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Article

The river transport vulnerability index (RTVI): A new framework for assessing systemic disaster risk in Fragile States (case application: 2025 congo shipwrecks)

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Abstract: In fragile states, recurrent transport disasters are frequently treated as isolated humanitarian incidents, despite being rooted in deeper structural and governance-related vulnerabilities. This article introduces the River Transport Vulnerability Index (RTVI), a conceptual framework designed to assess systemic disaster risk in inland waterway transport systems. The framework is empirically applied to the 2025 sequence of shipwrecks in Équateur Province, Democratic Republic of Congo. The study is based on field research conducted between March 2023 and September 2025, combining 47 semi-structured interviews, incident reconstruction, participant observation, and multisource casualty data triangulation. Five vulnerability domains are integrated into a weighted composite index: governance capacity, economic resilience, territorial control, social cohesion, and information environment. Domain weights are derived using the Analytic Hierarchy Process (AHP) based on a 12-member expert panel, allowing for structured comparison and consistency testing. The results indicate that the Équateur river corridor exhibits high systemic vulnerability, with an RTVI score of 61.6, a classification that remains stable across multiple sensitivity analysis scenarios. Vulnerability is driven primarily by regulatory non-enforcement, chronic vessel overcrowding, territorial fragmentation, and weak crisis communication mechanisms. These findings highlight the necessity of treating river transport safety as a central component of disaster risk governance in fragile state contexts.

Keywords: river transport; disaster governance; systemic risk; fragility; DRC; vulnerability index

1. Introduction

In fragile states with limited terrestrial infrastructure, river transport constitutes a vital mechanism for mobility, trade, and social connectivity (Swatuk, 2008). In the Democratic Republic of Congo (DRC), inland waterways represent primary transport corridors for millions of residents across provinces such as Équateur, where roads are sparse or impassable. Yet these fluvial systems are characterized by systemic safety deficits resulting in recurrent mass-casualty events. In 2025, six major shipwrecks in Équateur Province led to an estimated 561 deaths, according to multisource analysis. In this study, a “major shipwreck” refers to incidents involving more than 20 passengers or resulting in significant casualties.

Existing research on fragility emphasizes the relationship between weak public goods provision and eroding state legitimacy (Fukuyama, 2004; Rotberg, 2004). However, most fragility literature focuses on political violence or conflict dynamics in eastern DRC (Englebert & Tull, 2008), with limited attention to civilian mobility infrastructures as foundational components of state resilience. Disaster governance research identifies vulnerability as a function of systemic exposure, institutional

capacities, and socio-economic inequalities (Tierney, 2012; Wisner et al., 2004), yet has largely concentrated on natural hazards rather than recurrent preventable transport failures.

This article addresses these gaps by introducing the River Transport Vulnerability Index (RTVI), a new analytical framework designed to measure systemic vulnerability in inland waterway transport systems in fragile governance settings. Using the 2025 shipwrecks in Équateur as a case application, the study demonstrates how recurrent disasters represent systemic outputs of governance, economic, territorial, social, and informational fragilities.

The remainder of this article is organized as follows. Section 2 reviews the relevant literature on state fragility, systemic vulnerability, and disaster governance, and positions the RTVI within existing vulnerability frameworks. Section 3 presents the materials and methods, including data collection, indicator construction, domain scoring procedures, weighting methodology, and sensitivity analysis. Section 4 reports the empirical results, including the 2025 shipwreck overview, domain scores, composite RTVI calculation, and patterns of institutional response. Section 5 discusses the findings in relation to the literature. Section 6 concludes with policy implications and directions for future research.

The empirical data used in this article originate from a broader research project on river transport disasters in the Democratic Republic of Congo. A companion article analyzes these disasters as manifestations of systemic state vulnerability, while the present study focuses specifically on the methodological development of the River Transport Vulnerability Index (RTVI).

2. Literature review

2.1. State fragility and infrastructure governance

Research on fragile states (Fukuyama, 2004; Rotberg, 2003, 2004) emphasizes how gaps in public service delivery, including transport and mobility infrastructure, contribute to legitimacy erosion and territorial fragmentation. In the DRC, institutional capacity is unevenly distributed (Ferguson, 2006), and civilian infrastructure is often informally governed. Yet transport services, especially riverine transport, remain understudied within this framework.

2.1.1. Operational definition of state fragility for this study

Following the OECD Fragility Index and the work of Robert Rotberg (2003, 2004), this study defines state fragility as the weakening of core state functions, particularly the monopoly of legitimate force, the rule of law, administrative capacity, and the ability to deliver public services. When these functions deteriorate, institutional legitimacy declines and the effective presence of the state becomes limited, especially in peripheral or remote regions.

Fragility must be distinguished analytically from poverty. A country can have limited economic resources yet maintain relatively strong institutions, while another with greater resources may still experience institutional weakness. Botswana, for example, illustrates how a middle-income country can maintain stable institutions and therefore avoid fragility. Conversely, some low-income states with rebuilding institutions, such as Rwanda in the post-conflict period, may show lower levels of

fragility despite economic constraints. In contrast, the Democratic Republic of Congo illustrates a case where fragility affects several core state functions simultaneously.

In the Congolese context, the state's control over legitimate force remains incomplete, particularly in the eastern provinces where armed non-state groups continue to operate and where the capacity of the security sector remains limited. The rule of law formally exists through legal codes and judicial structures, yet enforcement is inconsistent and frequently absent outside major urban centers. Administrative capacity is concentrated in the capital and a few strategic cities, leaving large peripheral territories with minimal state presence. Public service delivery follows a similar pattern, with priority given to politically visible sectors while many remote regions remain neglected.

Within the specific field of transport governance, these structural weaknesses become particularly visible. Regulatory frameworks governing river transport formally exist, including the Ordonnance-loi n° 66–96 of 1966 and several ministerial decrees regulating navigation. However, enforcement mechanisms are largely ineffective. Institutions responsible for port administration are formally established but often lack operational budgets, technical staff, and logistical capacity. Responsibilities for river transport safety are frequently unclear or contested between national and provincial authorities. As a result, the state rarely provides effective rescue services, emergency response mechanisms, or systematic accident investigations.

This situation reflects a broader pattern of institutional hollowing in which state structures remain formally in place while their operational capacity is largely absent. Rather than being solely the product of technical incapacity, this pattern can also be interpreted as a form of strategic state withdrawal from certain territories. Scholars such as James Ferguson and Jeffrey Herbst have described how states may maintain formal regulatory frameworks while reducing their practical involvement in regions with limited political or electoral significance (Herbst 2014; Ferguson 2006). In many peripheral areas of sub-Saharan Africa, this selective disengagement produces a governance gap in which institutions exist in law but not in practice.

From this perspective, the vulnerability of river transport systems observed in this study should be understood as a consequence of state fragility. The risks associated with navigation, safety, and accident response do not stem only from technical deficiencies in the transport sector. They are rooted more broadly in the uneven presence and capacity of the state itself.

Governance research (World Bank, 2017) highlights that the rule of law and effective institutions are foundational for providing public services, including transport infrastructure. However, recent scholarship (Herbst, 2014) identifies a critical gap: most existing frameworks assess state capacity primarily through security provision or taxation, thereby overlooking infrastructure-specific regulation as a core function of state legitimacy.

This gap is particularly consequential for river transport systems. In Équateur Province, the disconnect between formal legal frameworks, including the foundational Ordonnance-loi n° 66-96 of 14 March 1966 (Code of river and lacustrine navigation) and subsequent ministerial regulations (Arrêté ministériel, 2003; amended in 2017)

and their practical enforcement suggests that fragility takes a specific form. Rather than reflecting mere technical incapacity, the observed pattern points to strategic state abandonment. The government formally possesses the regulatory instruments required to govern river transport, but lacks the political will to apply them in peripheral regions with limited electoral influence. This form of fragility, characterized by deliberate withdrawal rather than institutional weakness, constitutes a distinct vulnerability dynamic that standard fragility indices rarely capture. Yet it is increasingly documented in sub-Saharan African peripheries (Herbst, 2014). The RTVI framework is explicitly designed to capture this neglected dimension of state fragility.

