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Prioritizing Marine Water Pollution Factors from Marine Transportation Using the Analytical Hierarchy Process (AHP): A Case Study of Port Klang

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Abstract

The rapid growth of maritime trade and industrial activities in Port Klang, Malaysia, has intensified concerns regarding marine water quality, yet existing studies have not comprehensively addressed the cumulative and interrelated impacts of pollution factors associated with marine transportation. This study aims to fill this gap by utilized the Analytic Hierarchy Process (AHP) to evaluate and prioritize key pollution factors impacting Port Klang's marine water. Through a structured AHP analysis, this research identifies and ranks six critical pollution factors—chemical pollution, biological pollution, physical disturbances, antifouling paints, waste disposal, and technology, standards, and regulations—based on their environmental impacts as assessed by experts in maritime transport and environmental management. The findings reveal that chemical pollution, physical disturbances, and waste disposal are the most significant contributors, offering a new perspective on prioritizing interventions. This paper contributes novel insights to the literature on marine transportation management by presenting a data-driven framework for decision-makers to effectively allocate resources and design targeted pollution mitigation strategies for Port Klang and marine transportation.

1. Introduction

The rapid expansion of maritime trade and the concurrent growth of industrial activities in and around Malaysian ports have raised concerns about the quality of marine waters (Arof et al., 2021). According to Comtois & Slack (2007) study on an analysis of the websites of 800 ports and 120 shipping lines in North America, Europe, and Asia, the highest environmental issue mentioned by port authorities was water quality with 25% (Cusano, 2013). Marine transportation, while essential for global trade and economic development, significantly impacts marine water pollution. The study combines various fields, including environmental science, maritime transport, and port management. It provides an interdisciplinary perspective on the complex issue of marine transportation and marine water pollution, helping others understand the effects on Port Klang areas (Izyan et al., 2023).

Furthermore, understanding the relative importance and impact of these critical factors is crucial for prioritizing pollution mitigation efforts. The study objective is to determine the relative importance of each factor identified in marine water pollution caused by marine transportation. The Analytic Hierarchy Process

(AHP) utilized to establish a hierarchical structure of these critical factors and determine their rankings, helping decision-makers allocate resources efficiently and develop targeted strategies to mitigate marine water pollution effectively. The results offer policymakers and decision-makers a data-driven basis for formulating effective pollution reduction strategies and resource allocation. This is important not only to address the specific case of Port Klang but also to inform similar efforts in other maritime areas facing pollution challenges.

2. Literature Review

Marine water pollution associated with maritime activities primarily originates from multiple sources, including chemical pollution, biological pollution, physical disturbances, antifouling paints, waste disposal, technology, standards and regulation. Maritime transportation has been identified as a significant factor in the degradation of marine water quality (Izyan et al., 2024). The cumulative impacts of these pollutants can lead to severe environmental damage, including hypoxia, eutrophication, and harmful algal blooms, which affect both marine life and human activities such as fishing and tourism (Vafai et al., 2013).

The AHP has been widely used as a tool to support decision-making in environmental management. It allows stakeholders to prioritize factors based on multiple criteria, providing a systematic approach to complex problems. Saaty (1980) first introduced the AHP, which has since been applied in various fields, including marine environmental management. Zhang et al. (2016) applied AHP to prioritize strategies for mitigating coastal pollution in China, showing that AHP can effectively combine expert judgment and empirical data to rank pollution control measures based on their environmental, economic, and social impacts. Table 1 shows the comparison between AHP and other decision-making methods.

