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Identifying and Overcoming Challenges Towards Management of Ship-Generated Waste in Indian Ports

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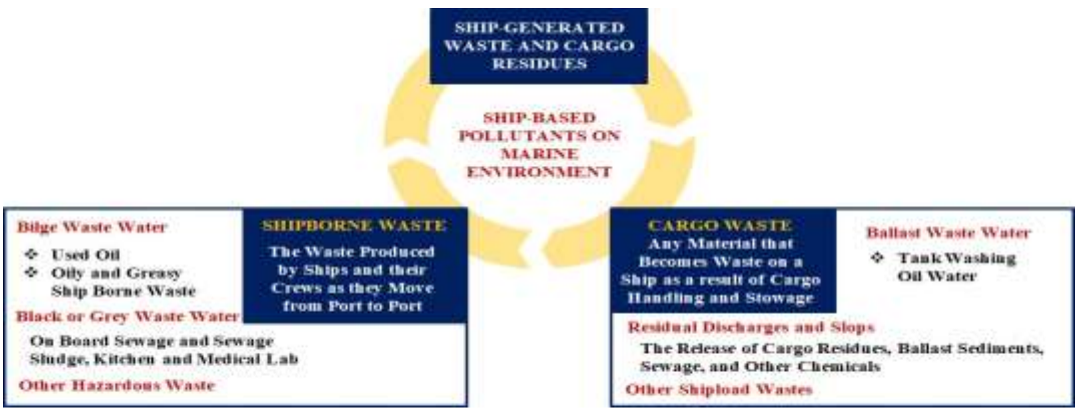
Abstract: *The management of waste received from ships at Indian ports plays a significant role towards the sustainable development of the maritime industry and aligns with the United Nations Sustainable Goals. Port Reception Facilities (PRFs) are arrangement that any port should offer for the collection of operational discharges like oily mixtures, residues, and garbage generated from a seagoing vessel. There was inadequate research that investigated the adequacy of PRF for Indian ports. Thus,* ***,*** *examining the adequacy of PRF in the ports of India with an emphasis on major ports is the aim of the study. The barriers to the effective management of waste in the major ports are also identified in the study from PRF plans of major ports of India, reports published by DG Shipping and Indian Port Association (IPA), and secondary data published by various journals and research articles. In the study, a qualitative approach is used. Alongwith that, the study finds that Indian major ports are required to provide more types of PRF for MARPOL compliance. Only 38% of the Advance Notification Forms (ANF) were converted into the delivery of waste in Indian ports for the calendar year 2022. Further, the study explores the policy initiatives like Ministry of Ports, Shipping, and Waterways (MoPSW) implemented and offers recommendations, such as the adoption of green technologies to optimize PRF in India.*
Keywords: *Port Reception Facilities, Sustainable development, MARPOL, Inadequacies, Waste Handling, Green Ports, and Swachh Sagar Portal.*

1. INTRODUCTION

The goal 14 of "The United Nations Sustainable Goals" Life Below Water focuses on conserving and sustainably using the oceans, seas, and marine resources. Target 14.1: 'Reduce Marine Pollution By 2025', prevent and significantly reduce marine pollution of all kinds, including marine debris and nutrient pollution. The waste produced by ships is one aspect contributing to the upsurge in negative influences of shipping (Sanches et al., 2019). The development of marine transport, global trade, and the size of ships have increased the risk of pollution from ships in the form of operational discharges, leading to a greater need to conserve the marine environment (Ringsberg & Cole, 2020). Numerous environmental threats may be created on account of the nature and range of the products, activities, and services conducted in the port area, which contributes to the port's environmental footprint (Puig et al., 2022). The wastes from the ships are regulated incidentally within the MP regime, and ship-source pollution prevention relies on the provision of sufficient PRF on land (Argüello, 2020). Marine garbage, oil residues, wastes from ships, and several other similar kinds of waste may have detrimental impacts on marine ecosystems (



Kaptan et al., 2020). Figure 1 depicts the classification of SGW.
Figure 1: Ship-generated pollutants

Adequacy of PRF is critical step towards the mitigation of the SGW's environmental influence is a well-developed Waste Management (WM) plan. Without them, ships would have to find other ways to dispose of the waste, causing more pollution (Osmundsen, 2023).

The MP at sea has always been an environmental concern. The 1st international attempt to regulate oil pollution produced by ships was the International Convention for the Prevention of Pollution of the Sea by Oil, 1954 (OILPOL Convention). Nevertheless, as it focused solely on oil and neglected other significant pollutants, such as chemicals, sewage, garbage, and air emissions, it was limited. It also lacked strong enforcement mechanisms, relying heavily on self-reporting by ships and leading to non-compliance. The absence of mandatory PRF was another major drawback, making it difficult for ships to discharge waste properly (Szepes, 2013).

To overcome these shortcomings and expand the scope of MP control, MARPOL 73/78 was introduced. MARPOL mandates that adequate PRFs should be provided by the ports to receive waste from ships safely and efficiently. Ships should maintain comprehensive records of waste handling, and any complaints about insufficient port facilities are addressed through the IMO's Global Integrated Shipping Information System (GISIS).