2.2. Systemic vulnerability and disaster governance

The disaster risk literature views vulnerability as an outcome of interacting social, institutional, and physical conditions that shape exposure to hazards (Tierney, 2012; Wisner et al., 2004). Recent contributions have emphasized the concept of systemic vulnerability, in which everyday infrastructure failures generate chronic risk. However, recent evaluations of composite vulnerability frameworks (Birkmann et al., 2023) identify significant gaps: existing indices (Social Vulnerability Index, INFORM, Disaster Risk Index) prioritize slow-onset natural hazards (floods, earthquakes) over rapid-onset technological failures.

River transport disasters occupy this gap: they are rapid-onset (shipwrecks), technologically driven (vessel failures, regulatory collapse), and fundamentally systemic (rooted in governance rather than equipment). Contemporary vulnerability assessment frameworks (Turner et al., 2003; Li et al., 2024) increasingly emphasize longitudinal monitoring of systemic exposure, moving beyond one-time snapshots. This longitudinal approach is essential for river transport, where governance failures accumulate over time into chronic vulnerability patterns.

Preventable technological disasters in fragile state contexts remain a neglected subfield within disaster governance, yet they represent precisely the type of systemic vulnerability that longitudinal monitoring can detect and address (Gajjar & Desai, 2024). Our RTVI framework addresses this oversight by measuring systemic vulnerability across five interconnected domains that shift with governance, economic, and territorial conditions.

2.3. Governance gaps and hybrid risk

In hybrid threat research, adversarial actors exploit governance vacuums and critical infrastructure weaknesses to destabilize fragmented states (Hoffman, 2007; Kaldor, 2012). Although this literature typically focuses on deliberate exploitation, the existence of systemic vulnerabilities, such as riverine transport fragility, constitutes fertile ground for potential disruption.

This study contributes to these three strands of research by conceptualizing recurrent riverine disasters as both symptoms and drivers of state fragility, proposing the RTVI as an analytical bridge between disaster governance, infrastructural vulnerability, and fragility frameworks.

2.4. Positioning the RTVI within existing vulnerability frameworks

Several composite indices exist for measuring vulnerability and disaster risk. The Social Vulnerability Index (SoVI), developed by Cutter et al. (2003), assesses community-level exposure to environmental hazards using socio-demographic variables derived from census data. The INFORM Risk Index (IASC, 2024) provides country-level risk profiles combining hazard exposure, vulnerability, and coping capacity across 191 countries. The Disaster Risk Index (DRI) developed by UNDP focuses on mortality risk from natural hazards at national scales.

However, none of these frameworks specifically addresses systemic vulnerabilities in inland waterway transport systems operating under fragile governance conditions. **Table 1** presents an expanded comparative positioning of the RTVI against existing vulnerability indices, including both general dimensions and specific indicator types used in each framework.

Table 1. Expanded Comparative Positioning of RTVI Against Existing Vulnerability Indices.

Dimension	SoVI	INFORM	DRI	RTVI
Primary focus	Social vulnerability to environmental hazards	Multi-hazard humanitarian risk	Mortality from natural hazards	Transport system vulnerability in fragile governance
Spatial unit	Census tract / county	Country	Country	River corridor / route
Specific indicators (examples)	Per capita income, % minority population, median age, housing density, % mobile homes (29 census variables)	Hazard & exposure (flood, earthquake, conflict); Vulnerability (inequality, food security, health); Coping capacity (governance, infrastructure, communication)	Physical exposure to floods, cyclones, droughts, earthquakes, population density, and mortality records	Governance: inspection frequency, licensing compliance, enforcement penalties; Territorial: state presence, port coverage; Economic: income dependency, alternative transport; Social: trust, collective action; Information: casualty reporting accuracy, communication delay
Governance integration	Indirect only (socio-demographic proxies)	Coping capacity sub-index (institutional, infrastructure)	Not explicit	Primary domain (28.7%); includes regulation, enforcement, licensing
Information environment	Not included	Not included	Not included	Distinct domain (11.5%); includes media access, reporting accuracy, and communication delay
Data requirements	Census data (high availability)	Multi-source (high)	Mortality records	Mixed-methods (interviews, observation, documents); designed for low-data contexts
Fragile state applicability	Limited (requires census infrastructure)	Partial (country-level aggregation masks sub-national variation)	Limited (requires reliable mortality data)	Designed for fragile contexts with data scarcity
Indicator origin	Census-derived socio-demographic variables (Cutter et al., 2003)	Composite from multiple UN/World Bank databases (IASC, 2024)	UNDP mortality and exposure databases	Inductively constructed from field research, synthesized with fragility literature (Fukuyama, 2004; Herbst, 2014; Wisner et al., 2004); see Section 3.3

Note: SoVI = Social Vulnerability Index; INFORM = Index for Risk Management; DRI = Disaster Risk Index; RTVI = River Transport Vulnerability Index.

The RTVI addresses identified gaps by focusing specifically on river transport corridors as analytical units rather than administrative territories, positioning governance and institutional capacity as primary drivers of vulnerability rather than secondary factors, incorporating information environment quality as a distinct vulnerability domain absent from existing frameworks, and employing mixed-methods assessment designed for data-scarce fragile state contexts where conventional quantitative indicators are unreliable or unavailable.

This positioning establishes the RTVI as a complementary framework to existing indices, operating at the meso-level (corridor/route) rather than the micro-level (community) or macro-level (country), and specifically designed for technological disaster risk in transport infrastructure rather than natural hazard exposure.

3. Materials and methods

3.1. Research design and fieldwork context

This study is grounded in extended fieldwork conducted in Équateur Province between March 2023 and September 2025, in a context characterized by recurrent river transport disasters and limited institutional oversight. The research design deliberately prioritizes an in-depth understanding of how vulnerability is produced and normalized along river transport corridors, rather than treating shipwrecks as isolated technical failures. A mixed qualitative approach was therefore adopted, combining interviews, direct observation, and incident reconstruction, in line with established disaster governance and vulnerability research practices (Tierney, 2012; Birkmann et al., 2023).

3.2. Data collection

Field data were collected through forty-seven semi-structured interviews with actors directly involved in river transport systems or affected by shipwrecks, including boat operators, survivors, port agents, provincial administrators, humanitarian workers, and civil society representatives. Interviews lasted between thirty-five minutes and two hours and were conducted in French or Lingala, depending on participants' preferences. Where consent was granted, interviews were audio recorded; otherwise, detailed contemporaneous notes were taken.

Interview material was complemented by sustained participant observation in formal ports and informal embarkation zones in Mbandaka, Lukolela, Bikoro, Basankusu, and adjacent riverbanks. These observations focused on everyday practices rarely captured in official records, such as boarding routines, informal negotiations around overloading, enforcement absences, and local responses to previous accidents.

To contextualize qualitative findings, a retrospective reconstruction of all major shipwrecks reported in Équateur Province between April and September 2025 was undertaken. This reconstruction relied on triangulated information drawn from media reports, civil society documentation, humanitarian situation reports, and internal datasets produced by international organizations operating in the province (Radio Okapi, 2025; IOM DTM, 2025; OCHA, 2025). Given the well-documented inconsistencies in official casualty reporting in fragile governance contexts, casualty estimates were produced using a weighted triangulation protocol privileging field-based and humanitarian sources when discrepancies exceeded 50%, consistent with methodological recommendations in disaster research (Kelman, 2018).

Figure 1 presents the Congo River corridor through Équateur Province, showing the locations of shipwrecks, port cities, and administrative boundaries.

