

MARINE CRIME IN INDONESIA: A SPATIO-TEMPORAL ASSESSMENT OF EMERGING TRENDS AND HOTSPOTS

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Received: 07-10-2024; Revised: 10-10-2024; Approved: 11-10-2024

Abstract. Indonesia, with its vast maritime domain, faces significant challenges related to maritime crime, including illegal, unreported, and unregulated (IUU) fishing, piracy, human trafficking, and smuggling. The country's strategic position, bordering key shipping routes like the Strait of Malacca and the Sunda Strait, exacerbates its vulnerability to transnational crimes. This study provides a spatio-temporal assessment of emerging trends and hotspots of marine crime in Indonesia during the period of 2022-2023. Through an analysis of crime incidents, the research identifies key areas of concern, such as the Java Sea, Sumatra, and Eastern Indonesia, where illegal activities have shown persistent and intensifying patterns. The Strait of Malacca and Aceh emerged as critical zones, with increased incidents of piracy and human trafficking, partly linked to the Rohingya refugee crisis. Additionally, the study highlights the environmental impact of illegal activities in ecologically sensitive regions, such as Papua and the Coral Triangle, where illegal logging, mining, and destructive fishing practices threaten marine ecosystems. The analysis also reveals seasonal trends, with the highest concentration of incidents occurring between July and September, coinciding with peak fishing activities. Despite efforts by the Indonesian government, including the Sinking of Foreign Vessels Policy and regional cooperation initiatives like ReCAAP, enforcement gaps remain, particularly in remote regions. The study identifies critical gaps in maritime security, including the need for improved technological surveillance and enhanced community engagement in enforcement efforts. The findings underscore the importance of spatial-temporal monitoring to inform targeted law enforcement and policy responses, thereby protecting Indonesia's marine resources and enhancing national security.

Keywords: *Marine crime, Spatio-temporal analysis, Emerging Hotspot Analysis, Maritime security*

1 INTRODUCTION

Indonesia, the world's largest archipelagic nation, encompasses over 17,000 islands and a vast Exclusive Economic Zone (EEZ), making it a strategically vital maritime state. With more than 3.1 million square kilometers of maritime territory, Indonesia's waters serve as critical shipping routes that connect the Indian and Pacific Oceans. The strategic location of Indonesia's maritime zones, such as the Strait of Malacca, Sunda Strait, Makassar Strait,

and the Arafura Sea, has made the country highly susceptible to various forms of maritime crime, including illegal, unreported, and unregulated (IUU) fishing, piracy, human trafficking, and smuggling (Sun & Yu, 2020; ReCAAP ISC, 2022).

The complex challenges posed by maritime crime are of increasing concern, given Indonesia's heavy reliance on its marine resources for economic and environmental sustainability. The country's fisheries sector plays a critical role in the livelihoods of millions of Indonesians.

However, rampant illegal fishing by both local and foreign actors threatens the sustainability of these resources. According to the Food and Agriculture Organization (FAO), Indonesia is among the most affected countries in the world by IUU fishing, suffering annual losses in the billions of dollars (FAO, 2018).

Beyond IUU fishing, Indonesia's waters have become a hotspot for transnational crimes such as piracy and armed robbery, particularly in high-traffic areas like the Strait of Malacca. This region is identified as one of the world's most piracy-prone zones, with frequent incidents of hijacking, robbery, and smuggling targeting commercial vessels (ReCAAP ISC, 2022). Additionally, Indonesia's waters serve as a major transit hub for human trafficking and smuggling networks, exacerbated by porous borders and vast, difficult-to-monitor coastlines. The Rohingya refugee crisis in Aceh, which saw the arrival of hundreds of asylum seekers fleeing persecution in Myanmar, has further compounded these challenges, raising concerns over the exploitation of vulnerable populations by trafficking networks (Amnesty International, 2023; UNHCR, 2023). Environmental degradation also remains a significant concern in Indonesia's maritime zones. Illegal activities such as mining and logging, particularly in ecologically sensitive areas like Papua and the Coral Triangle, have caused widespread damage to vital marine ecosystems, including coral reefs and mangrove forests. These ecosystems are crucial for maintaining marine biodiversity and supporting local fisheries (WWF Indonesia, 2021). WPPNRI 718, which includes parts of Papua, has been notably impacted by illegal mining activities, leading to pollution and habitat destruction (Coral Triangle Initiative, 2019).

