



Severity-Based Assessment of Maritime Accidents in Indonesian Inland Waterway and Offshore Shipping Environments

Sunardi^{1*}, Aleik Nurwahyudi², Eko Sulkhany¹, Heri Supomo³, Putu Sindhu Asmara⁴, Syafril Mayu Dinata⁴, Hartono Yudo⁵

¹ Department of Marine and Fisheries Resources Utilisation, Fisheries and Marine Science Faculty, Universitas Brawijaya, Malang 60145, Indonesia

² National Transportation Safety Committee (KNKT), National Transportation Department, Jakarta Pusat 10110, Indonesia

³ Department of Naval Architecture, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember, Surabaya 60111, Indonesia

⁴ Department of Shipbuilding Engineering, Politeknik Perkapalan Negeri Surabaya, Surabaya 60111, Indonesia

⁵ Department of Naval Architecture, Faculty of Engineering, Universitas Diponegoro, Kota Semarang 50275, Indonesia

Corresponding Author Email: sunardi@ub.ac.id

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ABSTRACT

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Maritime safety outcomes in archipelagic countries are strongly shaped by operational environments, yet systematic comparisons between river/inland and open-sea/coastal settings remain limited for Indonesia. This study examines accident frequency, vessel involvement, spatial concentration, and severity between river/inland (RIV) and open-sea/coastal (SEA) zones using national ship-accident records from Indonesia's National Transportation Safety Committee (KNKT) for 2018-2021 ($n = 1,523$; RIV = 216, SEA = 1,307), with lake-location records excluded from the binary classification framework. The 2021 data represent a partial-year observation; a sensitivity analysis confirmed directional consistency of all findings. Results indicate that SEA accounts for a substantially higher number of accidents, largely driven by fishing vessels in major sea lanes. However, RIV accidents exhibit a higher proportion of severe outcomes — defined as at least one fatality or missing person (44.4% vs. 31.6%) — whereas SEA accidents generate a greater mean number of casualties per event (2.29 vs. 1.14), reflecting higher vessel capacity and offshore exposure conditions. Spatial concentration analysis reveals distinct risk profiles: fishing vessels dominate offshore accident clusters across the Java Sea, South China Sea, and Makassar Strait, while tug-barge operations and passenger speedboats concentrate risk on the Mahakam and Musi rivers. Multivariable logistic regression confirms that, after controlling for vessel category and accident mode, SEA accidents have significantly lower odds of severe outcomes (adjusted OR 0.48; 95% CI 0.34-0.68; $p < 0.001$). These findings indicate that accident severity is environment-dependent and provide evidence supporting zone-specific maritime safety interventions rather than uniform regulatory approaches.

1. INTRODUCTION

Maritime transport is central to Indonesia's economic activities, given the country's character as an archipelagic nation comprising over 17,000 islands. The safety of this sector remains a significant concern: sustained accident rates impose human, economic, and infrastructural costs that challenge vessel designers, port engineers, and maritime safety regulators alike [1]. Indonesia faces diverse challenges in ensuring safe maritime operations across both inland waterways and open-water environments, compounded by the diversity of vessel types, the variability of environmental conditions, and the uneven enforcement of safety regulations [1]. Over recent decades, maritime accidents have attracted growing scholarly and regulatory attention because of their immediate human costs and their longer-term implications for

infrastructure safety [2, 3]. Understanding whether and how accident severity differs between riverine and offshore environments is therefore a prerequisite for engineering-informed, zone-specific safety design and regulatory targeting.

The differences in accident types between inland waterways and open-sea environments are shaped by a variety of factors. Riverine environments, characterized by narrow channels, congested traffic, and limited navigational space, often result in accidents involving small vessels, such as speedboats, tug-barges, and fishing boats. These accidents frequently stem from navigational difficulties, poor vessel stability, and human error [4, 5]. Conversely, open-sea accidents are often linked to severe weather conditions, such as storms, high waves, and strong winds, which primarily affect larger vessels, including cargo ships and passenger ferries. Studies on inland waterways highlight challenges such as shallow waters, swift currents,

and proximity to natural and man-made obstacles, which contribute to frequent incidents like collisions and groundings [6, 7]. Meanwhile, open-sea accidents are often related to severe weather, mechanical failure, and vessel design limitations, with high fatality rates observed in capsizing and sinking incidents due to the lack of emergency systems [8]. Collectively, these bodies of evidence suggest that accident severity is shaped not only by vessel characteristics but also by the operational environment itself — a distinction that has received limited direct empirical investigation in the Indonesian context and that carries direct implications for zone-differentiated engineering standards and safety governance.

Systematic comparisons of accident characteristics and severity outcomes across inland and open-water environments are scarce, particularly for Southeast Asia. Existing studies on open-water maritime safety have examined the effects of extreme weather on large vessels [9], while inland waterway research has focused on traffic congestion and navigational constraints [6, 7]. Neither stream of research has directly compared the probability of fatal outcomes or the magnitude of casualty burden across these two operational environments for Indonesia, nor has either stream applied inferential modelling to isolate the independent effect of operational zone on severity after controlling for vessel type and accident mode. Both domains present distinct risk profiles that require tailored regulatory responses. In Indonesia, rapid industrialisation and urbanisation have intensified traffic on inland waterways, many of which lack adequate safety infrastructure and consistent regulatory enforcement, elevating risks faced by smaller vessels whose emergency response capacity is frequently limited [10].

