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DELPHI ANALYSIS IN FORMULATING A FRAMEWORK FOR POLICY AND PLANNING DEVELOPMENT OF OIL POLLUTION ON COASTAL WATER IN THE WEST COAST OF SABAH

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ABSTRACT
Effective management of marine oil pollution is essential for meeting the Sustainable Development Goals in Sabah's West Coast regions. This study employed the Delphi method, systematically gathering expert opinions through multiple rounds of questioning. Participants included government officials, industry experts, academics, and other stakeholders. Over three rounds of structured questionnaires, 76.47% of respondents identified land-based operations as the main source of pollution (standard deviation: 0.44), and the same percentage agreed that marine biology is the most affected receptor (standard deviation: 0.59). The panel reached a 94.12% consensus on the importance of policies to prevent oil pollution (standard deviation: 0.24). These results provide valuable guidance for Sabah, supporting improvements to the current framework and aiding the development of effective strategies for preventing and remedying oil pollution.

Keywords: Delphi, oil spillage, consensus, Likert scale, sustainability, environment

1.0 INTRODUCTION

Over the past several decades, oil and gas development has expanded significantly throughout Malaysia, particularly in the state of Sabah, making the industry increasingly vital to national economic growth (Lim & Goh, 2019). This rapid expansion, however, has introduced numerous ecological challenges, notably the management of oil pollution, as the region's sensitive ecosystems and coastal communities experience adverse environmental impacts. In response, the Malaysian government has enacted several legislative measures, including mandates for Environmental Impact Assessments (EIAs) under Section 34 of the Environmental Quality Act 1974 (EQA 1974). The Environmental Quality (Prescribed Activities) (Environmental Impact Assessment) Order 2015 further strengthens this legislative framework. Despite these regulatory efforts, oil spills and hydrocarbon pollution continue to pose a threat to Sabah's maritime environment and coastal populations. A significant incident occurred in 2004, when a crude oil leak from a subsea pipeline transporting oil from offshore fields to an onshore terminal resulted in a spill into the South China Sea, approximately 2 kilometres off the southwest coast of Labuan Island. The response escalated from Tier 1 to Tier 2, coordinated by the Labuan Beach Clean-up Committee, which included representatives from government agencies, the oil and gas sector, and non-governmental organisations. This event highlights the necessity of robust emergency response strategies, comprehensive oil spill contingency plans, and effective collaboration among stakeholders in addressing oil pollution. To address the complex issue of oil pollution management in Sabah's coastal waters, this paper presents findings on the primary causes of oil pollution, including offshore oil and gas production and exploration, pipeline and shipping spills, and land-based sources such as urban runoff and industrial effluents. The study utilised a panel of experts, including officers, administrators, managers, engineers, planners, academic scholars, and fishery professionals with a minimum of five years of experience. The panel also included environmental researchers, marine biologists, oil spill response engineers, representatives from environmental protection agencies, local community leaders, and industry stakeholders from shipping and oil companies, as illustrated in Figure 1. Synthesising the perspectives of these panellists enables identification of the key causes and effects of oil and grease pollution. The report further outlines a framework designed to develop a balanced strategy for managing oil and grease pollution, which safeguards the environment, promotes public health, supports economic activity, and incorporates the perspectives of all major stakeholders. Implementation of these measures is expected to reduce pollution and ecological degradation associated with oil and gas production, while promoting sustainable management practices across other industries and sectors (Esiri et al., 2024).