Indonesia has made several efforts to combat these maritime crimes. The Sinking of Foreign Vessels Policy, implemented by the Ministry of Marine Affairs and Fisheries (KKP), aims to deter IUU fishing through stringent enforcement measures (Indonesia Ministry of Marine Affairs and Fisheries, 2022). In addition, Indonesia has engaged in regional cooperative

initiatives, such as ReCAAP, to address piracy and promote information-sharing among Southeast Asian nations. Despite these initiatives, the vastness of Indonesia's maritime territory presents unique enforcement challenges, with patrols and monitoring systems often being inadequate to cover remote and extensive regions (Widodo et al., 2020).

Several studies have focused on the scope and impact of maritime crime in Indonesia. Sun and Yu (2020) provided a global overview of piracy, identifying the Strait of Malacca as a critical area for piracy due to its heavy commercial traffic. Similarly, Teh et al. (2016) examined the economic costs of IUU fishing in Southeast Asia, estimating that Indonesia loses up to USD 4.6 billion annually due to these illegal activities. Their findings emphasized the urgent need for better enforcement strategies, such as satellite monitoring and enhanced international collaboration. Widodo et al. (2020) highlighted the Java Sea as a key area affected by IUU fishing, stressing the importance of cross-border cooperation to address illegal fishing by foreign vessels.

On the environmental side, studies by WWF Indonesia (2021) and the Coral Triangle Initiative (2019) have documented the severe ecological impacts of illegal activities like dynamite fishing, mining, and logging in Papua. These studies pointed to the destruction of critical marine habitats, which jeopardizes biodiversity and local livelihoods. While Marine Protected Areas (MPAs) have been proposed as a solution to protect these ecosystems, Yulianto et al. (2017) noted that the effectiveness of MPAs is often limited by inconsistent enforcement and lack of community engagement.

The Rohingya refugee crisis has further exacerbated maritime security challenges in Indonesia, particularly in Aceh. Reports by Amnesty International (2023) and UNHCR (2023) describe how trafficking networks exploit vulnerable refugees, adding to the complexity of securing Indonesia's northern waters. These developments underscore the need for coordinated strategies to address both humanitarian and security concerns.

Despite a growing body of research on maritime crime in Indonesia, significant gaps remain. First, while studies such as those by Sun and Yu (2020) and ReCAAP ISC (2022) have analyzed piracy and IUU fishing, there is limited research that integrates the spatial-temporal dynamics of different forms of maritime crime, including smuggling and human trafficking. Additionally, most studies have focused on high-traffic areas like the Strait of Malacca, leaving Eastern Indonesia and other less-studied regions under-explored. Moreover, the role of technology, such as artificial intelligence (AI) and machine learning in enhancing surveillance and monitoring systems, has yet to be thoroughly examined in existing literature.

The Emerging Hotspot Analysis (EHA) method offers a valuable approach for identifying and analyzing dynamic crime patterns over time and space. Unlike traditional static crime analysis, EHA focuses on detecting evolving trends, enabling the identification of regions where illegal activities are intensifying, emerging, or diminishing. This spatio-temporal method has been widely applied in urban crime studies, providing insights into how crime hotspots develop and shift (Levine & Kim, 2019; Zhang & Peterson, 2017).

By categorizing areas into different types of hotspots—such as new, intensifying, persistent, or diminishing hotspots—EHA helps policymakers and law enforcement allocate resources more effectively, particularly in high-risk regions. In the study of maritime crime, applying EHA can highlight the temporal and geographic trends in activities such as piracy, IUU fishing, and smuggling, allowing for more targeted and proactive interventions (Sun & Yu, 2020).