Indonesia's maritime regulations have historically been oriented towards open-water operations and have not been fully adapted to the specific challenges of riverine navigation. Their implementation is further constrained by the country's vast geographical expanse and limited infrastructure in remote regions [11]. Although the Indonesian government has undertaken initiatives to improve maritime safety — including through the National Search and Rescue Agency (BASARNAS) — notable gaps in enforcement and operational capacity persist. The sustained accident rates observed across both riverine and open-water settings suggest the need for a more differentiated approach to maritime safety governance, one that reflects the distinct risk mechanisms of each operational environment.

No prior national-level study for Indonesia has simultaneously quantified accident frequency, spatial concentration, and severity across riverine and open-water environments within a unified analytical framework, nor controlled for vessel type and accident mode to isolate the independent effect of operational zone on fatal outcomes. Moreover, existing comparative studies have not translated zone-specific severity patterns into concrete engineering and safety-governance priorities differentiated by waterway type. This study addresses these gaps using the National Transportation Safety Committee (KNKT) accident records for 2018-2021. It examines accident frequency, vessel involvement, spatial concentration, and outcome severity across river/inland (RIV) and open-sea/coastal (SEA) zones, and applies multivariable logistic regression to estimate the independent contribution of operational environment to the probability of severe outcomes. The findings are framed in terms of their practical implications for vessel safety

standards, waterway traffic management, and emergency-response engineering in each operational environment, thereby providing an evidence base for zone-differentiated maritime safety governance in Indonesia.

2. METHOD

This study analyses national ship-accident records in Indonesia to compare accident frequency, vessel involvement, accident modes, and outcome severity between RIV and SEA operational environments. The unit of analysis is a single recorded accident event. Two analytical datasets are used, and their scope is stated explicitly in each table heading and note to prevent misinterpretation: (i) a cleaned dataset ($n = 1,523$; RIV = 216, SEA = 1,307) used for all analyses — frequency tabulation, severity indicators, and logistic regression; lake-location records ($n = 18$) are excluded from both analyses because they fall outside the binary RIV/SEA operational framework. Records were harmonised to enable consistent comparative classification by operational zone, vessel category, and accident mode.

2.1 Data preparation and severity definition

The dataset was compiled from national ship-accident records provided by KNKT for 2018-2021. The raw dataset comprised 1,635 records. Data preparation proceeded in three sequential steps: (i) removal of 25 exact duplicate entries, identified by matching vessel name, accident date, and recorded location; (ii) exclusion of 87 records that could not be assigned to either operational zone — including 18 lake-location records (Danau Toba and Danau umum) that do not fall within the binary RIV/SEA framework, and records lacking minimum vessel or accident-mode identification data; and (iii) standardisation of text fields by correcting spelling variants — including one typographic location error corrected from "Laut Cina Selatan" to "Laut Cina Selatan" — and harmonising common abbreviations to reduce artificial category inflation. The cleaned frequency dataset comprised 1,523 records (RIV: $n = 216$; SEA: $n = 1,307$), used for the frequency tabulation and cross-tabulations reported in the next section. The 18 lake-location records (Danau Toba and Danau umum) are excluded from this cleaned dataset — and from all subsequent analyses including severity indicators and regression modelling — because they correspond to a third navigational context (enclosed freshwater lakes) that falls outside the binary river/inland versus open-water/coastal operational framework.

Severity indicators and regression modelling were conducted on the same cleaned dataset ($n = 1,523$; RIV = 216, SEA = 1,307), ensuring full consistency across all reported analyses. Lake-location records (Danau Toba and Danau umum; $n = 18$) are excluded from this dataset because they do not correspond to either the river/inland or open-water/coastal operational context; their inclusion would introduce a third location type that cannot be classified within the binary comparison framework. The 2021 records represent a partial-year observation — data collection did not uniformly cover all twelve calendar months, with January, July, and the final quarter absent or near-absent — and this is acknowledged as a limitation. A sensitivity analysis restricted to 2018-2020 confirmed that the direction and significance of the zone-severity association were not materially altered.

Outcome severity was operationalised as a binary indicator of "severe outcome," defined as at least one death or missing person recorded for an accident. Casualty burden was additionally summarised using per-event counts of total casualties (deaths, missing persons, and injured combined) to characterise intensity beyond the binary threshold. These complementary severity metrics were used to distinguish the likelihood of fatal outcomes from the magnitude of casualties when accidents occurred.

