones are designed to separate particles based on their masses, they are highly ineffective at removing organisms that have specific gravities very close to that of their liquid environment and particles smaller than 100 µm. Their effectiveness depends on the difference in density and size of the particles contained in the ballast water, the speed of rotation and residence time. Hydrocyclones are less effective with an increasing salinity as this increases the specific weight of the water but may not affected by water temperature as long as no ice is formed.

- **ULTRAVIOLET TECHNIQUE**

This is based on sterilization process, by using UV lamps in providing photons which can attack and break down cell membranes of aquatic micro-organisms and pathogens, or destroying their ability to reproduce (**ABS 2011, Lloyd 2010**). As ballast water passes through chambers that contain the lamps, the ultraviolet light is highly sensitive to many organisms, impacting the DNA of the organisms and renders them non-viable, or incapable of reproduction. The two basic types of UV-lamp technology include the low-pressure (LP) UV lamp which can emits UV-C radiation causing DNA damage, and the medium-pressure (MP) UV lamp emits UV-A, -B, and –C radiation resulting in damage to DNA, proteins, and enzymes (**Rivas-zaballos et al., 2021; Romero-martínez et al., 2020**). The major drawback facing the effectiveness of UV treatment technology consist of several physical and technical conditions, including the UV lamp source and its wavelength, the radiation dose, exposure time, light or dark storage conditions, temperature distance between applied field and light source, and the treatment conditions, such as the microbiological content, turbidity , salinity, and absorbing matter of the ballast water. However, UV can be affected by waters with low TSS (total suspended solids), as larger aquatic organisms limit its effectiveness but exhibits higher disinfection efficiency for smaller organisms such as bacteria and viruses compared to bigger organisms like microalgae (**Gregg et al., 2009**). Its limitation is the fact that, by-products such as aldehydes, carboxylic acids, organ halogens, nitrite, and bromate are formed during the UV light irradiation and UV can cause degradation of suspended organic matter into dissolve organic matter (DOM), resulting to higher turbidity which can impair the UV transmission and becoming less effective (**Čulin and Mustać, 2015**).

- **HEAT TREATMENT TECHNIQUE**

Heat treatment involves heating ballast water until it kills any organisms present inside of the ballast water. The technique is very convenient because it does not require any complex components that can generate harmful byproducts and has exhibited a higher efficiency even for moldy seawater (**Wang et al., 2018**). It has been observed that higher temperatures between the range of 40–55 °C has high efficiency and inactivation capability for killing microorganisms such as bacteria, phytoplankton, and zooplankton, as such aquatic microorganisms are highly sensitive to significant change in the ambient temperature of their environment. There are common ways to complete heating process, involves, heating the ballast water in their tanks or heating the water by running it past the ship's engines. The limitation involve in this technique is that they are only suitable for short distance voyage as a longer operating times is needed for heating up the ballast water. Also, an increasing energy demand is required to perform this process and possibility of corrosion on the surface of the ballast tank, due to the high heat generated.

- **ULTRASOUND TECHNIQUE**

The method uses high energy ultrasound to eliminate organisms in the ballast water. It is also referred to as cavitation treatment and are among the recently developed technologies that utilized ultrasonic resonator-based ballast water disinfection and anti-fouling applications for ballast water treatment systems. The high pressure caused by the ultrasound ultimately breaks down organisms' cell walls and killing them. Ultrasonic treatment is an attractive choice because it is having a lower maintenance cost and involve the use of non-chemical; however, research indicates that this ballast water treatment system works best when combine with other treatment methods like ultraviolent (UV) or biocides method.

- **MICROWAVE TREATMENT TECHNIQUE**

This technique has been identified for solving the limitation posed by longer heating operating time in heat treatment method. Experimental studies have been used to show that microwave treatment technique can attain a higher heating temperature within a very shorter time range. **Boldor et al. 2008** in his study has investigated the efficiency of a microwave treatment system in killing specific microorganisms, using a continuous microwave system and the result observed shows that the targeted microorganisms were inactivated at 55 °C in 200 seconds. **Balasubramanian et al., 2008** has shown in his study on the efficiency using continuous microwave system with heat recovery to remove Artemia Salina cysts. The results obtained shows that the inactivation of Artemia salina cysts was achieved at 64 °C with 100 s holding time. However, all the results were obtained on a pilot-scale test condition at very low flow rates between 2 L/mins to 3L/mins. Its major limitation is that it requires higher energy and fuel consumption are required.

- **OZONE TECHNIQUE**

Ozone is one of the known chemicals' biocides, commonly used as ballast water treatment for killing living organisms by oxidation process. The use of ozone in the treatment of ballast water has shown to be unstable in different water condition because they react differently in seawaters as well as in freshwater. In seawater the ozone converts bromide, that is naturally present in seawater, into hypobromite ions and hypobromous acid, which is less effective, but longer lasting disinfectant (Kazumi 2007). As a result, ozone might thus be even more effective as disinfectant in marine water than in fresh water. The study, conducted by **Oemcke and Van Leeuwen, 2005**, confirms that the reason was because of the presence of bromide, Br^-, in seawater. further investigation on the effects of pH, presence of iron, and bacterial has shown that these environmental conditions can affects the efficacy ozone in seawater. **Wright et al., 2007** and **de Lafontaine et al., 2008** carried out an investigation using Bacillus subtilis spores as an indicator, under different simulated ballast conditions to test for the environment effects on the ozone treatment system. Their results confirms that ozone treatment technique is not a good choice for the control of spore-forming organisms in ballast water but may be suitable for the controlling other species. The main environmental drawback observed using ozonation techniques, include the uneven distribution of ozone in the ballast tanks, corrosion of ballast tanks, and regrowth of microorganisms. The residual chemicals and by-products generated are discharged into the environment and may cause residual toxicity at discharged waters.

- **ELECTROCHLORINATION (EC)**

has shown a high rate of inactivation for different planktonic fractions (**First et al., 2015; Tsolaki et al., 2010**). The efficacy of electro-chlorination (EC) has been proven to can meet the IMO discharge standard for viable smaller plankton and bacteria in rivers and brackish water (**Echardt and Kornmueller, 2009**) based on the shipboard trial conducted in several studies. However, major limitation of the electro-chlorination (EC) is its higher cost when compared to others treatment system and their use of quenching agents to reduce the high levels of total residual oxidant (TRO). In his study, **Gray et al., 2006** and **Jang et al., 2020** in their separate studies, had used the electrochemical treatments in the removal of plankton from ballast water and the results shows an efficiency greater than 99%.

- **OTHERS ACTIVE BIOCIDE**

Certain active chemical biocides have been used in type approved BWMS ballast water treatment system, including SeaKlean® - vitamin K3 (**Wright et al., 2009**), Peraclean® Ocean- peroxyacetic acid, and Vibrex® - chlorine dioxide (**Maranda et al., 2013**). Peraclean® Ocean (Evonik Degussa AG, Germany) for example, is a commercially available biocide with peroxyacetic acid as the primary active substance and hydrogen peroxide as the secondary active substance. Studies have shown that the effectiveness of these biocides has resulted to the mortality of over 99% of culturable bacteria at high doses (1.6 mg·L−1). **Gregg and Hallegraeff, 2007** has shown using their experiment that phytoplankton and zooplankton were observed to be immediately disrupted after the addition of Peraclean® Ocean, without any occurrence of regrowth, even after 40 days. The growth of bacterial inside the ballast water decreased while hydrogen peroxide was present, but their regrowth increases rapidly after the hydrogen peroxide had been degraded. However, there efficiency is limited to the fact that environmental factors like lower temperature reduces the effectiveness of these oxidizing biocides and affecting the decay of degradation products. **La Carbona et al., 2010,** and **Stehouwer et al., 2013** in their studies with Peraclean® Ocean, have seen that its residual substance acetate might be present at high concentrations in discharged ballast water, particularly on short voyages in cold waters due to its slow degradation at low temperatures. Also, a low water temperature, the presence of light, and organic matter negatively influences the disinfection efficiency (**de Lafontaine et al., 2008**).

The discharges of ballast water treated by Peraclean® Ocean in harbors and bays that do not have a high rate of water exchange may cause eutrophication due to acetate build-up (**Stehouwer et al., 2013**). The application of such biocides has greater advantage to the ship owners because of the lower risk of corrosion but ship owners have been faced with problems involving their residual toxicity, high cost, and human-safety (**Stehouwer et al., 2013**).

- **DE-OXYGENATION**

This treatment methods involve the installation of de-oxygenation plants on board ship, used in removing dissolved oxygen in the ballast water and injecting inert gases, such as nitrogen into the tank to asphyxiate the organisms. The removal of oxygen kills the aerobic organisms present in the ballast water, as well as reducing corrosion rates, provided that the oxygen content is maintained at the correct levels. This system is effective and can be used for both fresh or salt water as well as clear or turbid water. However, it requires a prolonged period of treatment time, as it takes two to four days for ensuring that the organisms and pathogens are rendered harmless to the receiving waters. Several studies have shown that the time required for achieving hypoxia is inversely related to temperature with much longer times needed in cold water. Hence, deoxygenation technique is not recommended for short transits voyages. The challenges encounter in this system is that the ships ballast tanks have to be sealed against atmospheric oxygen for it to be highly effective and low temperatures reduce the metabolic rate of organisms enabling them to cope better with low oxygen levels.

2.3.3. DISCUSSIONS

As several ballast water treatment system has its advantages and limitation, thus the selection and application of ballast water treatment technique by shipping operators should be based on the shipping route, biota and indigenous organisms in the region. The physical and mechanical methods have a high level of efficiency, but for the removal of microorganisms, additional chemical methods are preferred. The short- and long-term effects of many system characteristics, especially those using active substances, are of greater concern, regarding their effects relate health risks**.** As majority of ballast water treatment using chemical methods always generates its relevant chemicals in varying amounts when discharged, which affects the coastal waters due to the accompany disinfection by-product. The release of certain disinfectant by-product (DBP) from treatment system employing the chemical method have been reviewed to be highly toxic and can result to the adverse problems to the marine organism leading to carcinogenicity, genotoxicity, cell cytotoxicity, and acute toxicity, to aquatic organisms. As for treatment system employing heating and electric field technology, there effectiveness is not affected by the composition, salinity, or temperature level of the ballast waters and maybe considered to be more suitable, but they still require higher energy for operations and may be feasible for shorter distance voyage. The deoxygenation technique is not dependent on water composition but at low temperatures it takes longer time for this treatment to become effective and are only applicable during longer voyage travels. The UV radiation, which is not influenced by salinity, but their performance is reduced in turbid water or water that is rich in (dissolved) organic matter which might cause problems under specific circumstances. The release of effluent into the coastal waters, the high energy consumption, cost of OPEX and CAPEX are also important issues been considered by in most of Ballast water treatment technologies. Based on our studies review, all treatment techniques are to some extent, effectiveness but has their pros and cons, and it can be concluded that the combination is necessary to cope with all conditions for providing a more effective result. Further studies and research are still needed to be carried out on improving the ballast water treatment system detection methods, post-treatment effects of the ballast water treatment organism and the improvement the chemical disinfectant on their impacts to the coastal waters.

2.3.4. CONCLUSION

This study has reviewed the various ballast water treatment system technology and provides understanding on their operational mechanism, efficiencies, as well as their limitations. The assessment carried out on the current list of sixty-five approved ballast water treatment systems shows that 52% employs the Ultraviolence technology, 29% utilize electrochemical treatment, while the remaining 19% uses technological processes such as ozonation, ultrasound, the addition of biocides, or deoxygenation. As the qualities and constituents' particles of the ballast water to be treated, in terms of organic and inorganic matter, organisms, physical and chemical parameters are different, it can be concluded that, the effectiveness of each ballast water treatment depends on the application of the appropriate treatment technology. The use of physical method like filtration and hydro cyclones techniques has always results to a better primary treatment system as they effectively removing larger microorganism and sediments when applied at all maritime environmental conditions but since their performance are affected by smallest organisms, so additional treatment methods are always required to compensate their weaknesses. In achieving a more sustainable maritime ecosystem, more research aimed at improving the current technology should be carried out as there has been instances, where certain type-approved ballast water treatment systems have been reported being non-compliant to the IMO discharge standards.

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CHAPTER 3.

