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The Effect of Land Transportation Accessibility Vulnerability on Disaster Risk in The Perspective of Defense Economics in Gorontalo Province

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Abstract
Gorontalo Province occupies a geostrategic position opposite the Indonesian Archipelago Sea Route (ALKI) II, yet its land transportation system depends absolutely on a single spine network of 748.60 km of national roads and 643.61 km of provincial roads without equivalent alternative routes. This structural condition creates a single point of failure, where a disaster at one critical node can paralyze regional logistics, disrupt defense supply chains, and trigger severe economic losses. This study aims to quantitatively map the vulnerability of land transportation accessibility based on disaster risk and to measure its implications within the defense economics framework. A quantitative descriptive method was employed, combining Spatial Multi-Criteria Evaluation (SMCE) and GIS Network Analysis with transportation cost modeling of Vehicle Operating Cost (VOC) and detour costs. The results show that all districts and cities in Gorontalo face high disaster vulnerability, with sinuosity index values reaching 1.43 in Pohuwato, indicating severe topographic distortion. Disaster scenarios reduced the Spatial Accessibility Index by 45%–70% and escalated truck operating costs by 75%–91%, with transportation costs per ton rising from IDR 150,000–250,000 to IDR 380,000–650,000 and triggering commodity inflation of 18%–35%. Within the defense economics perspective, these findings demonstrate critical threats to defense logistics security, significant regional economic multiplier losses, and opportunity costs far exceeding preventive mitigation budgets. The study concludes that Gorontalo's single spine network constitutes a systemic threat to regional economic stability and national defense logistics, and recommends integrating the provincial network into the Defense Region Logistics System, accelerating redundancy route development, and incorporating GIS-based accessibility mapping into spatial planning documents.

INTRODUCTION

Gorontalo Province occupies an important geostrategic position in eastern Indonesia, situated near the Indonesian Archipelagic Sea Lane II (ALKI II) and bordered by Tomini Bay and the Sulawesi Sea (Anwar et al., 2025). In the context of national development and defense, regional connectivity plays a vital role in supporting economic activities and strategic mobility. Land transportation networks in strategically important regions require high network reliability, alternative routes (network redundancy), and accessibility that remains resilient to disruptions

caused by natural disasters (Hardiansyah et al., 2020; Koks et al., 2023; Yücel et al., 2018). From a defense economics perspective, road infrastructure serves not only as civilian public infrastructure but also as a strategic defense asset that supports the continuity of regional defense supply chains, the stability of strategic commodity prices, and regional defense mobilization readiness within the framework of Indonesia's Universal People's Defense and Security System (Sistem Pertahanan dan Keamanan Rakyat Semesta, or Sishankamrata) (Yog, 2026).

However, Gorontalo Province's existing transportation system is heavily dependent on a single primary road network, with limited alternative routes of comparable capacity connecting regencies, municipalities, and access points to neighboring provinces. This vulnerability is further exacerbated by potential disruptions at major transportation nodes, including Dungingi Type A Terminal, Isimu Type A Terminal, and Limboto Type B Terminal. Local operational constraints, such as market activities encroaching on roadways around Limboto, frequently impede traffic flow and increase travel times (Dinas Perhubungan Provinsi Gorontalo [Dishub Prov. Gto], 2026). When compounded by natural disasters, these disruptions could severely affect regional supply chains (Colon et al., 2020; Nocera et al., 2024). Gorontalo Province's topography, characterized by extensive hilly terrain, steep slopes across more than 68% of its territory, and numerous river basins, increases the exposure of national and provincial road corridors to landslides, floods, and earthquakes (Badan Nasional Penanggulangan Bencana [BNPB], 2022; Kushari et al., 2026; Yao et al., 2023).

This structural vulnerability creates the potential for a single point of failure, whereby a disaster affecting a critical transportation node or corridor could significantly disrupt regional accessibility and connectivity (Papilloud & Keiler, 2021; Zhang et al., 2026). Such disruptions could interrupt logistics distribution, cause shortages of essential food and energy commodities, and substantially increase vehicle operating costs (VOC), known in Indonesian as Biaya Operasional Kendaraan (BOK), because of lengthy alternative routes and additional travel requirements (Allen et al., 2026). These conditions could undermine regional economic resilience, disrupt the continuity of defense logistics, and increase emergency response expenditures. Accordingly, this study examines land transportation accessibility vulnerability in Gorontalo Province through a quantitative disaster risk assessment and evaluates its implications from a defense economics perspective. The analysis focuses on the exposure of the primary road network to disaster-related disruptions, the effects of reduced accessibility on logistics distribution and strategic services, and the economic and defense consequences of critical corridor closures. The study is limited to freight transportation operations along national and provincial road networks within Gorontalo Province.