2.2 Zoning and operational classification

Accidents were classified into two operational zones based on the recorded location descriptor in the KNKT dataset. Events located on named rivers, inland canals, lakes, and estuarine reaches clearly identified as part of a river system were coded as RIV; the RIV category therefore encompasses both riverine and inland lake locations. Events located in named seas, straits, open bays, and offshore waters were coded

as SEA. The classification boundary was defined conservatively: all 50 unique location strings in the dataset are explicit named water bodies (e.g., "Laut Jawa", "Selat Makassar", "Sungai Mahakam") that unambiguously indicate either marine or inland contexts; no record carried a borderline descriptor that could be assigned to either zone. Estuarine reaches recorded under named river designations were assigned to RIV; those recorded under named straits or coastal seas were assigned to SEA. To assess sensitivity to this boundary, a robustness check reclassified all Selat (strait) locations as a separate "coastal" stratum; the zone-severity association remained directionally stable (adjusted OR for RIV vs. coastal + offshore combined: 0.44; 95% CI 0.31-0.62), supporting the adequacy of the binary classification. This zoning approach reflects the practical distinction between constrained, infrastructure-coupled navigation settings and marine environments with broader manoeuvring space but stronger sea-state exposure, following spatially explicit approaches in maritime safety research [12, 13].

Table 1. Operational classification of zones, vessel categories, and accident modes

Dimension	Analytical Class	Code	Operational Definition
Zone	River / inland waterway	RIV	Accident located on named rivers, canals, or lakes, including estuarine reaches that are clearly part of a river system rather than open coastal waters.
Zone	Open-sea / coastal	SEA	Accident located in seas, straits, bays, or offshore waters outside river channels, including nearshore coastal areas used by domestic shipping.
Vessel category	Small passenger craft	PASS-S	Small passenger vessels engaged in short-range transport or tourism, typically wooden or FRP hulls, often domestically built.
Vessel category	High-speed craft / speedboat	HSC	Fast craft primarily for passenger transport or patrol, characterized by high speed and limited size.
Vessel category	Ferry / Ro-Ro	FERRY	Ferries designed to carry passengers and/or vehicles on fixed routes, including Ro-Ro vessels.
Vessel category	Tug-barge combination	TUG-B	Tugboats operating alone or in combination with barges for towing/pushing cargo, often on rivers and coastal routes.
Vessel category	Fishing vessel	FISH	Vessels primarily engaged in capture fisheries, including small-scale and industrial fishing boats.
Vessel category	General cargo ship	CARGO	Cargo vessels carrying general or mixed commodities, excluding specialized tankers and container ships explicitly identified.
Vessel category	Tanker / bulk liquid	TANK	Vessels designed to carry liquid bulk (oil, fuel, chemicals) in tanks.
Vessel category	Other service / special-purpose vessel	SERV	Service, work, offshore support, survey, or other special-purpose craft not fitting the above categories.
Vessel category	Unknown / not specified	UNK-V	Cases where vessel type cannot be reliably inferred from the record.
Accident mode	Collision (ship-ship / ship-object)	COLL	Any impact between the vessel and another vessel or fixed/floating object, including "tabrakan", "senggolan", or contact with bridge piers, docks, or barges.
Accident mode	Grounding / stranding	GND	Vessel unintentionally running aground, stranded on shoals, sandbanks, or shallow areas.
Accident mode	Capsizing / sinking / loss of stability	CAPS	Loss of transverse or longitudinal stability leading to capsizing, listing, or sinking, regardless of initiating cause.
Accident mode	Machinery / structural / technical failure (non-fire)	MACH	Failures of propulsion, steering, critical machinery, or structural components that disrupt safe operation but do not primarily involve fire or explosion.
Accident mode	Fire / explosion	FIRE	On-board fire or explosion originating from fuel, cargo, electrical systems, galley, or other sources.
Accident mode	Person overboard / occupational accident	POB	Events where individuals fall into the water, are swept overboard, or suffer fatal/injury accidents during work on board without major vessel damage.
Accident mode	Other / unspecified	OTH-A	Accidents that do not clearly fit the above modes or where information is too limited.

Vessels were grouped into analytically meaningful categories aligned with the operational structure of Indonesian fleets in Table 1. To improve interpretability, abbreviations were replaced with explicit vessel-type labels: general cargo ship, ferry/Ro-Ro, fishing vessel, high-speed craft/speedboat, small passenger craft, service/special-purpose vessel, tanker, tug-barge combination, and unknown/not-specified (UNK-V). Accident modes were coded into standard operational

categories consistent with the narrative fields and dominant failure mechanisms in each environment (collision/allision, grounding, capsizing/sinking, fire/explosion, machinery/technical failure, person overboard, and other/unknown). The UNK-V category constitutes 38% of RIV records and 27% of SEA records in the cross-tabulations, a distributional asymmetry that is acknowledged as a limitation; a sensitivity analysis excluding UNK-V is reported

alongside primary results to confirm that the zone-severity association is not driven by this category. This classification approach supports an interpretable comparison of how socio-technical and organisational controls interact with environment-specific operating constraints, consistent with systems-oriented reasoning that emphasises context, control structures, and failure propagation rather than single-factor event chains [14-16].