Table 1 *Comparison between AHP and other decision-making methods*

Method	Explanation	Strength of AHP
AHP (Analytic Hierarchy Process) (Saaty, 1980)	▪ Structured hierarchy for complex problems ▪ Incorporates expert judgment ▪ Handles both qualitative and quantitative data ▪ Pairwise comparisons of criteria	▪ Allows for detailed prioritization using expert knowledge ▪ Combines qualitative and quantitative data effectively ▪ AHP allows integration of subjective and expert judgments, while TOPSIS lacks flexibility for qualitative environmental factors ▪ AHP's structured hierarchy and clear decision-making framework are more intuitive and transparent in complex environmental problems
TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) (Hwang et., 1981)	▪ Good for quantitative decisions ▪ Simple and quick to compute ▪ Does not handle qualitative data well ▪ Assumes independence of criteria	
Fuzzy Logic (Zadeh, 1965; Boardman et., 2017)	▪ Handles uncertainty and imprecision well ▪ Lacks structured hierarchy ▪ Less intuitive for decision-makers without expertise in fuzzy theory	

2.1 Factors of marine water pollution by marine transportation

Previous research has explored various aspects of marine water pollution caused by marine transportation. However, there remains a notable gap in our understanding of its comprehensive and long-term impact on ecosystems and communities (Rajendran et al., 2018). One key area of research has focused on the types and sources of pollutants introduced by marine transportation. A critical gap in the existing research on marine transportation pollution lies in assessing the cumulative and synergistic impacts of multiple pollutants. The factors contributing to marine water pollution from marine transportation are considered acceptable based on the wealth of scientific research, empirical evidence, and international agreements that acknowledge their role in polluting marine environments (Izyan et al., 2023). Policymakers, researchers, and industry stakeholders use this knowledge to develop regulations, best practices, and technologies aimed at mitigating these factors and preserving the health and sustainability of marine ecosystems (Vega-Muñoz et al., 2021). Table 2 below shows the factors that contribute to marine water pollution by marine transportation. With the various factors from previous research, the AHP utilized to establish a hierarchical structure of these critical factors and determine their rankings.

Table 2 *Summary of factors of marine water pollution by marine transportation*

Aspects	Factor That Contributes to Marine Water Pollution	Source
Chemical Pollution (CP)	Oil spills from tanker accidents or operational discharges	(Jaswar et al., 2013; Lu et al., 2014; NRC (National Research Council), 2003)
	Discharge of ballast water containing harmful chemicals	(Hewitt et al., 2009; Walker et al., 2018)
	Leakage of hazardous cargo during transportation	(Popek, 2019)
	Cleaning and maintenance activities leading to the release of pollutants into the water	(Sany et al., 2013)
Biological Pollution (BP)	Transporting ballast water from one region to another, introducing non-native species	(Bailey et al., 2020)
	Inadequate ballast water treatment and management practices	(Bailey et al., 2020; Hewitt et al., 2009)
	Attachment of invasive species to ship hulls (biofouling) and subsequent release in new locations	(Bailey et al., 2020; Hewitt et al., 2009; Miller et al., 2018)
	Release of pathogens through sewage discharge from ships	(Aminu et al., 2015)
Physical Disturbances (PD)	Bottom trawling and dredging, leading to habitat destruction	(Bailey et al., 2020)
	Underwater noise pollution from ship engines and construction activities	(Cusano, 2013; Walker et al., 2018)
	Coastal erosion caused by changes in sedimentation patterns due to shipping	Cusano, 2013; Walker et al., 2018)
	Groundings and collisions of vessel	(Bailey et al., 2020)
Antifouling Paints (AP)	Application and scraping of antifouling paints containing toxic substances like tributyltin (TBT)	(Walker et al., 2018)
	Disposal of old or scraped antifouling paint	(Walker et al., 2018)
Waste Disposal (WD)	Improper disposal of plastic waste, packaging materials, and other solid waste	(Jha et al., 2020)
	Dumping of untreated sewage and waste into the sea	(Popek, 2019)
Technology, standards and regulation (TSR)	Not using cleaner fuels and technologies in shipping	(Miller et al., 2018)
	Lack of Environmental Regulations	(Popek, 2019)
	Lack of Pollution Monitoring and Enforcement	Cusano, 2013; Walker et al., 2018)

3. Methodology

The AHP is a systematic method designed to organize and assess intricate decisions, especially useful in group decision-making scenarios. It aids decision-makers in selecting the most suitable option aligned with their objectives and comprehension of the issue. It provides a comprehensive for structuring a decision problem and for evaluating alternative solutions. Once the hierarchy is established, decision-makers methodically assess its components by pairwise comparisons, considering their influence on elements positioned higher in the hierarchy. Figure 1 shows the flowchart of obtaining the final ranking of marine water pollution factor by marine transportation.