MARPOL encompasses 6 annexes addressing various kinds of ship-related contamination at the ocean. Five of the MARPOL annexes have regulations directly associated with the provision of sufficient PRF. MARPOL indicates that port States should make sure that there are adequate PRFs throughout the area to aid with convenience. MARPOL doesn't recommend specific procedures for handling waste as operators of the ship can choose the PRF they utilize; given that they have adequate storage capability.

The IMO through MEPC circulars has developed guidance for PRF users and providers to assist them in complying with MARPOL. This guidance comprises good practices for ships and PRFs and standardized formats for reporting inadequacies, notifying port operators, and waste delivery receipts. The IMO has a simplified reporting form that ship masters can utilize for reporting insufficiencies in PRF. The shipping community along with PRF providers carry out the operations centered on the guidelines established by the IMO to enhance the effectual delivery of MARPOL garbage and residuals to PRF. The IMO guidelines are,

(a) 2014 Consolidated guidance for PRF providers and users.
(b) Guidelines to ensure the adequacy of Port Waste RFs, MEPC 83(44), 2000.
(c) 2011 Guidelines for RFs under MARPOL Annex VI: Resolution MEPC.199.
(d) 2012 Guidelines for the implementation of MARPOL Annex V; MEPC 219.
(e) The IMO manual "Port RFs – How to Do It, 2015.

The Indian Regulatory framework adequately covers the provision of PRF and WM from ship's discharge waste, following international conventions, including MARPOL and Basel conventions on the control of transboundary Movements of Hazardous Waste (HW) and its disposal. India has ratified MARPOL and their annexures. Several provisions of MARPOL are passed in the Merchant Shipping Act, of 1958.

Through the HW (Management, Handling, and Transboundary Movement) Rules, 2016, the provisions of the Basel Convention are implemented to manage waste received from the ship. It ensures the generation, conversion, safe handling, processing, packaging, treatment, storage, usage reprocessing, transportation, gathering, and contribution to the sale, destruction, and discarding of HW. These regulations ensure that waste is handled, stored, and disposed of in an environmentally responsible manner (Rani & Srivastav, 2022). These rules' salient features are the categorization of hazardous substances into three classifications centered on their probability of causing harm to the environment and human health. The rules necessitate the maintenance of records and submission of annual returns to the Central Pollution Control Board (CPCB) and the State Pollution Control Boards (SPCBs) (Ministry of Environment, Forest and Climate Change, 2016). These are supplemented by the management rules on solid, plastic, battery, and e-waste rules by the Ministry of Environment, Forest, and Climate Change, the nodal agency to implement rules for end disposal of waste ashore.

The Directorate General of Shipping (DGS) has aligned its approach with international guidelines set by the MEPC to ensure that sufficient PRFs are provided by the Indian ports. The "Swachh Sagar Portal" has been started to gather data related to operational waste onboard ships. Assessing how regulatory frameworks, such as MARPOL and the International Maritime Organization (IMO). According to MEPC, adequacy means that ports should meet the operational requirements of visiting vessels and can receive the sorts and amounts of waste typically produced by them. These operational needs are further clarified by the resolution MEPC 83(44). Advance notification is the important aspect of PRFs. This advance notice assists in ensuring timely and efficient WM without causing delays to ship operations.

Moreover, the need for regular review of data collected through advance notifications is highlighted by Resolution MEPC 83(44). This data allows ports to assess the sufficiency of their waste RFs and supports efficient WM planning (IMO, 2000).
Furthermore, the government initiatives and funding programs, including the role of the MoPSW in improving the efficiency of PRF, are discussed in the study. Additionally, suggestions for improving the PRF in major ports of India are provided in the study.