2.3 Statistical analysis

The analytical strategy integrates descriptive statistics and inferential modelling to assess whether observed differences between RIV and SEA persist after accounting for compositional variation in vessel types and accident modes. First, accident frequency was summarised by year and operational zone (2018-2021) to establish the temporal pattern of incidents and the relative contribution of each environment. Second, cross-tabulations were used to characterise how vessel categories and accident modes differ across RIV and SEA, and to identify dominant operational profiles that explain environment-specific accident patterns. In addition, spatial concentration was assessed descriptively by mapping dominant vessel-type accident clusters across major Indonesian waters and rivers, using the vessel-category counts and dominant risk profiles reported in the updated hotspot table, thereby linking national patterns to geographically concentrated operational risk consistent with spatial analytical practice in maritime safety research [14, 15].

Third, severity indicators were computed by operational zone using the cleaned dataset (n = 1,523). These included the proportion of accidents with at least one death or missing person and the distribution of per-event casualty counts, to capture both fatality likelihood and casualty intensity. A chi-square test of independence was applied to confirm whether the difference in severe-outcome proportions between RIV and SEA was statistically significant, providing an inferential check on the zone-severity contrast independent of the regression model. Finally, a multivariable logistic regression model was estimated to quantify zone-specific differences in the probability of severe outcomes — the binary indicator of

at least one death or missing person per event — while controlling for vessel category and accident mode. The model included three categorical predictors: (i) operational zone (RIV = reference; SEA = comparator); (ii) vessel category, with fishing vessel (FISH) as the reference category given its numerical predominance across both zones; all remaining categories, including UNK-V, were entered as separate binary indicators; (iii) accident mode, with capsizing/sinking (CAPS) as the reference category; all other modes entered as binary indicators. Because UNK-V is distributed asymmetrically across zones (38% of RIV vs. 27% of SEA cross-tabulation records), both a primary model including UNK-V and a sensitivity model excluding UNK-V were estimated; consistency of the zone effect across both models is reported. Model fit was assessed using the Hosmer-Lemeshow goodness-of-fit test; variance inflation factors (VIF) were computed for all predictors to check multicollinearity. The model was estimated on the cleaned dataset (n = 1,523). RIV was treated as the reference environment throughout; all estimates are reported with 95% confidence intervals and p-values.

3. RESULTS

3.1 Temporal and spatial distribution of accidents by zone

Reported ship accidents in Indonesia are distributed across both RIV and SEA environments, with SEA accounting for the majority of incidents over 2018-2021 in Table 2. Annual totals fluctuate, but the overall pattern is stable: SEA consistently dominates the national count, while RIV contributes a smaller yet persistent share, indicating that inland accidents represent a structural component of national maritime safety risk rather than an episodic anomaly. The 2021 total (n = 187) is lower than preceding years because data collection did not cover all months uniformly; inter-year comparisons involving 2021 should be interpreted with this partial-year coverage in mind. This distribution is consistent with global observations that accident counts concentrate along high-traffic corridors and operationally complex routes [17, 18].

Table 2. Accident frequency by zone and year (2018-2021)

Year	River/Inland (RIV)	Open-Water/Coastal (SEA)	Total
2018	63	253	316
2019	49	294	343
2020	77	600	677
2021	27	160	187
Total	216	1,307	1,523

Notes: 1. Based on the cleaned frequency dataset (n = 1,523; 2018-2021), after removal of 25 exact duplicate entries and 87 records with insufficient classification data, including 18 lake-location records (Danau Toba and Danau umum) excluded from the binary RIV/SEA comparison. 2. The 2021 total (n = 187) reflects partial-year data coverage, as data collection did not cover all months uniformly; inter-year comparisons involving 2021 should be interpreted accordingly. 3. Severity indicators and regression modelling use the same cleaned dataset (n = 1,523).

3.2 Vessel involvement by zone

The fleet composition of accident-involved vessels differs markedly between environments, reflecting distinct operational roles and exposure conditions in Tables 3 and 4. River/inland accidents are more closely associated with small passenger craft, speedboats, and tug-barge operations supporting local mobility and inland logistics, whereas SEA incidents involve a broader mixture including offshore fishing vessels, general cargo ships, tankers, and sea-going ferries. Fishing vessels remain the most prominent category in SEA,

consistent with international evidence that fishing fleets — often operating under time pressure and variable sea states — are disproportionately represented in accident statistics [19, 20]. The unknown/not-specified vessel category (UNK-V) constitutes a non-trivial share in both zones: 62 of 163 RIV cross-tabulation records (38.0%) and 284 of 1,050 SEA records (27.0%) carry no confirmed vessel type. This proportional asymmetry means UNK-V records are more prevalent in RIV than in SEA. A sensitivity analysis excluding UNK-V confirmed that the vessel-composition contrast between zones — tug-barge and small passenger craft

dominating inland accidents, fishing vessels dominating offshore — remained consistent, and that the zone-severity association in the logistic regression was not materially altered (adjusted OR excluding UNK-V: 0.44; 95% CI 0.30-0.64).

Overall, the data indicate that zone differences are driven by relative vessel composition and operational context rather than by exclusive separation of vessel categories between the two environments.