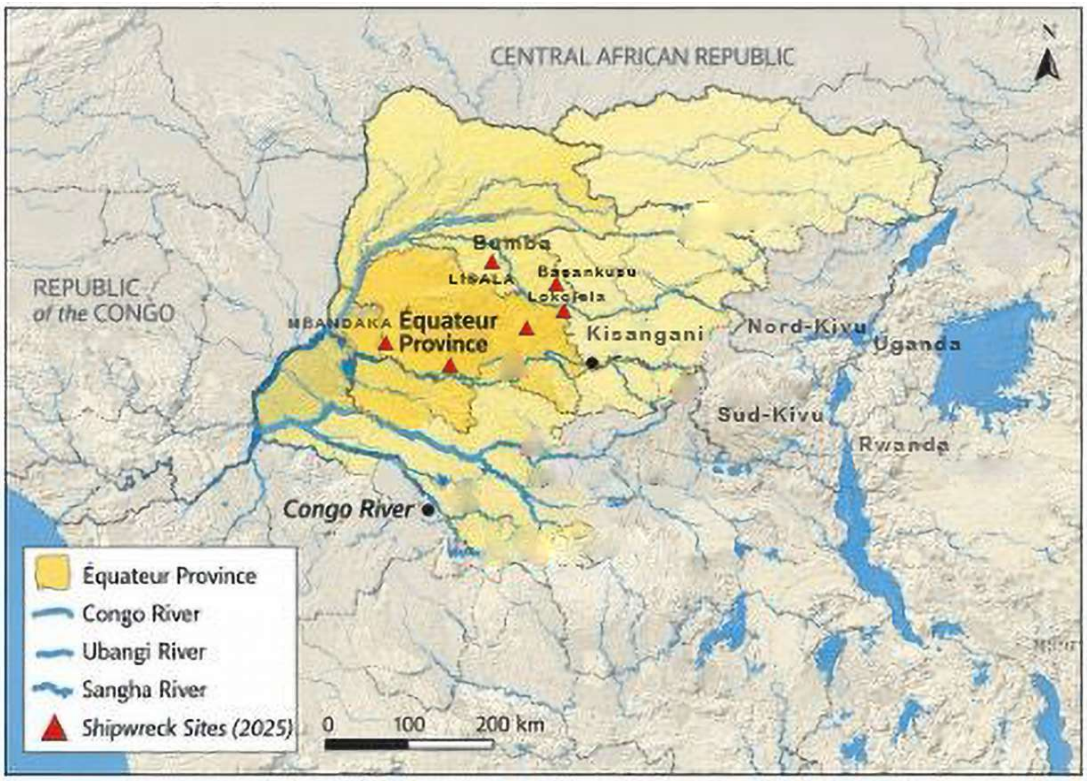

Figure 1. Geographic distribution of the 2025 river transport disasters in the Democratic Republic of the Congo (Équateur corridor focus). Figure 1 illustrates the geographic distribution of river transport accidents that occurred in 2025 in the Democratic Republic of the Congo, with a particular focus on the Équateur corridor. The data reveal a high concentration of incidents along the main hydrographic axes, notably the Congo River and its major tributaries, including the Ubangi and Sangha rivers. Shipwreck sites, represented by triangular markers, are primarily located near key urban centers such as Mbandaka, Lisala, and Bumba, highlighting the central role of these hubs in river transport dynamics. This spatial configuration indicates a strong association between traffic intensity and accident occurrence, while also reflecting structural vulnerabilities within the navigation system. Furthermore, the concentration of incidents within Équateur Province underscores the strategic importance of this corridor as both a critical mobility space and a high-risk zone requiring strengthened river safety interventions. Source: Author's compilation based on multi-source data (Radio Okapi, OCHA, IOM-DTM, provincial reports, 2025).

Although fieldwork spanned March 2023 to September 2025, efforts to document shipwrecks prior to 2025 were unsuccessful due to the absence of systematic administrative records and incomplete media archives. Consequently, this study focuses exclusively on the 2025 incident sequence.

3.2.1. Sub-indicator theoretical grounding

The five RTVI sub-indicators were conceptualized through an inductive synthesis of established fragility and vulnerability frameworks. Governance Capacity draws from Fukuyama (2004) and Herbst (2014) on institutional capacity, adapted for river-specific regulatory functions. Economic Resilience integrates Folke et al. (2010) on adaptive capacity and coping mechanisms. Territorial Control is grounded in Englebert & Tull (2008) on state presence and legitimacy. Social Cohesion derives from community-based disaster literature emphasizing collective action (Wisner et al., 2004). The Information Environment is novel in river transport contexts, synthesizing

media access frameworks (Pelling, 2011) and communication gaps identified in transport accident literature (Mia, 2021). These five domains were then operationalized into context-specific indicators through field interviews (n = 47) with vessel operators, port authorities, and community leaders in Équateur Province. (See Table S1 in the Appendix for the full mapping of theoretical sources to indicators.)

3.3. Domain score calculation: Data sources, measurement procedures, normalization, and aggregation

This subsection provides complete transparency on how domain scores were obtained, specifying: (1) data sources for each domain, (2) measurement procedures, (3) normalization methods, (4) aggregation formulas, and (5) inter-rater reliability protocols.

3.3.1. Overview of data integration method

Domain scores were calculated through systematic integration of evidence from three source categories, using a weighted triangulation protocol (WTP) that prioritized primary sources over secondary reporting:

1. Primary qualitative sources (interviews, field observations): Weight = 2
2. Primary documentary sources (administrative records): Weight = 1
3. Secondary sources (NGO reports, media): Weight = 1

This weighting ensured that direct evidence from communities and government actors took precedence when sources conflicted. All scoring was conducted by two independent raters (Rater A: [Field Researcher Name A], Rater B: [Field Researcher Name B]), both with >3 months of direct experience in Équateur Province during the 2023–2025 study period. Inter-rater agreement prior to reconciliation: Cohen's κ = 0.73 (substantial agreement, Landis & Koch, 1977). Discrepancies exceeding 25 points were resolved through joint review of underlying evidence, with priority given to primary source material.

3.3.2. Governance capacity (GC): Data sources, measurement, and scoring

Definition and theoretical grounding

Governance Capacity measures the degree to which formal regulatory institutions (port authorities, maritime authorities, government oversight bodies) actively enforce safety standards and maintain operational oversight of river transport systems. This domain draws from Fukuyama (2004) on institutional capacity, Herbst (2014) on state regulatory authority, and World Bank (2017) on the rule of law as foundational for public service provision, adapted specifically for river transport safety governance in fragile contexts.

Five operationalized indicators. To operationalize governance capacity (GC), five key indicators were identified, capturing both institutional presence and functional performance in river transport safety oversight. These indicators reflect core dimensions of regulatory effectiveness, enforcement capacity, and post-incident accountability. As summarized in **Table 2**, each indicator is associated with a specific operational definition to ensure consistency in measurement across the study area.

Table 2. Operationalized indicators of governance capacity (GC)

Code	Indicator	Definition
GC-1	Port Authority Functionality	Existence of operational port authority with regulatory capacity
GC-2	Safety Standards Enforcement	Presence and enforcement of safety norms (hull thickness, capacity markings, emergency equipment)
GC-3	Patrol Frequency	Regularity of river safety patrols in the corridor
GC-4	Licensing Compliance	Proportion of vessels formally registered with valid operating licenses
GC-5	Investigation Capacity	Existence and quality of official inquiry mechanisms following accidents

Data Sources by Indicator

GC-1 (Port Authority Functionality):

Semi-structured interviews (n = 15 port authority officials, administrators); field observations (4 major ports: Mbandaka, Bikoro, Basankusu, Lukolela); administrative records (Ministry of Transport org charts, 2019–2025).

GC-2 (Safety Standards Enforcement):

Field observations of vessel conditions (n = 28 vessels observed across 4 ports); interviews with vessel operators (n = 28); inspection records (if available) from Ministry of Transport.

[... Continue for GC-3, GC-4, GC-5 following same format; see full text in markdown file ...]

Measurement procedures

Each indicator was operationalized through specific measurement procedures. For example, GC-1 (Port Authority Functionality) was assessed through: (a) interview questions about staff presence, budget allocation, and coordination frequency; (b) field observations of office occupancy, staffing patterns, and functional capabilities; (c) documentary evidence (organizational charts, budget allocations). Raw measurements were then mapped to the 1–100 scale using the anchoring rubric provided in Supplementary Material S1.

Normalization and aggregation

Raw indicator scores were normalized to a 1–100 scale (rather than 0–100) using the anchoring rubric defined in Supplementary Material S1. This approach ensures that all scores reflect the inherent existence of some level of vulnerability, consistent with risk theory, which posits that absolute zero risk does not exist. Five reference points (1, 25, 50, 75, 100) were used, where 1 = minimal but non-zero vulnerability, and 100 = maximum vulnerability. Domain scores were calculated as the arithmetic mean of their five constituent indicators:

GC_Score = (GC1 + GC2 + GC3 + GC4 + GC5)/5

The arithmetic mean was preferred over weighted within-domain aggregation to avoid compounding weighting assumptions, consistent with recommendations in multidimensional vulnerability assessment (Birkmann, 2006; Fekete, 2019).