2. LITERATURE REVIEW

Athanasios A. Pallis et al. (2017) examined the PRF of the Mediterranean and its bordering seas. Through an online survey, the data regarding the practices, operations, and availability of PRF were gathered. The questionnaire data was garnered from 40 MedCruise port entities. The surveyed ports had Reception Facilities (RFs) for several sorts of waste, including food wastes, cooking oil, animal carcasses, operational wastes, plastics, incinerator ashes, cargo residuals, fishing gear, and domestic wastes. According to the study, the fee concerning the garbage type had no significant differences. Further, the fee was low when the garbage was delivered segregated. Nevertheless, the study did not compare the results, which provided less information about the port WM system.
Nurullah Ozdogan et al. (2024) aimed to analyze an approach to improve the properties of sludge produced in the course of the process of bilge water treatment. The study was carried out at Haydarpaaa PRF in Istanbul, Turkey. Also, it utilized a radial-effect uninterrupted ultrasound system. The sludge composition, concentration, and sample homogeneity affected the efficacy of the ultrasound treatment. According to the study, a lower total organic carbon content was provided by 400 W/L ultrasound for 20 minutes. Based on the ultrasonic power, sonification improved the total dissolved solids and chloride levels. The study did not use multiple ultrasonic reactors, increasing the disposal costs.
Gbadamosi Kolawole T et al. (2020) analyzed the criteria to find out the adequacy of PRF in Nigeria. Through the structured questionnaire, the data was collected from 160 workers of the Nigeria Maritime Administration and Safety Agency, the Port Pollution Control Department, African Circle Pollution Management, and ship captains. By utilizing descriptive statistics, the data was examined. As per the study findings, the efficiently handled wastes were oil bilge water, sludge, slops, sewage, plastic, operational waste, and cargo waste. Furthermore, in solid and liquid waste categories, the segregation of waste was practiced adequately. Nevertheless, there were insufficient facilities to handle the wastes, including cooking oil, incinerator ash, animal carcasses, municipal waste, and dirty Ballast Water (BW).
Kayode Peters John and Amedu Nosa Marvis (2019) concentrated on the assessment of PRF and WM control in Nigeria. To collect and analyze data, the study used both quantitative and qualitative methods. The data required for the study was acquired via a questionnaire. The study unveiled that Tin Can was the 2nd major port in Nigeria. There had been a huge upsurge in vessel traffic, which resulted in an increase in SGW at the port. The data associated with the volume of recyclable materials had not been collected.
Erjola Kec and Osman Metalla (2016) investigated SGW and cargo residuals in Albania. Furthermore, in the study, the resources needed to meet the requirements of the directives and to implement the administrative actions for compliance were analyzed. For the analysis, the study used secondary data. The PRF for SGW and cargo residuals reduced the discharge of this garbage into the sea. As per the study, the ship should deliver all the SGW to the PRF before departure from the port. The ships that didn't deliver the waste devoid of valid reasons weren't permitted to leave the port.
Donatus Eberechukwu Onwuegbuchunam et al (2017) explored the MP sources and the impacts of ship-centric pollutants on the maritime atmosphere. The research was carried out in Nigerian ports. From secondary sources, the data required for the research was collected. The result of a study was examined based on a theoretical framework. As per the study, the contamination in the ports emerged from black, bilge, and ballast wastewater. Furthermore, the SGW control services as well as waste RFs' provision were contracted out to a private firm without requiring an activity audit. However, based on qualitative design, the study was designed.
Yehonnou T. Fabrice Metonwaho (2018) analyzed the management of SGW and cargo residuals. For data collection, quantitative and qualitative approaches were adopted by the study. The data was gathered from the Republic of Benin's Directorate of the Merchant Marine, the Ministry of Environment, the Port Authority, the municipality of Cotonou, and waste gatherers' firms. According to the study, cruise ships generated more garbage compared to commercial ships. The harmful wastes were combined with other kinds of wastes, gathered through trucks, and disposed of together, thus generating environmental and safety risks. Yet, the study only concentrated on Contonou port, which was not generalized to other ports.

Duygu Ulker et al. (2023) examined the waste reception performance indices of Ambarli and Haydarpasa ports. The study was carried out during the period between 2014 and 2019. From Ambarli and Haydarpasa Ports, the data regarding the port size and waste reception had been collected. In the study, statistical analysis was utilized to analyze the relationship betwixt the number of ships and the garbage reception quantities. According to the study, an important factor in waste generation was the kind of ship. Subsequently, the study showed that the PRF's adequacy was enhanced by the port size, amount of waste discharge, and the type of waste. Nevertheless, the study considered only two ports in the Sea of Marmara.

D. E. Onwuegbuchunam et al.(2017) concentrated on the microbiological and physicochemical features of SGW water from the ships at berth. A total of 9 waste samples were collected from the ships berthed at various locations. Laboratory examination was carried out to analyze the above mentioned features of the wastewater samples. According to the laboratory investigation, the port environment was polluted in Nigeria. The study found that the total bacterial counts were notably higher. Centered on the samples from only 2 ports, including the Apapa port and Calabar port, the study was analyzed.

Nermin Hasanspahic et al (2022) explored the BW Discharge (BWD) profile of the Port of Ploce. The information was gathered from the Croatian Incorporated Marine Information System during the period from July 2013 to January 2022. For the analysis, the BW Risk Assessment (BWRA) approach was utilized in the study. The study found that the major risk factors for assessing the BWD profile were the type and age of the ship, voyage duration, call frequency, donor port salinity and sea temperature, and Deballasting ship's flag. The study found the BWD profile for only one port.

Linda Meijere (2018) aimed to identify the appropriate treatment methodologies for establishing BW and sediment RFs in a liquid bulk terminal. Qualitative research techniques were utilized in the study. Through interviews, the study collected data from the employees of Kymen Vesi Oy. Based on a theoretical framework, the study was analyzed. The sequential and the pump-through methods were used to exchange BW. The study found that the technologies for BW and sediment treatment were coagulation, chlorination, filtration, deoxidation, UV irradiation, and cavitation.

Magda Wilewska Biena and Stefan Anderberg (2018) investigated the sewage reception in the Baltic Sea. The study utilized a case study approach. The data was collected from 22 Baltic ports through questionnaires and interviews. As per the study, the ports were interfaced betwixt the regions regulated by global marine regulations and various rules and regulations on land. To manage the environmental aspects, practices like rendering shore-centric electricity, monitoring air quality, encouraging cruise ships to sort and recycle waste, and sewage and greywater-free offloading were used. The study was only carried out in the Baltic ports.

Irina Svaetichin and Tommi Inkinen (2017) analyzed the cruise SGW handled in the Baltic Sea area. The study encompassed 4 ports, such as Helsinki, Copenhagen, Stockholm, and Tallinn. From 12 participants, the qualitative data used for the study was gathered through semi-structured interviews. Using thematic analysis, the interview data was investigated. The study revealed that due to the growth of PRF, WM plans, and laws and regulations, the effect of waste streams varied. Further, Helsinki as well as Stockholm ports specialized in collecting wastewater from ships. The Tallinn port specialized in collecting oil wastage. Nevertheless, the sample size was limited.

