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

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Introduction

One significant impact associated with SLR was extreme coastal flooding. Several studies have shown that land subsidence worsens flooding (Tampubolon et al., 2018; Yoseki et al., 2019). 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 D-InSAR method and verified with benchmarks position
• SLR trends of ECNS were derived from the sea level anomaly (SLA), distributed from 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

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 result 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-Gao et al., 2024)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Level</th>
<th>Score</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope (%) (Tampubolon, 2018; modified)</td>
<td>Very low</td>
<td>1</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Land use (Hermon, 2015)</td>
<td>Settlement, mixed garden, and yard crop</td>
<td>Very high</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Agriculture, rice fields, and forest</td>
<td>Medium</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Agriculture, rice fields, and forest</td>
<td>Low</td>
<td>2</td>
</tr>
<tr>
<td>Local subsidence trend (cm/year) (Gorret et al., 1992; modified)</td>
<td>Very low</td>
<td>1</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Relative sea level rise (cm/year) (Penelitian 2010)</td>
<td>Very low</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>Soil type (Zam, 2003)</td>
<td>Regosol and Podzol</td>
<td>Very high</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Histosol, Vertisol, Aridisol, and Gleysoil</td>
<td>Medium</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Regosol and Podzol</td>
<td>Low</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Regosol and Podzol</td>
<td>Very low</td>
<td>1</td>
</tr>
</tbody>
</table>

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-Gao et al., 2021).

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.

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.

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.

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Reference


Figure 1. Study sites and distribution of benchmarks sites

Figure 2. SLR trend on (a) ECNS and (b) global from 1950 to 2022 (Lumban-Gao et al., 2024)

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

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