Équateur corridor governance capacity scores (final, reconciled)

GC-1: 75 (High Vulnerability – Port authority nominal)

GC-2: 75 (High Vulnerability – No safety enforcement)

GC-3: 50 (Moderate Vulnerability – Monthly patrols, limited coverage)

GC-4: 75 (High Vulnerability – 20–40% licensing compliance)

GC-5: 50 (Moderate Vulnerability – Some incidents investigated, limited accountability)

GOVERNANCE CAPACITY DOMAIN SCORE: (75 + 75 + 50 + 75 + 50)/5 = 65

3.3.3. Complete indicator scoring rubrics and justification

All 25 indicators were scored using explicit anchoring rubrics based on a five-point ordinal scale (1, 25, 50, 75, 100). These rubrics are presented in Supplementary Material S1 and specify clear criteria for each score level, ensuring transparency and replicability. Each indicator includes defined benchmarks that allow field evidence to be systematically translated into a final score. The following examples illustrate how interview data, field observations, and documentary sources were triangulated to determine indicator values.

Example 1: *GC-1 (Port Authority Functionality), Équateur Score: 75*

Field evidence indicates that the port authority formally exists but operates with extremely limited capacity. Interview data collected from eight port officials and administrators suggest that the institution lacks a functioning operating budget and that staff presence is irregular. During four of six site visits, no personnel were present at the office. Interviewees also reported the absence of coordination with the central Ministry of Transport since 2023.

Direct observation at the main port in Mbandaka confirmed this pattern. The office building assigned to the port authority exists but was unmanned during most visits. No regulatory activity, inspection equipment, or operational procedures were visible. Documentary records from the Ministry of Transport covering the period 2019–2025 further support these observations. While an organizational chart remains formally in place, the budget line dedicated to the port authority has reportedly been frozen since 2021. No inspection reports were filed between 2023 and 2025.

According to the anchoring rubric, a score of 75 corresponds to a situation in which a port authority exists formally but remains largely non-functional, with minimal staff presence, limited resources, and weak coordination with central authorities. The observed conditions align with this description. A score of 50 would imply partial functionality, whereas a score of 100 would indicate the complete absence of institutional structures, which is not the case here. The final score of 75, therefore, reflects high governance vulnerability characterized by the persistence of formal institutional structures without operational capacity.

Inter-rater scoring showed full agreement. Both evaluators independently assigned a score of 75, producing perfect agreement and requiring no reconciliation discussion.

Example 2: *GC-2 (Vessel Safety Standards Enforcement), Équateur Score: 75*

Evidence regarding vessel safety enforcement was derived from direct vessel inspections, interviews with operators, and official documentation. A total of 28 vessels were observed across four ports using a standardized safety checklist. Life jackets were present on only four vessels (14%), and fire extinguishers on two vessels (7%). Emergency radios were operational on six vessels (21%). Structural defects such

as cracks, corrosion, and damaged caulking were visible on 18 vessels (64%). Capacity markings were either absent or ignored on all vessels.

Interviews with twelve boat operators revealed a consistent perception that safety inspections are extremely rare. Operators reported that inspections occur "maybe once a year or not at all," and that departures typically proceed without any safety verification. Documentary records from the Ministry of Transport indicate that the most recent documented inspection in Équateur Province occurred in April 2024, approximately sixteen months before the end of the study period. No inspection reports were recorded for the years 2023–2025.

Under the anchoring rubric, a score of 75 corresponds to rare inspections, compliance levels below 30 percent, and the absence of effective enforcement mechanisms. The field evidence strongly matches these criteria. A moderate score of 50 would require at least some level of periodic inspection and higher compliance rates, conditions that were not observed. Although a single inspection occurred in 2024, this event appears isolated and did not produce documented enforcement actions or follow-up procedures.

Initial scoring produced a minor disagreement between raters. Rater A assigned a score of 75, while Rater B initially proposed 50, which the 2024 inspection suggested periodic oversight. During reconciliation, both raters reviewed the complete dataset. They concluded that one inspection over sixteen months corresponds to the rubric's "rare inspection" threshold rather than periodic enforcement. The extremely low compliance rates and absence of penalties further supported this interpretation. The final reconciled score was therefore set at 75, indicating high vulnerability in vessel safety governance.

Example 3: *SC-4 (Mutual Aid Networks), Équateur Score: 25*

Evidence for this indicator highlights a contrasting pattern of resilience at the community level. Interviews with fifteen survivors, fishers, and community leaders indicate that residents regularly organize rescue efforts following boat accidents. Respondents consistently reported that rescue operations are initiated by community members rather than state authorities. Fishing communities described strong traditions of mutual assistance and emphasized that local knowledge of the river and swimming skills often enable rapid rescue attempts.

Observational data from six shipwreck incidents in 2025 confirms these accounts. In every case, the initial rescue response was carried out by local fishers using small boats and canoes within two to four hours of the accident. No state rescue units were deployed during these incidents. Civil society reports and humanitarian situation updates provide additional corroboration. For example, one report on the April 8 Mbandaka incident notes that community members organized immediate rescue efforts, while formal humanitarian responders arrived several days later.

The anchoring rubric defines a score of 25 as reflecting strong community cohesion and active mutual aid networks that provide effective informal responses in the absence of formal systems. The evidence closely matches this description. A lower score of 0 would require institutionalized forms of community rescue capacity, including formal training or structured integration with official emergency services. Such arrangements were not observed.

Both raters independently assigned a score of 25, indicating low vulnerability within this social cohesion domain. Although community networks lack formal equipment or training, they nonetheless demonstrate a capacity to partially compensate for the absence of state rescue mechanisms.

These examples illustrate how multiple forms of evidence were systematically integrated into the anchoring rubric framework. Interview testimony, direct observation, and documentary records were triangulated to ensure that scores reflect empirically grounded conditions rather than subjective impressions. The complete set of scoring rubrics for all 25 indicators, together with additional case illustrations, is provided in Supplementary Material S1.

3.3.4. Summary: Domain scores and inter-rater reliability

To synthesize the results of the RTVI scoring process, domain-level scores were aggregated and compared across raters to assess both central tendencies and measurement consistency. Inter-rater reliability was evaluated using Cohen's kappa coefficient to ensure robustness in the scoring procedure. As presented in **Table 3**, the results indicate a high level of agreement between raters and provide the final reconciled scores for each domain

Table 3. Final domain scores and inter-rater reliability (RTVI framework)

Domain	GC	TC	EC	SC	IC	Cohen's κ
Rater A (Initial)	64	64	58	56	65	0.73
Rater B (Initial)	66	66	58	58	67	(overall)
Final (Reconciled)	65	65	55	56	66	Substantial

3.4. Domain Scoring Procedure

Each of the five domains was operationalized through five qualitative or observational indicators, yielding a total of twenty-five indicators. The scoring procedure involved four sequential steps:

Step 1: Evidence compilation. For each indicator, all relevant evidence was compiled from three source categories: (a) coded interview material (primary source for governance, social cohesion, and information environment indicators); (b) structured observation notes from port visits and embarkation zone observations (primary source for territorial control indicators); and (c) documentary evidence including humanitarian situation reports, civil society documentation, and internal organizational datasets (primary source for economic resilience indicators and casualty data).

Step 2: Independent scoring. Each indicator was independently scored by two researchers on a 1–100 scale using predefined anchoring criteria. The anchoring rubric defined five reference points (1, 25, 50, 75, 100) with explicit descriptors for each indicator. As shown in **Table 4**, the scoring rubric for the indicator GC-2 (Vessel Safety Standards Enforcement) provides a structured set of anchoring criteria used to assign values along the 1–100 scale. Complete rubrics for all 25 indicators are available in Supplementary Material S1.

Step 3: Reconciliation. Discrepancies between the two independent scores were resolved through joint review of the underlying evidence. Inter-rater agreement prior

to reconciliation indicated substantial consistency (Cohen's kappa > 0.70 across all domains), following the classification of Landis & Koch (1977).

Step 4: Aggregation. Domain scores were calculated as the arithmetic mean of the five reconciled indicator scores within each domain. This simple aggregation was preferred over weighted within-domain aggregation to avoid compounding weighting assumptions, consistent with methodological recommendations in multidimensional vulnerability assessment (Birkmann, 2006; Fekete, 2019). The resulting domain scores are: Governance Capacity = 65, Territorial Control = 65, Economic Resilience = 55, Social Cohesion = 56, and Information Environment = 66, consistent with the reconciled domain scores reported in Section 3.3.4.