However, despite its potential, the use of EHA in the maritime context remains underexplored. Most existing studies have focused on static crime data, without integrating spatio-temporal analysis to understand the evolving nature of illegal activities at

sea. Additionally, the incorporation of advanced technologies such as AI and machine learning into EHA could further improve the precision of identifying and predicting hotspots (Andresen, 2016).

This study seeks to address these gaps by providing a spatio-temporal analysis of marine crime in Indonesia during 2022 and 2023, focusing on emerging trends and hotspots. Through a detailed assessment of the evolving dynamics of maritime crime, this research aims to contribute to the development of more targeted law enforcement strategies, thereby helping to safeguard Indonesia's marine resources and enhance national security.

2 MATERIALS AND METHODOLOGY

2.1 Data Collection

The data utilized in this study comes from the Indonesian Maritime Information Center (IMIC), a division of Badan Keamanan Laut (BAKAMLA), Indonesia's maritime security agency. IMIC serves as the central repository for reports on maritime security incidents, including piracy, smuggling, illegal fishing, and other marine crimes. The data covers the period from January 2022 to December 2023, providing comprehensive and detailed records of marine crime activities within Indonesia's Exclusive Economic Zone (EEZ) and territorial waters.

This dataset is highly valuable due to its granularity, encompassing incident types, geographic coordinates, dates, and involved vessels. The inclusion of both spatial and temporal attributes allows for a robust spatio-temporal analysis of marine crime patterns. Each incident is recorded with exact geographic coordinates, facilitating the mapping of crime hotspots across different maritime regions.

BAKAMLA's IMIC dataset is recognized for its accuracy and relevance, as it aggregates information from various sources, including the Indonesian Navy, coastal patrols, international maritime organizations, and civilian reports. This level of integration ensures a comprehensive

view of marine crime occurrences across Indonesia's vast maritime domain, enhancing the validity of the analysis.

For this study, the dataset has been pre-processed to focus on significant crime types, including piracy, illegal fishing, smuggling, and armed robbery at sea. Outlier incidents and incomplete records were excluded to ensure the integrity of the spatial and temporal analysis. The selected data represents one of the most extensive and up-to-date marine crime datasets available for Indonesia, making it a critical resource for understanding the evolving trends and hotspots of illegal activities in Indonesian waters.

2.3 Methods

This study employs a spatio-temporal analysis approach to investigate marine crime patterns in Indonesia, using data obtained from the Indonesian Maritime Information Center (IMIC) under BAKAMLA. The primary method applied is the Emerging Hotspot Analysis, a powerful geospatial technique used to identify trends in crime hotspots over time.

2.3.1 Spatio-Temporal Analysis

Spatio-temporal analysis combines both spatial and temporal dimensions to uncover patterns of crime across space and time. It is particularly useful in maritime security studies, where illegal activities often cluster in specific regions but vary significantly over time. By using the data's geographic coordinates and timestamps, we can map and analyze how marine crime incidents evolve, providing insights into both static hotspots (areas with consistently high crime rates) and dynamic hotspots (areas where crime is increasing or decreasing over time).

2.3.2 Emerging Hotspot Analysis (EHA)

The core analytical tool in this study is the Emerging Hotspot Analysis (EHA), a spatial statistical method implemented using GIS software. EHA categorizes locations based on how the density of incidents changes over time, allowing us to classify areas into the following categories (Esri, 2016):

