Sea Level Rise, Land Subsidence, and Flood Disaster Vulnerability Assessment: A Case Study in Medan City, Indonesia

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Introduction


Coastal damage caused by SLR

Global sea level **rising** at an alarming rate!

3.2 ± 0.4 mm year−1


Flood occurrence in Medan City (2022)

One significant impact associated with SLR was **extreme coastal flooding**


Land deformation measurement (2023)

Several studies have shown that **land subsidence worsens flooding** (Sumantyo et al., 2011; Yastika et al., 2019; Antonioli et al., 2020)


Mangrove planting in Medan (2022)

Integrated studies on regional **flood vulnerability** assessment of **SLR** and **land subsidence,** combined with local actions are crucial to support effective adaptation strategies.

Methodology

DATASETS

- Slope, soil type, and land use data were derived from study literature (Dian et al., 2018; Tampubolon, 2018)
- Land subsidence was derived from SAR Sentinel-1 mission, processed using the DInSAR method and verified with benchmarks position
- SLR trends of ECNS were derived from the sea level anomaly (SLA), distributed by the Copernicus Marine Environment Monitoring Service (CMEMS)
- The global SLR trends were derived from satellite altimetry data released by the Colorado University Sea Level Group

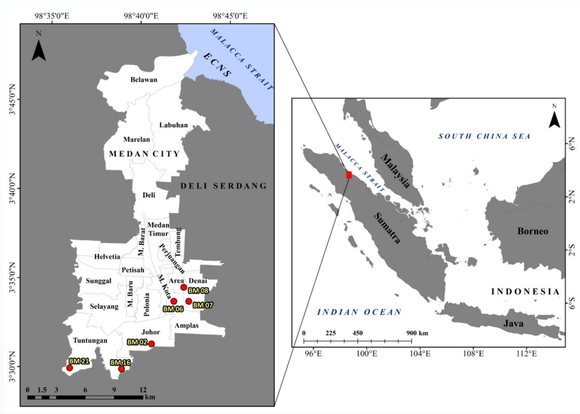

Figure 1. Study site and distribution of benchmarks site

FLOOD VULNERABILITY ASSESSMENT

The spatial model of flood vulnerability in Medan City was developed using a model builder in QGIS, based on the MCDA procedure. Weights obtained by AHP method were assigned to the designated parameters, which used in the vulnerability assessment (Saaty, 1977). The resulted Flood Vulnerability Index represents the sum of scores multiplied by weights for each parameter (For further details, please refer to Table 1)

Table 1. Criteria for each parameter in the flood vulnerability assessment of the ECNS and Medan City (Lumban-Gaol et al., 2024)

Parameter	Criteria	Level	Score	Weight
Slope (%) (Tampubolon, 2018; modified)	>45	Very low	1	0.32
	25–45	Low	2	
	15–25	Moderate	3	
	8–15	High	4	
	0–8	Very high	5	
Land use (Hermon, 2015)	Forest	Very low	1	0.24
	Plantation and bush	Low	2	
	Agriculture, rice fields, and moor	Moderate	3	
	Settlement, mixed garden, and yard crop	High	4	
	Open land, river, reservoir, and swamp	Very high	5	
Local subsidence trend (cm year^{-1}) (Gornitz et al., 1992; modified)	<−10 Land rising	Very low	1	0.19
	−1.0–1.0	Low	2	
	1.0–2.0	Moderate	3	
	2.1–4.0	High	4	
	>4.0 Land sinking	Very high	5	
Relative sea level rise (mm year^{-1}) (Pendleton et al., 2010)	<1.8	Very low	1	0.14
	1.8–2.5	Low	2	
	2.5–3.0	Moderate	3	
	3.0–3.4	High	4	
	>3.4	Very high	5	
Soil type (Zain, 2002)		Very low	1	0.11
	Regosol and Podzol	Low	2	
	Andosol, Lithosol, and Ferralsol	Moderate	3	
		High	4	
	Histosol, Gleysol, Vertisol, Acrisol, and Grumusol	Very high	5	

Conclusion

- Observed SLR in the ECNS is occurring at a rate of 4.79 mm per year, which is higher than the global SLR rate
- The ECNS and Medan City are experiencing significant land subsidence, with values ranging from −0.01 to −19.00 cm per year
- A total of 80% of the ECNS and Medan City are classified as “very high” and 20% as “high” vulnerability areas
- Further studies combining satellite and field data should be conducted in regions that are similarly affected by SLR and land subsidence to those currently being addressed by ECNS and Medan City to develop effective mitigation strategies

Results

- Trends of SLR (Figure 2) in ECNS waters exceeding **4.79 mm/year**, which is higher than the global average SLR and the average SLR in Indonesian waters of 4.3 mm/year (Lumban-Gaol et al., 2021)