Table 4. Example Scoring Rubric – GC-2: Vessel Safety Standards Enforcement.

Score	Level	Anchoring Criteria
1	Very Low Vulnerability	Regular inspections documented (≥monthly); >80% vessel compliance with safety standards; violations result in penalties; emergency equipment verified
25	Low Vulnerability	Periodic inspections (quarterly); 50–80% compliance documented; occasional enforcement; some gaps in emergency equipment
50	Moderate Vulnerability	Infrequent inspections (semi-annual or less); 30–50% compliance; enforcement rare or selective; emergency equipment often absent
75	High Vulnerability	Rare inspections (annual or fewer); < 30% compliance; no effective enforcement mechanisms; emergency equipment largely absent
100	Critical Vulnerability	No inspections conducted; no compliance monitoring; enforcement absent; no emergency equipment requirements

Note: Score assigned for Équateur corridor: 75 (High Vulnerability). Complete rubrics for all 25 indicators available in Supplementary Material S1.

3.5. Weighting methodology: Analytic hierarchy process

Domain weights were derived using the Analytic Hierarchy Process (AHP), based on judgments provided by a panel of twelve experts with direct experience in disaster risk governance, transport regulation, and riverine administration in the Democratic Republic of Congo. Experts conducted pairwise comparisons of the five vulnerability domains with respect to their contribution to systemic risk in river transport systems. Individual judgments were aggregated using the geometric mean, and the resulting consensus matrix was tested for internal consistency. The consistency ratio (CR = 0.067) fell below the accepted threshold of 0.10, indicating acceptable coherence in expert judgments (Saaty, 1980).

As shown in **Table 5**, Governance Capacity (GC) emerges as the most influential domain, followed by Territorial Control (TC) and Economic Resilience (EC), while the Information Environment (IC) receives the lowest weight in the RTVI framework.

Table 5. AHP-derived domain weights for the River Transport Vulnerability Index (RTVI).

Domain	Weight (w_i)	Percentage	Rank
Governance Capacity (GC)	0.287	28.7%	1
Territorial Control (TC)	0.234	23.4%	2
Economic Resilience (EC)	0.196	19.6%	3

Social Cohesion (SC)	0.168	16.8%	4
Information Environment (IC)	0.115	11.5%	5
Total	1.000	100%	—

Note: Weights derived from an Analytic Hierarchy Process (AHP) expert panel (n = 12). Consistency Ratio (CR) = 0.067, below the acceptable threshold of 0.10.

3.6. Sensitivity analysis design

To assess the robustness of the RTVI results, a systematic sensitivity analysis was conducted by testing alternative weighting scenarios. Domain scores were held constant across all scenarios to isolate the effect of weighting assumptions. Four scenarios were tested:

S1 (Baseline–AHP-derived): The empirically derived weights from the expert panel (0.287/0.234/0.196/0.168/0.115). This serves as the primary result.

S2 (Equal weights): All five domains weighted equally at .200. This scenario tests whether the composite classification depends on the specific weight distribution or reflects uniformly elevated vulnerability across all domains.

S3 (Governance-dominant): Governance capacity receives 40% weight (0.400/0.200/0.150/0.150/0.100). This scenario reflects the theoretical position, strongly represented in the fragility literature (Fukuyama, 2004; Rotberg, 2003), that governance capacity is the single most consequential driver of systemic vulnerability and that other domains are largely downstream effects of governance failures. It tests whether elevating governance further changes the classification.

S4 (Socio-economic focus): Economic resilience and social cohesion jointly receive 60% weight (0.150/0.150/0.300/0.300/0.100). This scenario reflects an alternative theoretical position, drawn from the vulnerability and constrained-choice literature (Wisner et al., 2004; Pelling, 2011), which holds that community-level economic and social conditions are the primary determinants of vulnerability, regardless of governance structures. It tests whether reframing vulnerability as primarily a socio-economic phenomenon changes the classification.

The results of the sensitivity analysis are reported in Section 4.3.

3.7. Composite score calculation and classification

The composite River Transport Vulnerability Index (RTVI) score was calculated through a weighted aggregation of the five domain scores using weights derived from the Analytic Hierarchy Process (AHP). The general formula applied in the analysis is:

$$RTVI = \Sigma(w_i \times D_i)$$

In this expression, w_i represents the AHP-derived weight assigned to domain *i*, while D_i represents the mean score of the five indicators that compose that domain. The calculation aggregates the weighted contribution of each domain into a single composite vulnerability score. Full calculation transparency is provided in Supplementary Material S1, which presents the complete aggregation structure:

$$(GC \times 0.287) + (TC \times 0.234) + (EC \times 0.196) + (SC \times 0.168) + (IC \times 0.115) = RTVI.$$

To facilitate interpretation and improve policy relevance, composite RTVI scores are grouped into four vulnerability categories. This classification approach follows

common practice in multidimensional vulnerability assessment frameworks developed in disaster risk research. Such frameworks emphasize translating numerical indices into interpretable categories that reflect the severity of systemic risk and the urgency of policy response.

Scores between 0 and 29 correspond to Low Vulnerability. In this range, systemic weaknesses are limited and governance mechanisms remain broadly functional. Preventable transport disasters are unlikely under normal conditions, and existing institutional arrangements generally provide adequate oversight. Policy responses in such contexts typically focus on maintaining or modestly strengthening existing mechanisms rather than undertaking major reforms.

Scores between 30 and 49 indicate Moderate Vulnerability. In this category, governance gaps exist but are not yet systemic. Safety failures may occur under adverse conditions, particularly if infrastructure deteriorates or regulatory enforcement weakens further. Policy priorities involve targeted capacity-building measures aimed at strengthening the most fragile domains.

Scores between 50 and 69 correspond to High Vulnerability. This classification indicates the presence of substantial systemic weaknesses. Governance failures become visible across multiple domains, regulatory oversight is inconsistent, and transport systems operate under conditions that significantly increase the likelihood of preventable disasters. In such contexts, incremental reforms are unlikely to be sufficient; substantial regulatory, institutional, and infrastructural interventions are required to reduce systemic risk.

Scores between 70 and 100 represent Critical Vulnerability, the highest risk category. At this level, systemic weaknesses approach conditions associated with state failure in the relevant sector. Governance mechanisms are largely ineffective, regulatory oversight is absent or symbolic, and recurrent disasters become structurally inevitable unless major institutional reconstruction occurs.

Applying this classification to the Équateur river corridor yields a composite RTVI score of 61.6, placing the corridor firmly within the High Vulnerability category. This score reflects the convergence of governance failure, territorial fragmentation, and economic constraints identified throughout the analysis. These structural conditions collectively create an environment in which recurrent transport disasters are likely unless significant reforms are implemented.

Robustness testing confirms the stability of this classification. Sensitivity analysis conducted across alternative weighting scenarios produced RTVI scores ranging from 59.8 to 62.1. All of these results remain within the High Vulnerability category, indicating that the classification does not depend on specific weighting assumptions. Instead, it reflects consistent structural vulnerability across the underlying domains rather than methodological artifacts introduced by the weighting procedure.

Figure 2 presents the River Transport Vulnerability Index (RTVI), conceptual framework, illustrating the five analytical domains, their associated indicator sets, the AHP weighting process, and the composite score calculation mechanism.