Zinovia Kyramargiou and Ioannis Vardopoulos (2019) explored the adequacy of the PRF of the ships at the port of Corinth, Greece. The study utilized a qualitative approach. Through semi-structured interviews, the data was collected from 7 respondents. According to the study outcome, waste amounts discharged from the ship were decreased in the port of Corinth. Additionally, the economic incentives were not strong for ships to discharge the waste at the Corinth port. Nevertheless, the study included only one port in Greece, while other ports were not included.

Vidya Selasdini and Nafi Almuzani (2022) examined the factors affecting the PRF performance at the Port of Tanjung Priok. In the study, a case study approach was used. Using an unstructured questionnaire, the sample was collected. By utilizing gap analysis, the opinions and anticipations of the port performance were analyzed. The study found that solid waste recovery significantly reduced the quantity of waste treated and input materials for the process of production. Further, the waste oil was treated in the sewage oil treatment method. According to the properties of the contaminants in the waste, the sewage treatment method was selected.

3. Research Gap

Various existing studies described that the PRF did not concentrate on the efficiency of the facilities. Furthermore, none of the conventional studies focused on the PRF in Indian ports. Also, there is a gap in the field of identification of challenges faced by the Indian major ports.

4. Research Objectives and Hypothesis

It is hypothesized that port reception facilities available at Indian Major ports are not adequate and facing various challenges. The research objectives are as follows:

a. Examining the adequacy of PRF of the Indian major ports to fulfil their obligations under MARPOL.
b. Identifing challenges faced by the ports of India in providing PRF and proposing solutions.

5. METHODOLOGY

A qualitative research method is utilized to collect and analyze data as it allows for an in-depth exploration of complex phenomena like PRF. The research intends to explore the adequacy of PRF at the major Indian ports. The legislative framework, with emphasis on the Indian regulatory setup for PRF and management of ships, sourced operational waste to study the efficiency. Further, the study identifies the challenges and barriers to effective WM in ports of India. As a qualitative research, the study utilizes the secondary source of data available through Journals and Research articles on the subject. Through a comprehensive analysis of secondary data, the research has been conducted. This includes a comprehensive review of existing government publications associated with shipping firms, port authorities, regulatory bodies and books, academic journals, and research papers related to the study settings. When studying populations that are hard to reach or engage directly, secondary analysis can be particularly valuable. Furthermore, to collect the data and understand the regulatory framework, various reports by relevant maritime agencies and guidelines by IMO are studied. To understand the type and quantity of waste discharged by ships that come to ports of India, the data published by the Indian Ports Association (IPA) and DG Shipping reports are also studied.

6. Analysis and Interpretation

PRF evaluation is a process of ensuring that ports have sufficient facilities for meeting the necessities of visiting vessels while disposing of ship waste in an environmentally responsible way. This comprises meeting the operational conditions of the facility and the environmental management of the facilities. Hence, an assessment of PRF is required to ensure the compliance of MARPOL towards offering adequate PRF in major Indian ports.

According to the major port traffic report by the IPA, the ports of India have recorded 7,45,313 ships in the year 2024 and the traffic is likely to increase to 7,71,014 in 2025 (Indian Ports Association, 2025). Since the number of ships increases, the requirement of PRF required by them also increases. The quantity and type of waste that is discharged at Indian ports are shown in the below table.

Type of Waste	Quantity Discharged (m3)	Type of Waste	Quantity Discharged (m3)
Oily Bilge Water	35,332.70	Domestic Waste	9,385.25
Oily Residues (Sludge)	75,536.03	Cooking Oil	1,969
Oily Tank Washings	64,360.99	Incinerator Ashes	833.7
Dirty BW	18,440.18	Operational Waste	3,774.80
Scale and Sludge from Tank Cleaning	5,541.50	Cargo Residuals	2,875.37
Annex II: Category X	38,218.90	Animal Carcasses	38.64
Annex II: Category Y	15,426	Fishing Gear	105.9

Annex II: Category Z	16,653.20	E-Waste	450
Annex IV: Sewage	22,395.40	Quarantine Waste	89.4
Plastics	10,633.85	ODS	922.2
Food Waste	3,014.90	Exhaust Gas Cleaning Residues	27.65

Table 2: Quantity and type of waste discharged by ships at Indian Ports

According to the above table, the ports of India are receiving various kinds of SGW. Various waste from ships, including garbage, oil waste, exhaust gas cleaning wash water, BW, sewage, and grey water, are handled by the Indian ports. Food waste, operational and domestic wastes, plastics, goods residuals, incinerator remains, cooking oil, fishing gear, and animal remains are included in the garbage. Ships must comply with the discharge necessities of waste covered under MARPOL Annexes I, II, IV, V, and VI (Jessen, 2025).

Table 3 renders the PRF available in major Indian ports. The table is centered on an in-depth study of PRF plans of major ports of India and is co-related with the data exhibited by the major ports in the GISIS portal of IMO and their respective PRF plans of major ports (IMO, n.d.). The non-availability of facilities is indicated by the red boxes and availability is indicated by the green boxes.