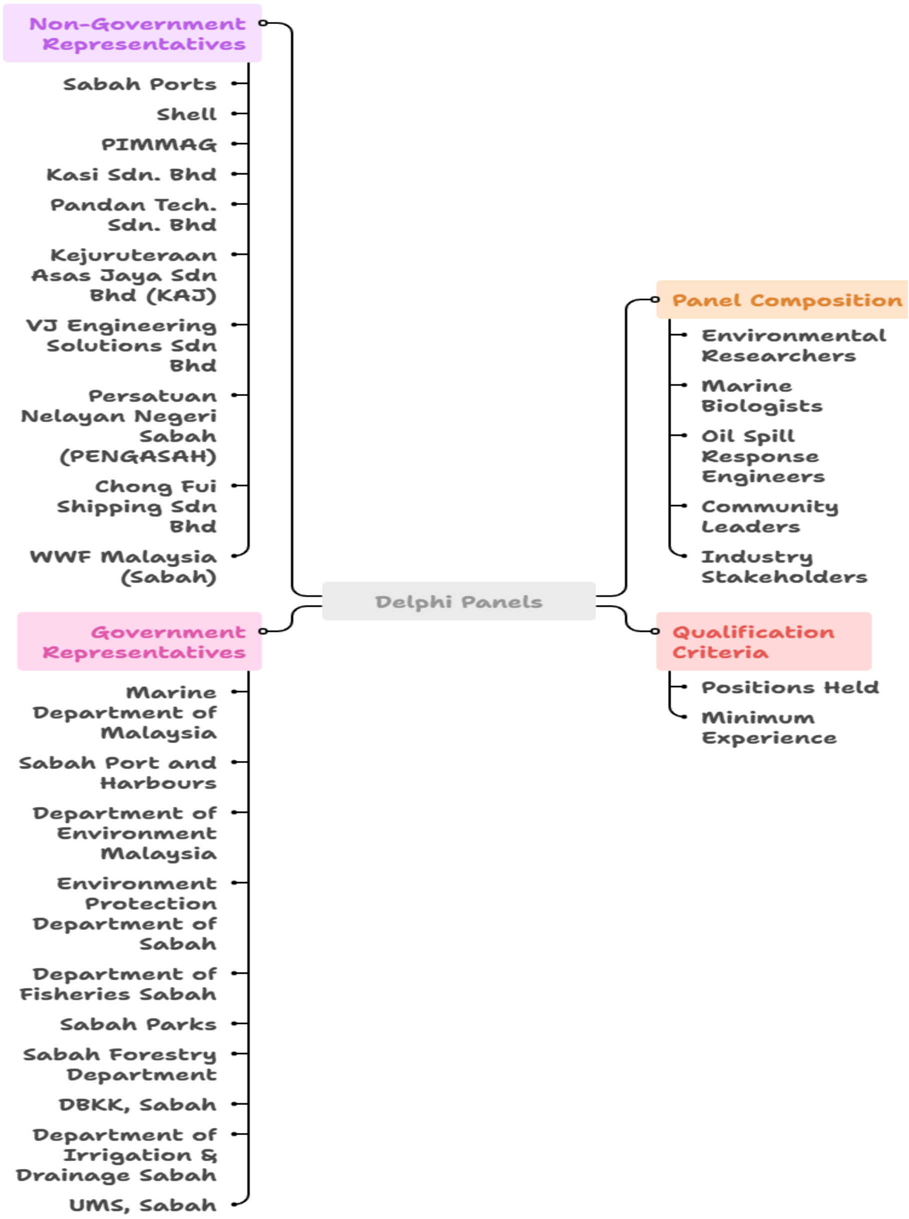

Fig. 1: Delphi panels backgrounds

2.0 LITERATURE REVIEW

Pollution in Malaysian waters is primarily caused by petroleum and gas exploration, high population density, intensive industrialisation, and evolving land use patterns along coastlines (Camara et al., 2019). Oil pollution poses a significant environmental concern, having a substantial impact on the marine ecosystem. The coastlines along the Straits of Malacca and the west coast of Sabah are particularly vulnerable, as oil spills and hydrocarbon contamination pose a significant threat to marine life and compromise water quality in these regions. Multiple studies have highlighted concerns regarding oil and grease pollution in Malaysian waters (Fadzil et al., 2017). Documented incidents of oil spillage, especially from offshore activities, have occurred around the West Coast of Sabah (Francis et al., 2024b). In several critically affected areas, there is clear evidence of disruption to marine ecosystems and processes (Campagne et al., 2023). These disruptions include mass extinctions of marine species, loss of fishing grounds, and contamination of coastal waters used for aquaculture (Yuewen & Adzigbli, 2018), as well as a reduction in the region's value for recreational and other ecosystem services. Coastal communities, which depend on the coastal environment for food, livelihoods, and recreation, are among the most severely impacted (Andrews et al., 2021).