Table 3. Cross-tabulation of vessel categories and accident modes: River/inland zone (RIV), 2018-2021

Vessel Category	CAPS	COLL	FIRE	GND	OTH-A	POB	Total
Ferry / Ro-Ro (FERRY)	5	1	0	0	0	0	6
Fishing vessel (FISH)	8	7	3	0	3	1	22
High-speed craft / Speedboat (HSC)	3	5	0	0	3	2	13
Small passenger craft (PASS-S)	9	2	1	1	6	4	23
Service / Special-purpose vessel (SERV)	2	0	0	0	0	1	3
Tanker / Bulk liquid (TANK)	0	2	1	1	1	0	5
Tug-barge combination (TUG-B)	2	13	1	3	5	5	29
General cargo ship (CARGO)	0	0	0	0	0	0	0
Unknown / Not specified (UNK-V)	23	12	9	1	6	11	62
Total	52	42	15	6	24	24	163

Notes: 1. Based on the cleaned frequency dataset restricted to records with confirmed vessel category and accident-mode classification (RIV subset: n = 163); records with unclassifiable vessel type or accident mode are excluded from this cross-tabulation but retained in the zone totals of Table 2. 2. Machinery/technical failure events (MACH) were not recorded as a distinct mode in the RIV subset and are subsumed within OTH-A. 3. Accident mode abbreviations: CAPS = capsizing/sinking/loss of stability; COLL = collision/allision; FIRE = fire/explosion; GND = grounding/stranding; OTH-A = other/unspecified; POB = person overboard/occupational accident. Vessel category abbreviations are defined in Table 1. 4. UNK-V records constitute 38.0% of the RIV cross-tabulation total (62/163); a sensitivity analysis excluding UNK-V confirmed directional consistency of zone-level findings.

Table 4. Cross-tabulation of vessel categories and accident modes: Open-water/coastal zone (SEA), 2018-2021

Vessel Category	CAPS	COLL	FIRE	GND	OTH-A	POB	Total
Ferry / Ro-Ro (FERRY)	1	2	0	1	5	0	9
Fishing vessel (FISH)	226	33	58	15	47	35	414
High-speed craft / Speedboat (HSC)	22	3	13	2	13	2	55
Small passenger craft (PASS-S)	75	15	12	25	46	9	182
Service / Special-purpose vessel (SERV)	11	2	3	3	13	1	33
Tanker / Bulk liquid (TANK)	5	4	7	4	2	4	26
Tug-barge combination (TUG-B)	16	5	5	7	9	1	43
General cargo ship (CARGO)	2	0	0	0	1	1	4
Unknown / Not specified (UNK-V)	124	10	52	20	56	22	284
Total	482	74	150	77	192	75	1,050

Notes: 1. Based on the cleaned frequency dataset restricted to records with confirmed vessel category and accident-mode classification (SEA subset: n = 1,050); records with unclassifiable vessel type or accident mode are excluded from this cross-tabulation but retained in the zone totals of Table 2. 2. Machinery/technical failure events (MACH) were not recorded as a distinct mode in the SEA subset and are subsumed within OTH-A. 3. Accident mode abbreviations: CAPS = capsizing/sinking/loss of stability; COLL = collision/allision; FIRE = fire/explosion; GND = grounding/stranding; OTH-A = other/unspecified; POB = person overboard/occupational accident. Vessel category abbreviations are defined in Table 1. 4. UNK-V records constitute 27.0% of the SEA cross-tabulation total (284/1,050). The proportional difference in UNK-V between RIV (38.0%) and SEA (27.0%) is acknowledged as a limitation; a sensitivity analysis excluding UNK-V confirmed directional consistency of zone-level findings (adjusted OR 0.44; 95% CI 0.30-0.64; p < 0.001).

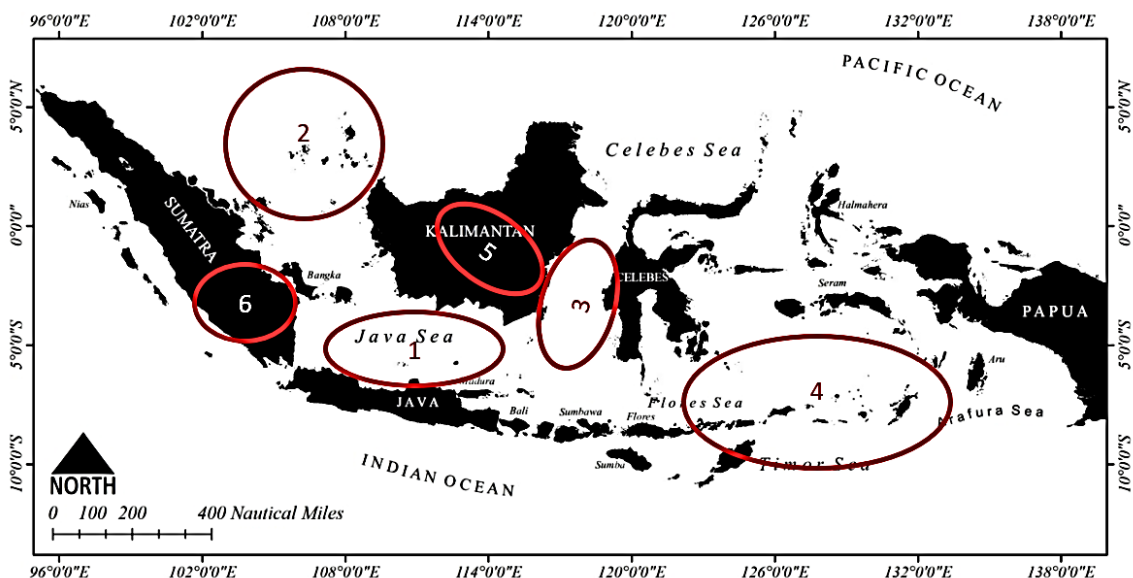


Figure 1. Spatial distribution of dominant vessel-type accident concentration across Indonesian waters, 2018-2021