1. No Pattern Detected: No significant hot or cold spot patterns found.
2. New Hot Spot: A new location showing significant clustering of high values (hot spot) for the first time.
3. Consecutive Hot Spot: A consistent clustering of high values for at least two consecutive time steps but never before that.
4. Intensifying Hot Spot: A location that has been a hot spot for 90% of time steps, with the intensity of clustering increasing over time.
5. Persistent Hot Spot: A location that has been a hot spot for 90% of time steps without a significant trend in the clustering intensity.
6. Diminishing Hot Spot: A hot spot for 90% of time steps, with the intensity decreasing over time.
7. Sporadic Hot Spot: A location that has been a hot spot on and off, with no consistent pattern and no cold spots detected.
8. Oscillating Hot Spot: A hot spot that has also previously been a cold spot at some time.
9. Historical Hot Spot: A location that has been a hot spot for 90% of time steps, but not in the most recent time period.
10. New Cold Spot: A new location showing significant clustering of low values (cold spot) for the first time.
11. Consecutive Cold Spot: A consistent clustering of low values for at least two consecutive time steps but never before that.
12. Intensifying Cold Spot: A location that has been a cold spot for 90% of time steps, with the intensity increasing over time.
13. Persistent Cold Spot: A location that has been a cold spot for 90% of time steps with no significant trend in intensity.
14. Diminishing Cold Spot: A cold spot for 90% of time steps, with the intensity decreasing over time.
15. Sporadic Cold Spot: A location that has been a cold spot on and off, with no consistent pattern and no hot spots detected.
16. Oscillating Cold Spot: A cold spot that has also previously been a hot spot at some time.

17. **Historical Cold Spot:** A location that has been a cold spot for 90% of time steps, but not in the most recent time period.

This method is particularly suited to understanding the shifting dynamics of marine crime, allowing for a predictive component in law enforcement and policy formulation. By identifying areas of growing concern, maritime authorities can allocate resources more effectively.

To identify spatial and temporal patterns in marine crime occurrences, we employed the *Emerging Hot Spot Analysis* tool in ArcGIS Pro. This tool was utilized to detect statistically significant trends in both space and time, focusing on identifying emerging, intensifying, or cooling crime hotspots within the study area. The analysis was conducted using the following parameters:

1. **Spatial Relationship:** K-Nearest Neighbors

We selected the *K-Nearest Neighbors* (KNN) option to conceptualize spatial relationships between incidents. This method ensures that each crime event is analyzed with respect to its closest neighboring incidents, rather than relying on a fixed distance. The KNN approach is particularly well-suited for unevenly distributed data across vast marine environments, where crime incidents may cluster in some regions (e.g., near high-traffic shipping routes) while being sparse in others (e.g., open ocean zones).

2. **Number of Spatial Neighbors**

The analysis was set to include 20 nearest neighbors for each crime incident. This number was chosen to capture a broad yet locally significant spatial context, reflecting the tendency for marine crimes such as smuggling, piracy, and illegal fishing to occur in clusters influenced by geographic features (e.g., coastlines, islands) and human activities (e.g., trade routes). The 20-neighbor setting ensures that spatial clustering trends are considered at both localized and regional scales.

3. **Temporal Neighborhood Time Step**

To capture the temporal dynamics of crime incidents, we set the neighborhood time step to **2 months**. This time step was selected to account for potential short-term trends and patterns in marine crime, such as seasonal fluctuations in illegal activities like fishing during monsoon seasons or piracy surges related to weather and navigation conditions. The two-month interval allows for sufficient temporal resolution to identify emerging trends without losing long-term trends in the dataset.

The combination of these parameters facilitated the identification of statistically significant hot spots and cold spots across both space and time. The output classified the study area into various categories, such as emerging, persistent, or diminishing crime hotspots, providing insights into the spatial-temporal dynamics of marine crime in the region.

2.3.3 Data Processing

Prior to analysis, the data from IMIC was cleaned and pre-processed. Duplicate entries, incomplete records, and outliers were removed to maintain data integrity. The remaining data was then formatted for input into GIS software, with each crime incident linked to a specific time and geographic location. The analysis was performed using the following steps:

1. **Data Input:** Geographic coordinates and timestamps for each marine crime incident were inputted into the GIS environment. The dataset included spatially referenced incidents across Indonesia's waters from January 2022 to December 2023.
2. **Time-Slice Creation:** The data was segmented into monthly intervals over the 24-month study period. This temporal segmentation allowed for the identification of trends and patterns on a month-by-month basis.

