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Study Tide Dynamics and Impact of Coastal Floods on the Settlement Areas of Batam City

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ABSTRACT

Batam City, strategically located as an economic and industrial center in the Riau Islands province, Indonesia, faces challenges stemming from rising sea levels due to climate change and unusual tidal patterns. These factors lead to recurrent coastal flooding and create new issues for coastal areas. This research project has three primary objectives: tidal forecasting, tidal flood hazard mapping, and vulnerability assessment of infrastructure and settlements in Batam City's coastal areas. To achieve these goals, a combination of methods is employed. Tidal forecasts rely on a semimean linear trend approach. Spatial flood analysis considers the Hloss scenario, with the loss distance referring to the peak of the sea flood. Additionally, losses resulting from coastal flooding disasters were assessed using the Economic Commission for Latin America and the Caribbean (ECLAC) budget base planning (RAB) method. The research results reveal that the Batam area experiences two semidiurnal tides with dynamic sea level fluctuations, reaching a peak flood height of 2 meters. Spatial analysis identified several areas affected by tidal flooding, particularly densely populated coastal areas such as Batuaji, Batuampar, Sekupang, and Bengkong subdistricts. These areas, characterized by tidal flats, are particularly vulnerable to significant coastal flooding during high tide. The impact extends to key infrastructure, including roads, mosques, housing, and social facilities, resulting in estimated losses. The number of buildings affected by flood on Batam City is 12,681 units, and the flood affected area covers approximately 10,975.76 hectares, with road infrastructure costs amounting to about US$337,131.36. Field investigations also reveal that several settlements in the region have initiated flood protection measures. However, many settlements are still directly affected, underscoring the immediate need to improve environmental quality in this area.

Keywords: coastal flooding, tidal flat, geospatial

1. Introduction

Batam City, as a special economic zone (SEZ) in Indonesia, plays a crucial role in the country's economy. Situated in close proximity to Singapore, the strongest economy in the ASEAN region, Batam City holds a strategic position as a hub for industrial development, business, investment, and commercial activities [1]. Its significance extends beyond its borders, significantly impacting the economy of the surrounding region due to its strategic location and continuous economic activities [2]. The city is profoundly influenced by the dynamics of tidal flood or in Indonesia namely as (Banjir rob), which have a substantial impact on coastal residential areas. Coastal flooding is a primary concern due to its potential negative effects on society, the economy, and the environment [3]. Coastal regions are inherently dynamic environments, constantly undergoing physical changes. Consequently, these areas are highly susceptible to natural hazards, including erosion, abrasion, landslides, land subsidence, river estuaries, and tidal [4, 5]. Moreover, the issue of rising sea levels, linked to global warming, is a pressing global concern [6]. Factors contributing to rising sea levels to tidal flood include polar ice melt, extreme climate events, and land subsidence resulting from land compaction [7]. Tidal flood can inflict damage on infrastructure, regional facilities, and have social and economic repercussions on local communities [8]. Over time, sea levels in coastal areas undergo periodic fluctuations, altering the landscape. Tidal flood, influenced by the gravitational forces of the moon, sun, and weather conditions, pose a significant threat to the environment and city infrastructure [4]. Areas like Sekupang, Batu Ampar, and Nongsa tend to be more vulnerable to sea level fluctuations. The combination of sea level rise due to climate change and tidal anomalies has led to recurrent coastal flooding, resulting in new challenges for coastal regions.

The impact of tides flood to coastal infrastructure such as docks, roads, and other public facilities should not be underestimated, because it can damage during extreme high tides. Tidal floods have the potential to inundate coastal areas and disrupt the daily lives of residents. Nevertheless, economic activities, particularly those related to ports and tourism, may also face disruptions. Consequently, this research project aims to predict tides, create a tidal flood hazard map, and assess buildings and infrastructure affected by flooding in the coastal areas of Batam City.

2. Material and Method

2.1 Material

The research was conducted through a combination of secondary data analysis and primary observations. The necessary data encompassed administrative records, land cover information, coastline data, and river flow data. DEM-NAS data was sourced from the Indonesian Geospatial Information Agency, specifically obtained from the Indonesian Geospatial Agency (BIG). The map detailing building units and infrastructure was acquired from the Regional Planning and Development Agency. DEM-NAS data served the purpose of generating ground surface slopes. During the data compilation process, we collected standard data analysis maps at a scale of 1:25,000. Residen-tial point data was gathered through the digitization of affected residential locations using Google Earth.