Name of the ports		Mormugao Port (GOA)	Mumbai Port	SPM Port	Paradip Port	Chennai Port	Ennore Port	VOC Port	Visakhapatnam	New Mangalore	Cochin Port	Jawaharlal Nehru	Deendayal Port
ANNEX I – Oil	Oily bilge water / Oily residues (sludge)	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
	Oily tank washing	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
	Dirty BW	Green	Green	Green	Green	Green	Green	Green	Green	Green	Red	Green	Green
	Scale and sludge from tank cleaning	Green	Green	Green	Green	Green	Green	Green	Green	Green	Red	Green	Green
ANNEX II – NLS	Category X/Y/Z substance	Green	Green	Green	Green	Green	Green	Green	Green	Green	Red	Green	Green
		Green	Green	Green	Green	Green	Green	Green	Green	Green	Red	Green	Green
		Green	Green	Green	Green	Green	Red	Green	Green	Green	Red	Green	Green
ANNEX IV – Sewage		Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
ANNEX V - Garbage	Plastic	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
	Food wastage	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
	Domestic wastage	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
	Cooking oil	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
	Incinerator ashes	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
	Operational wastages	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
	Animal carcasses	Green	Red	Green	Green	Green	Green	Red	Green	Green	Red	Red	Red
	Fishing gear	Green	Green	Green	Green	Green	Green	Red	Green	Green	Red	Green	Red
	E-waste	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
	Cargo residues (non-HME) [2]	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green

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	Cargo residues (HME)[2]												
ANNEX VI - Air pollution	ODS												
	Exhaust gas cleaning residues												

Table 3: Port Reception Facilities

A common conversion rate for the waste delivered is provided by the Marine Environment Management Report- 2023 by DGS India. Nevertheless, the data should be based on the type of waste as per different annexes of MARPOL; thus, the efficiency of the PRF with a particular type of waste can be evaluated. For the year 2022, out of 66 ports registered on the Swach Sagar portal, RFs have been supplied by 61 ports. ANF is raised for 49 ports. Only 38% of the total ANF raised is converted into delivery of waste and 65% of it leads to the uploading of receipts (DG Shipping, 2023).

The ports are supposed to upload the facilities available in GISIS and Swach Sagar portals. The Swach Sagar site does not have public access in contrast to GISIS, which renders a public interface. Transparency, accountability, and environmental awareness will benefit from public access to the Swach Sagar portal. All stakeholders should have access to the data that ports post on the facilities they have available. This limits the potential of researchers, environmental agencies, shipping firms, and the general public to evaluate and confirm port compliance with MP standards. Accountability is promoted by making the portal public. Public visibility would encourage ports to maintain up-to-date and accurate data, knowing that it is open to scrutiny. For informed decision-making, analysis, and trend monitoring, environmental researchers and policymakers could utilize the data. Public interfaces are a standard in international systems like GISIS. Providing similar access to Swach Sagar aligns with global expectations for environmental governance.

Based on new IMO guidelines on the sulphur cap, the ships are fitted with exhaust gas scrubbers (Zisi et al., 2021). For the year 2022, very few ports have received the waste as specified in IMO resolution -MEPC 83(44) regarding SGW as per MARPOL annex VI, which Ozone Depleting Substances (ODS) and Exhaust gas scrubber residuals. The major ports that have received the ODS and exhaust gas scrubber residues are shown in the below table. The table also indicates that the ports still do not have PRF for meeting the obligations under Annex VI of MARPOL.

S.No	**Major Port Name**	**Ozone Depleting Substances**	**Exhaust Gas Scrubber Residues**
1	Chennai Port Trust	✓	×
2	Cochin Port Trust	✓	×
3	Kamarajar Port Limited	✓	✓
4	Paradip Port Trust	✓	×
5	Haldia Dock Complex - KoPT	✓	×
6	New Mangalore Port Trust (NMPT)	✓	✓
7	Visakhapatnam Port Trust	✓	✓

Table 4 : PRF for MARPOL annex-VI

The ANF converted to waste delivery regarding total ANF raised by visiting ships to the port is indicated by the ANF conversion rate. Further, the percentage of waste delivery receipts uploaded is the percentage of the number of waste delivery receipts uploaded to the ANF converted to waste delivery. The ship or its representative is supposed to upload the waste delivery receipt for discharging the waste. The percentage of ANF converted into Waste delivery and the percentage of waste delivery receipts uploaded at major ports in India are depicted in the below table.

Port	% ANF Converted to Waste Delivery	% Waste Delivery Receipt Uploaded
Chennai Port Authority	10.70%	45.50%
Cochin Port Authority	64%	66.30%
Deendayal (Kandla) Port Trust	64.20%	36%
Haldia Dock Complex - KoPT	7.20%	2%
Jawaharlal Nehru Port Trust (JNPT)	14.80%	0.90%
Kamarajar Port Limited	36.90%	3.90%
Mormugao Port Authority	42.10%	0.70%
Mumbai Port Authority	33.30%	37.90%
New Mangalore Port Authority (NMPT)	31.10%	79.60%
Paradip Port Authority	36.10%	60.40%
Syama Prasad Mookerjee Port, Kolkata	3.90%	0%
V. O. Chidambaranar Port Trust, Tuticorin	28.80%	43.50%
Visakhapatnam Port Trust	76.40%	78.20%

Table 5: Waste delivery and waste receipt at Major Ports

The comparison of the percentage ANF converted to waste delivery and receipt upload is depicted in the below graph. In addition, the graph shows that the ships are not uploading the waste delivery receipt, which is an indication of non-adherence to regulations or a poor WM plan. It results in the failure of the system of transfer and collection of waste, making it challenging to conduct audits of WM as the loop is not completed and the receipts notes are not being uploaded in the Swachh Sagar Portal.