STUDY OF BALLAST WATER MANAGEMENT COMPLIANCE AMONG SHIPPING OPERATORS IN NIGERIA

In this section, ballast water compliance in Nigeria is studied to identifies the various challenges hindering the ship operators in the region from complying with the ballast water management. The qualitative method is employed using semi-structured interview and survey study using questionnaire were distributed among selected maritime experts and shipping operators to identify the various challenges and facilitate pairwise comparisons with respect to the different challenges with regards to each evaluation criterion. The AHP multicriterial analysis method is employed to prioritize the barriers to assist policy makers in understanding areas for consideration in decision making process.

ABSTRACTS

The problem of invasive species transfer through ships ballast water has resulted to the mandatory IMO D-2 standards for existing vessel to install ballast water treatment system (BWTS) onboard in compliance with the ballast water management system. Many ships owners are still not able to comply, due to the presence of several challenges. Hence, this study evaluates the challenges hindering the BWMS compliance of selected shipping operators from installation of ballast water treatment systems. Based on expert interview and sample conducted, the technical challenges (TC), environmental challenges (EC), economic challenges (EC) and other challenges (OC) where identified as the major challenges responsible for the non-compliance. These challenges were subjected to a qualitative synthesis, using the AHP multicriterial technique to analyze the qualitative data in providing insights and ranking of the challenges. The results obtained indicates that Other Challenges (OC) which includes external and internal influences on ship operators, Ship type, age and trading route obtained the highest rank (0.3666) and emerging as having the highest possibility influence on shipping operators' decision to comply with the BWMS. Second was the Economic challenges (0.3648), followed by the Technical Challenges (TC) which obtained the third rank (0.1456). The Environmental Challenges (EC) was regarded as the least concern (0.1223) hindering the shipping operators' decision in the region from compliance with the BWMS. This study will help decision-makers in the region towards making decision and prioritizing management measure that will promote the installation of BWTS and compliance of BWMS among shipping companies.

Keywords : BWTS, Barriers of BWMS in Nigeria, AHP Technique, Maritime regulation

3.1. INTRODUCTION

The expansion of maritime trade routes has contributed to increased shipping traffic around the world (**UNCTAD 2021**) and increasing the risks of invasive marine species to new regions through ballast water transfer (**Goldsmit et al., 2020**). Although, ballast water is necessary for providing draft and stability during ships operation but have also been identified as a major pathway for the introduction of marine invasive species to new regions (**Bailey et al., 2020**). The impacts of invasive species in maritime industry include the alteration of coastal water quality, the spread of diseases like paralytic poisoning, cholera outbreak, discharge of potential disinfection by-product and others toxic sediments substance contained inside the ballast water and can act as predators to local species (**Berger, 2017; Shah et al., 2015**). The maritime sector has been facing the challenge of managing the negative impacts posed by the spread of potentially invasive aquatic species through the transfer of ships' ballast water (**Gollasch and David, 2018**, **Shi et al. 2018**). Among the solutions currently introduced for managing this global maritime problem, involves the implementation of ballast water treatment systems regulation D-2 standard by the international convention for the control and management of ship's ballast water and sediments, which limits the number of viable organisms in ballast water discharged by ships and implies that new and existing ship must install ballast water treatment system onboard, based on the scheduled deadline of September 8, 2024 **(IMO, 2004).** In response to meeting the D-2 standard, several treatment systems incorporating a varieties of technology combination have been developed **(Tsolaki and Diamadopoulos 2009**). However, many shipowners are still facing several challenges hindering them from the installation, adaptation, and effectively using the ballast water treatment system (BWTS). Based on current literature review, the challenges can be group as physical, including the size and shape of the vessel and the footprint and weight of the device; economic, comprising electric consumption, and capital and operation costs; environmental, emphasizing residual toxicity and safety; and biological, meaning the organisms treated and the inactivation efficacy (**Ren, 2018**). As we approach the IMO scheduled deadline in meeting up with the D-2 standard by 2024, industry regulators and stakeholders are currently looking for ways of achieving compliance with the D-2 Ballast water regulation. It has become imperative at this point in time for us to understand the various challenges faced by shipowners to enable us provide strategy for solving them. Hence, in this study, we integrate the AHP analysis method to a survey study sampled among ship operators in Nigeria to identify the challenges faced in selecting the ballast water treatment system and complying with the convention. The novelty of this study relies in the fact that, it prioritized the barriers of BWTS based on the perspectives of Nigeria shipping operators and will help policy makers in providing solutions as well as serving as a reference for future studies in others developing countries in the region.

3.2. STUDY LOCATION

Nigeria is a major hub for local and international trade in West Africa, accounting to over 60% of total seaborne traffic in volume and values in regions (**Ajibo et al.,2019; Dahou & Chalfin, 2020**).The huge coastline space of approximately 853km, bordering the Gulf of Guinea in the west that provides the basis for its substantial maritime activities (**Okafor-Yarwood et al., 2020**). The Nigerian coast started experiencing port development and influx of different sizes and classes of ships way back from the pre independence era in 1954, after the promulgation of the Nigeria Ports Act and the commencement of the Nigerian Ports Authority. Approximately around 75,000 international and domestic ships with short voyage duration visits the coastal waters of Nigeria every year, transporting goods such as crude oil export and bulk cargoes to foreign ports and returning with ballast water into Nigeria harbor every year. The shipping companies operating in the region comprises mainly of small and medium size companies with fleet less than ten ships, including tanker, bulk carriers and container ship operating within the coastal waters. Considering the growth in the international trade in Nigeria and the fact that most ports in the region have not yet adopted an ideal environmental management system for mitigating the spread of invasive species and also the lack of more effective national BWM measures, Nigeria could be considered to be under a great risk of biological invasions. Recent studies have reported the introduction of invasive species into the Nigeria waters, which is evidence of poor compliance with the ballast water management system. Example is the introduction of European zebra mussels (Dreissena polymorph) in Nigeria, which clogged the hull of maritime structures and resulted to their sinking (**Ukwe et al., 2006; Eke, 2015**). Also, is the case of the North Pacific Sea star (Asterias amurensis), which was introduced into Nigeria's fishing fields around the Niger Delta through ballast water and decimated the shellfish population (**Peters, 2011**).

Fig. 6. MAP OF THE STUDY AREA (source**:** based on data from IMO **(2019b))**

3.3. STUDY METHODOLOGY

Three-stage approach was applied in the collection of information, assessment, and analysis to enable us to understand the problem and obtain our study objective. To evaluate the implementation BWTS in Nigeria in terms of the key barriers influencing the compliance of ballast water in Nigeria, a stratified survey study among ship operators in the region was conducted. We developed and sampled electronical questionnaire to selected ship operators to assess their ballast water management compliance profile and challenges faced in their implementation. The information collected include ship type, BWTS type, place of installation of BWTS and BWTS issues and the challenges faced to obtain compliance. A total of 350 respondents from the registered ship owners operating in Nigeria were contacted from (December 2021-January 2022) and a total of 160 responded to our questions through email address, showing that the response rate is approximately more than 60%, which represents a highly successful outcome for our assessment. All the data obtained were explored to provide a statistical view of the status of the problem.

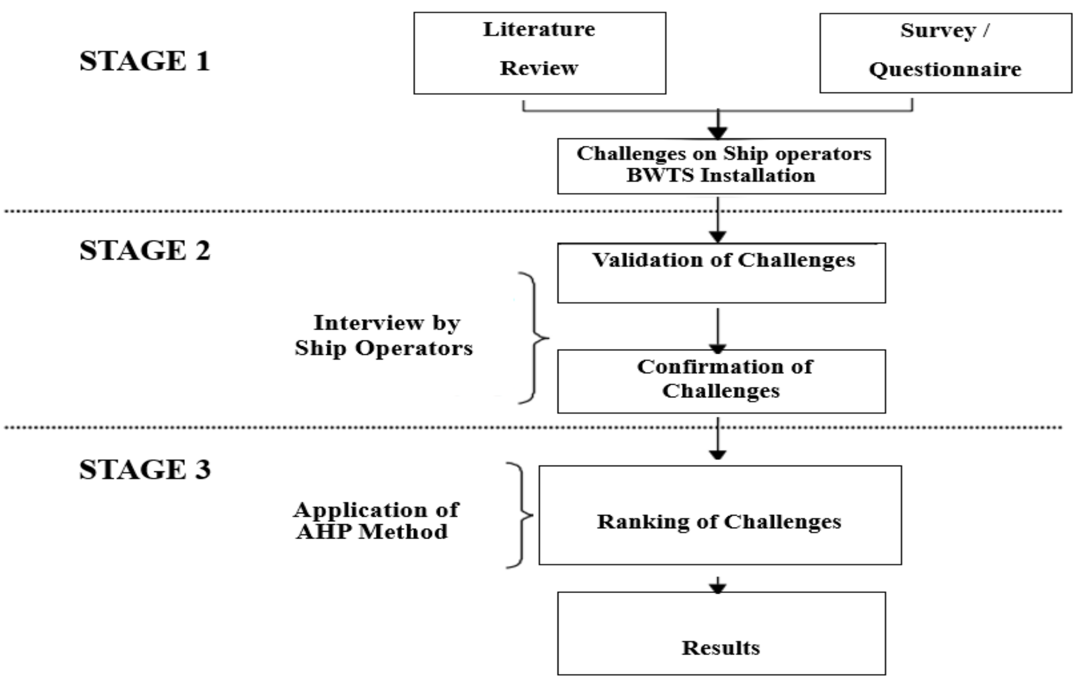

Fig 7. Graphical representation of study methodology

3.4. SUEVEY SAMPLED ON SELECTED SHIPPING OPERATORS

Based on our sampled questionnaire survey (n =160) on the shipping companies in the region, the respondents were asked about the implementation of the ballast water treatment measures on board their ship and **figure 8** shows that 60% of the respondents have not implement any ballast water treatment system onboard their ship despite the ballast water regulation in the region due to several reasons, while 40% of the ship operators have installed BWTS. The shipping operators without ballast water treatment system were also asked about the various barriers hindering them from installation and their response is represented in **figure 9** below. Also, in regard to the type of ships that have install includes container ships (48%), followed by oil tankers (15%), bulk carriers (10%), passenger ships (8%), offshore support vessel (12%) and other ship types (8%) as can be seen in **figure 11**. The majority of the shipping companies administer uses their internal management system to train their crew members, while only 26% of the companies mainly large shipping company employs their BWTS manufacturers. Also, **figure 12** shows that a large proportion of several ships operating in the region uses filter and UV technology (35%) treatment system followed by chemical injection BWTS (25%) and filter and electrolysis technology (28%) and electrolysis (12%). In addition, significant potential issues regarding the operation of their ballast water treatment system were also raised by the ship operators, regarding fitter clogging, hardware's and software's problems and the lack of availability of spare parts.