A structured survey was conducted to collect expert judgments on the relative importance of various pollution factors. Experts from different fields, including maritime transportation, environmental management, port authorities, and academia, were selected based on their experience and knowledge of marine environmental issues, especially in Port Klang. A pairwise comparison questionnaire was developed based on the factors identified in the literature review. The survey was designed following the AHP methodology, where experts were asked to compare pairs of factors based on a 9-point scale. This scale ranged from 1 (equal importance) to 9 (extreme importance of one factor over another) (Rahim et al., 2018). The survey was distributed to the experts via email and conducted in person for some respondents. A total of 20 experts participated in the survey, ensuring a broad range of insights and experiences were captured.

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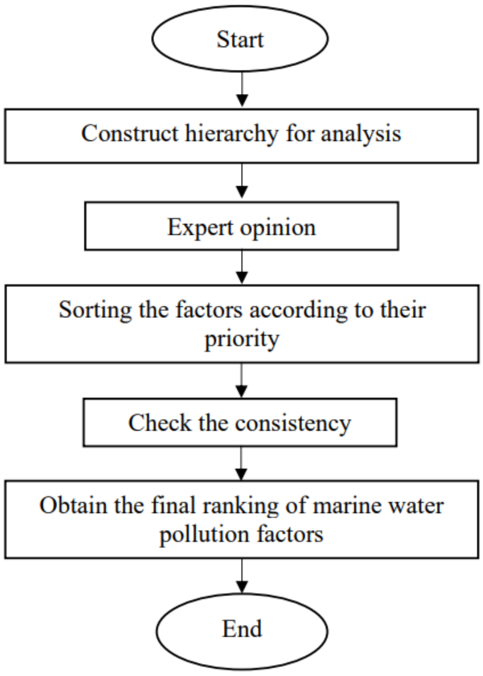

Fig. 1 *Flowchart of obtaining the final ranking of marine water pollution factor by marine transportation*

3.1 Factors of marine water pollution by marine transportation

The strengths of AHP in marine water pollution assessment lie in its capacity to encompass diverse criteria and stakeholder preferences, foster transparent decision-making processes, and facilitate consensus-building among multiple stakeholders. However, challenges such as reliance on subjective judgments, sensitivity to input data, and complexity of implementation hinder its application in real-world decision contexts. Moreover, scalability to large-scale marine pollution issues and the incorporation of uncertainty and variability necessitate further research and development efforts. These are the six factors contributing to marine water pollution which are chemical pollution (CP), biological pollution (BP), physical disturbance (PD), antifouling paints (AP), waste disposal (WD) and technology, standards, and regulation (TSR). Figure 2 shows the factors for marine water pollution that have been obtained from previous research. The objective is to rank the factors contributing to marine water pollution from marine transportation based on multiple criteria.