3. **Spatial Grid Definition:** A fishnet grid of 100 km x 100 km cells was created to partition the study area. Each grid cell acted as a spatial unit of analysis, enabling the study to capture localized crime hotspots and their spatial evolution.
4. **Neighborhood Setting:** A neighborhood distance of 20 (in spatial units) was applied in the Emerging Hotspot Analysis (EHA) to account for spatial clustering. This parameter defined how much surrounding area (in relation to the grid cells) was considered when identifying significant hotspots.
5. **Space-Time Pattern Mining:** The EHA was applied to the monthly time-slices to detect emerging marine crime hotspots. This analysis focused on classifying areas into patterns such as new, intensifying, consecutive, and diminishing hotspots. The EHA categorized the grid cells based on the consistency and change in hotspot intensity over time.
6. **Visualization:** The results were mapped using GIS software to visualize the spatial distribution of hotspots. This enabled the detection of evolving crime patterns in Indonesia's waters, highlighting key areas where marine crimes were intensifying or diminishing. The generated maps provided stakeholders with valuable insights for targeted maritime surveillance and intervention strategies.

2.3.5 Limitations

While Emerging Hotspot Analysis provides valuable insights into crime patterns, the accuracy of the results is contingent upon the quality of the input data. Incomplete or underreported crime incidents could affect the reliability of the analysis. Additionally, the method assumes that historical patterns are indicative of future trends, which may not always hold true in dynamic and complex maritime environments.

3 RESULT AND DISCUSSIONS

The spatial distribution of various marine crimes and illegal activities across Indonesia's waters during 2022

and 2023 is depicted in Figure 1. The map highlights incidents related to ecosystem damage, illegal fishing, human trafficking, piracy, and other violations occurring within key Fisheries Management Areas (WPPNRI). The highest concentration of incidents is observed in WPPNRI 711, which covers areas around the Java Sea, Sumatra, and the Natuna Sea. This region shows numerous occurrences of IUU fishing, robbery/piracy, and fishing with explosives, reflecting heightened maritime law enforcement challenges in these densely trafficked waters. According to ReCAAP ISC (2022) and Sun & Yu (2020), this area's vulnerability is linked to its proximity to important global shipping lanes. Additionally, significant instances of human trafficking and territorial violations are reported, particularly near Batam and Riau islands, which are major maritime transit points. Human trafficking in this area has been a significant concern for both Indonesian authorities and international agencies such as UNHCR (2023) and Amnesty International (2023), particularly in light of the Rohingya refugee crisis.

WPPNRI 718, located in eastern Indonesia, near Papua, is marked by notable incidents of illegal mining and ecosystem damage, emphasizing the environmental threats in this ecologically sensitive region. This area also experiences sporadic IUU fishing and smuggling activities (WWF Indonesia, 2021). The environmental threats here are underscored by reports from the Coral Triangle Initiative (2019), which highlight that Papua's waters are part of a critical biodiversity zone, increasingly under threat from illegal activities such as logging and mining.

The radial chart in the bottom-right corner of the map illustrates the temporal trends of incidents over the two-year period. The highest frequency of reported crimes occurred between July and September, peaking in the third quarter of each year. This timing coincides with heightened fishing activities and smuggling attempts during calm seas (FAO, 2018). In contrast, fewer incidents were recorded during the first quarter, suggesting possible seasonal influences or

variability in enforcement efforts. This trend is consistent with seasonal patterns noted by Widodo et al. (2020), who observed increased fishing activity and associated illegal activities during calmer weather periods.

The Figure 1 also demonstrates a clear clustering of illegal activities around critical maritime chokepoints such as the Malacca Strait, Makassar Strait, and Arafura Sea, underscoring their strategic importance for both legal

and illegal maritime operations (ReCAAP ISC, 2022). These chokepoints have long been identified as vulnerable to both piracy and smuggling operations, as noted in the global perspective on maritime piracy by Sun & Yu (2020). The Strait of Malacca, in particular, remains one of the world's most piracy-prone areas due to its high volume of commercial traffic and the difficulty in maintaining comprehensive enforcement (IMO, 2021).