Within Indonesia, Gorontalo Province represents a particularly vulnerable case of land transportation accessibility. Its mountainous terrain includes slopes exceeding 40% in several regencies, while its geological characteristics, influenced by historical volcanic activity and active fault systems, increase the susceptibility of major road corridors to landslides, particularly during periods of intense rainfall and seismic activity. In June 2025, flash floods and landslides in Pohuwato Regency reportedly affected 7,508 residents and damaged critical road access,

necessitating emergency evacuation and infrastructure rehabilitation. The province's substantial dependence on a single primary road network, combined with the limited availability of equivalent alternative routes connecting regencies and the Trans-Sulawesi corridor, creates structural vulnerabilities in which disaster-related disruptions at critical locations could severely interrupt regional logistics and transportation connectivity.

Previous studies have examined road network vulnerability in various Indonesian contexts; however, several research gaps remain. Lestari et al. (2024) analyzed the vulnerability of interprovincial roads in South Kalimantan to hydrometeorological disasters and found that approximately 20% of the road network was disrupted by flooding. However, their research primarily focused on vaccine transportation rather than broader logistics systems and defense-related implications. Similarly, Sudibyo et al. (2026) employed graph theory and least-cost distance simulations to assess urban transportation resilience to megathrust earthquake-generated tsunamis in southern Java. Their findings demonstrated substantial transportation network isolation, with a Gini coefficient of 0.995 indicating pronounced inequality in vehicular accessibility. Nevertheless, their analysis was restricted to a coastal district rather than an interconnected provincial road network. Meanwhile, studies examining transportation vulnerability in Gorontalo Province have primarily focused on localized slope stability along the Gorontalo Outer Ring Road, with limited integration of network-level accessibility modeling, disaster risk assessment, and defense economics evaluation.

The urgency of this research arises from the increasing exposure of transportation infrastructure to hydrometeorological hazards associated with climate change and the strategic importance of maintaining logistics continuity in geographically vulnerable regions of Indonesia. The National Disaster Management Agency's (BNPB) 2022 disaster risk assessment for Gorontalo Province estimated potential economic losses of IDR 1.89 trillion from flooding, IDR 1.47 trillion from landslides, and IDR 2.41 trillion from earthquakes. These estimates indicate substantial potential fiscal exposure, although the losses associated with individual disaster scenarios should not necessarily be interpreted as simultaneous or cumulative. Disaster-induced road closures could therefore generate immediate humanitarian and economic consequences while increasing pressure on regional budgets that might otherwise support preventive infrastructure investments. This perspective is consistent with the United Nations Office for Disaster Risk Reduction (UNDRR), which has highlighted the potential economic benefits of investing in disaster resilience, including an estimated net benefit of USD 4 for every USD 1 invested in resilience measures.

The novelty of this study lies in the integration of three complementary analytical frameworks: Geographic Information System (GIS)-based spatial accessibility modeling, transportation cost analysis, and defense economics. By quantifying changes in the Spatial Accessibility Index under simulated disaster scenarios and translating these changes into increased vehicle operating costs and detour-related expenditures, the study provides an empirical basis for assessing the economic implications of transportation network disruptions and the potential benefits of alternative route development. Furthermore, by examining the findings through three dimensions of defense economics—logistics security, regional economic multiplier effects, and

opportunity costs—the research extends conventional transportation vulnerability assessment beyond regional infrastructure planning to encompass national strategic resilience (Miller & Blair, 2022). This integrated approach is particularly relevant to Indonesia's Universal People's Defense and Security System (Sishankamrata), which emphasizes the strategic importance of national resources and infrastructure in supporting defense preparedness.

This research aims to quantitatively assess land transportation accessibility vulnerability in Gorontalo Province under multiple disaster risk scenarios and evaluate its economic and defense implications within an integrated analytical framework. Specifically, the study examines the susceptibility of the province's primary road network to multiple natural hazards, assesses the consequences of declining transportation accessibility for logistics distribution and strategic services, and evaluates the economic and defense-related implications of disruptions to critical road corridors. The analysis focuses on freight transportation along national and provincial road networks within the administrative boundaries of Gorontalo Province, emphasizing the relationship between infrastructure vulnerability, regional economic resilience, and defense logistics continuity.

The contributions of this research are both methodological and policy-oriented. Methodologically, the study demonstrates the integration of Spatial Multi-Criteria Evaluation (SMCE), GIS-based network analysis, and transportation cost modeling into a comprehensive framework for assessing disaster-related transportation accessibility vulnerability. This integrated approach offers a potentially replicable analytical framework for other regions characterized by similar topographic conditions, limited network redundancy, and high exposure to natural hazards. From a policy perspective, the findings provide an evidence base for prioritizing investments in alternative transportation routes, strengthening critical infrastructure resilience, and incorporating spatial accessibility assessments into Regional Spatial Planning (Rencana Tata Ruang Wilayah, RTRW) documents. The results may also inform the designation and management of strategic logistics corridors within Indonesia's national defense logistics system.