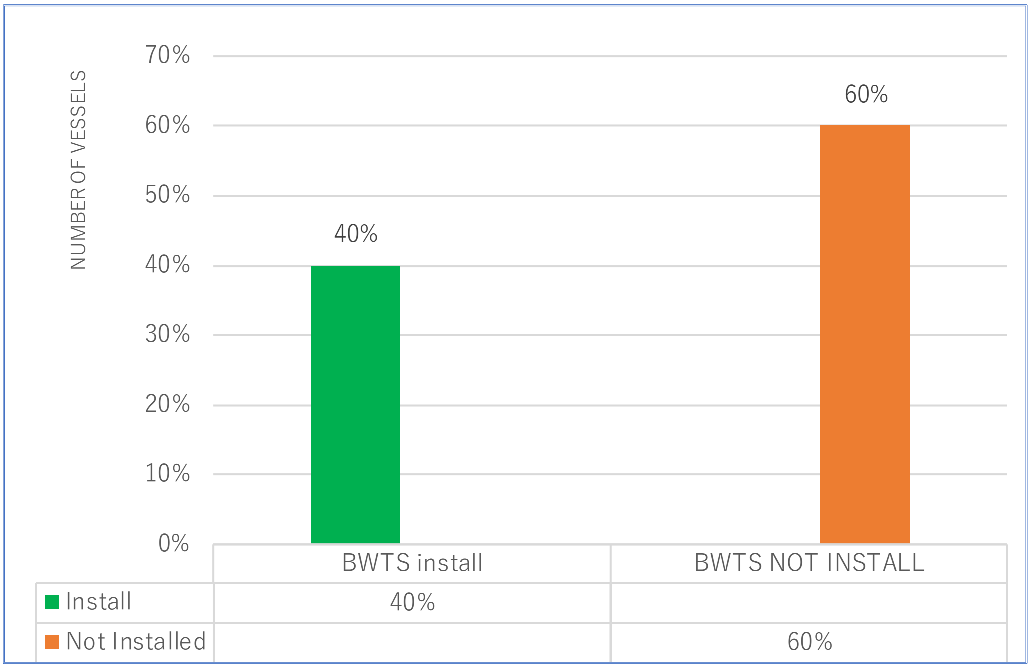

FIG 8. SUEVEY OF BWTS ON SELECTED SHIPPING OPERATORS

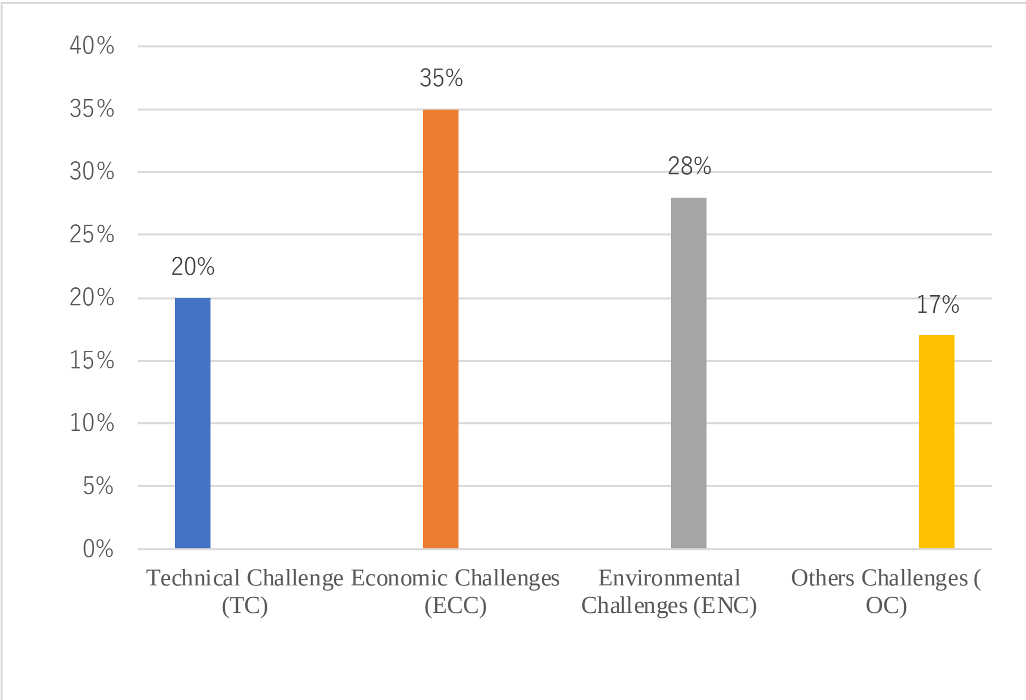

FIG 9. BARRIERS HINDERING INSTALLATION OF BWTS

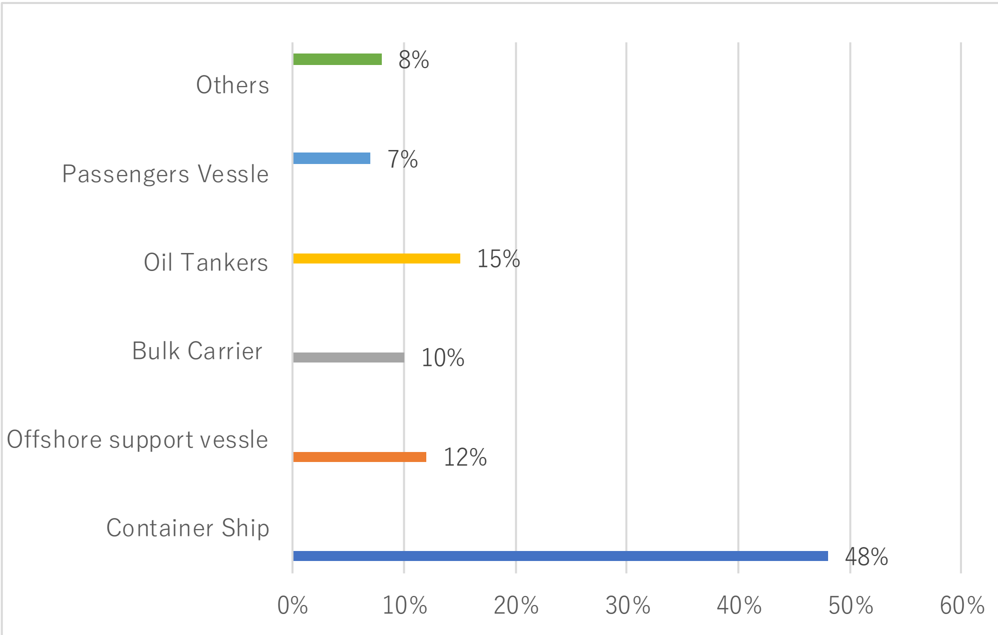

Fig 10. SHIP TYPES WITH BWTS

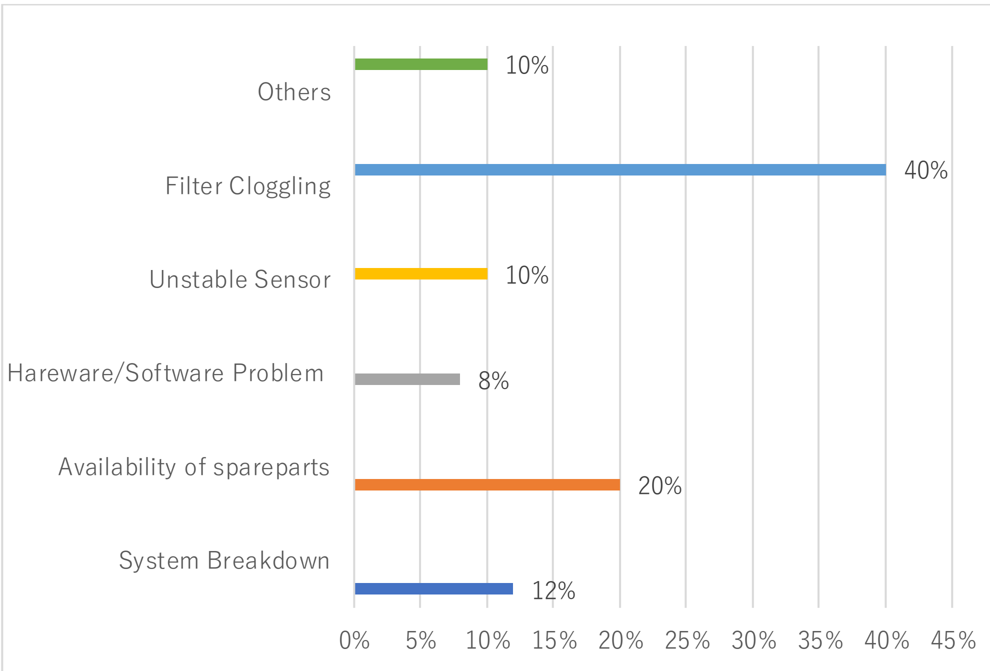

Fig 11. TECHNICAL ISSUES WITH BWTS

3.5. APPLICATION OF AHP METHOD FOR RATING THE BARRIERS

3.5.1. INTRODUCTION OF ANALYTICAL HIERARCHY PROCESS (AHP)

The Analytic Hierarchy Process (AHP) is a powerful mathematical technique established by Saaty (1977). It is a theory of measurement through pair-wise comparisons that relies on the expert's judgement to derive the priority scales when dealing with complex and conflicting criteria in decision making problems (**Huoa et al., 2011, Zheng et al., 2012**). The decision attributes and alternatives are arranged into a hierarchical structure with the help of a series of pairwise comparisons (**Tavana and Hatami-Marbini, 2011**). As several studies have demonstrated the applicability of AHP in the shipping industry (**Ung et al., 2006, Kandakoglu et al., 2009, Karahalios et al., 2011**). The concept of AHP is to design a hierarchy tree including the level of goals, criteria, sub-criteria and alternatives and each element in the hierarchy can be compared with the other elements for its relative significance (**Tavana and Hatami-Marbini, 2011**). AHP calculations are not complex, and if the judgements made, about the relative importance of the attributes have been made in good faith, then, AHP calculations lead inexorably to the logical consequence of those judgements. The pairwise comparison enables the decision maker to evaluate the impact of each factor on the objective (**Veisi et al., 2016**) in an arbitrary random reciprocal matrix A, each criterion aij (i, j = 1, 2, 3, … n) is the relative importance of ith elements compared to the jth elements.

3.5.2. Survey study of shipping Operators :

Literature reviews were conducted to understand the problems and compare their challenges and the results of our survey questionnaire as sampled among selected shipping operators in the region to assess their ballast water management compliance profile and related challenges hindering their compliance, as depict in **Fig 8** and **Fig 9** above. The information collected on their ballast water treatment systems profile and the challenges faced to obtain compliance are used in our AHP analysis.

3.5.3. Experts Interview and Opinion

In validating the challenges for our AHP evaluation, five maritime experts with wider experience in the Nigeria shipping industry were contacted for their opinions and confirmation. The maritime experts were selected among top industry leaders and consultant with over 5 years of experience. Their judgement on the pairwise comparison of the challenges was used as input in the AHP analysis process.

3.5.4. Application of the AHP Technique

The AHP is a multicriteria decision making technique developed by saaty and used in solving complicated decision-making problem by decomposing them into multilevel hierarchical structure of objective, criteria, and alternatives and a pairwise comparisons is used to derive the relative importance of the variable using the saaty scale of preference from 1-9 as seen in **fig 2** below, to represent the expert opinions on the relative importance of the variable (**Doğan & Akbal, 2021**).

IMPORTANCES	RANK	EXPLANATION
Extreme importance	9	Criterions I is extremely more importance than j
Very strong importance	7	Criterion I is strongly more important than j
Strong importance	5	Criterion I is significantly more important than J
Moderate importance	3	Criterion I is slightly more important than j
Equal importance	1	Criterions I and j are of equal importance

Table 2. Saatys' 1-9 Pairwise scale of preference index

The following four steps below are applied in the application of the AHP method.

STEP 1: The decision hierarchy is established by identifying the problem, selecting barriers, and possible alternatives. The criteria $\boldsymbol{C_i}$ is used for evaluating the problem.

STEP 2: Next, questionnaire was distributed to decision makers (K) for establishment of the pairwise comparison matrix, using established ratio of relative importance of the criteria (n). The selected barriers were compared in pairs using Saaty's nine-point rating as shown in **Table 1,** and weights are assigned from the pairwise comparison of the decision makers judgement and used to form matrix $\boldsymbol{A^k}$**.**

$$\boldsymbol{A^k = \left(a_{ij}^{k}\right) n \times n \;=\; \begin{matrix} a_{1,1}^{k} & a_{1,2}^{k} \ldots\ldots\ldots & a_{1,n}^{k} \\ a_{2,1}^{k} & a_{i,j}^{k} \ldots\ldots\ldots & a_{2,n}^{k} \\ \vdots & \vdots & \\ a_{n,1}^{k} & a_{n,2}^{k} \ldots\ldots\ldots & a_{n,n}^{k} \end{matrix}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where $\boldsymbol{a_{ij}^{k}}$ is the K–nth term on expert judgement criterion $\boldsymbol{i}$ compared to $\boldsymbol{j}$

And $\quad \boldsymbol{a_{ij}^{k} > 0 \quad a_{ij}^{k} = \frac{1}{b_{ij}^{k}} \quad a_{ii}^{k} = 1}$

when $\quad \boldsymbol{a_{ij}^{k} = a_{ji}^{k} = 1}$, and $\quad \boldsymbol{k = 1, 2, 3 \cdots z.}$

STEP 3: The weights assigned to criteria $\boldsymbol{C_1 \ldots . C_2 \ldots . C_3 \ldots . C_n}$ are then calculated through the pairwise comparison matrix $\boldsymbol{A^k}$. The weights of the criteria are obtained by dividing each criterial in the pairwise comparison matrix by the sum of its column and the calculating the arithmetic mean of each row.

$$\boldsymbol{W_i^k = \frac{1}{n} \sum_j \frac{a_{ij}^{k}}{\sum_i a_{ij}^{k}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where $\boldsymbol{W_i^k}$ denotes the weight of each criterial $\boldsymbol{C_1}$**.**

STEP 4: The final step is the consistency check of the judgement of the decision makers. This is achieved by calculating the value consistency index (CI) and the random consistency index or consistency Ratio (CR). To fulfil a condition of consistency, the value (CR) must be less than 0.1, then in this case, the judgments of the decision maker(s) can be accepted as been consistent. For calculating the values of the Consistency Index (CI) and Consistency Ratio (CR),

we Apply equation (3) and (4) as seen $\boldsymbol{CI} = \frac{(\lambda\mathbf{max} - \mathbf{n})}{(\boldsymbol{n} - \mathbf{1})}$ **........ (3)**

Where λmax is the maximum eigenvalue and mean weight of coefficient λi which is calculated from equation (5), while n is the number of compared elements or matrix size.

$$\boldsymbol{\lambda}\mathbf{max} = \frac{\mathbf{1}}{\boldsymbol{n}} \sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{n}} \boldsymbol{\lambda i} \text{ .... } \mathbf{(4)}$$

$$\text{Where } \boldsymbol{\lambda}\mathbf{i} = \frac{(\boldsymbol{Aw^k})_{\boldsymbol{i}}}{\boldsymbol{W_i^k}} \Leftrightarrow \frac{\sum_{\boldsymbol{j}=\mathbf{1}}^{\boldsymbol{n}} \boldsymbol{aji} \,.\boldsymbol{Wi}}{\boldsymbol{Wi}} \text{ .... } \mathbf{(5)}$$

$$\text{Then} \qquad \mathbf{CR} = \frac{\boldsymbol{CI}}{\boldsymbol{RI}} \text{ .... } \mathbf{(6)}$$

RI is the corresponding average random index of *CI* for an $n \times n$ Matrix depending on the number of compared elements (n) and its value is seen in **Table 3** below.

