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Identification, classification, and management of ports hazardous waste (A case study: Anzali Port, Southwest Iran)

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ABSTRACT
Guilan Ports and Maritime Administration, located in Anzali Port, Guilan Province, Southwest Iran is one of the most important and active ports of the southern part of the Caspian Sea. The aim of this study is to assess the current state of hazardous and non-hazardous waste management in Anzali Port and provide practical solutions. The study performed from July 2017 to June 2018, to quantify and classify waste generated from various operations, including loading and unloading, repairs, and construction activities. Shapiro-Wilk test was performed to evaluate the normal distribution of data, and the One-Way ANOVA and Tukey tests were used to examine significant differences. The total waste generated was 3,082.200 tons year^{-1}, consisting primarily of wood waste (2,544 tons year^{-1}), steel scrap (344.97 tons year^{-1}), and unusable tires (368.25 tons year^{-1}). The hazardous wastes were categorized based on its characteristics such as toxicity, corrosiveness, flammability, and reactivity, in line with the Basel Convention and the Resource Conservation and Recovery Act (RCRA). Approximately 4% of the waste was classified as hazardous. The findings showed that effective waste management practices could result in the recycling and reuse of approximately 96% of the generated waste, leaving only 4% to be disposed. This study also analyzed the efficiency of current waste management strategies in the port, including waste segregation at the source, recycling, reuse, and the sale of certain waste materials such as metal scrap and used tires. Based on the findings, several recommendations for improving waste management were proposed, including the establishment of dedicated storage facilities for hazardous waste, enhanced waste segregation at the source, and the implementation of staff training programs. The results highlight the importance of adopting a more comprehensive and sustainable waste management strategy to reduce environmental impact and improve resource recovery.

Keywords: Anzali Port, Hazardous waste, Solid waste management, Basel convention.
Article type: Research Article.

INTRODUCTION
In the last decade, the rapid advancement of technology and industries, along with the discovery of the severe impacts of hazardous waste produced by industrial activities, have raised concerns about environmental health (Amirfazli *et al.* 2019). Industrial waste is a major threat to the environment, and its treatment also leads to the depletion of natural resources (Liu *et al.* 2015). On the other hand, many of the characteristics of industrial waste, such as the amount of generated waste and its composition, aggregation methods, and various methods of disposal, need to be carefully implemented by planners and managers, and practical measures must adopt (Souri & Haghi, 2017). However, the recognition and evaluation of the quantity and quality of industrial waste are considered to be the most fundamental part of industrial waste management (Mokhtarani *et al.* 2007; Shahbazi & Sofyanian, 2015; Alidadi *et al.* 2019). Effective and sustainable waste management is gaining more significance in addressing