The study specifically evaluates transportation accessibility vulnerability across 748.60 km of national roads and 643.61 km of provincial roads in Gorontalo Province. It identifies critical transportation nodes and corridors with elevated single-point-of-failure risks, quantifies potential reductions in spatial accessibility and increases in transportation costs under simulated disaster scenarios, and examines the resulting implications for defense logistics security, regional economic resilience, and opportunity costs. The anticipated practical contribution is a quantitative decision-support framework for provincial and national government institutions, including the Transportation Office, the Regional Disaster Management Agency, and defense logistics planning authorities. By identifying infrastructure segments with the greatest potential consequences of disruption, the framework can support more effective mitigation resource allocation, inform infrastructure investment priorities, and strengthen the economic justification for preventive

measures through cost–benefit assessments that consider both economic losses and strategic defense implications.

METHOD

This study employed a descriptive quantitative approach integrating Geographic Information System (GIS)-based spatial analysis and transportation modeling. The study area encompassed the main transportation corridors, comprising 748.60 km of national roads and 643.61 km of provincial roads within the administrative boundaries of Gorontalo Province.

Spatial GIS Modeling and Accessibility Index

In this modeling, the Wj variable represents the weight of the center of economic activity and strategic logistics nodes in Gorontalo (including the main market, the main food warehouse, and the Kwandang crossing port), while dij is calibrated based on the actual road network travel time under the constraints of topographic barrier parameters and disaster risk (Contreras et al., 2025).

Vulnerability analysis uses *the Spatial Multi-Criteria Evaluation (SMCE)* method to generate a Disaster Vulnerability Index (IKB) (Toyfur et al., 2018). Furthermore, GIS Network Analysis modeling using Service Area and *Nearest Facility functions* is applied to measure the Spatial Accessibility Index (Ai) with mathematical formulations (Badi & Pamucar, 2026):

$$A_i = \sum \frac{W_j}{d_{ij}^{\beta}}$$

where Wj is the weight of the center of economic activity or logistics node j, and dij expresses the distance or travel time of the road network from point i to j (Alabbad et al., 2021). This modeling is used to evaluate the decrease in accessibility and shrinkage of the radius of logistics services when there is a road network disconnection.

Vehicle Operating Cost (VOC) and Detour Cost Modeling

To accurately measure the degradation of logistics fleet efficiency, the fuel consumption level (KM/L) in (Kurth et al., 2020) was formulated as a function of average speed (V), road gradient obstacles (G), and road surface conditions due to disasters (D).

$$KM/L = f(V, G, D)$$

Where the basic consumption is calibrated by the average speed, road gradient, and coefficient of road surface degradation due to disasters. Vehicle Operating Cost Escalation per kilometer is calculated by integrating fixed cost and variable *cost components:*

$$BOK = \text{Fixed Cost} + (\text{Variable Cost} \cdot \alpha)$$

where α is the coefficient of detour of engine performance due to road damage or *detour routes,* and the fuel reference price is adjusted to the applicable industrial diesel tariff/subsidy in the regional area. To calculate the economic burden due to route diversion, the escalation of total logistics loss *(detour cost)* is formulated as follows:

$$\text{Detour Cost} = Q \cdot \Delta d \cdot \text{VoT} + \text{Emergency Recovery Cost}$$

Where Q is the volume of commodities in tons, Δd is the addition of mileage (km), travel time (hours), VoT *(Value of Time)* of goods and capital (Rp/Hour), and represents losses due to scarcity

and emergency recovery costs (El-Maissi et al., 2022)

The stages of this research are designed in five systematic steps as presented in **Table 1**.

Table 1. Research Process Model

Stages / Steps	Description of Activities & Outputs
STEP 1: Data Collection	Secondary & Spatial Data sourced from relevant agencies: • **BPBD** (Disaster Data) • **Dishub** (Traffic/Fleet Data) • **PUPR** (Road Network Data)
STEP 2: Processing & Evaluation	• GIS Processing & MCDA Spatial Analysis (*Multi-Criteria Decision Analysis*) • Road Network Evaluation based on *Single Spine* Analysis
STEP 3: Scenario Simulation	• Normal Conditions: Ai Spatial Accessibility Analysis • Disaster Conditions: *Detour Cost* Simulation ΔCTotal
STEP 4: Defense Economic Evaluation	In-depth analysis on the 3 Pillars of Defense Economics: 1. *Logistics Security* 2. *Multiplier Loss* 3. *Opportunity Cost*
STEP 5: Outcomes & Recommendations	• Formulation of Policy Recommendations & Mitigation of Redundancy Infrastructure • Final Output: Drafting of the Manuscript

Source: Author, 2026.