Table 3. RANDOM INDEX VALUES (RI) FOR MATRIX SIZE (n)

n	1	2	3	4	5	6	7	8	9
RI	0.0	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

3.5.5. SELCTION OF CRITERIALS/ CHALLENGES FOR EVALUATION

The results of the four challenges previously identified during the survey sampled on the ship operators in Nigeria were further subjected to reviews and validation using questionnaire representing pairwise comparisons from 1-9 scale. by five maritime experts with broader knowledge and experience of the Nigeria shipping industry. The experts were selected among top maritime consultant with over 10 years of shipping experience. The judgements of the expert's evaluation on the earlier four-challenge reviews a total of twenty-two sub-criteria (challenges) which were re-grouped and presented in **Table 4.** The experts also contributed to the evaluation of the weight of each criterion and the information's were processed using the AHP multi-criteria technique to enable us to rank the ship operator challenges in Nigeria. The pairwise comparisons of the evaluation criteria were conducted as shown in **Table 5**

Table 4. Challenges hindering shipping operators from installing BWTS.

	Challenges	Explaination and Definition of Challenges / Criterials
1.	Technical Challenge (TC)	This Include problems relating to the reliability of BWTS, energy efficiency, shipping crew safety, BWT System configuration , shipping operators technology preference and BWTS operational complexity .
2.	Economical Challenge (ECC)	This include problems relating to the capital cost of the BWTS (CAPEX), Operational cost (OPEX) and Life cycle cost .
3.	Environmental Challenge (ENC)	This problem include the Effect on Public Health , Marine Biodiversity and Extinction of Native species The Impact of the BWTS on the economic of coastal industry using Sea water like fishing
4.	Others Challenge (OC)	This challenges include External and Regional influence on ship operators, Ship type , age , size of fleets and trading route

Table 5 . Scale for pairwise comparison of evaluation criteria

Pairwise Comparison	More important Challenge	Level of Importance	Numerical Ranking
Environmental (ENC) and Technical Challenge (TC)	Technical Challenge	Moderately more	3
Environmental (ENC) and Economical Challenge (EC)	Economical Challenge	Moderately more	1
Environmental (ENC) and Others Challenge (OC)	Environmental Challenge	Moderately more	3
Technical (TC) and Economic Challenge (EC)	Economical Challenge	Moderately more	1/4
Technical (TC) and Other Challenges (OC)	Others challenge	Moderately more	2
Economical Challenge (EC) and Others Challenge (OC)	Economical challenge	Moderately more	2

In applying the numerical rankings associated with the pairwise comparison assessment from **Table 5** above, the 4x4 pairwise comparison matrix has been constructed using step 2 as represented in **Table 6**. Also, the AHP synthesis process was conducted using step 3 of the AHP techniques mentioned earlier as represented in **Table 7**

Table 6. Pairwise comparisons matrix of BWTS compliance challenge

CRITERIAL	Environmental Challenge	Technical Challenge	Economical Challenge	Others Challenge
Environmental Challenge	1.0000	3.000	1.0000	3.0000
Technical Challenge	1/3 (**0.3333**)	1.0000	1/4 (**0.2500**)	2.0000
Economical Challenge	1.0000	4.0000	1.0000	2.0000
Others Challenge	1/3 (**0.3333**)	1/2 (**0.5000**)	1/2 (**0.5000**)	1.0000
SUM TOTAL	**2.6666**	**8.5000**	**2.7500**	**8.0000**

Table 7. Evaluation of selected criteria to determine their weighted values.

Challenge	TC	ECC	ENC	OC
TC	1.0000/ 8.5000	0.2500/ 2.7500	0.3333/ 2.6666	2.0000/ 8.0000
ECC	4.0000/ 8.5000	1.0000/ 2.7500	1.0000/ 2.6666	2.0000/ 8.0000
OC	3.0000/ 8.5000	1.0000/ 2.7500	1.0000/ 2.6666	3.0000/ 8.0000
ENC	0.5000/ 8.5000	0.5000/ 2.7500	0.3333/ 2.6666	1.0000/ 8.0000

Then we determine the weight of each evaluation criterion, by summing up the values in each role of the pairwise comparison matrix and dividing it by the average value of the elements in each row (i.e. total number of criteria). The results are presented in **Table 8**

Table 8. Determination of Weighted values of selected criterial/challenge

	TC	ECC	ENC	OC	RANK	Rate
TC	0.1176	0.0909	0.1250	0.2500	**0.1456**	**3rd**
ECC	0.4706	0.3636	0.3750	0.2500	**0.3648**	**2nd**
OC	0.3529	0.3636	0.3750	0.3750	**0.3666**	**1st**
ENC	0.0588	0.1818	0.1250	0.1250	**0.1223**	**4th**

3.5.6. Calculation of the consistency of the pairwise Judgement

After obtaining the weight values (Ranking) of the evaluation criteria, the next stage in the AHP process is the calculation of the Consistency of the pairwise judgement of the decision makers. Equations 3 down to and 6 were applied in the process as follows.

Step i: Each value in the first column of the pairwise comparison matrix was multiplied by the priority of the first item as follows.

Table 9. Summation Of the Consistency Index

Environmental			Technical			Economical			Others	
0.3666*	1.0000	+	0.1456*	3.0000	+	0.3648*	1.0000	+	0.1223*	3.0000
	0.3333			1.0000			0.2500			2.0000
	1.0000			4.0000			1.0000			2.0000
	0.3333			0.5000			0.5000			1.0000

Table 10. Summation of average value of total criteria's

Environmental		Technical		Economical		Others	TOTAL CRITERIA	
0.3666	sum	0.4368	sum	0.3648	sum	0.3669	EQUALS	1.5351
0.1222		0.1456		0.0912		0.2446		0.6036
0.3666		0.5824		0.3648		0.2446		1.5584
0.1222		0.0728		0.1824		0.1223		0.4997

Step ii: Each Total Criterial Summation (j = 1,2,3,4,5) in Fig 9 is divided by determined weighted value or Ranking of the Criteria obtained in Fig 7.

Table 11 . The consistency index (CI)

Criteria Summation	λmax
1.5351 / 0.3666	**4.1874**
0.6036 / 0.1456	**4.1456**
1.5584 / 0.3648	**4.2719**
0.4997 / 0.1223	**4.0859**
Average of λmax **Total / 4**	**16.6908** **16.6908 / 4 = 4.1727**

Finally, we obtained the value for Cl as follows.

CI = (4.1727 – 4) / 4 – 1

CI = 0.1727 / 3

CI = 0.0576

Since there are 4 criteria's (Challenges) in the first level of the hierarchy resulting in the corresponding RI of 0.90, then CR will be calculated as follows.

$$\mathbf{CR} = \frac{CI}{RI} = \mathbf{0.0576 / 0.90 = 0.064}$$

The result of the pair-wise comparison for the weights of the evaluation criteria shows a consistency ration (**CR) of 0.064**. This indicates that the degree of consistency of the pairwise comparisons is acceptable as the result of the CR is less than **0.10.**

3.6. DISCUSSION

In this study, several challenges influencing the BWMS compliance among selected shipping operators in Nigeria have been evaluated. As evidenced by the data presented in this study, the challenges hindering the BWMS compliance in the region involves technical challenges (TC), environmental challenges (ENC), economic challenges (ECC), and other Challenges (OC). Based on the results of the ranking obtained in our AHP multicriteria analysis in descending order from the least importance to most influence challenge based on their weighted factor, as Rank = [0.1446, 0.1223, 0.3648, 0.3666] , representing Environment Challenge, Technical Challenge, Economic Challenge and Other Challenges [ENC, TC, ECC and OC]. Also, we were able to obtain the consistency ration (CR) of 0.064, which is lesser than 1 ($CR < 10\%$) and indicating that the information assigned for the weights of all our challenges were deemed consistent and satisfactory for the study. The results as seen in our AHP calculation in terms of the criterial / challenge ranking, shows that other changes (OC) which is defined to include external and regional influence on ship operators, Ship type , age and size of fleets and trading route is the most important influence factors hindering the decision of shipping operators in the region from installing BWTS and compliance with the BWMS. The result is evident as majority of the ships in the region operates withing the Africa continent which are not signatory of the Ballast water convention. Moreover, the environmental monitoring in these regions is weak, hence resulting to poor regulatory and monitoring influence on the shipping operators to comply with the BWMS. The Economic challenge (ECC) including problems relating to Capital Cost, Operational Cost, and Life cycle Cost of BWTS was ranked as the second most important challenge. The result is apparent since most of the ships are over 45 years older, and are mostly smaller vessel, which makes them become at higher risk from a financial point of view, since most of the shipping companies in the region are small scale ship company. The Technical Challenge (TC) followed by Environmental challenge (ENC) where considered as the third and the least important factors based on the result of the AHP analysis. The result is obvious because little or no consideration is given to the environmental protection in the decision making of the shipping operators in the region, particularly small and medium scale shipping operator. The environmental protection and awareness about the disinfectant by-product (DBP) of certain BWTS in the region in terms of installation and compliance of BWMS is considered low, which is an evident of environmental pollution caused by this pollutant in the coastal waters in the region.

3.7. CONCLUSION

The findings of this study review the problems hindering the compliance of ballast water in Nigeria. The AHP decision-making tools has been used to present a rationale and justification ranking of the several challenges. The ballast water regulatory compliance level among shipping operators in the region is still considered low. And urgent measures are needed to address the problems in order to encourage shipping operators in installing ballast water treatment system and compliance with the BWMC. It has been seen from our study evaluation that the general apathy towards installation of BWTS and compliance with the Ballast water convention among shipping operators in the study region is largely because of several challenges like Economic (ECC), Technical TC, Environmental (ENC), and other issues (OC). Each of these challenges has its own barriers that is needed to be overcome, but in tackling these challenges and obtaining compliance requires interaction and cooperation among all maritime stakeholders to participate in the process. Hence, the potential for achieving the Ballast water management standard and controlling the threats and advance effects of invasive species introduction in Nigeria waters will be impossible to achieve due to current challenges unless management actions are directed towards solving and providing solutions. The majority of the shipping companies may be needing support in terms of purchasing of BWTS, training of crew members. Since the regional and external influence, Ship type, age, and trading route are the most important factors influencing compliance. Hence, if the goal of the ballast water management system is to be achieved, then an alternative measure of compliance is necessary for supporting the shipping operators or proving alternative management measures of ensuring compliance like adoption of port-based reception facility with low service charge for ships operating within the regional waters or by proving a subsidized BWTS for purchase by small or medium scale ship operators. As we approach the mandatory installation date for compliance of the D-2 standard, coordinated policy measures should be deployed to counter the current challenges. Policy makers should focus more on proving solution to this problem that will encourage BWMS compliance as this will limit the problem of invasive species spread in the region. Besides the barriers discussed, there are several promising opportunities that may be available to ship owners, investors, by overcoming these barriers and meet the D-2 standard requirements such an enable business environment and a safer maritime ecosystem that is free from invasive species.

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CHAPTER 4.