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these challenges (Sulistiowati *et al.* 2023). This involves creating systems that reduce environmental impact, encourage recycling, and foster community involvement (Sharma *et al.* 2021). Solid waste management is a method that can implement industrial development measures and programs by environmental laws and prevent harmful effects on the environment from solid waste without interrupting industrial development (Pires *et al.* 2011; Lertpocasombut & Sriploy 2017; Song *et al.* 2017). The industrial waste management dates back to the Resource Conservation and Recovery Act (RCRA) in 1976 in the United States (Souri & Haghi 2017). The Basel convention came into force on March 22, 1989, with the aim of obliging member countries to reduce the movements of hazardous waste between nations. The subject matter of the convention was to minimize the amount and toxicity of generated waste and to ensure its appropriate and effective transportation and disposal environmentally. On January 5, 1993, Iran became a party to this convention. In developing countries, solid waste management practices still appear to be inadequate in fully (or even remotely) safeguarding human health (Perkoulidis *et al.* 2023). In this era, the promotion of efficient and continuous waste management programs is limited to inadequate documentation related to the characteristic and amount of generated waste (Olukanni *et al.* 2014). Additionally, many developing countries encounter specific fundamental challenges in solid waste management, which have grown increasingly complex due to factors such as limited resources, rising quantities and toxicity of waste, insufficient or conflicting information for making informed management decisions, an underdeveloped regulatory framework, lack of realistic long-term planning, and inadequate disposal sites (Perkoulidis *et al.* 2023). The relevant studies in this field in Iran, are primarily focused on determining the current state of production and how to deal with industrial waste materials. However, there are no executive strategies to improve their management (Yaghmaeian *et al.* 2013). For example, a study conducted by Mokhtarani *et al.* (2007) on the management of solid industrial waste in Bandar Imam Petrochemical Complex, Southern Iran revealed that approximately 65000 tons of various types of industrial waste are generated annually in this complex. In addition to reducing the amount of industrial waste, the environmental damage will also be greatly reduced if the precise methods of the various stages of the new management of industrial waste at the integrated level are applied (Mokhtarani *et al.* 2007). Another study by Hejri *et al.* (2011) examined the implementation of a solid waste recycling plan for the Ports and Marine Administration of Khuzestan, Southwest Iran, reporting the sources, amount, causes, nature, and current management practices of recyclable waste in the port complex. The results showed that approximately 243237 kg of recyclable waste, including glass, plastic, paper and carton, metal and wood is generated annually. Nasihinia *et al.* (2018) conducted a study on the amount of hazardous waste and its management in industries in Semnan Province, Central Iranreporting that the total amount of produced hazardous waste was 15,140 kg month^{-1}. Anzali port plays a vital role in facilitating the exchange of commercial goods in the region, especially in the fuel, iron, wood and grain sectors. The unique position of the port has been created by the benefits of tree trade zone, the creation of necessary infrastructure, and access to the most significant reserves and resources of the Caspian Sea oil and gas. Considering the capabilities and capacity of this port, the design of new transit routes such as the North-South corridor, and the existence of the Anzali Commercial-Industrial Special Zone, it is expected that the port will play an even more critical role in the future. More than 4 million tons of goods are imported annually, and over 288 thousand tons of fuel and 55 thousand tons of non-oil goods are transported either directly or indirectly through this port. Additionally, it has a roll-on / roll- off ship that facilitates road transport (Port and Marine Administration of Guilan Province, 2018). In Anzali Port, Guilan Ports and Maritime Administration are responsible to provide facilities for receiving and recycling waste materials, as a member of the Marpol Convention (Young *et al.* 1992). Therefore, critical components of proper waste management in the port include complying with waste collecting and disposal rules, ensuring the delivery and disposal of all wastes from ship entering the port, accurate monitoring the process of waste reduction and recycling centers, and raising awareness. Since a significant amount of waste is being generated daily in this complex, this research aims to investigate the current state of industrial waste management and provide practical solutions for optimizing the solid waste management practices in Anzali Port.

MATERIALS AND METHODS

Study area

Anzali Port is located in the southern part of the Caspian Sea. It has infrastructure facilities such as a nominal capacity of 17 million tons and an actual capacity of 7 million tons. The port has ten loading and unloading berths and the ability to accept 942000 tons of goods including wood, grain, iron, etc. The terminals generate various types of harmful and hazardous waste. Fig. 1 shows the location of sampling area in Anzali Port.