RESULT AND DISCUSSION

Analysis Results

Based on the results of spatial processing using *Spatial Multi-Criteria Evaluation (SMCE)* and *GIS Network Analysis* juxtaposed with BNPB's Disaster Risk Assessment (KRB) document and operational data from the Gorontalo Provincial Transportation Office, the main arterial corridor in Gorontalo Province is proven to be in a high vulnerability zone to various natural disaster threats. Structural dependence on the single *spine network* makes the region's logistics distribution system very vulnerable to *the single point of failure phenomenon*. The following is a visualization of the spatial conceptual map of the network and logistics nodes of the Gorontalo province area as presented in Figure 2:

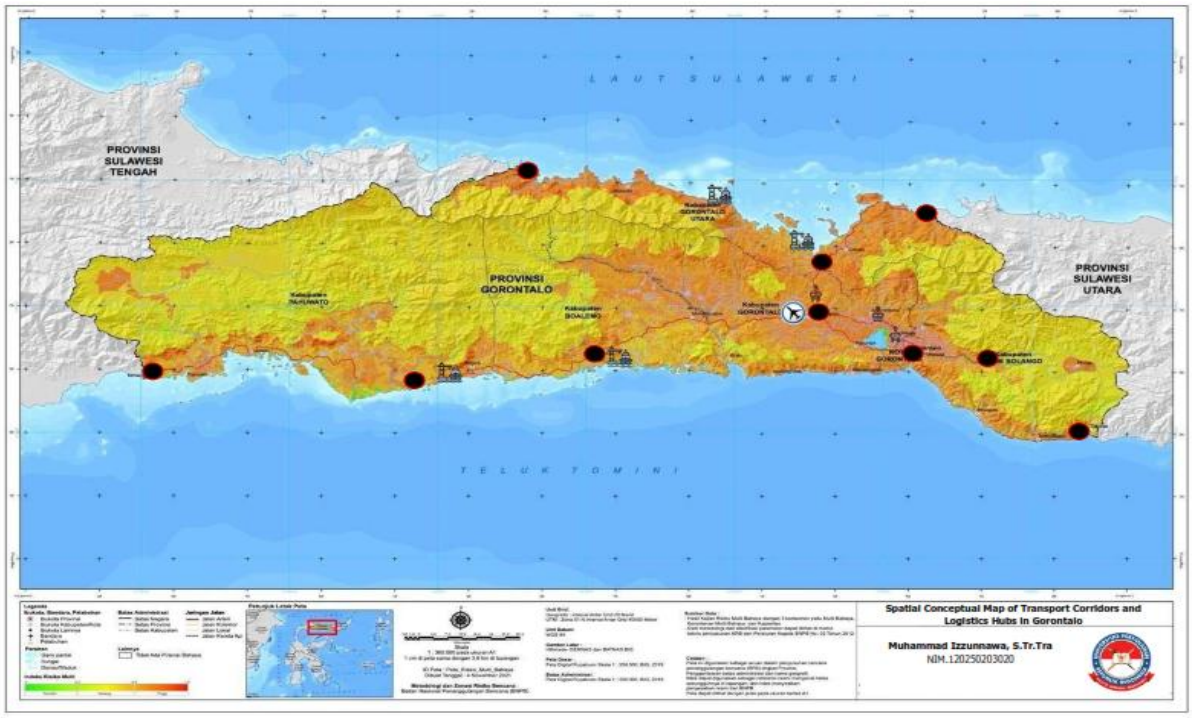


Figure 1. Map of Transportation Corridors and Logistics Centers in Gorontalo
Source: Author, 2026.

The results of *the GIS Network Analysis* show that logistics distribution in Gorontalo Province is highly dependent on several main nodes (Wj), such as Kwandang Port and Anggrek Port in North Gorontalo as well as Gorontalo Port and Dungingi Type A Terminal in Gorontalo City.

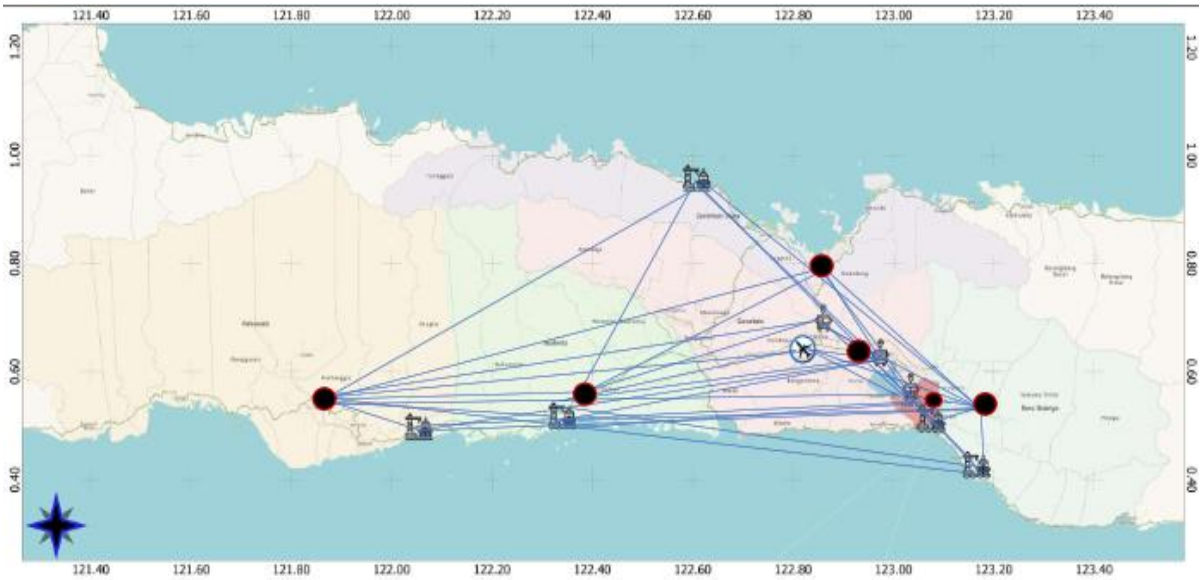


Figure 2. Traffic Network Accessibility Map
Source: Author, 2026.