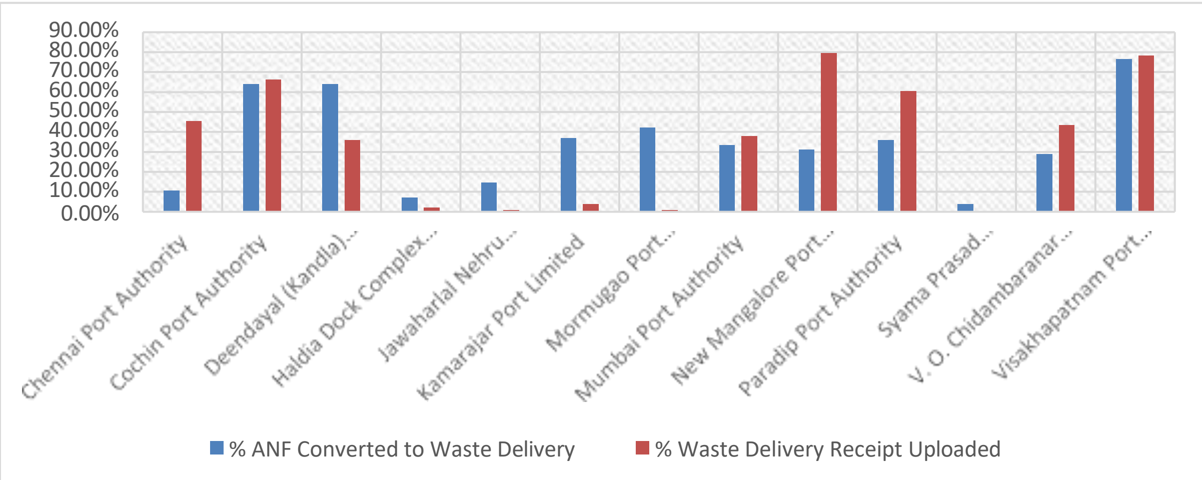

Figure 2: Comparision of %ANF converted to waste delivery and receipt upload

7. Major Findings , Suggestions and Conclusion

7.1 Challenges and Barriers to Effective Waste Management in Ports of India (Findings)

All kinds of waste and cargo residuals produced by ships are typically addressed by the WM plans for ships. Procedures to collect, store, process, and dispose of waste are included in those plans (DNV, 2016). To efficiently manage the variety and volume of wastes generated by ships, many Indian ports lack well-developed PRF. For efficient recycling, segregation of waste at the source is essential; yet, improper handling by ships and ports often causes mixed waste that is difficult to recycle. Some ports don't have sufficient sorting facilities, causing valuable recyclable materials to end up in landfills. Furthermore, ports have limited capability of processing HW, sewage, and oily residues, resulting in delays or improper disposal. Moreover, an environmental risk is posed by the limited availability of specialized treatment plants for hazardous and chemical waste (Vaneeckhaute & Fazli, 2020). The absence of advanced waste treatment plants within the port premises forces ships to either store waste for long periods or resort to illegal discharge into the sea (Argüello, 2020).

Significant investment is required for the establishment and maintenance of waste reception, segregation, and treatment infrastructure. Moreover, the cost of waste disposal and recycling services is higher, and some ship operators may be reluctant to pay designated waste disposal fees. Weak enforcement mechanisms remain a challenge despite strict MARPOL regulations and national environmental laws. To ensure compliance from ships, some ports lack sufficient regulatory oversight. Sometimes, inspections are infrequent or ineffective, allowing ships to discharge waste improperly. Also, limited monitoring of waste disposal companies can result in unauthorized disposal approaches, encompassing dumping in unregulated areas. Several ship operators, especially smaller or foreign-flagged vessels, may not be fully aware of waste disposal regulations at Indian ports. Some ships fail to report waste discharge requirements in advance, leading to inefficiencies in the handling of waste. In addition to that, due to a lack of awareness or unwillingness to pay for waste reception services, illegal waste disposal practices, such as direct discharge into the ocean, continue to be a concern (Dabrowska et al., 2021).

Smooth waste disposal and recycling operations can be hindered by delays in waste collection, lack of proper documentation, and inadequate tracking systems. For planning and improving WM facilities, accurate data on the sort, quantity, and disposal methods of vessel waste is essential. However, many Indian ports lack detailed waste tracking systems, causing challenges in monitoring waste flows and ensuring compliance with environmental regulations. Authorities struggle to measure the effectiveness of WM efforts without proper data collection (Lorenzon, 2020). Collaboration between port authorities, waste disposal companies, regulatory bodies, and ship operators is required for effective WM. Yet, inefficiencies are caused by poor communication and lack of coordination among these stakeholders.