MIMA (2018) identified oil pollution as a significant threat to both the maritime community and the environment. According to the marine environmental profile, the majority of oil pollution incidents result from operational discharges associated with routine tank operations. These incidents typically occur during deballasting, oil tank and cargo cleaning, and the operation of fishing boats and small vessels (Chua et al., 1997, 2000). The resulting residues are washed away with seawater and ultimately discharged into the sea. Zakaria et al. (2001) emphasised the importance of source identification in enabling effective control of marine-based oil pollution sources. Pourvakhshouri et al. (2003) highlighted the critical role of knowledge-based systems in efficiently determining optimal response strategies. Their approach involves assessing sensitivity factors that impact coastal environments, such as oil movement, environmental conditions, and the effectiveness of monitoring and clean-up operations. Integrating coastal development operations with marine environmental protection requires a multidisciplinary strategy that incorporates frameworks for sustainable development, environmental preservation, and effective management (Tiquio et al., 2016). The demand for petroleum-related products has increased due to rapid industrialisation. Since 1976, the Department of Environment (DOE) in Malaysia has implemented a marine water quality monitoring program to safeguard aquatic ecosystems and public health by ensuring marine water is suitable for ecological functions and human use. Malaysia's National Marine Litter Policy and Action Plan (2021–2030) currently prioritises land-based sources, waste management, clean-up activities, and multi-stakeholder coordination.

3.0 METHODOLOGY

Francis et al. (2024) identified significantly elevated oil and grease concentrations at specific sites along the West Coast of Sabah, suggesting the presence of a pollution source that requires further investigation and remediation. The Delphi technique is commonly utilised to address complex environmental challenges. This method involves defining the research problem, selecting expert panellists, maintaining participant anonymity, providing structured feedback, conducting multiple iterative rounds, establishing and analysing consensus criteria, applying closing standards, and verifying the stability of the results. The quality of Delphi studies was assessed using nine established criteria (Nasa et al., 2021). Panellists were invited via email to participate in a three-round evaluation, which included demographic questions. In rounds one and three, participants rated the importance of each indicator using a 5-point scale (Jamieson, 2004); round three also incorporated risk matrix analysis. Participants could also submit free-text comments. Two reminder emails were sent during each round. Outcomes were discussed until response patterns stabilised. When disagreements or insufficient information arose, additional efforts were undertaken to achieve consensus. Once an agreement was reached, a report was prepared. If conflicts persisted, more targeted questions were introduced to clarify responses. This iterative process continued until consensus was achieved for the final report, thereby reducing bias (Beiderbeck et al., 2021).

3.1 Delphi procedure

Panels were invited via email to participate in a three-round evaluation process, which commenced with the collection of demographic data. Participants subsequently rated the importance of each indicator using a 5-point scale (1 = very low relevance, 5 = extremely high importance) (Jamieson, 2004). Following the initial round, participants were consulted regarding the outcomes in subsequent rounds to promote response stability. In cases of disagreement or insufficient information, additional efforts were undertaken to achieve a reliable consensus. Upon reaching an agreement, a report was prepared based on the documented responses. If conflicts remained, more specific questions were incorporated into the questionnaire to clarify responses. This iterative procedure continued until consensus was achieved for the final report.

3.1.1 Design of the survey

The questionnaire addresses several key issues, such as the current state of oil pollution, existing management strategies, potential environmental impacts, socioeconomic effects, legal and regulatory frameworks, technological innovations, and stakeholder engagement initiatives. These topics were selected to ensure alignment with the study’s objectives and parameters, as shown in Figure 2.

Definition of the problem
To investigate the causes and consequences of oil pollution and manage oil pollution on Sabah's west coast.