INVESTIGATION OF BALLAST WATER QUALITY IN ONNE HARBOUR-PHYSIOCHEMICAL ASSESSMENT

This session is based on the results of the previous studies, to further check the compliance of the BWMS, in terms of risks of physiochemical parameters discharged in the region. The sampling method is employed to analysis the ballast waters introduced in the port to further assess their compliance status and risks posed to the coastal maritime ecosystem in the study region.

ABSTRACT

The non-compliance of ballast water management has become a global concern due to the environmental risks associated in the transfer of sediments and contaminant. In this study, the in-tank and in-line sampling procedure are employed in collecting ballast water samples from selected ships for investigating their physiochemical characteristics. The investigated parameters include, temperature, salinity, total suspended solids, hydrogen ions concentration, dissolved oxygen, and heavy metals. The result shows higher concentration of heavy metals, following an increasing order from ship 4 > ship 3 > ship 2 > ship 1 (27.897 > 20.941 > 16.636 >16.586) and according to the distance from the loading ports to ships destination port. While a complex correlation exists between parameters, the salinity and dissolved oxygen were higher in samples collected from offshore vessels and general cargo ships but decreases substantially with other samples and traced to certain reasons. This study will be useful for policy makers and maritime regulators in Nigeria, on the needs to monitor the qualities of ballast water discharged in the Nigeria ports and developing ballast water management strategy that will ensure compliance among shipping operators in the region.

Keywords; Ballast water, Risk assessment, Onne Port, Heavy metals

4.1. INTRODUCTION

Shipping as the primary mode of transportation of bulk commodities and has been recognized as a major vector in the transfer of maritime invasive organisms, through ballast water discharges (**Tempesti et al. 2022**). The shipping industry relies on ballast water for ensuring buoyancy, maintaining stability and maneuverability during its voyage at sea (S**aburova et al., 2022; Wang et al., 2021**). It has been estimated that over 5 billion tons of ballast water has been transferred yearly, around the world and contains different marine species, sediments, and heavy metals (**Queiroz et al. 2021; Saburova et al., 2022**). Ballast water discharge often influences the coastal water qualities, like turbidity, salinity, temperature, dissolved oxygen (DO) content, polycyclic aromatic hydrocarbons (PAHs), and heavy metals content if they are not properly treated or disposed which are poisonous if presence at a higher concentration (**Zhu et al., 2020; Imron et al., 2021)**. The harmful consequences of these physicochemical parameters of ballast water cannot be neglected as they pose potential ecological risk to public health and negatively affect aquatic organisms (**Valković and Obhođaš, 2020**., **Li et al., Lv et al., 2022**). In dealing with these problems and reducing the risks on the coastal waters, the international marine organization (**IMO**) has adopted the international convention for the control and management of ships' ballast water and sediments on the 16th of February 2004, which entered into force on 8 September 2017, along with guidelines for sampling and analyzing methods of ballast water (**IMO, 2015, 2008a**), and requirements for risk assessments and information about safety issues (**IMO, 2017, 2008b**). The Nigeria coastal waters are among the most vulnerable areas for the introduction of introduction of invasive species through ballast waters of ships due to the high maritime traffic in the region. Although, Nigeria had ratified the ballast water management convention (BWMC) on the 13 oct 2005 and established the shipping acts for managing ballast water. However, there are still compliance issues and enforcement in Nigeria, as many shipping operators are still contravened the standards of the BWMC convention resulting to ecological risk to the coastal waters. In this study, samples of ballast waters were collected between March 2022 – April 2022 from four selected ships docked in the Onne port, with the aim of investigating the presence of heavy metals and physicochemical quality of the ballast water samples. The Pearson's correlation multivariate statistical analysis matrix was performed using the Excel statistics software for determining the relationships between the investigated physicochemical parameters. This study is useful in determining the environmental risks level and will help policy makers in deciding the best management strategy and policy for controlling the problems caused by ballast water transfer in the region.

4.2. MATERIAL AND METHODOLOGY

4.2.1. STUDY LOCATION

This study was conducted in Onne multi-purpose cargo port, which is located in a strategic oil and gas exploration hub in River's state, Nigeria as seen in **Fig 8**. The port is being operated as a landlord port model, with two terminals (FLT & FOT) of 6,000 meters of jetty, 8-12m draft; 2,840,000 square meters of industrial area. The port is considered as one of the largest cargo ports in southern Nigeria, accounting for over 35% of the international and domestic ships calling on the Nigeria waters. The majority of the vessels are mostly tankers, container ships, bulk carriers, bulk carriers and oil and gas platform support supply calling on the port waters daily for the importation and exportation of cargo like crude oil and bulk commodities as can be seen from the shipping profile of the Onne port in **Fig 9**.

Fig 12. Onne Port Complex - (**Picture by integrated logistics services -Intel's)**

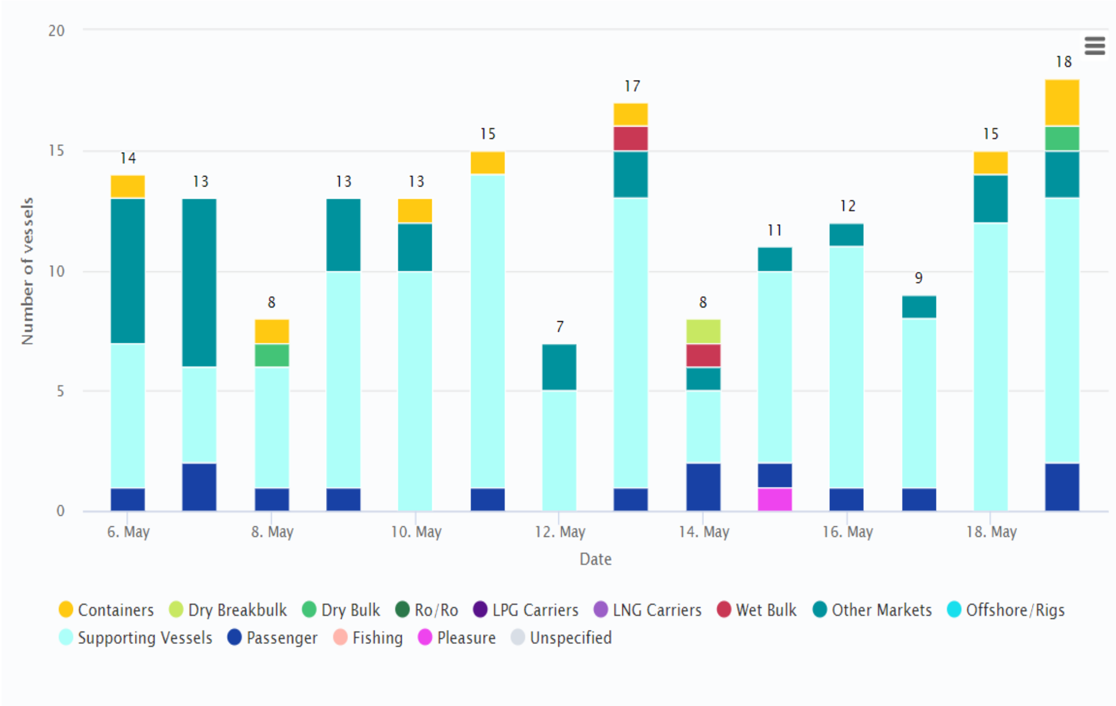

Fig 13. Shipping statistics of Onne port (**From www.marinetraffic.com for March 2022**)

4.2.2. FIELD SAMPLING OF BALLAST WATER

The Ballast waters samples were collected from four selected ships, labeled as **S1, S2, S3, and S4**, based on their operational routes and ballast water management system being operated as seen in **table 11**. The collection strategies employed were based on the availability to the targeted ship, ease of access to collection points and assistance available from the Onne port officials. The mixture of in-tank and in-line sampling method were employed for collecting the ballast water and port water samples. The Onne port water samples were collected directly by submerged a twenty-five liters (25L) plastic rubber that was severally rinsed with the port waters from dockside. The ballast water samples were collected from the ship ballast tank manholes for ships **S1,** and ship **S2** due to the easier access to sampling points from the ships deck and twenty Liters (20L) sampler was deepening approximately two meters below the water surface in the ship ballast tank for collecting the ballast water from both ships **S1** and **S2.** While for ship **S3** and **S4**, the sounding pipes were accessed due to its bigger space and accessible sampling points, and ballast waters were pumped out continuously at a speed of two liters per minute (2 L/m) through the pipe of net diameter of twenty-five centimeters (25cm) that was fitted into the point source sampler through the valve of about three millimeters (3mm) opening. The samples collected were filtered using filtering paper, and some amounts of nitric acid were added before storing them inside a glass bottle at the temperature of approximately four-degree census (4°C).

Ship	Type of vessel	Last Port of call	Type of BWMS
S1	Container ship	Jacksonville, USA	Treatment/Exchange
S2	Bulk carrier	Douala port, Cameron	Exchange/Exchange
S3	Offshore supply vessel	Lagos port, Nigeria	Treatment
S4	General cargo vessel	Port of Tema, Ghana	Treatment

Table 12 . Origin and Specification of selected vessels for BW sampling.

4.3. LABORATORY ANALYSIS OF BW SAMPLES

The hydrogen ion concentration (pH), and dissolved oxygen (DO) were measured directly in 200 ml sampler using a portable multimeter checker instrument (WTW Multiline® Multi 3630 IDS pocket pH meter) that is standardized with phthalate auto-calibration solution. The total suspended solid (TSS) were measures using gravi-metric method and 2100P turbidimeter (HACH model). The samples were first mixed with concentrated HNO3 in the ratio of 2:500 before using the atomic absorption spectrophotometer (AAS) (Perkin – Elmer, NY, USA) to determine the total heavy metal concentrations. Also, in determining the content of polycyclic aromatic hydrocarbons (PAH),samples were first mixed with concentrated H_2SO_4, and the EPA 3510C/827 method was performed to determine their concentration. The integrity of samples was maintained on site by labeling and safe storing, before sending to the laboratory, where all analysis was carried out in duplicate, and values were expressed as the mean values. The choice of analytical equipment used were based on the availability at the time of this study at the laboratory of the Nigerian Institute for Oceanography and Marine Research and are shown in **Table 12**.

No	Parameters	Method	Equipment
1	Total suspended solid (TSS)	Gravimetric method	2100P turbidimeter HACH model
2	Polycyclic aromatic hydrocarbons (PAHs)	EPA 3510C/827	Spectrometer Perkin Elmer LS-5
3	Heavy metals elements	St. Method 111B.C	Atomic Absorption spectroscopy (AAS) and X-ray fluorescence (XRF)
4	Hydrogen ion conc. (pH), Temp. (o C), Dissolved oxygen (DO), conductivity, and Turbidity	Portable multi-meter checker	WTW Multiline® Multi 3630 IDS pocket pH meter

Table 13. Analytical instruments and standard methods employed.

4.4. RESULTS

The results of the average concentration of heavy metals, including Zn, Cd, As, Hg, Pb, Ag, Cr, Cu, Fe, Ni, and Cu were detected at varying concentration levels, as presented graphically from **Fig 14** to **Fig 20** and the correlation analysis performed to determine the relationship between the concentration of heavy metals and the physicochemical parameters measured for the ballast water sampling between the ships (S1,S2,S3 and S4) and the Onne Port Water sampler and the results of the Pearson's correlation coefficients and their significance levels were given in as seen in **Fig 21** below**.** The total average heavy element concentration varied slightly in all the ballast water sampled and the total concentration increases sequential from S4 > S3> S2 > S1 as seen in **table 3**. The total heavy metal concentrations of the ballast water samples collected from ships labeled as S4, S3, S2 and S1 were 27.897, 20.941, 16.636, and 16.586 respectively and Ship 4 had the highest concentration while S1 the lowest. Among the measured heavy metals, Pb had the highest average concentration values of 21.010 , 15.800 , 10.550 and 12.500 for S4,S3,S2 and S1 respectively, followed by Zn with values ranging from 6.820, 5.080, 6.050, and 3.500 for S4,S3,S2 and S1 respectively. The average concentration values of copper, and nickel, iron, silver, mercury, and arsenic where all found in approximately the same trace quantity in all ship ballast water sampled (S1,S2,S3 and S4).