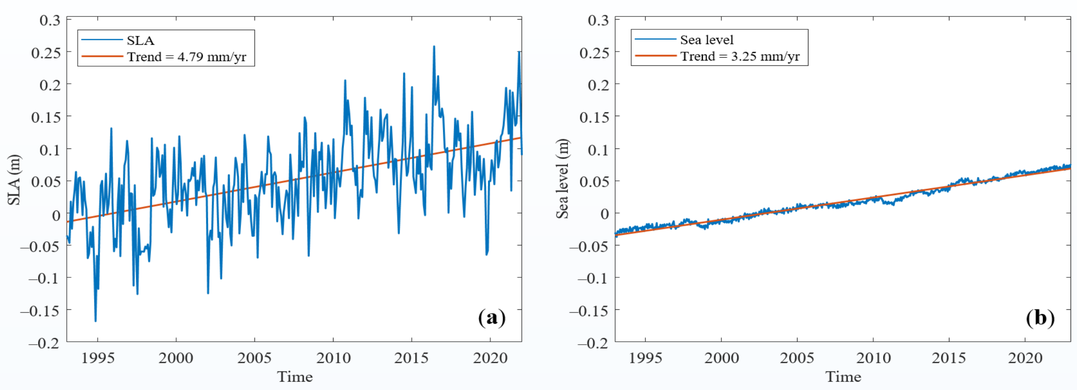

Figure 2. SLR trend on (a) ECNS and (b) global from 1993 to 2022 (Lumban-Gaol et al., 2024)

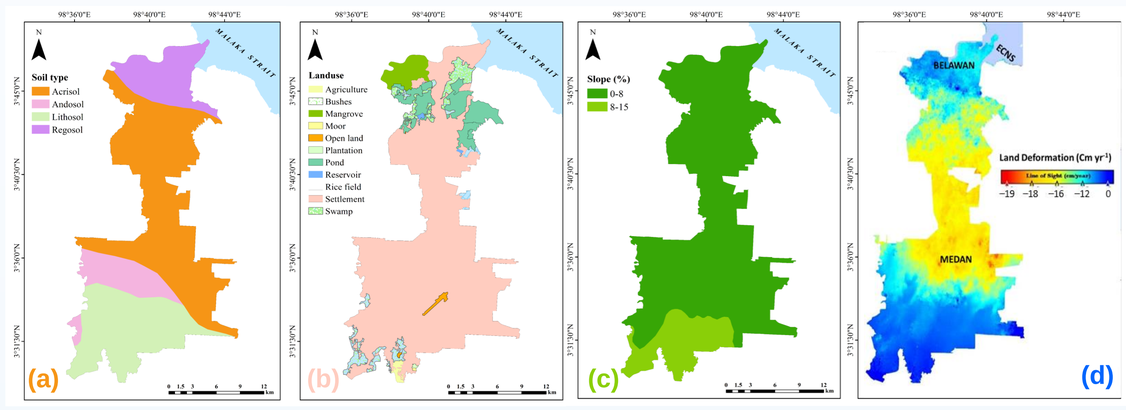

Figure 3. Map of (a) soil types, (b) land use, (c) slope, and (d) velocity of land deformation (Lumban-Gaol et al., 2024)

- The dominant soil type within Medan City is **Acrisols**
- **Settlements** are considered to be the largest type of land use in Medan City
- Approximately **90%** of Medan City is comprised of **slight slope**
- SAR Sentinel 1A satellite data indicates **significant land subsidence** along the ECNS and within Medan City, with rates ranging from **−0.01 to −19.00 cm per year**
- Flood vulnerability level in ECNS and Medan City is classified as "**high to very high**“. This study shows that **80%** of the area of Medan City falls into the **'very high**' vulnerability category, which represent the **dominant category**.
- The **spatial patterns of the flood vulnerability map** are in close alignment with areas that have been **historically documented as frequently experiencing flooding** in the ECNS and Medan City.

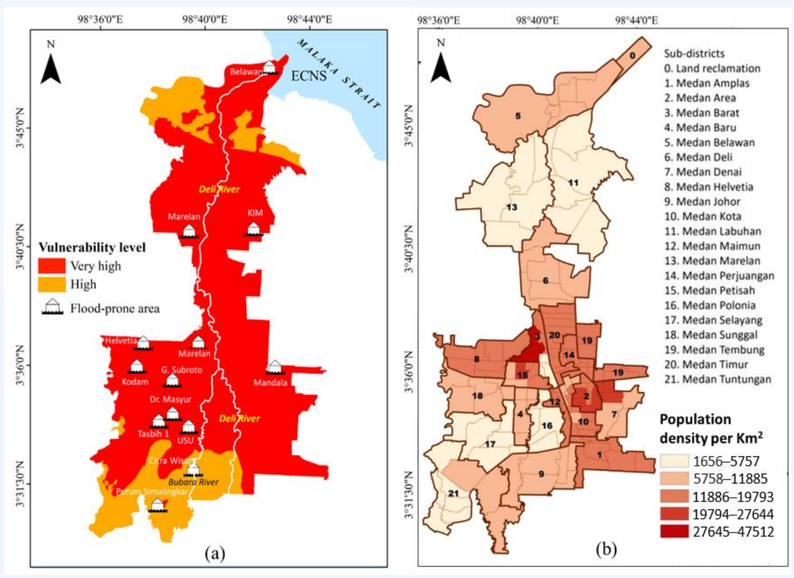

Figure 4. Map of (a) flood vulnerability and (b) people density (Lumban-Gaol et al., 2024)

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