2.2 Methodology

The method used is descriptive tidal data, then spatial analysis of flood inundation with the Hloss and cost distance scenarios, which refer to the maximum point of sea tide, as well as losses due to coastal flood disasters using the Economic Commission for Latin America and the Caribbean (ECLAC) method based on the Plan Cost Budget (RAB).

2.2.1 Tidal Dynamic

At this stage, tidal dynamics are being observed by examining the tidal trends occur in the Batam City area using data from one of the available tidal stations. The method being employed is a descriptive analysis of tidal data [9]. The primary objective of descriptive analysis is to present the fundamental characteristics of one or more datasets, whether they consist of numerical or categorical data [10]. This approach allows for a clearer understanding of the patterns, distribution, and other essential information contained within the data. Data visualization techniques, such as line charts, can be utilized for aiding in this understanding.

2.2.2 Impact of Tidal Flood on the settlement

The coefficient data is employed to analyze land surface roughness, and this data proves to be highly valuable as a foundation for computing surface roughness strength, which encompasses both water transmission and wave energy from the coastline during high tide [4]. The determination of each coefficient relies on the capacity of each object to diminish and absorb water and wave energy see table 1.

Table 1. Coefficient land surface roughness

Code	Land cover	Coefficient value
R1	Water body	0.007
R2	Shrub	0.04
R3	Forest	0.07
R4	Plantation	0.035
R5	Bare land	0.015
R6	Agriculture and farming	0.025
R7	Buil-up / settlement	0.045
R8	Mangroves vegetation	0.025
R9	Fish pond	0.01

Sources: Barryman [11].

Berryman's report provides a comprehensive explanation of a mathematical equation used to evaluate the land surface roughness index in relation to the transmission of tsunami waves during a tsunami disaster. Equation 1, as follows, plays a pivotal role in this assessment [11]:

$$H_{loss} = \left(\frac{167\ n^2}{H_0^{\frac{1}{3}}}\right) + 5\, sin\, S \qquad (1)$$

Where:

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H_{loss} : the land surface roughness,
n : the roughness coefficient of various types of land use,
H_0 : the maximum height scenario of tsunami waves on the coastline
s : the morphometric condition or slope of the slope.

The result of *Hloss* will become grid value for cost distance analysis for tsunami inundation. In this process about S where used the data from the data of DEM which was extract into slope map in raster format. The coastal flood model is constructed through a cost distance analysis. The raster cost factors include ground surface rough-ness and *Hloss*. Indarto [5, 12] explained the fundamental concept underpinning the calculation of distance costs involves determining the costs associated with each traversed cell. The outcomes of the cost distance analysis contain spatial information pertaining to coastal flood inundation [4]. The final step involves data overlay, where the map overlay method is employed to evaluate the impact of flood inundation on residential buildings and critical infrastructure. Subsequently, to calculate the budget losses causes impact of tidal flood on infrastructure using RAB value units (ECLAC Method) in accordance with established standards [12].

3. RESULTS AND DISCUSSION

The results of collecting tidal surface harmonic elevation data from January to December 2022 reveal fluctuations in tide dynamics at the Batuampar (Batam) observation station, as illustrated in Figure 1. In summary, it is evident that there are two tides occurring in a single day, indicating a double daily tide pattern (semidiurnal tide). A semidiurnal tide consists of two high tide periods and two low tide periods within a 24-hour observation window. This particular pattern significantly contributes to the potential for tidal flooding because the maximum likelihood of flooding can occur twice daily. This is particularly concerning in adverse weather conditions, as it results in two sources of water supply, namely tidal water and rainwater, inundating the land.

The impact of semi-diurnal tides has a significant effect on the distribution of water resources in coastal areas. An increase in sea tide height along the coastline leads to elevated water levels at river mouths and swamps that directly interact with sea-water [8]. As depicted in Figure 1, the harmonic component of the maximum tidal height elevation is projected to be approximately 1.5 meters during 2022. In reference to the findings presented by Irawan [13] it was observed that the highest tidal waves reached up to 2.77 meters during the tidal observation period. Consequently, for this scenario, the maximum flood tide height is determined by utilizing a 2.5 meter sea water tide height from the coastline. Subsequently, an analysis of tidal flood mapping and the calculation of its impact on land use, settlements, and infrastructure is con-ducted.