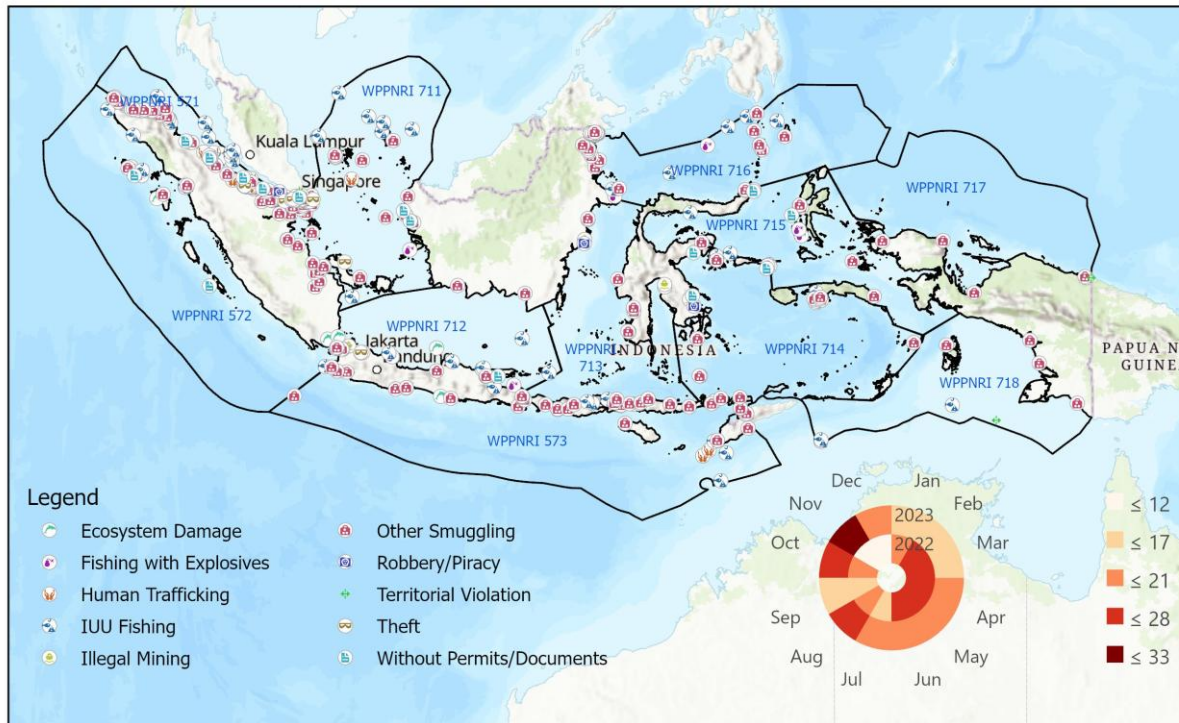


Figure 1. Marine Crime in 2022-2023 in Indonesia water

Overall, the Figure 1 provides critical insight into the spatial and temporal patterns of maritime crimes in Indonesia, revealing hotspots of illegal activities that demand targeted law enforcement and conservation efforts to safeguard the country's marine resources and national security. The Indonesia Ministry of Marine Affairs and Fisheries (2022) has acknowledged the need for enhanced enforcement in these hotspots, especially in regions where IUU fishing and environmental degradation are most acute.

The Emerging Hotspot Analysis (EHA) of marine crime incidents in Indonesia during 2022-2023, visualized in Figure 2, reveals key hotspot patterns across the country's vast maritime

domain. The findings from the hotspot analysis emphasize emerging patterns of illegal activities such as IUU fishing, smuggling, piracy, and environmental degradation, which reflect broader maritime security challenges faced by Indonesia and other Southeast Asian nations (UNODC, 2023). Localized issues, such as the Rohingya refugee crisis in Aceh, further influenced these patterns during the 2022-2023 period (Amnesty International, 2023; UNHCR, 2023).