In order to quantitatively measure the impact of these topographic obstacles on movement efficiency, this analysis also evaluates the comparison between straight *distance (Euclidean distance)* and actual distance *(network distance)* through the Sinuosity Index *approach*. Based on the visualization in Figure 2, urban areas recorded an index value close to 1.0 (ranging from 1.06 to 1.09), which indicates a relatively direct road network with minimal topographic distortion. In contrast, areas with hilly topography to steep slopes such as Boalemo and Pohuwato Regencies showed higher cynography indexes, reaching 1.21 and 1.38, respectively.

The following is the accessibility of the area in Gorontalo province as stated in **Table 2**.

Table 2. Accessibility Parameters of Transportation Nodes in Gorontalo Province

Region of Origin (i)	Destination Key Node (Wj)	Categories of Knot	JL (km)	JS (km)	(JS/JL)	Access Characteristics & Topography
Gorontalo City	Gorontalo Port	Port	2,5	3,1	1,24	Urban / Gulf Coast
	Kwandang Port	Port	35	42,6	1,22	Limboto Hill Crossing - Kwandang
	Orchid Port	Port	48	61,5	1,28	Inter-district hills
	Tilamuta Port	Port	93,5	121	1,29	Trans Sulawesi Corridor
	Djalaluddin Airport	Airports	22,5	30,9	1,37	Sloping Plains to Valley
	Dungingi Type A Terminal	Terminal	4,2	4,8	1,14	Urban / Flat
	Limboto Type B Terminal	Terminal	13,5	15,2	1,13	Connecting Cities - Kab
	Type A Terminal Isimu	Terminal	21	28,5	1,36	Sloping Plains to Valley
	Wells Transit Terminal	Terminal	7,5	8,9	1,19	City Border - Gorontalo Regency
Gorontalo Regency	Gorontalo Port	Port	14,2	16,5	1,16	Sloping Square / Urban Fringe
	Kwandang Port	Port	32,5	39,8	1,22	Trans Sulawesi Crossing
	Orchid Port	Port	45	57	1,27	Northern Hills
	Tilamuta Port	Port	79	102,5	1,3	Trans Sulawesi Western Crossing
	Djalaluddin Airport	Airports	14	18,2	1,3	Undulating ramps
	Dungingi Type A Terminal	Terminal	15	17,8	1,19	Urban Buffer Area
	Limboto Type B Terminal	Terminal	2,1	2,5	1,19	Regional Center / Flat
	Type A Terminal Isimu	Terminal	11,5	13,8	1,2	Sloping Plains
	Wells Transit Terminal	Terminal	4,5	5,2	1,16	Urban Transition Areas
Bone Bolango Regency	Gorontalo Port	Port	11,8	14,5	1,23	River Valley & Hills
	Kwandang Port	Port	46	59	1,28	East-North Track
	Orchid Port	Port	55	72,4	1,32	The Track Dividing the Regency
	Tilamuta Port	Port	104	135	1,3	East-West Track
	Djalaluddin Airport	Airports	32	41,5	1,3	Tracks Through Urban
	Dungingi Type A Terminal	Terminal	13,5	16,2	1,2	Urban Pathway - Regency