Many ports still depend on traditional WM approaches instead of investing in sustainable technologies, comprising Waste-To-Energy (WTE) conversion, biogas production, or advanced recycling systems. Adoption is discouraged by the high initial investment required for eco-friendly WM solutions although they offer long-term benefits in reducing environmental impact (Deja et al., 2018). The disposal of different types of garbage may be prioritized by different port states, leading to inconsistencies in WM practices and potentially causing environmental problems.

7.2 Methods to Overcome the Challenges (Suggestions)

In order to have sustainable use of marine environment it is important to efficiently manage waste discharged from ships for environmental sustainability and regulatory compliance at Indian ports. Several challenges faced by ports can be addressed through infrastructure upgrades, regulatory improvements, stakeholder collaboration, and sustainable WM solutions.

Numerous ports have lacked adequate PRFs in recent times, thereby resulting in inadequate handling of different types of ship waste. To conquer this, ports must invest in modern PRFs equipped with advanced infrastructure, such as oil-water separation units, sewage treatment plants, and dedicated HW disposal zones. Furthermore, to prevent ships from illegally dumping waste at sea, PRFs should be expanded to both major and minor ports. The efficiency can also be improved by establishing direct links between PRFs and WM plants, namely recycling plants and waste treatment centers. Mobile PRFs, such as barge-based units, can be deployed in areas where space is limited to collect and transfer waste for treatment. A significant challenge in recycling, particularly in the shipping sector, is the lack of proper segregation of waste. Several measures can be taken to enhance waste separation and recycling rates. Initially, mandatory waste segregation on ships is significant, where waste is separated at the source into categories. In addition, to separate and direct waste to the correct treatment facilities, ports should have dedicated waste sorting stations with trained personnel. Recycling rates can also be significantly improved by investing in advanced recycling technologies, such as WTE plants, biogas systems, and pyrolysis for plastic waste conversion. Moreover, encouraging circular economy practices by recovering and reprocessing materials like metal, plastic, and oil can diminish dependency on landfilling and encourage sustainability.

Ports experience budget limitations, hindering their capability of effective waste management. The Indian government can play an essential role through the allocation of financial grants, subsidies, and low-interest loans to support port WM projects. In addition, Public-Private Partnerships (PPP) can be leveraged, which engages private investors and WM companies in Build-Operate-Transfer (BOT) models to ease financial burdens on ports. Revenue for port WM can also be generated by implementing a standardized waste disposal fee for ships based on their waste volume. Also, as selling recovered materials such as reprocessed oil, scrap metals, and recycled plastics can provide a significant source of income, adopting cost-reduction strategies through recycling can help offset operational costs (Intovuori, 2020).

In Indian ports, improper waste disposal has resulted from the weak enforcement of environmental laws. Several measures can be taken to strengthen compliance and prevent such practices. Initially, stricter inspections and monitoring by the DGS and port authorities, comprising regular audits and surprise inspections, are required to ensure compliance with MARPOL and national WM laws. Penalties for non-compliance, namely fines and legal actions against ships failing to discharge waste properly, can also serve as a deterrent. Transparency and accountability can be enhanced by implementing a digital tracking system, where every ship reports waste discharge electronically through a waste manifest system. Additionally, leveraging surveillance technology, encompassing drones and AI-based monitoring systems, can aid in detecting illegal waste disposal in port waters, facilitating swift action against offenders (Akamangwa, 2017).

The majority of the ship operators are unaware of WM requirements, thus resulting in non-compliance. Mandatory training programs can be regularly carried out for ship crew members, educating them on waste disposal regulations and best practices. Furthermore, ports can render ships with comprehensive waste discharge instructions upon arrival, ensuring that they are aware of the specific requirements. To encourage ships to demonstrate sustainable WM practices, incentives for compliance, such as fee discounts or green certifications, can be offered. By implementing these measures, ship operators can be empowered to effectively manage waste, mitigating the risk of non-compliance and promoting environmentally responsible practices (Abdellaoui et al., 2025).

In ports, effective WM necessitates a collaborative effort between various stakeholders, such as port authorities, environmental agencies, waste collection firms, and ship operators. Several measures can be taken to improve coordination and ensure seamless WM operations. The review and improvement of WM strategies can be facilitated by establishing Port WM Committees, comprising representatives from all stakeholders. Implementing integrated digital platforms can also enhance efficiency by rendering a centralized system for tracking waste disposal status in real-time. Also, smooth operations can be ensured by conducting regular inter-agency meetings, such as quarterly meetings between port authorities, environmental regulators, and private WM firms. Along with that, they can also address any challenges that may arise. Ports can develop effective WM systems by fostering cooperation and coordination among stakeholders, minimizing environmental harm.

For effective planning and management of waste in Indian ports, accurate data is essential. Several measures can be taken to improve data collection. Primarily, the employment of smart waste tracking systems by using technologies, including RFID tags and barcode systems can facilitate real-time monitoring of waste movement from ships to disposal facilities. Secondly, a centralized WM dashboard can be developed in which ports report their waste collection, recycling, and disposal activities, offering a national database for tracking progress. Eventually, regular environmental reports, such as annual sustainability reports, should be published by Indian ports, detailing their WM progress, achievements, and challenges (Khan et al., 2021). Indian ports can make informed decisions, improve WM operations, and diminish their environmental footprint by enhancing data collection and transparency.