Metals (Mg/L)	Ship 4 (S4)	Ship 3 (S3)	Ship 2 (S2)	Ship 1 (S1)	Onne (PW)
Zinc (Zn)	6.820	5.080	6.050	3.500	6.050
Cadmium (Cd)	0.002	0.001	0.001	0.041	0.002
Arsenic (As)	0.001	0.001	0.001	0.031	0.003
Mercury (Hg)	0.001	0.001	0.001	0.031	0.001
Lead (Pb)	21.010	15.800	10.550	12.500	10.200
Silver (Ag)	0.001	0.001	0.001	0.036	0.003
Iron (Fe)	0.001	0.001	0.001	0.041	0.002
Nickel (Ni)	0.001	0.001	0.001	0.001	0.023
Cupper (cu)	0.060	0.055	0.030	0.405	0.020
Total Concentration	27.897	20.941	16.636	16.586	16.294

Table 14. Heavy metals concentration of ballast water and port water sample

	Temp (^{o} C)	pH	DO (mg/L)	Salinity (PSU)	Turbidity (NTU)	TSS (mg/L)	NH_4 (mg/L)	NO_3 (mg/L)	PO_4 (mg/L)
S1	21.50	8.20	6.0	18	120	205	0.040	0.314	0.001
S2	17.40	8.20	8.2	14	98	200	0.036	0.235	0.032
S3	18.45	8.30	9.1	25	107	315	0.049	0.085	0.015
S4	20.55	8.00	8.5	32	101	255	0.021	0.508	0.316
PW	28.65	7.77	6.8	20	400	150	0.035	0.400	0.200
S1=Ship1, S2=Ship2, S3=Ship3, S4=Ship4, S5=Ship5, PW=Port Water									