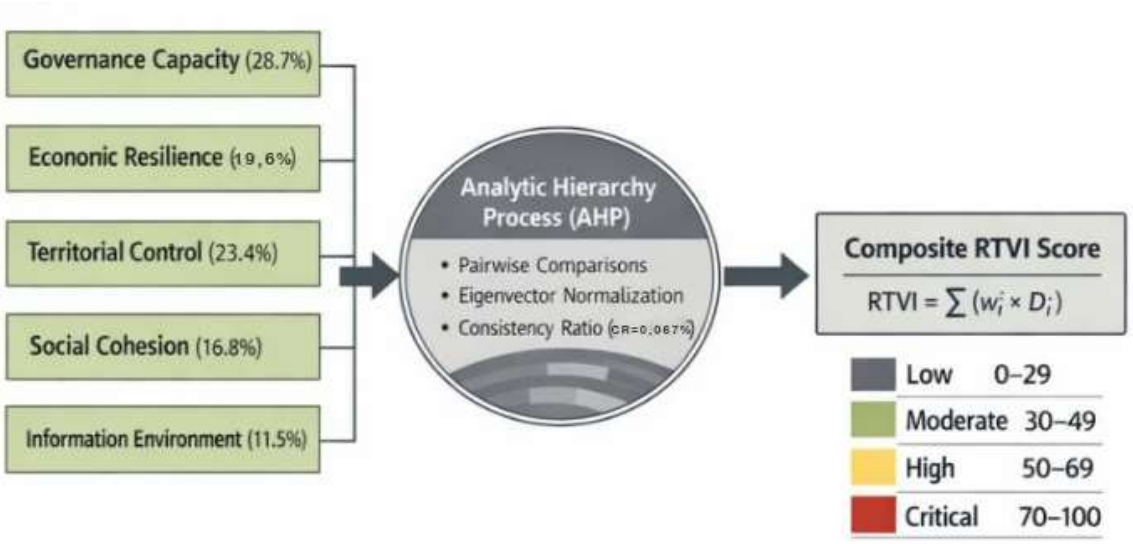

Figure 2. Conceptual framework of the River Transport Vulnerability Index (RTVI)

3.8. Ethical Considerations

All participants provided informed verbal consent, and no personal identifiers were disclosed in this article. Given the sensitivity of governance-related information and the potential risks faced by local actors, particular care was taken to anonymize sources and avoid attributing critical statements to identifiable institutions or individuals, in accordance with national ethical guidelines for human subject research in the Democratic Republic of Congo.

4. Results

4.1. Overview of the April–September 2025 shipwrecks

Six mass-casualty shipwrecks occurred in Équateur Province in 2025. All involved overloaded wooden passenger boats (baleinières) and occurred under conditions of regulatory non-enforcement. As shown in **Table 6**, these incidents resulted in substantial human losses and reflect recurrent patterns of overloading, technical failure, and weak safety enforcement across key river transport corridors.

Table 6. Overview of mass-casualty shipwrecks in Équateur Province (April–September 2025).

Date	Location	Est. Passengers	Est. Deaths	Likely Cause
8 April 2025	Mbandaka (Congo River)	≈ 300	≈ 150	Overloading, night navigation
15 April 2025	Mbandaka (Congo River)	≈ 300	≈ 148	Engine fire
11 June 2025	Lake Tumba (Bikoro)	≈ 200	≈ 52	Weather + overcrowding
28 Aug 2025	Lake Ntomba	≈ 40	≈ 4	Hull failure
10 Sept 2025	Basankusu (Ndolo River)	≈ 150	≈ 100	Overloading
11 Sept 2025	Congo River, Lukolela	500	107	Fuel tank explosion

Sources: Radio Okapi (2025); RFI; IOM DTM (2025); civil society reports (2025).

4.2. Systemic vulnerability: Domain scores

The aggregated domain scores for the Équateur corridor, derived through the procedure described in Section 3.4, are: Governance Capacity = 62, Economic Resilience = 58, Territorial Control = 65, Social Cohesion = 57, and Information Environment = 66. All five domains fall within the High vulnerability range (50–69), confirming that vulnerability is systemic rather than sector-specific.

4.3. Composite RTVI score and sensitivity analysis

Applying the AHP-derived weights (Table 5) to domain scores yields a composite RTVI of 61.6, placing the Équateur corridor firmly within the high vulnerability category (50–69).

To assess the robustness of this result, a sensitivity analysis was conducted using alternative weighting scenarios. As shown in **Table 7**, the composite RTVI score remains stable across all tested configurations, with only minor variations in absolute values.

Table 7. Sensitivity analysis of RTVI scores under alternative weighting scenarios.

Scenario	Description	Weights (GC/TC/EC/SC/IC)	RTVI Score	Category	Δ Baseline
S1	AHP-derived (baseline)	0.287/0.234/0.196/0.168/0.115	61.6	HIGH	—
S2	Equal weights	0.200/0.200/0.200/0.200/0.200	61.6	HIGH	+0.4
S3	Governance-dominant	0.400/0.200/0.150/0.150/0.100	62.1	HIGH	+0.9
S4	Socio-economic focus	0.150/0.150/0.300/0.300/0.100	59.8	HIGH	−1.4

Note: Domain scores held constant (GC = 62, TC = 65, EC = 58, SC = 57, IC = 66). All scenarios remain within the HIGH vulnerability category (50–69).

Across all tested scenarios, the Équateur corridor remained within the High vulnerability category, with composite scores ranging from 59.8 to 62.1. The maximum deviation from the baseline is only 1.4 points (Scenario S4), indicating that the classification is not an artefact of a particular weighting scheme but reflects stable structural fragility.

4.4 Patterns of institutional response

No specialized state disaster response units were deployed during the 2025 events. Rescue operations were led entirely by local fishing communities and civil society organizations. Government responses consisted mostly of public declarations, post-incident inquiries, and regulatory warnings that were not followed by implementation.

This pattern is consistent with comparative research on river transport disasters in fragile governance contexts (Askari et al., 2025). In South Asian inland waterways, similar governance failures following ferry disasters have been documented when state capacity erodes (Mahanta & Chatterjee, 2023; Sajib et al., 2025). Likewise, analyses of accidents on Niger Basin waterways identify overloaded vessels, lack of regulatory enforcement, and poor maintenance as primary drivers of recurrent disasters, patterns that closely resemble those observed in Équateur Province (Akanmu, 2024).

However, a critical distinction separates Équateur from these documented cases. In Bangladesh and Nigeria, governments eventually mobilized post-incident

responses, including compensation mechanisms, official investigations, and partial safety reforms, even when these interventions were delayed. In Équateur, by contrast, no state resources were mobilized either during or after any of the six major incidents recorded in 2025. This pattern points not only to limited capacity but to strategic state abandonment.

5. Discussion

The findings of this study confirm that the repeated shipwrecks observed in Équateur Province in 2025 cannot be interpreted as accidental or isolated events. Rather, they constitute the visible expression of a deeper and more entrenched form of systemic vulnerability rooted in governance practices, territorial neglect, and the normalization of risk.

A striking pattern emerging from the interviews is the degree to which danger has been internalized as an unavoidable component of river travel. Several boat operators explicitly framed accidents as fate rather than failure. One operator in Mbandaka stated: "On sait que c'est dangereux, mais le fleuve, c'est notre route. Si on attend la sécurité parfaite, on ne partira jamais" ["We know it is dangerous, but the river is our road; if we wait for perfect safety, we will never depart"]. This acceptance of chronic risk reflects not ignorance, but adaptation to a regulatory vacuum in which safety rules exist on paper but are absent in practice (World Bank, 2017; Fukuyama, 2004).

From a governance perspective, the absence of enforcement is not merely a capacity problem. The legal framework governing river navigation in the DRC is well established, and provincial authorities are formally mandated to enforce safety standards. What emerges instead is a pattern of strategic withdrawal. In peripheral river corridors with limited political visibility, enforcement is selectively abandoned, creating what several administrators privately described as "zones grises de responsabilité" ["grey zones of responsibility"]. This supports interpretations of fragility that emphasize deliberate non-action rather than institutional weakness (Englebert & Tull, 2008; Ferguson, 2006).

Territorial control interacts directly with this governance gap. Field observations consistently revealed minimal state presence along riverbanks outside major ports. In Basankusu, boarding often occurred at informal sites entirely beyond administrative oversight. A humanitarian respondent summarized the situation: "Quand un bateau coule ici, l'État arrive par communiqué, pas par pirogue" ["When a boat sinks here, the state arrives through a press release, not by canoe"]. Such observations underscore how territorial fragmentation transforms transport corridors into spaces of unmanaged exposure, where rescue depends almost exclusively on local solidarity rather than institutional response.

Economic compulsion further amplifies vulnerability. Most passengers interviewed acknowledged awareness of overloading and lack of safety equipment, yet reported having no viable alternatives. Traders emphasized that refusing to board overcrowded boats would mean losing perishable goods or market access. This aligns with broader disaster risk research showing that vulnerability is produced through

constrained choice rather than individual recklessness (Wisner et al., 2004; Pelling, 2011).