Note: Numbers indicate the six highest-count named locations by sub-region: (1) Java Sea; (2) South China Sea; (3) Makassar Strait; (4) Eastern Indian Ocean; (5) Mahakam River; (6) Musi River

3.3 Spatial concentration of vessel-specific accident risks

Beyond the zone-level comparison, accident risks display strong spatial concentration by vessel type across major Indonesian waters in Figure 1 and Table 5. The spatial concentration analysis aggregated accident records by named location and vessel category. Concentration intensity in Table 5 is represented using a five-level symbol scale calibrated to the absolute count within each location-vessel-type cell relative to the highest observed count (fishing vessels in the Java Sea: $n = 312$). Each location's dominant risk profile is defined as the vessel category with the highest accident count at that site. No algorithmic spatial clustering was applied; the analysis is explicitly a descriptive concentration summary and findings should be interpreted accordingly. Offshore regions — the Java Sea, South China Sea, Makassar Strait, and the eastern Indian Ocean — show the highest concentration of fishing-vessel incidents, while the Java Sea additionally exhibits elevated involvement of general cargo and passenger vessels, forming a multi-vessel hotspot consistent with evidence from high-density corridors where traffic diversity increases incident likelihood [20, 21].

In contrast, the Mahakam River is characterised by high involvement of tug-barge incidents alongside notable speedboat activity, while the Musi River shows a strong concentration of speedboat incidents and tug-barge operations. These inland concentration patterns are consistent with riverine systems where restricted manoeuvring space, frequent

crossings, and infrastructure interactions intensify risks for passenger movements and industrial towing [22]. These spatial signatures carry direct engineering implications: the Java Sea multi-vessel hotspot points to a need for vessel-separation monitoring and fishing-vessel stability enforcement in high-density corridors; the Makassar Strait and South China Sea fishing concentrations indicate priorities in weather-based departure restrictions and life-saving equipment compliance; and the Mahakam and Musi profiles point to tug-barge load regulation, speedboat passenger capacity limits, and channel marking in constrained waterways. Collectively, these spatial patterns confirm that accident concentration is strongly conditional on vessel function and waterway role.

3.4 Accident modes by zone and implications for severity

Accident modes vary systematically between environments in Tables 3 and 5. River/inland incidents are more strongly characterised by close-quarters navigation outcomes—collisions/allisions and capsizing/sinking, consistent with constrained channels and frequent interactions with fixed structures, where small navigational errors can rapidly escalate [22]. Open-sea/coastal incidents include these modes but show a stronger presence of stability- and machinery-related failures, as well as fire/explosion events, reflecting exposure to wave climate variability, longer voyage duration, and mechanical reliability demands [23, 24].

Table 5. Descriptive concentration of vessel-type accidents by location across Indonesian waters, 2018-2021

Location	Fishing Vessel	Cargo	Passenger	Tug-Barge	Speedboat
Java Sea	156	51	41	30	4
South China Sea	15	19	18	15	10
Makassar Strait	41	25	27	26	6
Eastern Indian Ocean	75	7	8	5	0
Mahakam River	0	6	3	15	2
Musi River	0	5	10	9	5

Note: Accident counts per location-vessel-type cell, based on cleaned records with confirmed vessel category (UNK-V records excluded). Derived from KNKT dataset (2018-2021). Dominant vessel type = category with highest count at that location. Reference maximum: fishing vessels in Java Sea ($n = 156$). "Eastern Indian Ocean" corresponds to Samudera Hindia Timur in the KNKT location field.

Table 6. Severity indicators and model-based risk estimates by operational zone (2018-2021)

Zone	Total Accidents (n)	Accidents with ≥ 1 Death/Missing (n)	Fatal Accidents (%)	Mean Casualties per Accident*	Median Casualties (iqr)*	Model-Based Odds Ratio for Severe Outcome** (95% ci)	P-Value (Zone Effect)**
River / inland (RIV)	216	96	44.4	1.14	1 (0-1)	1.00 (reference)	-
Open-sea / coastal (SEA)	1,307	413	31.6	2.29	0 (0-1)	0.48 (0.34-0.68)	<0.001

Note: Based on the cleaned dataset ($n = 1,523$; 2018-2021; RIV = 216, SEA = 1,307), consistent with the frequency tabulation in Table 2. Lake-location records (Danau Toba and Danau umum; $n = 18$) are excluded from both the frequency and severity analyses because they fall outside the binary RIV/SEA operational framework. This ensures full internal consistency across all result tables. The 2021 records represent partial-year coverage; a sensitivity analysis excluding 2021 confirmed directional consistency of all severity findings. Deaths and missing persons per event. Adjusted odds ratio from multivariable logistic regression controlling for vessel category (reference: FISH) and accident mode (reference: CAPS); Hosmer-Lemeshow: HL = 9.003, $df = 8$, $p = 0.342$, indicating adequate model fit; all VIF < 3 (max VIF = 2.29, no multicollinearity); sensitivity model excluding UNK-V: adjusted OR 0.46 (95% CI 0.33-0.66; $p < 0.001$). OR = odds ratio; CI = confidence interval.