Table 15. Physiochemical analysis of ballast water and port water sample

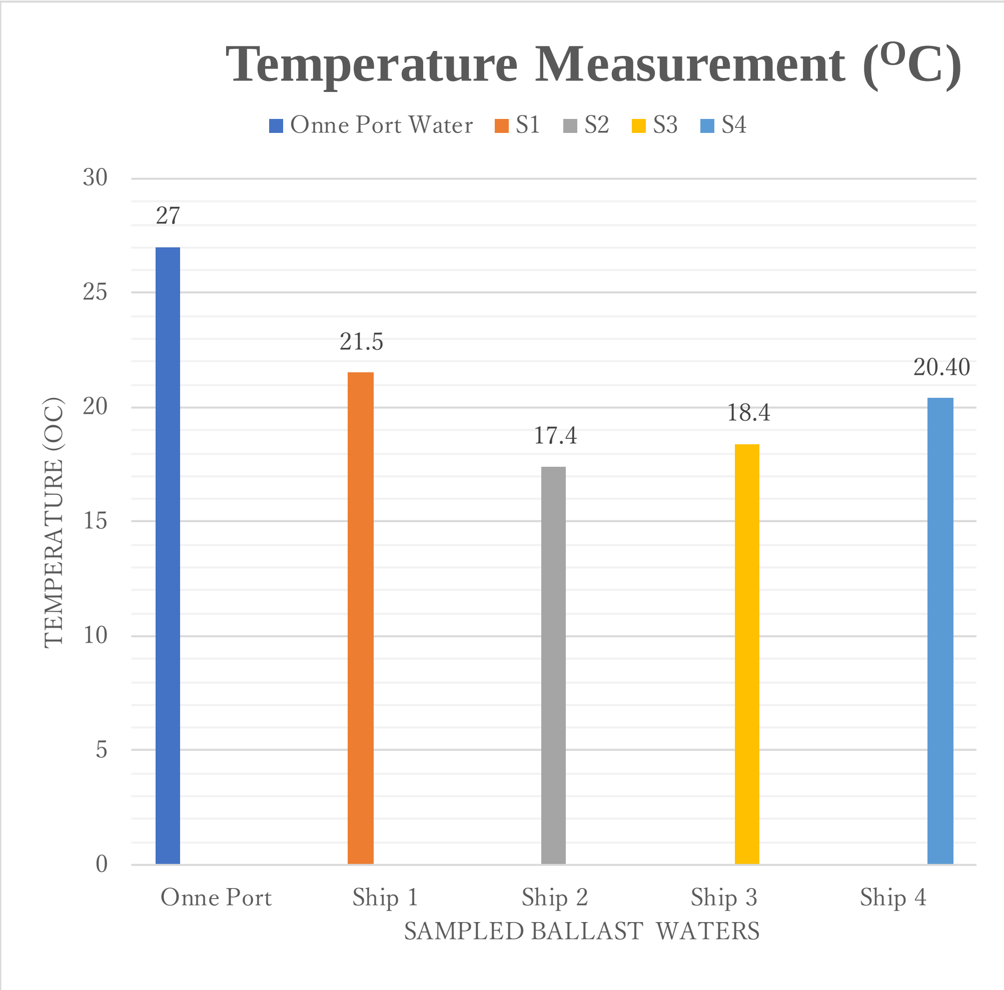

Figure 14. Temperature of sampled ships ballast and Onne port water

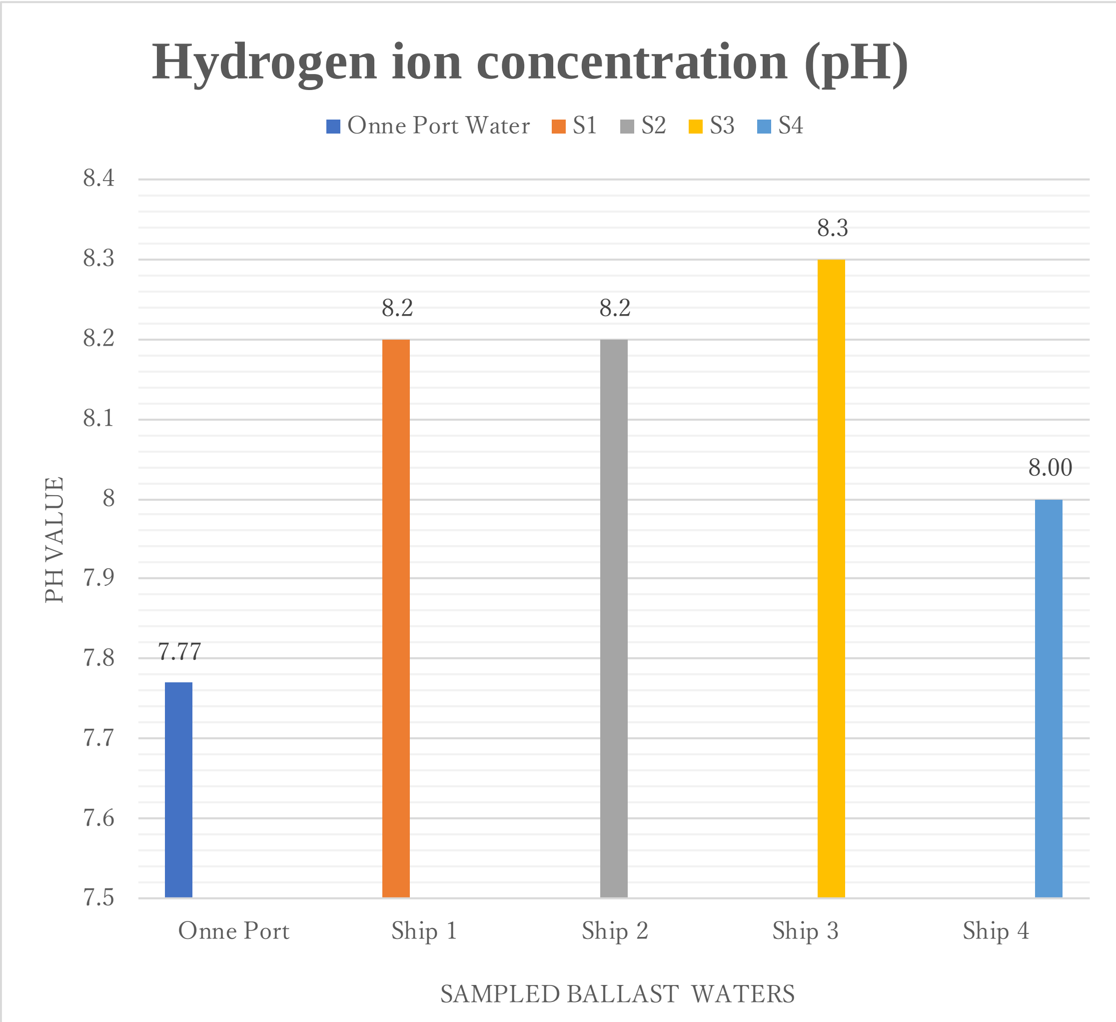

Figure 15. PH value of sampled ships and Onne port water

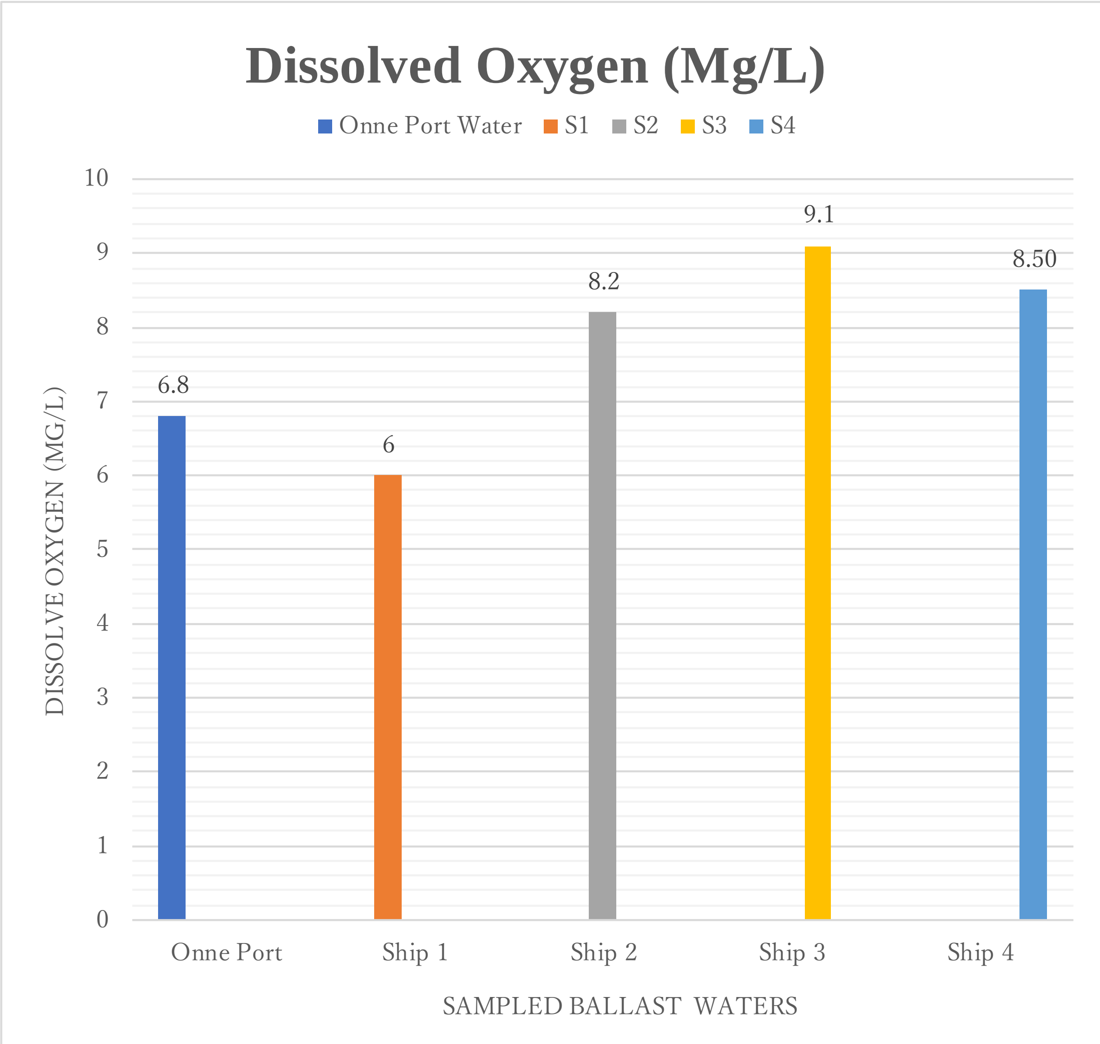

Figure 16. Dissolve Oxygen of sampled ships and Onne port water

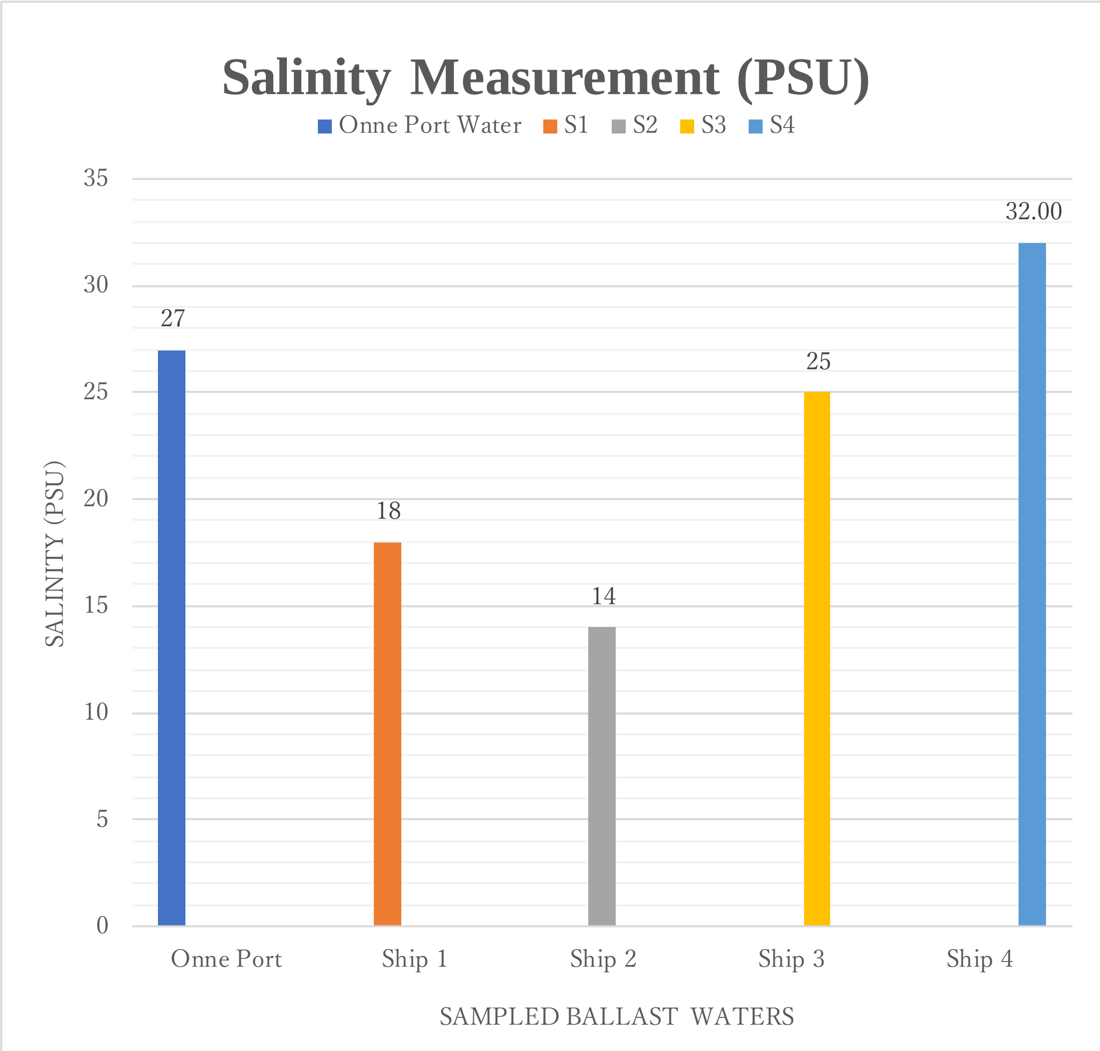

Figure 17. Salinity of sampled ships ballast and Onne port water

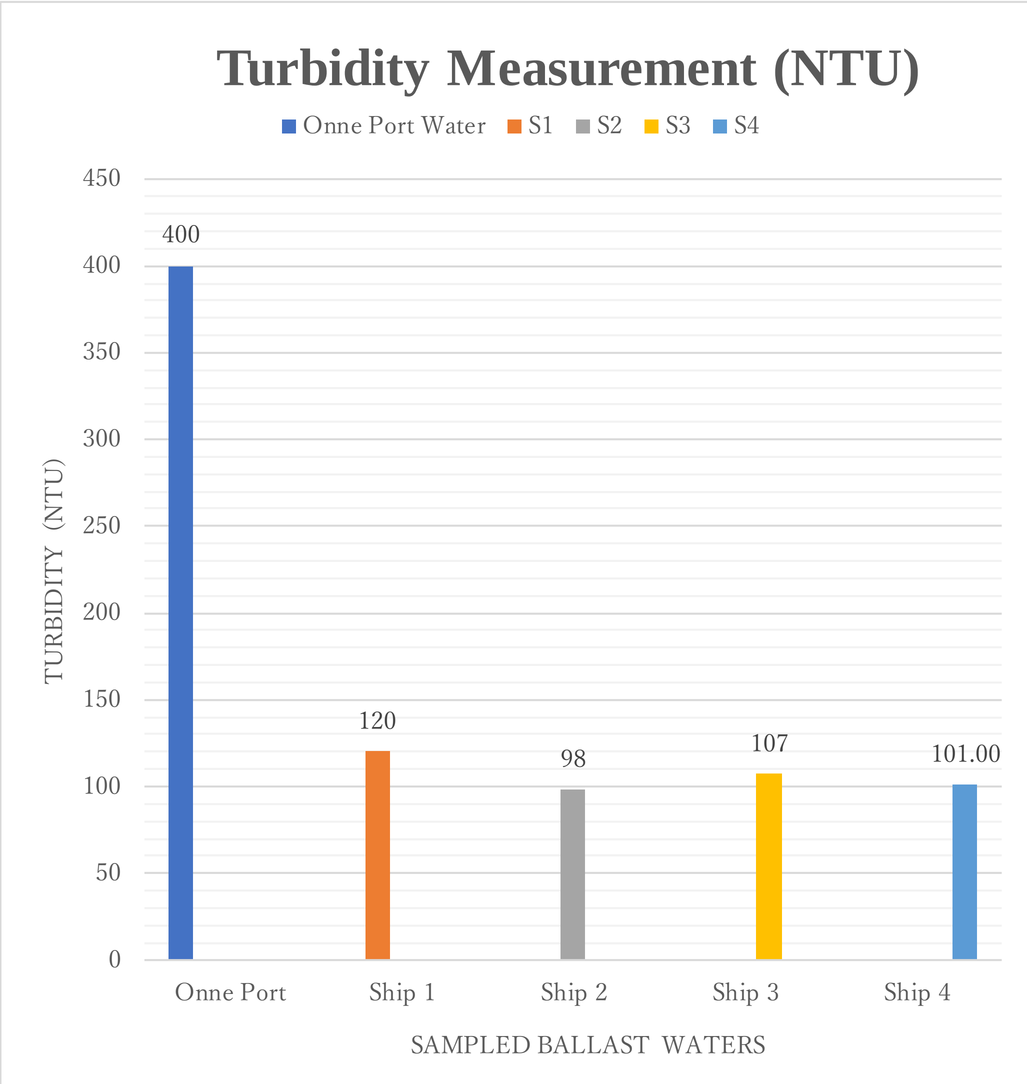

Figure 18. Turbidity of sampled ships and Onne port water

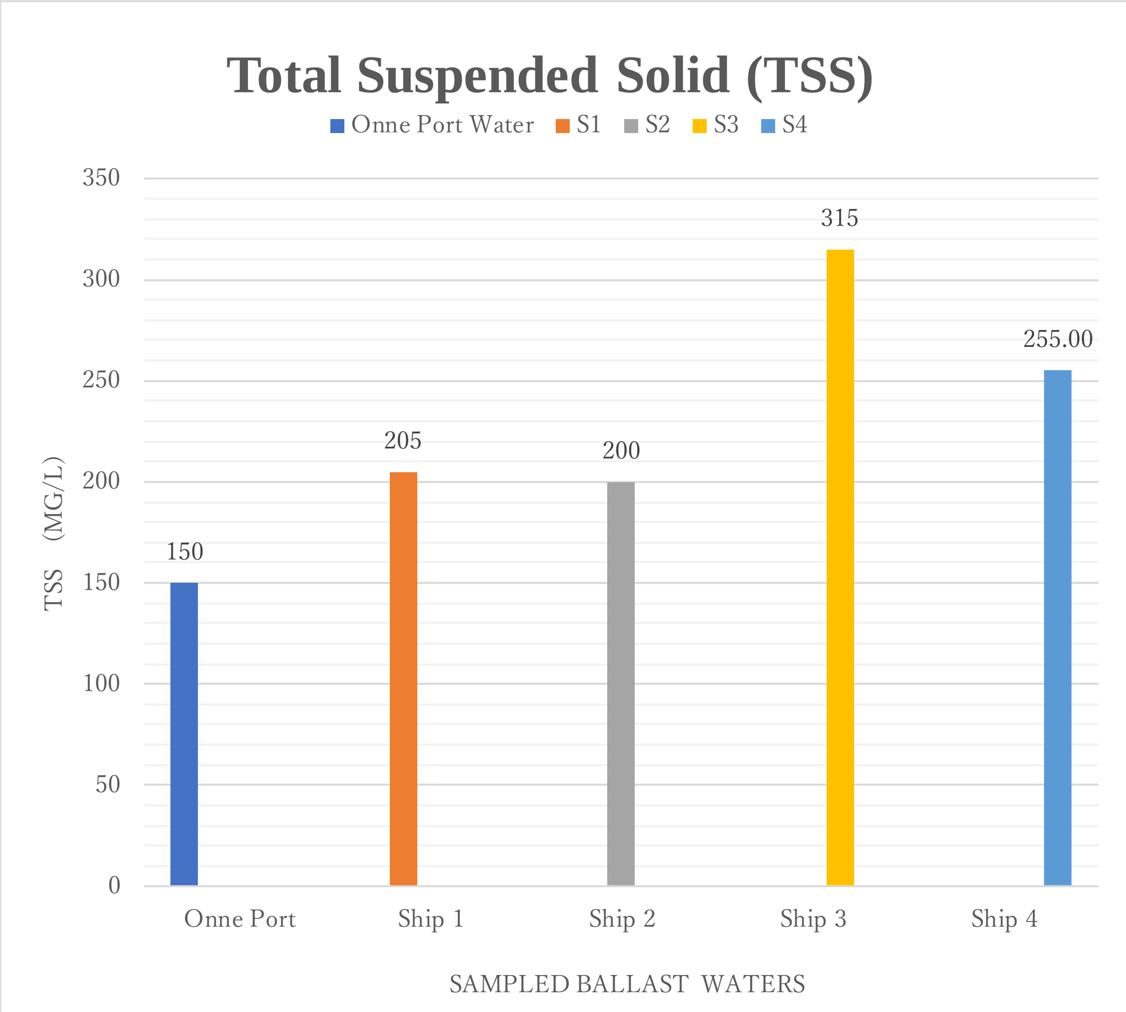

Figure 19. Total suspended Solid (TSS) of sampled ships and Onne port water

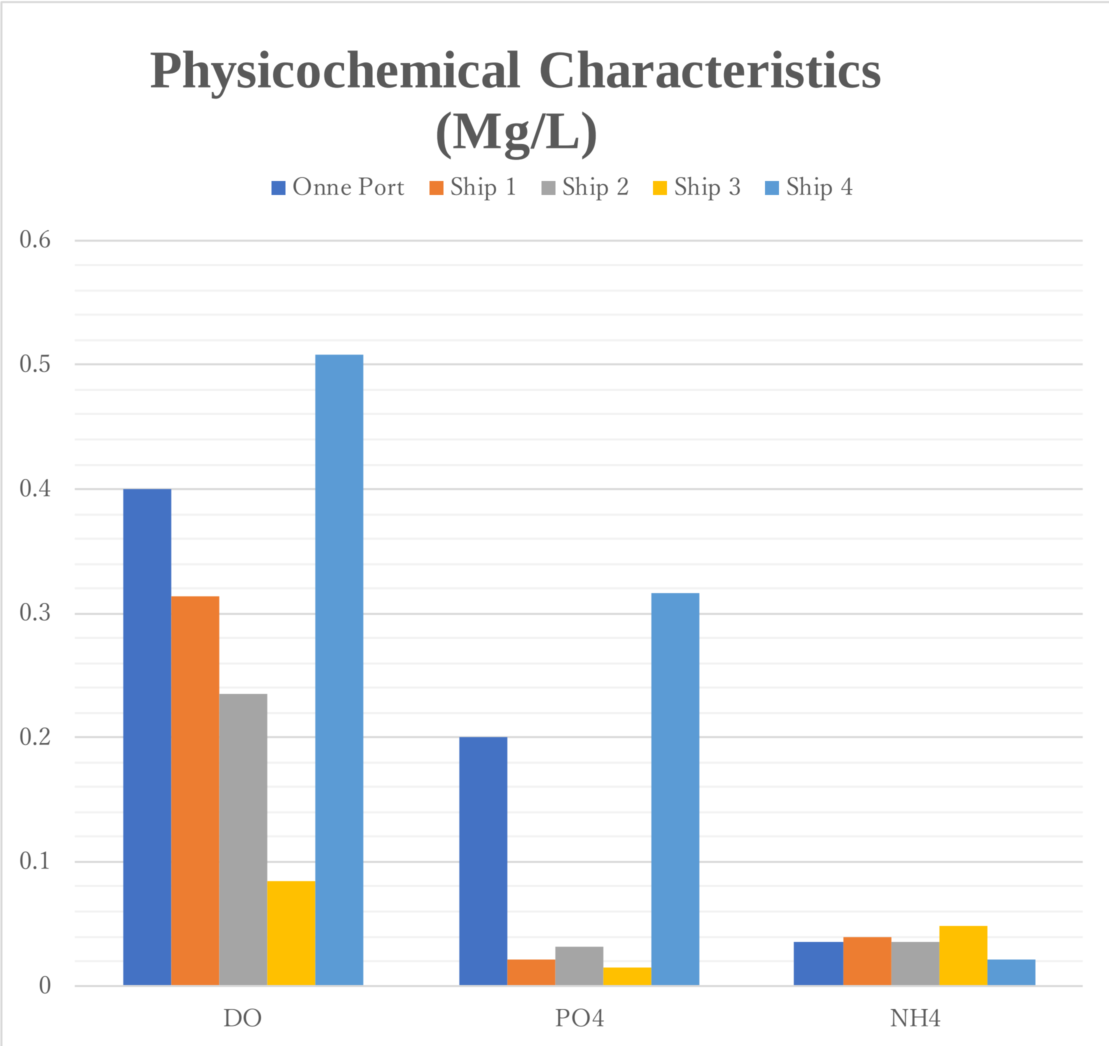

Figure 20. Nutrient values of sampled ships and Onne port water

	Temp	pH	DO	Salinity	Turbidity	TSS	NH4	NO3	PO4	Zinc	Cadmium	Arsenic	Mercury	Lead	Silver	Iron	Nickel	Copper
Temp	1																	
pH	-0.10932	1																
DO	-0.5593	0.31166	1															
Salinity	0.115397	-0.06007	0.336651	1														
Turbidity	0.958206	-0.15947	-0.36085	0.114617	1													
TSS	-0.52713	0.622276	0.720638	0.538443	-0.52723	1												
NH4	-0.17388	-0.95149	-0.16266	0.12465	-0.13574	-0.40295	1											
NO3	0.810912	-0.02885	-0.78349	-0.46208	0.72561	-0.74997	-0.24101	1										
PO4	0.881504	-0.22716	-0.24928	0.049073	0.978027	-0.56371	-0.06754	0.664244	1									
Zinc	0.200578	0.858119	0.256845	0.394971	0.132364	0.659468	-0.85461	-0.0096	0.016806	1								
Cadmium	-0.13639	-0.96492	-0.18169	0.107481	-0.09368	-0.44141	0.998806	-0.20225	-0.02288	-0.86547	1							
Arsenic	-0.08824	-0.97762	-0.21354	0.091336	-0.04456	-0.4848	0.994775	-0.15283	0.02603	-0.8721	0.998523	1						
Mercury	-0.14939	-0.9622	-0.19158	0.084382	-0.10978	-0.44789	0.998679	-0.1985	-0.03889	-0.87546	0.9996	0.997852	1					
Lead	-0.674	0.362856	0.955093	0.435947	-0.54254	0.868672	-0.14889	-0.89648	-0.47416	0.326742	-0.18015	-0.22268	-0.18786	1				
Silver	-0.09711	-0.97564	-0.21041	0.090354	-0.05401	-0.47959	0.995604	-0.15948	0.016643	-0.87281	0.998944	0.999955	0.998428	-0.2177	1			
Iron	-0.12674	-0.96841	-0.19984	0.087009	-0.08559	-0.46184	0.997729	-0.18162	-0.01478	-0.87465	0.999701	0.999152	0.999703	-0.2009	0.999497	1		
Nickel	0.936536	-0.01785	-0.2828	0.084382	0.987998	-0.44789	-0.27568	0.718376	0.968183	0.240751	-0.23408	-0.18604	-0.25	-0.47363	-0.19534	-0.22635	1	
Copper	-0.24008	-0.93476	-0.10154	0.096919	-0.18721	-0.37381	0.996572	-0.29061	-0.10593	-0.86955	0.994142	0.987706	0.994757	-0.09318	0.988989	0.992635	-0.32133	1

Figure 21. Correlation Analysis of Physiochemical Parameters

4.5. DISCUSSION

The result of the physiochemical analysis conducted on the ballast water samples shows variance in concentration of heavy metals were find in all samples of ballast water collected in the order of ship 4 > ship 3 > ship 2 > ship 1 , as depicts from **Fig 2** to **Fig 8**. The average temperature observed for the sample of Onne port water 28.65 °C which indicates a normal temperature considering the season and time of sample collection; However, there are some variant differences among the temperature of the ballast waters from the different ships, as they range from 17.40 to 21.5 °C. While Ship2 (S2) and Ship3 (S3) has the lowest temperature compared to those of ship4 (S4) and ship1 (S1) and what this suggests is that the temperature tends to be become higher with shorter distance journey by the ship. As for the turbidity, their values of ballast water samples ranging between 86.0 NTU to 121.4 NTU, while that of port water is slightly higher than expected. The pH values of the Onne Port water sample recorded were between the range 7.3 to 7.9 and slightly alkaline and were within the permissible level for the survival of aquatic organisms. While the pH values of the sampled ballast water were found to be non-homogenous among all the samples collected from the four ships. In terms of salinity Ship1 (S1) and ship2 (S2) have a lower salinity ranging from 14 to 32 PSU, which implied that their ballast water exchange where not perform effectively or had exchanged ballast water in coastal waters of Onne port, while ship 4 (S4) has the highest salinity, followed by Ship 3 (S3). The nutrient concentrations, including NO2, NO3, and PO4 for all ballast water samples, fluctuates relatively between 0.040 mg/l and 0.508 mg/l, with the highest values obtained from the Onne port water, which is cloudier and more suspected to be caused by particles and oil spilled from the nearby oil wells in the region. The result of the Pearson's correlation analysis performed to determine the relationship between the concentration of heavy metals and the physicochemical parameters measured for the ballast water sampling between the ships (S1, S2, S3 and S4) and Onne port water samples, shows a complex correlation, which can be due to the varying ballast water management system or as a result of sources of ballast water. However, a significance positive correlation at $p < 0.1$ exist between the heavy metal Cd, As, Hg, Fe, Ni and Cu. Also, Pb , Zn , TSS, DO and hydrogen ion concentration has a significantly negative correlated ranging from $p < -0.1$ to -0.9. Moreover, Cu, Cd, and Pb were significantly correlated, while no clear correlation was found between PO_4 and heavy metals. It can be deduced that the heavy metal concentration in ballast tank sediment was caused by complex and different contamination mechanisms, and the corrosion of ballast tank played an important role in accumulation of heavy metals. Based on the results of the Pearson's correlation analysis, it can be assumed that the heavy metals concentration in both the port water sample and ballast samples obtained from ship S2, S3 and S4, where the results of the polluted waters where ballast water exchange had taken place. These areas are seriously polluted by heavy metals from discharged oil spills from oil and gas exploration sites and pipeline and may find their way into the ballast tank during ballast water exchange. Since most of the ships operated in these regions were old and their ballast tank may be affected by corrosion on the hull metal plates. Another reason may be because of the constant discharge of industrial affluence and wastewaters discharge in the region that may find their ways back into the coastal water ways.