Selection of experts
Experts from various agencies in oil pollution control are selected based on their technical and policy expertise.

Delphi Study Round 1 (9th December 2020 – 3rd March 2021)
10 statements on the status and cause of oil pollution.
Statement questioners on the source of pollution from land, onshore and offshore: industrial, tourism, coastal activities, urbanisation, shipping, terminals/jetties & platforms operations.
Participants agree on indicators using a 5-point Likert scale, with response analysis conducted to achieve consensus and determine standard deviation.
Data presented in the Fault Analysis Tree (FTA)

Delphi Study Round 2 (5th March – 18th April 2021)
Participants' agreement on risk matrix analysis techniques for the consequences of oil pollution.
Statements question the probability of occurrences and risk severity of oil pollution to coastal hydrology, marine biology, human health, society, and the economy.
Response analysis for consensus and standard deviation.
Data presented in Risk Matrix Analysis.

Delphi Study Round 3 (22nd April – 31st July 2021)
Eighteen questionnaires related to oil pollution management and the roles of stakeholders during prevention, response, and aftermath.
Statement questions on existing laws, policies, and regulations on land, operations, onshore, and offshore for oil pollution.
Participants agree on indicators using a 5-point Likert scale, with response analysis conducted to achieve consensus and determine standard deviation.
Data presented in Hazard and Operability Analysis (HAZOP)

Fig. 2: Overview of Delphi study rounds

3.1.2 Analysis of Rating

This study incorporates three distinct types of analysis: Likert scale analysis, consensus analysis, and risk matrix analysis. By integrating these assessments, we develop a robust, data-driven framework that addresses significant issues, fosters expert consensus, and effectively manages the risks associated with oil and grease pollution. The Likert scale was utilised in rounds 1 and 3, while the risk matrix was employed in round 2. The Likert scale is a psychometric response measure commonly used in surveys to assess respondents' perceptions of a particular topic or issue. It presents ordinal data on a 5-point scale, assigning a numerical value to each item (Wadgave & Khairnar, 2016). Additionally, the Australian Standard AS/NZS 4360 (2004) supports this approach, stating that the risk matrix is a risk analysis technique used to determine the likelihood and consequences of risks and establish a risk rank (Pickering & Cowley, 2010). Identifying risks is crucial, as it also assesses their severity and enables organisations to manage their impacts (Aven, 2016). A 51% consensus was applied based on both the mean and mode (McKenna, 1989). When evaluating consensus information using standard deviation, a value less than 1.5 was considered acceptable (Christie & Barela, 2005). This flexibility facilitated the achievement of the research's goals and objectives, since there is no established standard procedure for reporting Delphi findings (Schmidt, 1997). Three sets of combined criteria measurements are utilised to evaluate consensus. The analysis includes a median score of ≥ 4, which is crucial (Horner et al., 2009), an interquartile range (IQR) of 1 or less, and a standard deviation of less than 1.0 on a 5-point Likert scale (Geist, 2010). The risk matrix analysis technique evaluates the level of risk associated with significant actions by examining the likelihood of a consequence occurring, along with the risk management framework and risk and safety management (Yang & Mannan, 2010). This approach simplifies the processes of analysis, recording, and reporting. The risk rank is calculated by summing the likelihood and consequence ranks, based on a matrix that uses probabilities and consequences as its axes. The risk matrix highlights the risks with the highest priority, providing a clear visual representation of varying levels of risk. This matrix provides a graphical representation of the relationship between consequences and their likelihood of occurrence.

3.2 Delphi methodology

There were three rounds of the questionnaire. The first round's eight questions covered the assessment's release, which aimed to identify the primary sources of oil pollution from land-based, offshore, and onshore activities. During this round, a 5-point ordinal data statistic was provided, with a scale ranging from "strongly disagree" to "agree strongly". Each level on the scale had a numerical value assigned to it. The data and the Fault Tree Analysis (FTA) method were used to identify the most significant environmental risks associated with human activities. Using a graphic representation of events and their relationships, FTA helps identify faults by ensuring that an event's cause and relationship to other occurrences are appropriate and reasonable (Dunjó et al., 2010).