Region of Origin (i)	Destination Key Node (Wj)	Categories of Knot	JL (km)	JS (km)	(JS/JL)	Access Characteristics & Topography
	Limboto Type B Terminal	Terminal	24	29,5	1,23	Ring Road
	Type A Terminal Isimu	Terminal	30,5	39,2	1,29	Track to the West
	Wells Transit Terminal	Terminal	14	17,2	1,23	River Valley Plain
North Gorontalo Regency	Gorontalo Port	Port	45	57,5	1,28	Cross-Provincial Lines
	Kwandang Port	Port	3,2	3,5	1,09	Coastal / Sloping
	Orchid Port	Port	15	18,8	1,25	Winding North Coast Strip
	Tilamuta Port	Port	75	98	1,31	Access to the North - West Track
	Djalaluddin Airport	Airports	45	58,2	1,29	South-North Connecting Line
	Dungingi Type A Terminal	Terminal	43,5	55,2	1,27	North-South Connecting Line
	Limboto Type B Terminal	Terminal	42	53,5	1,27	Intermediate Hills Trail
	Type A Terminal Isimu	Terminal	35	45,8	1,31	South Access Gorut
	Wells Transit Terminal	Terminal	40	51	1,28	Trans Sulawesi Cross Access
Boalemo Regency	Gorontalo Port	Port	95	124	1,31	Hilly Trans Sulawesi Road
	Kwandang Port	Port	62,5	77,4	1,24	North Coast
	Orchid Port	Port	78	98,5	1,26	Boalemo - Gorut Crossing
	Tilamuta Port	Port	3,5	4,2	1,2	Boalemo Regency Node Center
	Djalaluddin Airport	Airports	80	102,5	1,28	West - East Line
	Dungingi Type A Terminal	Terminal	94	122,8	1,31	Trans Sulawesi Utama
	Limboto Type B Terminal	Terminal	92	120,5	1,31	Trans Sulawesi Bumpy
	Type A Terminal Isimu	Terminal	82,5	106	1,28	Trans Sulawesi Corridor
	Wells Transit Terminal	Terminal	90	117,5	1,31	Main Corridor to the City
Pohuwato Regency	Gorontalo Port	Port	165	235,5	1,43	Long & Winding Topography
	Kwandang Port	Port	138,5	192	1,38	Steep Slopes (>40%) / Extreme
	Orchid Port	Port	155	215	1,39	Route of the West-North Region
	Tilamuta Port	Port	72	96,5	1,34	Trans Sulawesi Corridor Western Region
	Djalaluddin Airport	Airports	150	210	1,4	Trans Sulawesi Regional Access
	Dungingi Type A Terminal	Terminal	164	233,5	1,42	Long West - East Corridor
	Limboto Type B Terminal	Terminal	162	231	1,43	Long West - East Corridor
	Type A Terminal	Terminal	152	216	1,42	Trans Sulawesi Long Line

Region of Origin (i)	Destination Key Node (Wj)	Categories of Knot	JL (km)	JS (km)	(JS/JL)	Access Characteristics & Topography
	Isimu					
	Wells Transit Terminal	Terminal	160	228	1,43	Long Corridor to the Center

Source: analysis results (2026)

From the details of the data above, it shows the accessibility of the Gorontalo province area where all districts/cities in Gorontalo are in the category of vulnerability and high disaster risk, especially floods, landslides, and earthquakes that threaten land transportation networks and main logistics corridors. The characteristics of the region, logistics nodes, and risk levels are summarized in Table 3 below:

Table 3. Spatial Parameters, Logistics Nodes, and Disaster Vulnerability per Regency/City in Gorontalo Province

Regency/City	Capital	Area (km2)	Key Logistics & Infrastructure Nodes	Vulnerability	Dominant Disaster Risk
Gorontalo City	Gorontalo	79,59	Dungingi Terminal, Gorontalo Port, Trade Center	Height	Floods, Extreme Weather
Gorontalo Regency	Squirrelly	1.750,83	Isi Terminal, Limboto Terminal/Market, Food Warehouse Area	Height	Floods, Earthquakes
Boalemo	Stuttgart	1.521,88	Tilamuta Port	Height	Floods, Earthquakes
Pohuwato	Marisa	4.244,31	Bumbulan Port, UPPKB Marisa	Height	Landslides, Flash Floods
North Gorontalo	São Paulo	1.676,15	Kwandang Crossing, Orchid Port, Orchid Power Plant	Height	Floods, Landslides, Tsunamis
Bone Bolango	Squirt	1.984,31	UPPKB Moologtabu	Height	Flood Bandang, landslide

Source: analysis results (2026)

Table 3. shows the distribution of logistics supporting infrastructure in each administrative region that uniformly faces a high level of vulnerability to disasters. Vulnerability analysis specific to each district/city area shows diverse spatial characteristics and risks:

First, the Gorontalo City and Gorontalo Regency Areas, which are the center of economic and government attractions, the Limboto plains area and Gorontalo City face the dominant threat in the form of inundation floods and flash floods. Vital distribution nodes such as the Dungingi Type A Terminal, Isimu Type A Terminal, and Limboto Type B Terminal are directly in the hydrometeorological danger zone. Based on operational data from the Transportation Agency, the Limboto Type B Terminal serves daily passenger movements that fluctuate between 144 and 232 people. However, the spatial vulnerability of this area is further exacerbated by local operational obstacles, namely market activities spilling around Limboto on market days which often overflow to close the road body and exit lanes in the direction of Isimu. When flash floods hit these lowlands along with spillover market congestion, the distribution of staple foods from major food warehouses suffered a complete paralysis, triggering the threat of urban food scarcity.

Both areas are Pohuwato Regency and Bone Bolango Regency where these two areas are identified as having the highest vulnerability to landslides on the Trans Sulawesi Line. Topographically, the Pohuwato area, which has a wide geographical coverage (4,244.31 km²) and Bone Bolango which is flanked by mountains with steep slopes (>40%) are traversed by an active Watershed (DAS) system. This vulnerability is exacerbated by the unstable geological structure, so that when extreme rainfall occurs, landslide material immediately closes the national road body which is the only access to land connections between provinces (Gorontalo-Central Sulawesi). As a result, the primary logistics supply chain was immediately completely cut off and isolated the nodes in the western and eastern regions.