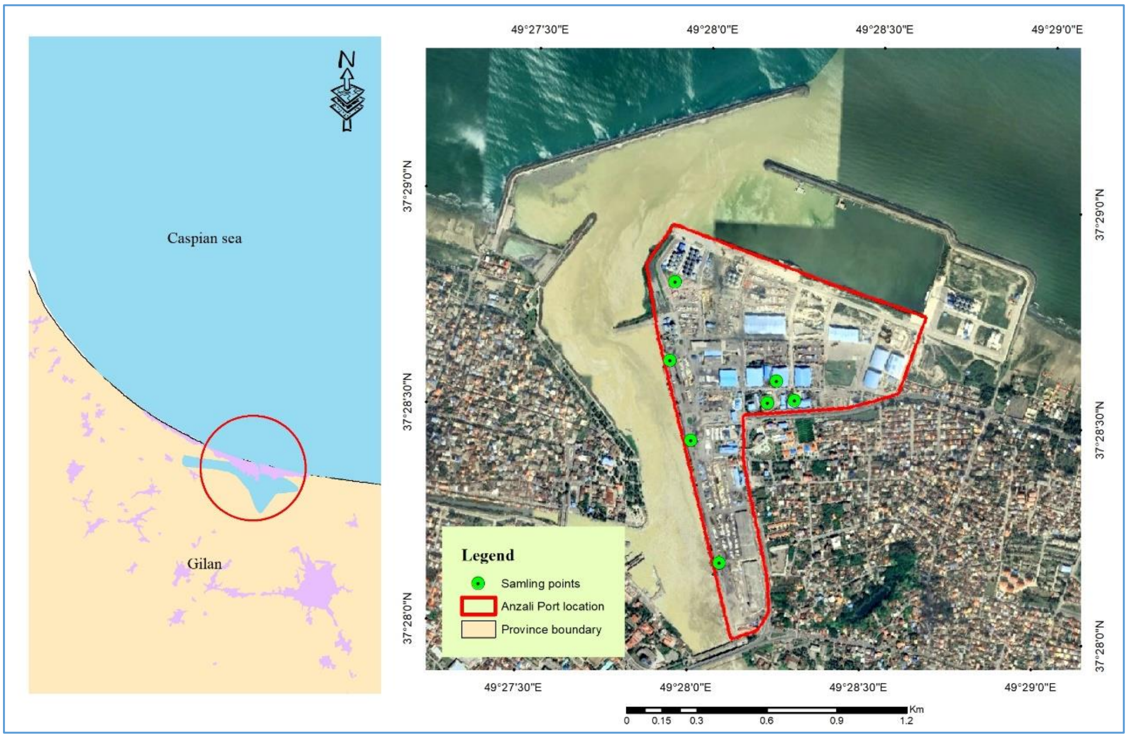

Fig. 1. Location of Anzali Port and sampling locations.

Methodology

Sampling locations

The selection of these three sites—repair shops, construction units, and loading/unloading terminals—was based on their high potential for waste generation as core operational areas at the port. These locations represent the primary activities that contribute to the overall waste stream in Anzali Port, covering a wide range of waste types, including hazardous and non-hazardous materials. The study's focus on the selected sites means that some types of waste, particularly those generated by administrative or non-operational activities, might not be fully represented in the data. Each of these locations was specifically chosen based on the following considerations:

Repair shops. These sites were selected, since they are responsible for the maintenance of port equipment, machinery, and vehicles, which generates various types of waste, such as metal scraps, used tires, oil waste, and industrial sludge. Repair activities are a significant contributor to waste generation in the port, and these shops were included to assess the waste generated from mechanical repairs and maintenance tasks.

Construction units. These units were selected due to the ongoing construction and renovation activities within the port. Construction activities generate a variety of waste types, including wood, metal, and concrete waste. These units are also involved in infrastructure development, which is a major source of waste at the port, especially in terms of construction debris and packaging materials.

Loading/unloading terminals. These terminals were chosen, since they are critical areas of operation where goods are loaded and unloaded, generating waste such as packaging materials (e.g., strapping), wood waste, and other transport-related refuse. The large volume of cargo handled at these terminals contributes to significant waste generation, particularly from the handling of raw materials and goods.

Waste water treatment. Chosen based on generated hazardous waste includes sludge.

Data collection and sampling procedure

To ensure that the sampling accurately represented the waste generation in each area, random sampling method was used. The data collection period spanned 12 months, from July 2017 to June 2018. During this time, waste generated at the selected sites was collected and weighed. Waste samples were taken at regular intervals to ensure accuracy and representativeness. A total of three samples per month were collected from each site. Waste was classified into different categories, including hazardous and non-hazardous waste, based on the Basel Convention and the Resource Conservation and Recovery Act (RCRA) criteria. The waste was analyzed for its composition, quantity, and hazardous nature.

Data Analysis

The samples were analyzed using statistical software, such as Microsoft Excel and SPSS. Shapiro-Wilk test was performed to evaluate the normal distribution of data, and the One-Way ANOVA test and Tukey test were used to examine significant differences. One-Way ANOVA was used to test if there were significant differences in the amount of waste generated across the four sites. Also, the Tukey's Post Hoc Test was performed to identify which specific sites had significantly different waste generation levels.