The second round examined the impact of oil pollution on human health, society, the economy, coastal hydrology, and marine life. In the study areas, twelve questions covered the likelihood of occurrence and level of risk. Questions 1–5 pertained to the probability of occurrence, while questions 6–10 addressed the risk severity using the risk matrix analysis statement format. Based on the possibility of a consequence, a standard method for assessing the degree of risk associated with priority actions combines the probability of occurrence and the severity of risk. The risk management framework extensively utilises risk analysis, recording, and reporting (Ale et al., 2015).

The third round aimed to prevent oil and grease pollution, as well as manage the situation during and after pollution events. It included eighteen questions about managing onshore operations, offshore oil drilling and associated activities, and managing on-land activities. It was, therefore, necessary to review the current regulations for preventing pollution during and after oil spills. This round's Delphi analysis was conducted in accordance with the Hazard and Operability Analysis (HAZOP) methodology. Risks were identified, and steps were taken to lessen or eliminate the potential sources of risk using HAZOP analysis (Kotek & Tabas, 2012)

4.0 RESULTS

Table 1 presents the results of the Delphi study ratings across three rounds. In each round, all consensus values exceed 50%, and the standard deviation is less than 1. The first round identified land-based operations as the primary source of pollution in the coastal waters along the west coast of Sabah. In the second round, it was determined that marine ecology is the most affected receptor, and that the most effective and efficient way to manage oil pollution is through prevention on land. It is crucial to revise all prevention strategies prior to any accidents or incidents occurring.

Table 1: Rating Results of Delphi Study in Three Rounds

Delphi round	Indicator	Consensus (%)	Median	Mode	Std. Deviation
1	On land (source of pollution)	76.47	1	1	0.44
2	Marine Ecology (Consequences)	76.47	2	1	0.59
3	Prevention on Land (Management)	94.12	2	2	0.24

5.0 DISCUSSIONS

A study by Delphi in round one (Table 1) indicates that the coastal waters on the west coast of Sabah have experienced substantial development, primarily driven by urbanisation, tourism, industrialisation, and coastal expansion, with a notable increase in oil and gas activities. Additionally, mining, reclamation, construction, erosion, untreated sewage, land runoff, agriculture, and aquaculture are significant contributors to land pollution associated with industrial activities (Polidoro et al., 2017). Industrial activities, manufacturing, and urbanisation in the coastal areas of West Coast Sabah are the primary contributors to oil and grease pollution—a key environmental concern in the region. Direct or indirect discharges from these sectors, such as those from the Sipitang Oil and Gas Industrial Park (SOGIP), Sabah Ammonia Urea (SAMUR), Sabah Forest Industries (SFI), and the Sabah Oil and Gas Terminal (SOGT), frequently enter rivers and the ocean. According to Hoegh-Guldberg et al. (2007), industrial activity accounts for up to 80% of ocean pollution. The Sabah Structure Plan 2020 further indicates that urban infrastructure and associated services, including water supply, solid waste management, sewerage, drainage, and transportation, are significant sources of pollution resulting from urbanisation.

Based on the study's findings on round two, as shown in Table 1, oil spills have the most severe effects on marine ecosystems. An oil spill occurs when liquid petroleum hydrocarbons are released into the marine environment, resulting in widespread pollution. Both natural and human activities can cause oil spills. Notable incidents include the Deepwater Horizon, Exxon Valdez, Arabian Gulf, and Mumbai oil spills, which are among the most significant in recorded history. Oil spills severely threaten marine ecosystems, harming diverse species and disrupting critical habitats such as coral reefs, mangroves, and seagrass beds (Kapila et al., 2021; Dudgeon et al., 2006; Sharma et al., 2024; Samiullah, 1985). These effects include health impairments, decreased survival and reproduction, and altered behaviour and physiology in marine organisms, depending on concentration (Holdway, 2002; Yuewen & Adzigbli, 2018b; Weis, 2015). Oil pollution degrades food sources and habitats, causes severe mortality, and leads to long-term biodiversity loss, with impacts persisting for years or decades (Shigenaka, 2017; Kingston, 2002; Deng & Adzigbli, 2018).