To improve PRF efficiency, government initiatives or funding programs are crucial. In India, MoPSW has taken concrete measures that intend to add pace to building capacity and enhance the Indian maritime sector's efficiency. To improve the efficiency of PRF of major ports in India, MoPSW has implemented policy initiatives. These initiatives comprise the Maritime India Vision 2030, the AmritKaal Vision 2047, and Harit Sagar. They specifically concentrate on operational efficiency improvement (Ministry of Ports, Shipping and Waterways, 2024). Ports can register themselves and ships can submit their requirements online to discharge the garbage at ports through the e-portal Swachh-Sagar. Ports can also ensure garbage's final disposal at the state-approved sites and upload essential certificates on the Swachh-Sagar portal. The MoPSW has created guidelines for green ports, comprising using energy-efficient equipment and reducing air pollution. The acquirement of equipment to monitor environmental contamination, acquirement of dust suppression schemes, development of garbage disposal schemes for ships and ports, and the establishment of shore RFs for wastes from ships are included in the green port initiatives. Promoting sustainable and environmentally friendly practices in ports, including the efficient management of waste and energy conservation, is the aim of the Harit Sagar Green Port guidelines. To achieve zero discharge of waste from port operations, waste should be minimized via the 5R concept (Refuse, Reduce, Reuse, Repurpose, and Recycle). To increase the efficiency of ports, MoPSW has used digital infrastructure. MoPSW constitutes State Maritime & Waterways Transport Committees for coordinating the employment of an extensive array of initiatives and systems to improve the PRF in the maritime sector (Ministry of Ports, Shipping and Waterways, 2021).

For reducing pollution in Indian ports, the adoption of Green Technologies for sustainable WM technologies is essential. Several initiatives can be taken to encourage the adoption of these technologies. Initially, WTE solutions, such as installing incinerators with energy recovery systems, can transform waste into usable electricity, mitigating the need for fossil fuels. Secondly, biogas plants can be established to convert organic waste from ships into biogas for the generation of energy. Moreover, to more effectively manage plastic waste, ports can invest in pyrolysis and plastic recycling units utilizing plastic-to-fuel technology. Lastly, waste treatment plants at ports should incorporate renewable energy sources, namely solar as well as wind power, to diminish the carbon footprint and reliance on non-renewable energy sources. By promoting the adoption of these sustainable WM technologies, Indian ports can mitigate the environmental impact and make a contribution to a cleaner, healthier environment. To enhance waste collection, processing, and disposal efficiency, ports worldwide are adopting advanced technological solutions. These innovations not only enhance operational effectiveness but also assist sustainability goals in the shipping industry. Key technological solutions that enhance PRF operations are given as follows (Micheo Navas, 2022),

(a) Adoption of automated waste notification systems shall facilitate ships to submit waste declarations prior to arrival. Reporting is streamlined by systems like SafeSeaNet in the EU, ensuring that PRFs are prepared in advance and reducing turnaround times (Morrall et al., 2016).

(b) To monitor waste levels in real-time, Internet of Things (IoT) sensors may be integrated into waste containers, tanks, and pipelines. These smart systems render automated alerts when facilities approach full capacity, permitting better planning and waste collection schedules. Artificial Intelligence (AI) analytics further enhance efficiency by predicting waste generation trends, thus assisting ports in allocating resources more efficiently (Ait Mouha, 2021).

(c) To meet the strict waste disposal standards outlined in MARPOL 73/78, ports may consider upgrading PRFs with top-notch waste treatment technologies, including Oil-Water Separation Units, Plasma Gasification & WTE Plants that convert ship-generated solid waste into syngas (fuel), mitigating landfill dependency while generating energy for port operations. Scrubber Sludge Treatment Systems to enhance the disposal of scrubber waste from exhaust gas cleaning systems align with MARPOL Annex VI (Makarichi et al., 2018).

(d) Circular economy initiatives have been implemented by the ports, such as Rotterdam and Singapore, converting plastic waste into 3D printing materials for infrastructure development (Nalla, 2024).

7.3. CONCLUSION

In the present study, the PRF of major ports in India was explored. The policy initiatives implemented by the MoPSW were also explored in the study. The challenges to the effective management of waste in ports were also identified in the study. The result identified improper waste separation facilities as the major obstacle to the effective management of SGW. PRFs were essential for ships for the prevention of SGW disposal at sea and thereby assisting in capacity building towards sustainable development of maritime industry. Port States should make sure that there are sufficient PRFs to aid with convenience. Numerous Indian Major ports did not have sufficient PRFs for the collection of waste. In Major ports, PRFs could be enhanced by increasing awareness, standardizing waste segregation, and utilizing digital infrastructure. The barriers to effective WM were inadequate RFs, challenges in the management of certain HW streams, slack usage of shipboard treatment technology, and varying port state priorities for garbage disposal. In the study, recommendations were also provided to improve the PRF in major ports.

Ports should ensure strict implementation of PRF guidelines. Shipmaster must report inadequacies of PRF at the port and must fill ANF for waste delivery to PRF. The waste delivery receipt should be filled by the reception facility provider to confirm that the waste has been handed over according to WM guidelines. The efficiency of PRF could be improved by increasing the waste handling capacity and adopting new technologies in ports.

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