Waste classification

In this study, the classification of hazardous waste was based on the guidelines set forth by two key international frameworks: The Basel Convention and the Resource Conservation and Recovery Act (RCRA). These frameworks provide a standardized approach to classifying hazardous waste based on certain characteristics, such as toxicity, corrosivity, flammability, and reactivity. The classification criteria used in this study explained below:

Basel Convention classification

The Basel Convention is an international treaty aimed at reducing the movement of hazardous waste between nations and ensuring that such waste is disposed of in an environmentally sound manner. In this study, we used the Basel coding system to classify hazardous waste based on the waste's composition and the risks it poses to human health and the environment. The classification was carried out based on the four primary hazardous characteristics outlined in the Basel Convention: toxicity, corrosivity, flammability, and reactivity. The classification process involves determining which properties of the waste are most relevant for safe handling and disposal. For example, used tires, which are highly flammable and contain toxic chemicals when burned, are classified according to these hazardous characteristics. Similarly, oil waste and industrial sludge were classified based on their toxicity and corrosivity. In Basel Convention, Y codes Used for wastes requiring special consideration under the convention; A& B codes Used for wastes listed in Annex IV and Annex III, respectively; D codes represent disposal operation; R codes for recovery operations; and H codes refer to hazardous characteristics.

Resource conservation and recovery act (RCRA) classification

The RCRA is a United States federal law that governs the disposal of solid and hazardous waste. Under the RCRA, hazardous waste is classified into two main categories: listed waste and characteristic waste. Each waste type is assigned a specific RCRA code, such as F-code for wastes from specific industrial processes, K-code for wastes from certain manufacturing processes, and P-code or U-code for discarded commercial chemical products. These codes help ensure that hazardous materials are tracked and managed according to their level of risk.

Waste management

The waste management system (WMS) is considered to management solutions, such as waste reduce, recycling, and reuse. WMS involves the coordination of all waste management activities, from waste minimization to disposal, recycling, and recovery, with a focus on reducing environmental impact and promoting circular economy principles.

RESULTS AND DISCUSSION

Waste generation

The results indicated that the total amount of waste generated by the repair shops, construction units, and loading/unloading terminals over the study period was 3,082.2 tons year^{-1}. Of this, approximately 4% was classified as hazardous waste, including materials such as used tires, oil waste, batteries, and contaminated soil. The household and hazardous waste is generated as a result of equipment and installations procurement and maintenance, discharging, loading, warehousing of goods, and equipment construction and repair. The waste generation varied significantly across the different sampling sites. Wood waste was the largest component, with approximately 2,844 tons year^{-1} generated at the loading/unloading terminals. Strap waste amounted to 97.347 tons year^{-1} and was primarily generated during cargo handling activities. Used tires, totaling 25.368 tons year^{-1} , were also a significant waste stream, primarily from the repair shops. Table 1 presents the current management of the different generated waste types in Anzali port. According to Table 1, the largest amount of waste is generated by repair shops during their collection, transportation, and temporary storage actions.

Table 1. Evaluation of the current management of various generated wastes.

	Type of waste	Annual production (Kg)	Current management	Production process
1	Metal scrap caused by repairs	11346	Sale	Mechanical repairs
2	Strap	97347	Separation at source production and sale	Loading and unloading
3	Chemical containers	9537	Recycling	Mechanical repairs
4	Metal barrels	7510	Reuse and recycle	Oil and lubricant containers
5	Wood waste	2842000	Separation at source	Loading and unloading
6	Cleaning tissue	5192	Deliver to the municipality	Mechanical repairs
7	Used tire	25369	Sale	Repairs
8	Industrial sludge	1135	Transfer to disposal site	Industrial wastewater treatment
9	Industrial battery	11963	Recycle and sale	Mechanical repairs
10	Oil waste	8837	Recycle	Loading and unloading
11	Waste and replacement oils	21553	Recycle	Fluidization of equipment
12	Contaminated soil	13477	Deliver to the municipality	Mixing while mechanical repairs
13	Recyclable dry waste (paper, carton and cardboard)	4892	Deliver to the municipality	Normal staff activities and opening packages
14	Bottles and plastic waste	5013	Deliver to the municipality	Normal staff activities
15	Food waste	14975	Deliver to the municipality	Employee use