The third round of Delphi analysis revealed a consensus among panellists that current land regulations are insufficient to address oil contamination risks in both prevention and recovery phases. Legalising preventive measures could help avert such incidents. Guiding an incident is regarded as an effective way to support affected parties. Additionally, Hazard and Operability Analysis (HAZOP) is instrumental in identifying hazards and recommending actions to minimise or eliminate potential risks (Pasman & Rogers, 2020). Table 1 summarises the current legislation and practices for oil pollution management in Sabah, as identified through the Delphi study. The panellists reached the highest level of agreement that these measures require improvement. Policy changes are proposed to address the environmental consequences of oil pollution, particularly in light of the increasing number of human activities along Sabah's West Coast. Figure 4 indicates that oil spills, vessel operations, leaks during ship repair, and vessel sinking were the most common causes of accidents from 2011 to 2019. Data from the Sabah

Department of Environment (DOE) confirm that these incidents significantly contribute to marine pollution in Sabah waters.

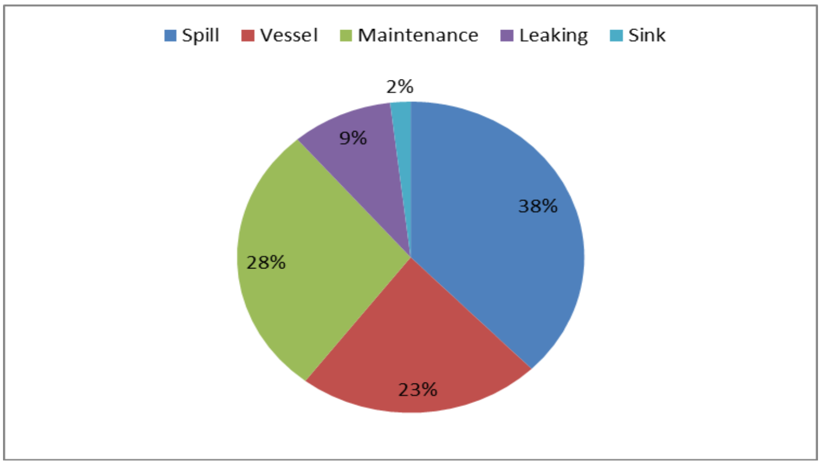

Fig. 4: The Cause of Marine Incidents in Sabah Waters
Source: Department of Environment Report 2011-2019

The proximity of sensitive receptors to pollution sources determines the effects of oil spills and the necessary response actions. Safeguards for oil pollution prevention in Sabah currently include laws, policies, and regulations. The Delphi study established guidelines for preventing and responding to oil pollution incidents. The expert panel's recommendations were assessed to identify the authorities responsible for mitigating risks and protecting sensitive receptors. To develop an effective framework for oil pollution control on Sabah's west coast, it is necessary to employ Delphi analysis to engage stakeholders from multiple sectors, conduct stakeholder mapping and analysis, establish coordination mechanisms, enforce existing laws, prioritise research and development, and implement public awareness and education campaigns (Shi et al., 2019; Maidin, 2005).

6.0 CONCLUSION

Enhancing local policy and coastal management leads to more effective responses to pollution events. The results reinforce the Sabah state government’s initiatives to position the region as a biodiversity hotspot and underscore the need for stronger safeguards against pollution from shipping and industry. Healthier marine ecosystems, in turn, bolster Sabah’s eco-tourism and blue economy, both of which are vital to its tourism-driven economy. Strengthening state-level contingency plans—such as improved emergency response coordination and oil spill monitoring—enhances disaster preparedness and response capabilities. By providing scientific support for stricter marine pollution regulations and enforcement, this study advocates for the improvement of policy and regulatory frameworks, ensuring compliance with global environmental standards.

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