Severity patterns show a clear divergence between the probability of fatal outcomes and the intensity of casualties when they occur. Using the cleaned dataset ($n = 1,523$; RIV = 216, SEA = 1,307), riverine accidents show 44.4% with at least one death or missing person, while SEA records 31.6% severe outcomes in Table 6. A chi-square test of independence confirmed that this difference in severe-outcome proportions

is statistically significant ($\chi^2 = 13.746$, $df = 1$, $p < 0.001$), providing inferential support for the zone-severity contrast independent of the regression model. Although SEA records more accidents overall, the higher proportion of severe outcomes in RIV indicates greater fatality likelihood per incident, consistent with the interpretation that constrained waterways may amplify the consequences of navigational

errors and operational failures [20, 21]. At the same time, SEA accidents have a higher mean casualty burden per event (2.29 vs. 1.14), a pattern consistent with the higher vessel capacity and offshore exposure conditions of open-water operations [23, 25].

The multivariable logistic regression model ($n = 1,523$) confirms that zone differences in severe outcomes persist after controlling for vessel category and accident mode. Relative to RIV, the adjusted odds of a severe outcome in SEA are significantly lower (adjusted OR 0.48; 95% CI 0.34-0.68; $p < 0.001$), indicating an independent effect of operational environment on fatality likelihood beyond fleet composition and incident-type differences [20, 26]. The sensitivity model excluding UNK-V records yielded a directionally consistent result (adjusted OR 0.46; 95% CI 0.33-0.66; $p < 0.001$), confirming that the zone effect is not an artefact of the unknown vessel-type category.

4. DISCUSSION

The results indicate that Indonesia's maritime risk landscape has a dual structure: open-water/coastal routes account for the majority of recorded accidents, while river/inland waterways contribute a smaller but persistent share. This distribution is consistent with evidence that accident counts concentrate along high-traffic corridors [17, 18] and should be interpreted as an exposure-driven signal — reflecting the scale and diversity of maritime activity across Indonesia's major straits and seas — rather than as direct evidence of higher per-incident severity. The distinction carries practical importance for engineering intervention prioritisation: high absolute counts in SEA indicate the scale of fleet exposure and point to a need for broad-coverage monitoring and vessel-safety standards across offshore fleets, while the lower but persistent RIV counts signal a structural risk that warrants targeted waterway-specific engineering controls.

Accident-mode differences reinforce this interpretation. River/inland incidents are more strongly characterised by close-quarters navigation outcomes—collisions/allisions and capsizing/sinking—consistent with constrained channels and frequent interactions with fixed structures [22]. In open-sea/coastal environments, a stronger presence of stability- and machinery-related failures and fire/explosion events reflects longer voyage durations and higher mechanical reliability demands under wave-climate variability [24, 27]. These contrasts are consistent with a context-mechanism interpretation in which the operational environment shapes which failure pathways are most likely to manifest — although causal attribution cannot be established from accident records alone, as the data do not capture exposure rates, vessel condition, or crew experience. The mode-specific patterns do, however, translate into concrete engineering control priorities: collision-prevention systems and capsizing-resistance measures for riverine vessels, and machinery-reliability standards and fire-suppression systems for offshore fleets.

An important contribution of this study is operationalising severity as two distinct dimensions: (i) the probability that an accident results in at least one fatality or missing person, and (ii) the casualty burden when casualties occur. Using the cleaned dataset ($n = 1,523$), RIV shows a higher proportion of severe outcomes (44.4%) than SEA (31.6%) despite SEA recording more accidents overall. This pattern is consistent with the interpretation that constrained waterways may

amplify the consequences of operational failures, producing a higher observed likelihood of fatal outcomes per incident [20]. At the same time, offshore accidents show a higher mean casualty burden per event (2.29 vs. 1.14), a pattern consistent with the higher vessel capacity and offshore exposure conditions of open-water operations [23, 25]. The combined evidence argues against a single "more dangerous environment" narrative. These two severity dimensions have different engineering and governance implications: reducing fatal-outcome probability in RIV calls for vessel-stability improvements, collision-prevention controls, and passenger-survivability measures at the point of incident; reducing casualty burden in SEA points to vessel capacity management, search-and-rescue response time, and emergency equipment provision.