One-Way ANOVA and Tukey test results

The results of the Shapiro-Wake test demonstrated that the collected data followed a normal distribution. One-Way ANOVA was performed to determine the significance generated waste of the four different sampling sites ($p < 0.05$). The results shown in Table 2 indicated a significant difference. The *p*-value obtained from the ANOVA test was less than 0.05 ($p = 0.000$), indicating that there is a statistically significant difference in the amount of waste generated among these sites. This suggests that the waste production varies across different areas of the port, which is an important insight for tailoring waste management strategies to the specific needs of each area.

Table 2. Results of One-Way ANOVA on the generated waste.

ANOVA					
Weight	Sum of squares	df	Average of squares	F	Sig.
Between groups	512000000000	3	170700000000	1141.237	0.000
Inside the group	6580000000	44	149600000		
Total	518600000000	47			

To further investigate which specific pairs of sites differed significantly in waste production, the Tukey test was performed. The comparison of the means (Tukey test) revealed that the loading and unloading docks had the highest amount of waste production (Fig. 1). This finding is consistent with the nature of activities at these terminals, which involve high volumes of cargo handling and frequent material turnover. There were no significant differences between the amount of waste generated at repair shops, construction and repair units, and the waste treatment plant. This suggests that these areas have relatively similar waste generation patterns, possibly due to the specialized nature of the activities conducted at these sites, which might not involve as much raw material handling or large-scale equipment use compared to the loading/unloading terminals.

Classification of hazardous waste

Given that about 4% of the total waste generated is hazardous, these materials can be classified according to various criteria, including waste type, production period, disposal method, and risk level. Table 3 presents the waste categories based on the level of risk and type of material. This classification was based on information obtained from the Basel Convention list (Sousa Ferro 2006), the US Environmental Protection Agency (Fry 1981), and Material Safety Data Sheet (MSDS). A detailed classification of hazardous waste found in Anzali Port is presented in Table 3. The results indicated that 45% of hazardous waste was classified under Basel code Y, 40% under code A, and 15% under code H. The result conducted with a study by Ahrampush *et al.* (2017) that found approximately 4.5% of the waste were hazardous and according to Basel coding system, 55% of the hazardous waste was categorized as Y, 33.3% as A and 22.2% as H. The study by Karami *et al.* (2012), on the management of industrial waste of industries between Tehran and Karaj, revealed that 12% of the average generated waste was hazardous.

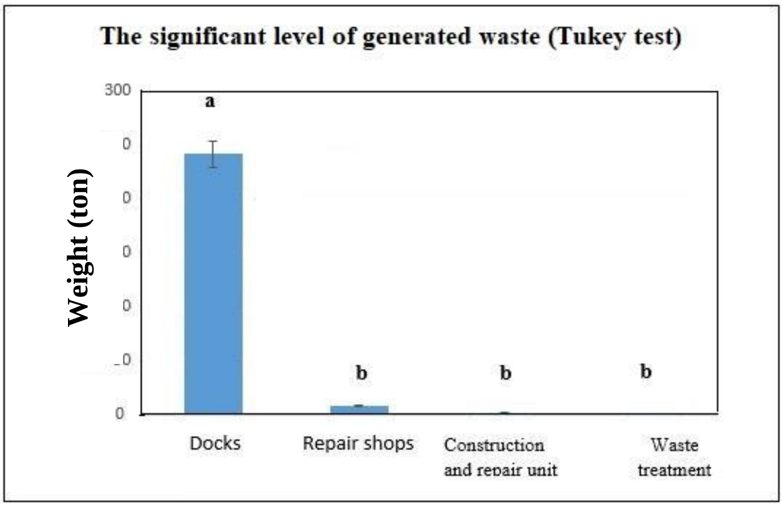

Fig. 1. The level of generated waste in different parts of port according to Tukey test.

Table 3. Hazardous waste classification based on the RCRA and the Basel Convention.