The Strait of Malacca, adjacent to WPPNRI 571, remains a critical global maritime route for commercial shipping as well as transnational crimes,

including piracy, human smuggling, and refugee movements (ReCAAP, 2022). The crisis surrounding Rohingya refugees significantly impacted maritime activity in Aceh, where new hotspots emerged in response to increasing smuggling and human trafficking (Amnesty International, 2023; IOM, 2022). Since 2017, Rohingya refugees have been fleeing persecution in

Myanmar, often attempting dangerous crossings in the Bay of Bengal and the Andaman Sea (UNHCR, 2023). The influx of refugees into Aceh during late 2022 and early 2023 has raised both humanitarian and security concerns for the Indonesian government, which has struggled to manage the logistical challenges posed by this crisis (Amnesty International, 2023).

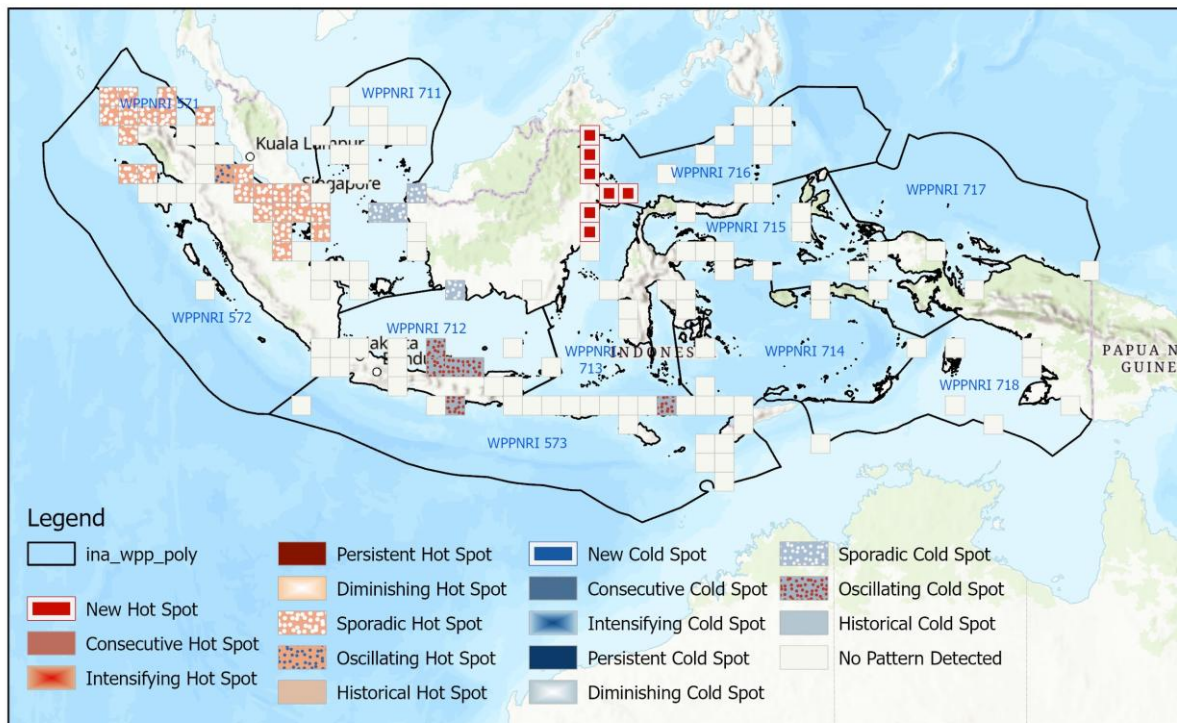


Figure 2. Emerging Hot Spot of Marine Crime in 2022-2023 in Indonesia water

In the Java Sea, particularly in WPPNRI 712, oscillating cold spots were observed, reflecting fluctuating patterns of illegal fishing and territorial violations (Indonesia Ministry of Marine Affairs and Fisheries, 2022). The Sinking of Foreign Vessels policy, initiated by the Ministry of Marine Affairs and Fisheries (KKP), targeted illegal fishing vessels, particularly from Vietnam and China, leading to a reduction in IUU fishing activities (Indonesia Ministry of Marine Affairs and Fisheries, 2022). However, the problem persists due to intermittent maritime patrols and the sheer volume of fishing vessels operating in the region (Widodo et al., 2020).