Third, the Boalemo and North Gorontalo Regency Areas, where the Boalemo Region which is supported by Tilamuta Port and North Gorontalo which has strategic nodes of Anggrek Port, Kwandang Crossing, and Anggrek Power Plants, are highly dependent on the smooth running of the northern and western coastal corridors. The dominant threats in this region include abrasion, flash floods, and extreme waves that threaten the stability of energy supply (coal/electrical logistics of the Anggrek Power Plant) and the mobility of essential logistics goods.

Based on the BNPB Disaster Risk Assessment Document (KRB) (2022), the potential losses due to various types of disaster threats are summarized in Table 4 below:

Table 4. Recapitulation of Potential Disaster Losses in the Gorontalo Transportation & Economic Sector

Types of Disaster Threats	High Hazard Area (Ha)	Potential Physical Loss	Potential Economic Losses	Risk Level
Flood	48.657	IDR 3.34 Trillion	IDR 1.89 Trillion	HEIGHT
Flash Flood	33.434	IDR 791,7 Billion	IDR 615,2 Billion	HEIGHT
Landslides	462.935	IDR 639,0 Billion	IDR 1.47 Trillion	HEIGHT
Earthquakes	786.067	IDR 12.37 Trillion	IDR 2.41 Trillion	HEIGHT
Extreme Weather	44.626	IDR 5.84 Trillion	IDR 1.82 Trillion	HEIGHT

Source: BNPB (2022)

A simulation of the calculation of transportation costs to the economy shows that logistics fleets experience a significant spike in vehicle operating costs (BOK) per kilometer in each regional corridor during a disaster, as presented in Table 5:

Table 5. Comparison Matrix of Normal vs. Disaster BOK by Region Source: Authors, 2026.

Spatial Corridors	Fleet Type	Normal Consumption (KM/L)	Disaster Consumption (KM/L)	BOK Normal (Rp/km)	BOK Disaster (Rp/Km)	Cost Escalation (%)
Western Corridor (Isimu - Marisa)	Medium Trucks	5,0 - 5,5	2,8 - 3,2	IDR 6,200 -7,500	IDR 11,000 - 13,500	**77%**
	Fuso	2,8 - 3,0	1,6 - 1,8	IDR 10,200 - 11,800	IDR 18,000 - 22,500	**91%**
Central Corridor (Telaga - Limboto)	Medium Trucks	5,2 - 5,8	3,0 - 3,5	IDR 6,000 - 7,000	IDR 10,500 - 12,500	**75%**
	Fuso	3,0 - 3,2	1,8 - 2,0	IDR 10,000 - 11,500	IDR 17,500 - 21,000	**82%**
Eastern Corridor (Suwawa - Kabila)	Medium Trucks	4,8 - 5,2	2,5 - 2,9	IDR 6,500 - 8,000	IDR 12,000 - 14,500	**81%**
	Fuso	2,6 - 2,8	1,5 - 1,7	IDR 10,500 - 12,500	IDR 19,000 - 23,500	**88%**
Northern Corridor (Kwandang - Atinggola)	Medium Trucks	4,5 - 5,0	2,2 - 2,6	IDR 6,800 - 8,500	IDR 12,500 - 15,000	**83%**
	Fuso	**2,5 - 2,8**	**1,4 - 1,6**	**IDR 11,000 - 13,500**	**IDR 20,000 - 24,500**	**85%**

The derivative impacts of BOK swelling and disrouting on the macro efficiency of the region are summarized in Table 6:

Table 6. Quantitative Comparison Matrix of Transportation Conditions and Defense Economic Impact

Evaluation Parameters	Normal Conditions *(Baseline)*	Detour	Totally Isolated *(Insulation)*
Extra Distance (ΔKm)	0 Km	+45 Km to +120 Km (Alternate Crossing)	**Unaffordable (∞)**
Extra Time (ΔJam)	0 Hours	+2.5 Hours to +6.5 Hours	**Logistics Stop Completely (Stagnation)**
Transportation Cost Per Ton (Rp/Ton)	IDR 150,000 – IDR 250,000	IDR 380,000 - IDR 650,000	**Escalation of Infinite Costs**
Cost of Goods (%)	0%	+18% to +35% (Commodity Inflation Surge)	**Total Scarcity of Staples (=>100%)**
Spatial Accessibility Index (AI)	Optimal (100%)	Decreased to 30% - 55%	**Plummeting to 0% (Insulated)**
Economic Multiplier Loss	**Low**	**Significant (Regional Distribution Disruption)**	**Critical (Regional Economic Collapse)**

Source: Author, 2026.