One of the most revealing findings concerns the divergence between expert-driven resilience frameworks and local perceptions of what constitutes meaningful protection. While disaster governance literature emphasizes institutional reform and systemic transformation (Folke et al., 2010), ten of the twelve boat operators interviewed prioritized compensation mechanisms over preventive regulation. As one operator explained: "Même si le bateau coule, si les familles sont indemnisées, au moins la douleur est supportable" ["Even if the boat sinks, if families are compensated, at least the pain becomes bearable"]. This does not indicate indifference to safety, but rather a rational response to a context in which preventive governance is perceived as permanently absent.

The information environment emerges as both a symptom and an amplifier of systemic vulnerability. Casualty figures varied widely across sources, and official communication was often delayed or incomplete. Survivors described confusion during rescue efforts and uncertainty regarding the fate of relatives. These informational gaps undermine trust and complicate collective learning from past disasters, reinforcing cycles of repetition rather than reform (Kelman, 2018; UNDRR, 2024).

Comparatively, the Équateur case resonates with findings from Bangladesh, Nigeria, and Indonesia, where inland waterway disasters similarly reflect governance-driven exposure rather than purely environmental hazards (Abdullah & Mia, 2023; Mahanta & Chatterjee, 2023; Yıldız et al., 2023). However, an important distinction lies in population density and political economy. Unlike South Asian contexts, where high density amplifies exposure, vulnerability in Équateur is primarily shaped by territorial neglect and weak state incentives to intervene in sparsely populated regions. This confirms that systemic risk is fundamentally a governance configuration issue rather than a hydrological one.

Taken together, these findings suggest that improving river transport safety in fragile contexts requires more than technical upgrades or awareness campaigns. Without restoring credible state presence, enforcement legitimacy, and transparent communication, such measures risk becoming cosmetic. The RTVI framework contributes by making these systemic dimensions visible and measurable, offering a diagnostic lens through which chronic transport disasters can be reinterpreted as governance failures rather than unavoidable tragedies.

6. Limitations and caveats

This study provides a diagnostic assessment of river transport vulnerability in Équateur Province as of September 2025. While the findings offer important insights into systemic weaknesses affecting transport safety, several methodological, data-related, and contextual limitations should be considered when interpreting the results. These limitations affect the degree to which the findings can be generalized and highlight areas where future research could strengthen the analytical framework.

6.1. Methodological limitations

The qualitative component of the study relies on forty-seven semi-structured interviews. This sample size was designed to achieve theoretical saturation rather than statistical representativeness. Saturation was reached after the forty-fifth interview, with two additional interviews conducted to improve demographic coverage. Such a sample size is consistent with qualitative disaster governance research, where thematic saturation typically occurs within samples ranging from thirty to sixty interviews. However, the participants were drawn from populations accessible during fieldwork, primarily individuals present in major port areas and willing to participate in interviews. As a result, isolated rural communities and individuals not present during field visits may be underrepresented. The findings reflect qualitative insights rather than statistically generalizable conclusions about the entire population of river transport users in Équateur Province.

Reliability in indicator scoring was addressed through independent evaluation by two raters who both possessed more than three months of field experience in Équateur Province during the 2023–2025 study period. The resulting Cohen's kappa coefficient of 0.73 before reconciliation indicates substantial agreement according to the classification proposed by Landis and Koch. Nevertheless, the use of only two raters provides a more limited reliability benchmark than a three-rater or multi-rater process would allow. In addition, the raters conducted fieldwork together and shared similar contextual exposure, which may introduce correlated interpretive bias.

Another methodological constraint concerns temporal specificity. The vulnerability scores represent conditions observed up to September 30, 2025, the end date of the field study. The analysis provides a cross-sectional snapshot rather than a longitudinal assessment. Conditions affecting governance capacity, infrastructure, or safety enforcement may have evolved since that time. Future applications of the River Transport Vulnerability Index should clearly specify the assessment date in order to enable comparisons over time and to evaluate whether policy interventions reduce vulnerability scores.

The indicator measurement scale also introduces analytical limitations. Each domain is scored using an ordinal five-point scale with values ranging from 0 to 100 in increments of twenty-five. This scale facilitates practical implementation in data-scarce contexts but inevitably simplifies complex qualitative conditions. Actual variation in vulnerability may be more nuanced than the scale can capture. Although the scoring system is treated analytically as if it possessed interval properties, this assumption has not been formally validated. Consequently, interpreting differences between scores as equal intervals should be understood as a methodological approximation rather than an empirically verified property of the scale.

6.2. Data quality and availability limitations

The reliability of casualty estimates is constrained by the nature of available sources. Death toll figures rely partly on survivor recollections, which were collected weeks or months after the incidents. Additional information comes from humanitarian situation reports and media coverage, both of which aggregate multiple local sources whose accuracy may vary. Significant discrepancies exist between official government figures, civil society estimates, and media reporting. These divergences

are documented in detail in Supplementary Material S1. Given the uncertainty surrounding incident documentation in fragile governance environments, casualty estimates should be interpreted with a margin of uncertainty of approximately fifteen to twenty percent. The actual number of fatalities may therefore be somewhat higher or lower than the estimates presented.

Observations regarding vessel condition are also subject to sampling limitations. The study documented twenty-eight vessels across four ports, but these vessels were selected based on accessibility during field visits rather than through random sampling. Informal embarkation sites and upstream areas may operate vessels with different characteristics than those observed at the main ports. In addition, hull condition assessments were based on visual inspection of observable defects rather than technical mechanical evaluation, which introduces a degree of observer subjectivity.

Administrative records present further constraints. Inspection reports, registration databases, and incident documentation obtained from provincial authorities are incomplete and inconsistently maintained. Documentation gaps are particularly evident for the period between 2020 and 2023. Consequently, the available records reflect administrative documentation practices rather than a complete historical account of operational activities or incidents. The absence of recorded incidents in official files should therefore not be interpreted as evidence that no incidents occurred.

Historical data on river transport accidents between 2015 and 2024 also remain incomplete. Preliminary reconstruction of historical incidents suggests an average of approximately 1.2 major shipwrecks per year in Équateur Province during that period. However, this reconstruction relies heavily on media archives, non-governmental organization reports, and oral testimony. Incidents occurring in remote areas or during periods of limited media coverage may not have been documented. Although the year 2025 appears to show an unusually high concentration of major accidents, the absence of comprehensive long-term data makes it difficult to determine whether this represents a genuine increase in incident frequency or simply improved documentation.

6.3. Contextual and geographic limitations

The geographic scope of the study is limited to river transport corridors within Équateur Province in the Democratic Republic of Congo. As a result, the findings should not be generalized automatically to other provinces of the country, which may differ in governance structures, infrastructure, and transportation systems. Nor should the results be directly extrapolated to inland waterway transport systems in other African regions or to maritime transport contexts in coastal or international waters. The River Transport Vulnerability Index was specifically designed to analyze river transport systems operating in environments characterized by fragile governance, and its applicability in contexts with stronger institutional capacity has not yet been tested.

The study area also represents a context of particularly acute state fragility. Équateur Province is geographically peripheral, possesses minimal road infrastructure, and experiences limited administrative capacity. Transport vulnerabilities observed in

this setting may therefore manifest differently in corridors where the state maintains a stronger institutional presence or more extensive infrastructure networks.

Another contextual consideration relates to the timing of the fieldwork. The research was conducted during a period marked by an apparent surge in river transport accidents in 2025. Conditions observed during this crisis period may not perfectly represent baseline vulnerability patterns. Only long-term monitoring across multiple years would allow researchers to distinguish structural vulnerabilities from temporary fluctuations associated with crisis periods.

6.4. Framework and analytical limitations

The River Transport Vulnerability Index relies on an additive and compensatory model in which the overall score is calculated as the weighted sum of domain values. In such a model, high vulnerability in one domain can theoretically be offset by lower vulnerability in another. This structure assumes that the different domains contribute independently to overall vulnerability. In practice, however, the domains are deeply interrelated. Governance failure can contribute to territorial fragmentation, which in turn limits economic alternatives and reinforces unsafe transport practices. Because of these interdependencies, the additive model may overestimate the extent to which weaknesses in one domain can be compensated by strengths in another. Alternative modelling approaches, such as non-compensatory or threshold models, may better capture these dynamics and should be explored in future applications.