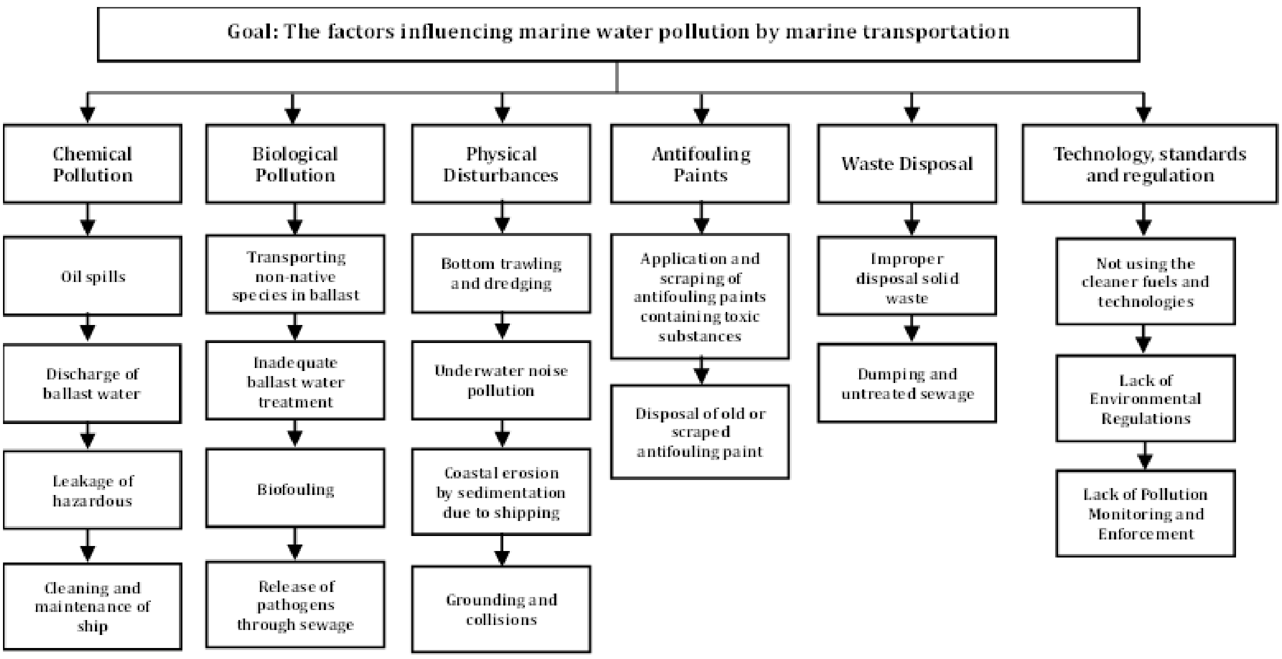

Fig. 2 *Hierarchy of factors for marine water pollution*

After understanding the calculation technique and AHP idea, the Expert Choice 11 programmer makes it easier to perform calculations quickly and accurately. The following are the results gathered from experts who participated in the paired survey that was conducted.

4. Result and Analysis

Table 3 shows AHP pairwise comparison data for the six factors contributing to marine water pollution. The matrix reflects comparisons based on a 9-point scale where 1 represents equal importance, and 9 represents extreme importance of one factor over another.

Table 3 *Summary of factors of marine water pollution by marine transportation*

Factors	CP	BP	PD	AP	WD	TSR
CP	1	5	3	7	4	6
BP	5	1	3	2	2	3
PD	3	3	1	5	2	4
AP	7	2	5	1	3	2
WD	4	2	2	3	1	4
TSR	6	3	4	2	4	1

After understanding the calculation technique and AHP idea, the Expert Choice 11 programmer makes it easier to perform calculations quickly and accurately. The following are the results gathered from experts who participated in the paired survey that was conducted.

Table 4 *Normalized matrix for the pairwise comparisons and priority vector*

Factors	CP	BP	PD	AP	WD	TSR	Priority Vector
CP	0.455	0.529	0.462	0.438	0.421	0.379	0.447
BP	0.091	0.106	0.154	0.125	0.053	0.189	0.120
PD	0.152	0.318	0.154	0.313	0.211	0.253	0.233
AP	0.065	0.053	0.031	0.063	0.035	0.126	0.062
WD	0.114	0.212	0.231	0.188	0.211	0.253	0.202
TSR	0.076	0.071	0.077	0.063	0.070	0.063	0.070

From this sample AHP data, Chemical Pollution (CP) is considered the most critical factor contributing to marine water pollution, with the highest priority vector (0.447). Physical Disturbance (PD) and Waste Disposal (WD) follow as the next most important factors. Antifouling Paints (AP) is ranked as the least important factor in this context. This structured comparison can guide decision-makers in prioritizing efforts to control marine pollution from marine transportation, focusing more resources on controlling chemical discharges and physical impacts. Next, table 5 shows result from the pairwise comparison matrix for sub-criteria within each main criterion. Table 6 shows the final ranking for criterion.