Type of waste	**RCRA**				**Basel Code**	**Amount (Kg year^{-1})**
	Reactivity	**Inflammable**	**Corrosive**	**Toxic**		
	R	I	C	T		
Metal scraps caused by repairs				*	Y9, Y10	**11346**
Chemical containers		*		*	Y34	**9537**
Cleaning tissue		*		*	Y18	**5192**
Used tire		*			Y23, Y26, A1080	**25368**
Industrial sludge				*	Y9, Y18	**1135**
Used batteries			*	*	Y31, A1150, H12	**11963**
Oil waste	*	*		*	Y18, A4060, H12	**8837**
Waste and replacement oils	*	*		*	Y18, H12, A3020	**21553**
Contaminated soil			*	*	Y21, Y23, A1010	**13477**

The main reason for this difference is attributed to projects aimed at reducing waste production, reusing waste, separation waste at the source, and establishing comprehensive integrated waste management systems. According to a study by Niyakan Lahiji *et al.* (2011) on the environmental assessment of the “Guilan Steel complex”, soil contamination primarily occurs due to the loss, leakage and penetration of oily residues, as well as the transit and transport by trucks. This finding is consistent with the results of the current study. As a corrective method for waste management at Guilan Steel Industry, the authors suggested implementing a drain system, appropriate flooring, and proper land usage, which are also recommended for the study site. In this port complex, hazardous liquid and semi-liquid residues are stored in specialized containers until disposal, indicating the port's emphasis on managing hazardous liquid waste. However, no solution is proposed for the hazardous solid wastes, which is currently stacked in an open area until disposal. This issue aligns with the findings obtained by Binavapour *et al.* on waste materials in Hamedan Industrial Town, Central Iran, reporting the absence of dedicated storage facilities for 30% of the generated waste (Binavapour *et al.* 2009). Mesgarof *et al.* (2002) working on Kermanshah Industrial Town, West Iran, highlighted that 86% of industrial waste is also stored in an open area until disposal. These results reflect the industry’s reluctance to invest in proper industrial waste management practices.

Implementation of waste management systems

The study identified several types of waste generated in the port, including wood waste, metal scraps, used tires, and hazardous chemical containers, as shown in Tables 1 and 3. The quantities and characteristics of these waste types directly inform the proposed management methods. For example, wood waste, which constitutes the largest proportion of generated waste (2,544 tons year^{-1}), is proposed to be managed through source separation and recycling, as this method is both cost-effective and environmentally friendly for materials that are easily recyclable. The study found that approximately 4% of the total waste generated was classified as hazardous, including substances like used tires, industrial sludge, and oil waste. Based on these findings, the management methods proposed for hazardous waste including safe storage and disposal methods, as well as recycling and reuse where feasible. The recommended actions for hazardous materials are directly based on the characteristics and risks associated with the specific waste types identified in the study, such as toxicity, flammability, and reactivity. In Anzali Port, the following elements should be implemented as part of waste management system (WMS):

Waste minimization and reduction at the source

Designing waste-reducing processes. For example, reducing packaging materials used in the import/export of goods and encouraging suppliers to adopt eco-friendly packaging.

Waste audits and tracking systems. Establishing a waste tracking system to monitor the amount and types of waste generated at various terminals and docks.

Waste sorting and segregation

One of the primary recommendations for improving waste management in Anzali Port is enhancing the segregation of waste at the source. This would involve establishing clear guidelines for sorting different types of waste, including hazardous and non-hazardous materials, at the point of generation. The waste should be categorized based on its physical characteristics and hazard classification (toxicity, flammability, reactivity, and corrosivity), in line with the Basel Convention and RCRA guidelines.

Anzali Port should enforce mandatory waste segregation at the source (repair shops, terminals, and construction units). This could include providing dedicated containers for different waste streams (e.g., recyclables, hazardous waste, food waste, and general waste).

Conducting regular training on waste segregation for employees and contractors working at the port. This step would ensure proper sorting and prevent cross-contamination of waste streams.

Recycling and resource recovery

Anzali Port should invest in a centralized recycling facility for recyclable waste (plastics, metals, paper, and cardboard).