In WPPNRI 573, covering the waters around East Nusa Tenggara, both consecutive hotspots and oscillating cold spots were detected

(FAO, 2018). This region remains vulnerable to IUU fishing due to its rich biodiversity and the difficulty of monitoring remote waters (FAO, 2018). Joint patrols and international cooperation, particularly between Indonesia and Australia under the Indonesia-Australia Comprehensive Economic Partnership Agreement (IA-CEPA), have contributed to periods of reduced illegal activity (FAO, 2018). However, persistent hotspots signal ongoing challenges, particularly from smuggling and illegal fishing networks (UNODC, 2023).

The waters off North Kalimantan (WPPNRI 711) showed new hotspots in 2022-2023, reflecting the region's susceptibility to transnational crime, including illegal logging, smuggling, and IUU fishing (Environmental

Investigation Agency, 2023). The proximity to international borders makes this area a focal point for illicit activities, as noted by the EIA (2023), particularly the maritime smuggling of timber to markets in China. UNODC's 2023 report also emphasized that Kalimantan's maritime routes are increasingly being used for smuggling both wildlife and drugs (UNODC, 2023).

In the Papua region (WPPNRI 716 and 718), no significant patterns of illegal activity were detected, although this does not imply the absence of threats (WWF Indonesia, 2021). The Coral Triangle Initiative (2019) and WWF Indonesia (2021) have highlighted that Papua's waters, being rich in biodiversity, remain vulnerable to future illegal fishing and environmental degradation.

The spatial and temporal patterns identified in these hotspot analyses underscore the need for a coordinated, multi-faceted approach to maritime security in Indonesia. ReCAAP (2022) and IMO (2021) suggest that joint patrols, satellite-based monitoring, and the expansion of marine protected areas (MPAs) are critical in mitigating illegal activities and ensuring the protection of marine resources (IMO, 2021). In addition, the involvement of local communities in surveillance and monitoring efforts, as proposed by WWF Indonesia (2021), can help address enforcement gaps, particularly in remote and ecologically sensitive regions like Papua and East Nusa Tenggara.

In conclusion, the persistence of illegal activities, including IUU fishing, smuggling, and piracy, in key areas such as the Strait of Malacca, Java Sea, and North Kalimantan, reflects the ongoing challenges Indonesia faces in securing its maritime zones (Sun & Yu, 2020; UNODC, 2023). The emergence of new hotspots also highlights the adaptive nature of these illegal operations, which continue to evolve in response to enforcement efforts. Moving forward, Indonesia's approach will need to incorporate enhanced international cooperation, community engagement, and the use of advanced surveillance technologies to safeguard its vast maritime domain.

4 CONCLUSIONS

This study analyzed marine crime in Indonesia from 2022 to 2023 using Emerging Hotspot Analysis, revealing key patterns across the nation's waters. New crime hotspots were identified in North Aceh, while consecutive hotspots in Jakarta Bay and Tanjung Pinang highlight persistent challenges. The Malacca Strait remains an intensifying hotspot, underscoring its vulnerability to illicit activities. These findings suggest that targeted enforcement, enhanced surveillance, and international collaboration are essential for addressing marine crime in Indonesia. By leveraging spatio-temporal tools, authorities can better allocate resources and respond to emerging threats effectively.

ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude to SESKO TNI AL (Sekolah Staf dan Komando Tentara Nasional Indonesia Angkatan Laut) for their continuous support and valuable insights that contributed significantly to the development of this study. We also extend our appreciation to BAKAMLA (Badan Keamanan Laut Republik Indonesia) for providing access to the Indonesian Maritime Information Center (IMIC) dataset, which was crucial for the spatio-temporal analysis of marine crime patterns in Indonesia. Without their assistance, this research would not have been possible.

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