4.6. CONCLUSION

In this study, we have examined the physiochemical parameters among ballast water obtain from the selected ships and Onne port water and it is evident that ballast water delivered in the Onne Port contains different heavy metals contaminations. The result can be attributed to the non-uniformity in their ballast water management system and compliance level, particular for vessels operating in the coastal waters and may lead to ecological risks to the aquatic ecosystem. which may affect the aquatic ecosystem directly or indirectly. The presence of high concentrations of Pb and Zn detected in the ballast water and Onne port water will have significantly adverse effects on the aquatic organisms that may affects the maritime ecosystem. The major sources of heavy metals in the study area can be possibly attribute to the poor compliance among shipping operators, the open wastes disposal activities and direct contamination of the water by oil and gas spill discharged in the study area. In managing these ecological risks posed by the impacts of heavy metal contamination and preventing risks of heavy metals on marine ecological environment through the secondary spreads of these contaminants, there is an urgent need for the implementation strict management measures and monitoring strategy for achieving a sustainable maritime ecosystem. It is recommended for maritime authorities to adopt management strategy such as port based or barge-based system in managing the ballast water, particularly for ships operating within coastal waters and entering from others neighboring countries in the coast.

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CHAPTER 5.
STUDY SUMMARY AND CONCLUSION

5.1. SUMMARY

The shipping industry is one of the greatest risks for the introduction of toxic sediments and non-invasive species (NIS) into the marine ecosystems. The Nigerian coastal water, which is one of the most important economic hubs and densely populated coastal area in Africa, is likely to be at great risks of non-indigenous marine invasive species and toxic sediments, as a consequent of the poor ballast water management practices among shipping operators in the region. This study has assessed the ballast water management problems in Nigeria, with greater focus on shipping operators in the region and their compliance to the convention, as well as the risks posed to the region. Although, the current IMO D-2 standards are certainly a step forward, but despite the strict international and national ballast water management regulations that has been put in place, significant amounts of shipping operators are still operating without ballast water management treatment system. The challenges hindering the implementation and compliance of ballast water management convention among selected shipping operators and resulting to the risk of NIS introductions has been studied, to enable a proper understanding and management of the problem. The information's provided, based on the region's perspective in this study has provided some useful insights on the present situation and challenges hindering the compliance of ballast water management, as well as proposing recommendations for achieving compliance and preventing the potentially toxic substances from ballast sediment in Nigeria. There is optimism that D-2 standards will help to prevent introductions, but there is concern that more efforts are current needed in terms of the development of ballast water treatment systems that can work for all aquatic ecosystems (e.g., freshwater, brackish water, and saltwater). It has become evidence that the failure in achieving compliance is because of several shortcomings from shipping operators and policy regulators and if appropriate measures are not taking towards achieving the compliance of ballast water management in Nigeria, both human health and marine ecosystems will be at great risks. Ballast water management convention is intended to limit and control the risks involved in the ballast water problem but unfortunately, there is no effective management measures of the ballast water convention in this region. In order to effectively implement the ballast water convention and achieve compliance among shipping operators, a stronger regional institution with the establishment of proper monitoring system for ships entering the coastal waters should be setup. In addition, a stricter standard for the enforcement of ballast water management, should be setup, with a working mechanisms, coordination and cooperation between all related governmental agencies, ministries, policy makers and shipping regulators in the region.

5.2. CONCLUSION

In the framework of this study, the ballast water problems and challenges hindering shipping operators in Nigeria have been evaluated. The risks and vulnerability of the coastal waters, due to the non-compliance of ballast water from shipping operators, resulting to the discharge of sediments in the coastal waters have also been assessed and the results of this study have been presented. It is paramount to state that, the Nigeria government should act fast in regard to compliance enforcement and managing this problem by developing appropriate ballast water treatment system. Although, there are currently many treat approaches been practiced, but any treatment approach should be easily supervised by the port authority and assessed by all shipping operators in the region. Hence, it is recommended that the treatment such as the port base or reception facilities should be established at an affordable cost to local shipping operators, establishment of standard ballast water sampling and testing laboratory, development of effective regulations and monitoring system for shipping operators, establishment of authorized classification societies with working agreement with NIMASA, application of stricter standards in areas with higher risks of exposure, calibration of testing equipment's and sampling methods will results to a higher ballast water compliance level. Also, more research and technology are still needed to be carried out on improving the currently ballast water treatment system, as there has been instances, where certain type-approved treatment systems have been reported being non-compliant to the IMO discharge standards.