Empirical findings from GIS simulations and Vehicle Operational Cost (BOK) escalation where medium and fuso trucks experienced a surge in operational costs of up to 75% – 91% due to route diversion (*detour*) as far as 45 to 120 km proves that absolute dependence on a single spine *network* creates systemic vulnerabilities that have direct implications for regional economic stability and regional defense. An in-depth discussion of these findings is elaborated through three main pillars of Defense Economics:

Defense Logistics Security

Within the framework of the Universal People's Security Defense System (Sishankamrata), highway infrastructure and terminal nodes do not only function as civilian mobility facilities, but as non-military strategic *defense assets* that act as force *multipliers*. The absence of an alternative route network (*redundancy route network*) in Gorontalo Province makes defense logistics mobility, the movement of reserve troops, and the distribution of military emergency logistics completely paralyzed when the *single-spine corridor* is cut off due to landslides or earthquakes. These findings confirm that the security of the defense logistics supply chain is highly determined by the structural resilience of the road network to disaster disruptions. Without a logistical reserve line, the territorial defense capability in the buffer area of the Indonesian Archipelago Sea Channel (ALKI) II will experience a massive degradation of capabilities in responding to national crises.

Regional Economic Resilience & Multiplier Loss

The paralysis of the primary arterial road network and distribution nodes triggered a domino effect in the form of *defense multiplier loss* and *cascading failures* in the regional engineering logistics network. The Gross Regional Domestic Product (GDP) of Gorontalo Province, which is strongly supported by the agriculture, fisheries, and trade sectors, experienced severe external shocks when commodity distribution was stopped. The surge in basic prices of 18% to 35% due to the swelling of BOK and transportation costs per ton from Rp150,000 to Rp650,000 per ton caused a drastic decrease in people's purchasing power. This condition triggers regional economic *stagnation and* collapses the region's macroeconomic efficiency exponentially.

Defense *Opportunity Cost & Cost-Benefit Analysis*

Based on data, potential macro losses due to disasters physical and economic losses due to floods reached IDR 1.89 trillion, landslides reached IDR 1.47 trillion, and earthquakes reached IDR 2.41 trillion (BNPB, 2022)

The accumulated financial losses far exceed the regional annual emergency recovery budget allocation. Through the *Cost-Benefit Analysis* (CBA) approach, this study proves that preventive investment policies in the construction of alternative route networks (*redundancy route networks*), strengthening the physical structure of links (*link strengthening*), and structuring traffic engineering management at critical terminal nodes are much more economically efficient. Budget allocation for structural mitigation of non-military defense has proven to be able to reduce the risk of economic losses of trillions of rupiah while ensuring the continuity of national logistics operations in border and outermost areas.

The in-depth discussion links the empirical findings in Gorontalo Province with the three main pillars of Defense Economics:

Defense Logistics Security

The absence of alternative routes makes nonmilitary defense logistics mobility and martial law preparedness completely paralyzed when a single corridor is cut off. This is in line with the findings (Chung et al., 2025), which emphasize the importance of the security of the nonmilitary defense logistics supply chain in maintaining territorial sovereignty during a disaster crisis.

Regional Economic Resilience

The paralysis of the arterial road network triggers a defense multiplier loss. The disruption of the distribution of agricultural and fishery commodities that support regional GDP causes a massive decline in economic output and triggers inflation in the price of basic goods at the local level. These findings are in line with the theory of the interconnectedness of regional economic systems in the face of external shocks.

Defense Opportunity Cost & CBA

The accumulated economic losses due to repeated disasters such as potential physical and economic losses of floods amounting to Rp1.89 trillion, landslides of Rp1.47 trillion, and earthquakes reaching Rp2.41 trillion far exceeded the preventive budget allocation. Cost-Benefit Analysis proves that investment in the development of alternative routes (redundancy route networks) is much more efficient than incurring macroeconomic losses due to repeated paralysis

CONCLUSION

The vulnerability of land transportation accessibility in Gorontalo Province represents a systemic threat to regional economic stability and national defense logistics security due to its dependence on a single primary road network comprising 748.60 km of national roads and 643.61 km of provincial roads. Simulated disaster-induced disruptions to critical transportation corridors resulted in a 45%–70% reduction in the Spatial Accessibility Index, decreased the geographic coverage of logistics services, and increased detour-related transportation costs. These disruptions could generate substantial regional economic losses, potentially reaching trillions of Indonesian rupiah, while producing adverse multiplier effects on defense logistics and regional economic activities.

From a geostrategic perspective, Gorontalo Province serves as a supporting region for the Indonesian Archipelagic Sea Lane II (ALKI II). Disruptions to land-based logistics networks could therefore undermine not only regional economic activities but also the mobilization and distribution of strategic logistics reserves supporting territorial defense in eastern Indonesia. Accordingly, this study recommends integrating Gorontalo Province's land transportation network into the Regional Defense Logistics System through the designation of Strategic Defense Logistics Corridors, accelerating the development of alternative routes to strengthen network redundancy, and pre-positioning emergency Bailey bridge components to facilitate rapid infrastructure restoration. Furthermore, Geographic Information System (GIS)-based spatial accessibility maps should be incorporated into the province's Regional Spatial Plan (Rencana Tata Ruang Wilayah, RTRW) to support nonmilitary defense preparedness and disaster-resilient infrastructure planning. Local governments should also establish an emergency land logistics task force (Satuan Tugas,

Satgas) to coordinate with Type A and Type B terminal operators, strengthen interagency disaster response, and accelerate the restoration of transportation connectivity following disasters.

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