From the ranking, oil spills give the most critical sub-criterion, with a global priority of 0.2354. Plastic waste disposal and bottom trawling also rank highly in terms of their impact on marine pollution. The ranking of sub-criteria in the analysis of marine water pollution caused by marine transportation reflects the relative importance of various factors contributing to pollution in Port Klang. Higher-ranked factors indicate immediate concerns that require urgent intervention, while lower-ranked factors, though still important, may be addressed through long-term strategies and existing regulatory frameworks. This analysis helps policymakers focus resources effectively to tackle the most pressing pollution issues related to marine transportation.

Table 5 *Pairwise comparison matrix for sub-criteria and priority vector*

Factors	CP 1	CP 2	CP 3	CP 4	Priority Vector
CP 1 (Oil spills)	0.554	0.632	0.455	0.467	0.527
CP 2 (Ballast water discharge)	0.185	0.211	0.364	0.400	0.290
CP 3 (Hazardous cargo leakage)	0.111	0.053	0.091	0.200	0.114
CP 4 (Cleaning activities)	0.079	0.105	0.091	0.067	0.069
Factors	BP 1	BP 2	BP 3	BP 4	Priority Vector
BP 1 (Ballast water introduction)	0.543	0.615	0.455	0.412	0.506
BP 2 (Ballast water treatment)	0.136	0.154	0.273	0.294	0.214
BP 3 (Invasive species)	0.109	0.051	0.091	0.235	0.122
BP 4 (Pathogens through sewage)	0.078	0.077	0.182	0.059	0.158

Table 5 *Continued*

Factors	PD 1	PD 2	PD 3	PD 4	Priority Vector
PD 1 (Bottom trawling)	0.543	0.615	0.455	0.412	0.506
PD 2 (Underwater noise pollution)	0.185	0.205	0.364	0.353	0.277
PD 3 (Coastal erosion)	0.109	0.051	0.091	0.176	0.107
PD 4 (Groundings & collisions)	0.078	0.051	0.091	0.059	0.110
Factors	AP 1		AP 2		Priority Vector
AP 1 (TBT Application)	0.833		0.833		0.833
AP 2 (Paint Disposal)	0.167		0.167		0.167
Factors	WD 1		WD 2		Priority Vector
WD 1 (Plastic waste disposal)	0.75		0.75		0.75
WD 2 (Untreated sewage dumping)	0.25		0.25		0.25
Factors	TSR 1	TSR 2	TSR 3		Priority Vector
TSR 1 (Cleaner fuels/tech)	0.543	0.615	0.455		0.538
TSR 2 (Lack of regulations)	0.185	0.205	0.364		0.251
TSR 3 (Lack of monitoring)	0.109	0.051	0.091		0.211

Table 6 *Final ranking for criterion*

Sub-Criteria	Global Priority	Ranking	Sub-Criteria	Global Priority	Ranking
CP 1	0.2354	1	BP 4	0.0189	11
WD 1	0.1515	2	BP 3	0.0146	12
PD 1	0.1173	3	PD 4	0.0256	13
CP 2	0.1296	4	PD 3	0.0249	14
BP 1	0.0607	5	TSR 2	0.0176	15
CP 3	0.0508	6	WD 2	0.0505	16
PD 2	0.0645	7	TSR 3	0.0148	17
TSR 1	0.0377	8	CP 4	0.0308	18
BP 2	0.0257	9	AP 2	0.0104	19
AP 1	0.0517	10			

Next, calculate the consistency ratio (CR) to ensure that the pairwise comparisons made by experts or decision-makers are logically consistent. In other words, the CR checks whether the judgments about the relative importance of different criteria are coherent and reliable. The consistency index (CI) is calculated using the formula:

$$CI = \frac{(\lambda_{max} - n)}{n - 1} \quad (1)$$

Where:

- λ_{max} is the average of the λ values.
- n is the number of factors

$$CI = \frac{(6.08 - 6)}{6 - 1} = \frac{0.08}{5} = 0.016 \quad (2)$$

The CR is calculated by dividing the CI by the Random Index (RI) value. Since the Consistency Ratio (CR) is 0.013, which is less than 0.1, the pairwise comparisons are consistent, and the results are valid.

$$CR = \frac{CI}{RI} = \frac{0.016}{1.24} = 0.013 \quad (3)$$

5. Conclusion

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