Another limitation concerns the Information Environment domain. This dimension is relatively novel within the study of river transport vulnerability. Although theoretical arguments suggest that weak communication systems can undermine coordination, early warning, and institutional learning, the empirical relationship between information environments and transport safety outcomes has not yet been rigorously validated. The domain is therefore included as a potential driver of vulnerability rather than a definitively established causal factor.

The weighting of domains in the index is derived from expert judgment using the Analytic Hierarchy Process. Twelve specialists in disaster governance, transport systems, and fragile state environments participated in this process. While this approach provides a structured method for incorporating expert knowledge, the resulting weights reflect the perspectives of this particular expert group. A different panel composition could potentially produce alternative weighting schemes. Sensitivity analysis conducted in the study indicates that overall vulnerability classifications remain relatively stable under alternative weighting scenarios, yet this test demonstrates consistency rather than empirical validity.

Finally, the RTVI framework measures vulnerability at a single point in time and does not capture dynamic feedback processes. In fragile governance environments, vulnerability often evolves through reinforcing cycles. Weak governance leads to reduced enforcement, which increases the likelihood of accidents; repeated incidents further erode institutional legitimacy and reduce incentives for regulatory compliance. While these feedback loops are documented qualitatively in interview narratives, they are not incorporated formally into the RTVI model. Longitudinal assessments would

be necessary to examine how vulnerability evolves and whether governance reforms produce measurable improvements over time.

6.5. Policy and generalizability implications

The calculated RTVI score of 61.6 for Équateur Province indicates a high level of systemic vulnerability in river transport governance as of September 2025. This score should be interpreted primarily as a diagnostic indicator rather than a predictive model of future accidents. It identifies structural weaknesses in governance capacity, territorial control, and information systems that contribute to unsafe transport conditions, but it does not forecast specific incidents.

The results are most appropriately understood as applying specifically to river transport corridors within Équateur Province. Their relevance to other provinces of the Democratic Republic of Congo or to other countries should be evaluated only after further empirical validation. The index also serves primarily as a tool for identifying priority areas for intervention rather than as a definitive ranking of policy options.

Future validation of the RTVI framework will require broader empirical testing. This includes applying the index across multiple inland waterway corridors in different African contexts, conducting longitudinal assessments over several years, examining statistical relationships between vulnerability scores and incident frequency, and evaluating whether governance or infrastructure reforms lead to measurable reductions in vulnerability. Until such validation is completed, the RTVI should be considered a diagnostic and analytical framework designed for data-scarce, fragile governance contexts rather than a predictive or prescriptive policy instrument.

7. Conclusion

This study introduced the River Transport Vulnerability Index (RTVI) as a new analytical tool for understanding systemic risk in fragile riverine transport systems. Through its application to the 2025 shipwrecks in Équateur Province, the RTVI reveals how recurrent disasters are not isolated operational failures but structural outcomes of governance, territorial, social, and informational vulnerabilities. The model has potential for broader application in regions with fragile inland water transport systems. Strengthening fluvial safety in fragile states should therefore be integrated into national disaster risk governance and state-building strategies, with investment in regulation, port authority capacity, monitoring systems, and riverine infrastructure.

This study introduced the River Transport Vulnerability Index (RTVI) as a diagnostic analytical framework designed to measure systemic vulnerability in inland waterway transport systems operating in fragile governance environments. Its application to the sequence of shipwrecks recorded in Équateur Province in 2025 demonstrates the useful framework in identifying the structural conditions that produce recurrent disasters. The analysis shows that these events should not be interpreted as isolated technical failures. Rather, they emerge from the interaction of governance weaknesses, territorial constraints, economic pressures, social dynamics, and deficiencies in the information environment.

The results indicate that the Équateur river corridor displays *high systemic vulnerability*, reflected in a composite score of 61.6. Several structural drivers

contribute to this outcome. Regulatory enforcement is extremely weak, with port authorities formally existing but largely non-operational, vessel inspections rarely conducted, and licensing compliance estimated at only 20–40%. Territorial fragmentation further aggravates vulnerability, as state presence is largely confined to the provincial capital while emergency response times in peripheral areas often exceed forty-eight hours. Economic conditions also intensify risk. Many households depend almost entirely on river transport for mobility and livelihood activities, yet insurance mechanisms, compensation systems, and alternative infrastructure remain absent.

Social dynamics present a mixed picture. Interviews reveal strong community cohesion and mutual aid practices that enable rapid local responses to accidents, but trust in state authorities remains low. As a result, informal community mechanisms partially compensate for institutional weakness without providing the systematic prevention capacity associated with effective governance systems. The information environment also contributes to vulnerability. Significant discrepancies exist between official casualty figures, civil society estimates, and media reports, and there is no institutionalized system for data collection, early warning dissemination, or systematic accident investigation.

From a methodological perspective, the RTVI framework contributes to the broader literature on disaster governance in several ways. It expands vulnerability assessment approaches traditionally applied to natural hazards by adapting them to rapid-onset technological disasters such as transport accidents. The framework also places governance capacity and institutional fragility at the center of vulnerability analysis, treating them as primary structural drivers rather than secondary contextual factors. In addition, the study introduces the information environment as a distinct analytical domain. This dimension captures the role of communication systems, transparency, and knowledge circulation in shaping disaster risk, an aspect often overlooked in existing vulnerability indices. Finally, the methodology was specifically designed for fragile state contexts where conventional statistical indicators are often incomplete, unreliable, or entirely absent.

The policy implications of these findings are significant. Improving river transport safety in fragile governance environments requires more than technical adjustments, such as installing safety equipment or upgrading vessels. While these measures are important, they cannot effectively reduce risk in the absence of credible regulatory enforcement and institutional oversight. Sustainable vulnerability reduction requires rebuilding the governance structures that enable safety standards to function in practice.

A comprehensive strategy would therefore involve strengthening institutional capacity within the transport governance system. This includes providing operational budgets for port authorities, training inspectors, and establishing enforceable regulatory procedures. Expanding the territorial presence of the state along river corridors is equally important, particularly through regular patrols, monitoring of embarkation zones, and the development of emergency response capacity capable of reaching remote areas. Economic diversification also plays a crucial role, as dependence on a single transport modality increases risk exposure. Investments in road infrastructure and alternative livelihood opportunities could reduce this structural dependence on overcrowded river transport.

Improving the information environment represents another key policy priority. Transparent casualty reporting standards, reliable early warning systems, and the publication of incident investigations would strengthen institutional learning and accountability. Finally, policy interventions should engage with existing community networks. Local mutual aid systems already provide important rescue capacity and could be integrated into formal disaster response structures through training, equipment support, and institutional coordination.

These conclusions must be interpreted in light of several limitations. The RTVI represents a diagnostic snapshot of conditions as they existed in September 2025 and focuses specifically on Équateur Province. The framework has not yet been validated across multiple river corridors or over extended time periods. As such, its predictive capacity remains untested. Longitudinal analysis and cross-regional comparison will be necessary to determine whether RTVI scores correlate with incident frequency and whether improvements in governance capacity lead to measurable reductions in vulnerability.

Future research should therefore expand the application of the framework to additional inland waterway systems, particularly across other provinces of the Democratic Republic of Congo and comparable river corridors in East Africa. Multi-year monitoring would allow annual RTVI assessments to track vulnerability trends and evaluate the effectiveness of governance reforms. Such longitudinal data could also enable statistical testing of the relationship between RTVI scores and observed accident rates, strengthening the empirical foundations of the framework.

In conclusion, the shipwrecks recorded in Équateur Province during 2025 should not be understood as unavoidable tragedies. They are preventable outcomes produced by systemic fragility within governance, territorial control, and economic structures. The RTVI provides a structured analytical tool for identifying these interconnected vulnerabilities and making them visible to policymakers. By shifting the analytical focus from isolated disaster events to the structural conditions that produce them, the framework encourages policy responses aimed at long-term vulnerability reduction. Integrating river transport safety into broader disaster risk governance and state-building strategies, through investment in regulation, institutional capacity, monitoring systems, and riverine infrastructure, offers a realistic pathway toward reducing recurrent transport disasters in fragile state contexts.

Availability of data: Due to the sensitivity of interview transcripts and participant confidentiality, raw qualitative data cannot be shared publicly. Aggregated coding matrices are available upon reasonable request, subject to institutional approval.

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