Establish formal agreements with certified recyclers to ensure that the recyclable waste is properly processed and turned into reusable materials.

The port can explore technologies for converting certain types of non-recyclable waste (such as certain plastics and biomass) into energy through waste-to-energy technologies. This could reduce the total volume of waste sent to landfills and contribute to sustainable energy production.

Hazardous waste management

Given the significant amount of hazardous waste generated at Anzali Port, establishing a centralized hazardous waste storage facility would be an essential step for improving waste management.

The facility should include appropriate containment systems (e.g., sealed containers, bunds) to prevent leaks and spills. Regular inspection of the storage facility would ensure its integrity and safety.

Anzali Port could introduce similar systems for storing hazardous materials, especially oils, industrial solvents, and chemicals.

For hazardous waste, a comprehensive disposal system should be established. This system should ensure that specialized contractors handle hazardous materials and dispose of them according to international standards (such as those outlined by the Basel Convention and RCRA).

Used oils can be filtered, refined, and reused for non-critical applications (e.g., asphalt production). Scrap metals and batteries can be sent to specialized facilities for material recovery.

Policy and regulatory framework

A well-defined policy framework is essential to support the proposed waste management practices. Anzali Port could benefit from:

Develop port-wide regulations for waste management, ensuring consistency in practices across different terminals and facilities.

Introducing incentive programs for employees and contractors who achieve high levels of waste diversion and recycling. Programs like the Port of Oakland’s Green Port Initiative encourage environmental stewardship and incentivize sustainable practices. Working closely with local government authorities, environmental agencies, and international organizations to ensure compliance with national and international waste management standards.

Moreover, the most critical practical solutions for reducing the amount of generated waste were mentioned in Table 4:

Table 4. Proposed waste management in Anzali Port.

Type of the solution	Proposed waste management	
Management	* Organizing environmental and waste management training courses for employees	
	* Implementing an encouragement system in order to enforce the improvement of waste management	
Technical and operational	Other waste	* Cohesive planning for disposing biodegradable waste
		* Using recycle bins to manage recyclable materials like paper, cardboard, plastic, glass, metal
	Industrial waste	* Classifying generated industrial waste (in terms of hazard)
		* Using resistant and suitable containers to store industrial waste and control safety issues related to storage containers
		* Waste sorting by constructing containers for used lubricants, used oil and cleaning tissue

CONCLUSION

This study presents a detailed assessment of waste generation and management practices in Anzali Port, focusing particularly on hazardous waste. The findings show that the port generates approximately 3,082.2 tons of waste annually, with 4% classified as hazardous. The analysis identifies key waste types, such as wood waste, metal scrap, and used tires, and provides an overview of current management practices, which include recycling, reuse, and disposal. Furthermore, the research highlights the need for a more comprehensive and integrated waste management approach, particularly for hazardous materials that require specialized handling. While the current waste management system in Anzali Port has been somewhat effective, there are significant gaps in the management of hazardous waste and in the integration of modern waste management practices. Specifically, issues related to waste segregation at the source, appropriate treatment of hazardous materials, and capacity for recycling are critical areas that need urgent attention. The study proposes several strategies for improving waste management, including the establishment of more efficient waste sorting systems, enhanced recycling facilities, and targeted training programs for port staff. The findings from Anzali Port can serve as a model for other ports in the region, especially those facing similar challenges related to waste management. This study underscores the importance of regulatory frameworks and international conventions, such as the Basel Convention, in guiding the proper disposal of hazardous waste. For policymakers, the results highlight the need for stronger enforcement mechanisms and compliance strategies to ensure that waste management practices at ports meet international standards. Future research could focus on the long-term effectiveness of the proposed waste management solutions, particularly in terms of economic sustainability and environmental impact. A cost-benefit analysis of implementing advanced waste treatment technologies, such as waste-to-energy systems or automated waste sorting, could provide valuable insights into the financial viability of such systems for other ports. Moreover, additional studies could examine the feasibility of implementing circular economy principles in port waste management, where materials are reused and recycled in closed-loop systems to minimize waste generation.

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