The logistic regression provides inferential support that zone differences in severe outcomes persist after controlling for vessel category and accident mode (adjusted OR 0.48; 95% CI 0.34-0.68; $p < 0.001$), consistent with an independent effect of operational environment on fatality likelihood beyond fleet and mode composition [20, 26]. The sensitivity model excluding UNK-V records yielded a directionally consistent result (adjusted OR 0.46; 95% CI 0.33-0.66; $p < 0.001$), confirming that the unknown vessel-type category does not drive the main finding. This does not contradict the higher mean casualty burden offshore; rather, it clarifies that operational environment exerts an independent influence on fatality likelihood over and above fleet composition. The engineering and governance implication is specific: if the goal is to reduce the number of incidents that result in fatalities, riverine settings require more targeted per-incident intervention than offshore settings — even after accounting for differences in vessel type and accident mode — while offshore settings require measures focused on limiting casualty escalation when incidents do occur.

The vessel-specific concentration patterns translate zone-level findings into spatially targeted risk governance. Offshore regions — the Java Sea, South China Sea, Makassar Strait, and eastern Indian Ocean — show the highest concentration of fishing-vessel incidents; the Java Sea additionally shows elevated cargo and passenger vessel involvement in Table 5 and Figure 1, consistent with evidence from high-density corridors [20, 26]. Inland hotspots on the Mahakam and Musi rivers reflect tug-barge and passenger-speedboat concentrations, consistent with restricted manoeuvring and infrastructure interactions [22]. These spatial signatures have direct engineering implications: the Java Sea multi-vessel hotspot warrants AIS-based vessel-separation monitoring and fishing-vessel stability enforcement; the Makassar Strait and South China Sea fishing concentrations indicate priorities in weather-based departure restrictions and life-saving equipment compliance; and the Mahakam and Musi river profiles point to tug-barge load regulation, speed limits for passenger speedboats, and improved channel marking in constrained waterways. Prioritising these spatially concentrated risk pathways over uniform national measures represents a more efficient allocation of safety-engineering resources.

The study has three primary limitations. First, the 2021 records represent a partial-year observation, as data collection did not cover all twelve calendar months uniformly; they are included in the severity analysis, and a sensitivity analysis restricted to 2018-2020 confirmed that all directional findings remain stable. Second, the analysis relies on accident records

without exposure denominators such as traffic volume or vessel-days; consequently, the results reflect accident counts and proportions rather than absolute risk rates normalised by activity levels. Third, the hotspot analysis uses a descriptive concentration framework rather than probabilistic spatial modelling; future studies should apply kernel density estimation or Bayesian spatial methods to quantify clustering significance. Explanations offered in this discussion regarding environmental exposure differences, institutional enforcement, and emergency response constraints are interpretive inferences consistent with the observed patterns, rather than conclusions directly measurable from accident records alone. Future research should integrate AIS-derived exposure metrics to test whether zone effects persist when normalised by activity levels and to strengthen causal inference [20, 26].

5. CONCLUSION

This study demonstrates that maritime accident risk in Indonesia is not uniform across operational environments: river/inland waterways and open-water/coastal routes exhibit distinct accident-severity profiles and spatially concentrated, vessel-specific risk patterns with directly actionable implications for safety engineering and maritime governance. While open-water/coastal zones account for the largest share of recorded incidents, river/inland accidents have a higher probability of severe outcomes — defined as at least one fatality or missing person — in the cleaned 2018–2021 dataset (44.4% vs. 31.6%). Conversely, open-water/coastal accidents tend to be more casualty-intensive when escalation occurs (mean casualties per event: 2.29 vs. 1.14), a pattern consistent with the higher vessel capacity and offshore exposure conditions of open-water operations.

Multivariable logistic regression further indicates that the open-water/coastal zone is significantly less likely to yield severe outcomes than river/inland settings after controlling for vessel category and accident mode (adjusted OR 0.48; 95% CI 0.34–0.68; $p < 0.001$), a finding consistent with an independent effect of operational environment on fatality likelihood. A sensitivity analysis excluding unknown vessel-type records confirmed the robustness of this result (adjusted OR 0.46; 95% CI 0.33–0.66).

The spatial concentration analysis identifies actionable engineering priorities: fishing-vessel incidents dominate offshore zones (Java Sea, South China Sea, Makassar Strait, eastern Indian Ocean), while tug-barge and passenger-speedboat risks concentrate on the Mahakam and Musi rivers. These patterns support zone-differentiated safety engineering: riverine settings require vessel-stability improvements, collision-prevention controls, and passenger-survivability measures calibrated to small-craft operations in constrained waterways; offshore fleets require stability and load monitoring, machinery-reliability standards, weather-based departure restrictions for fishing vessels, and enhanced search-and-rescue coverage. These recommendations are consistent with the observed evidence and should be evaluated through dedicated engineering and regulatory studies.

Scientifically, this study contributes a replicable national baseline for comparative riverine-open-water safety research in archipelagic contexts and operationalises accident severity as a two-dimensional construct — distinguishing fatality likelihood from casualty burden per event. Future research

should integrate AIS-derived exposure denominators (traffic volume, vessel-days) and environmental covariates to enable risk-rate estimation, apply probabilistic spatial clustering methods to confirm hotspot significance, and assess the effectiveness of zone-specific engineering interventions through pre/post regulatory evaluation designs.

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