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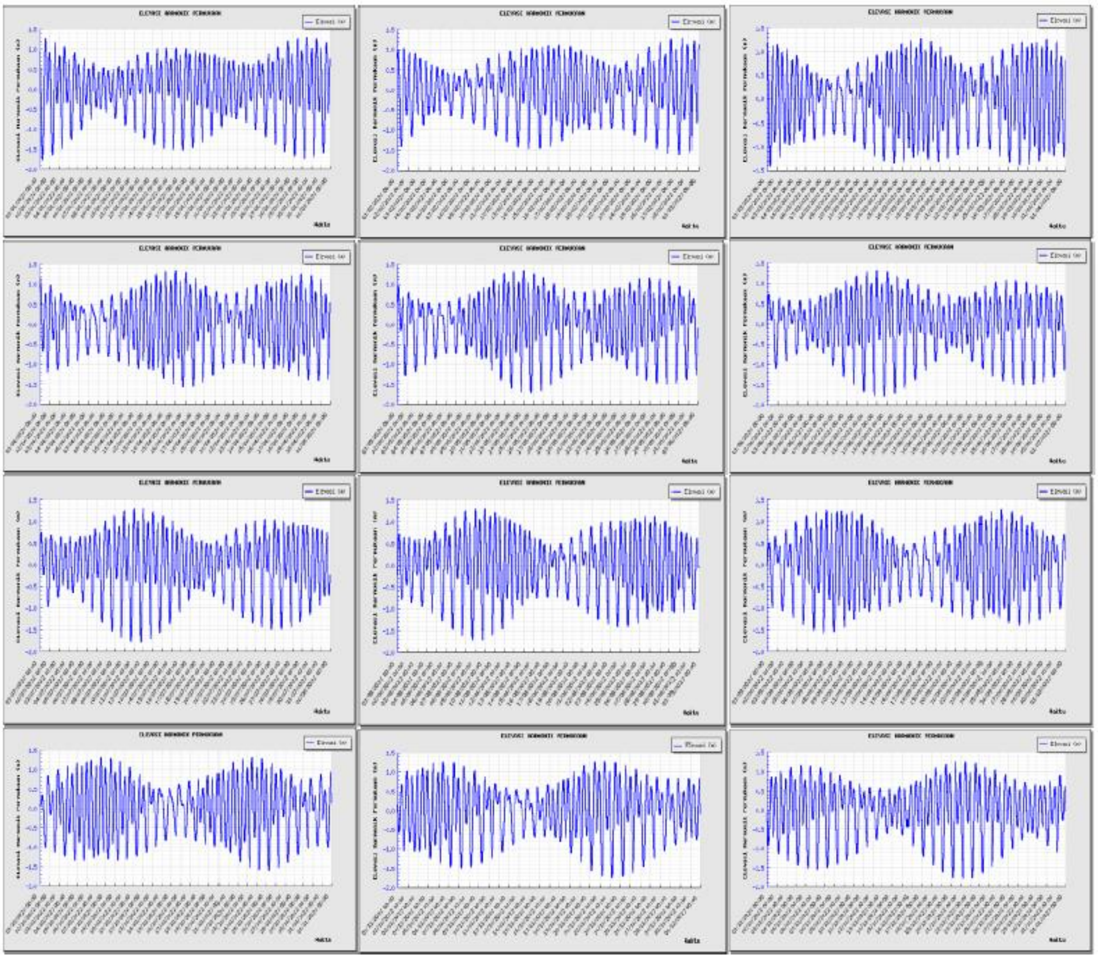

Figure 1. Tidal dynamic from 01 January to 31 December 2022, Sources: *Balai Riset dan Observasi Laut, Indonesia* 2022

The tidal flood analyze based on principle of cost distance with *Hloss* as the coefficient which are representing ground surface roughness, it shown an ideal inundation scenario. In this study, we consider a coastal flood scenario with a maximum height of 2 meters (H0). The inundation model disperses flooding across coastal areas that are relatively flat and basin. Overall, several wide-ranging villages within the study area, Batam, experience inundation. The land cover types in the tidal flood are as vary, including buildings or settlement, road networks/built-up areas, mangrove forests, and tidal flat swamps.

Based on the image figure 2, it is evident that the sub-district with the highest susceptibility to flooding is Galang Sub-district, encompassing an area of 3,396.11 hectares, primarily because it is situated along the coastline. Conversely, the sub-district with the lowest vulnerability to flooding is Lubuk Baja Sub-district, covering an area of 61.21 hectares. Among residential areas, Batu Aji Sub-district is the most significantly affected by flooding, spanning 95,933 hectares. In contrast, the residential area least impacted by flooding is Batam Kota Sub-district, with an area of only 3.46 hectares. Furthermore, the highest number of affected buildings is found in Bengkong Sub-district, totaling 3,758 houses, whereas the lowest number is in Kuala Kampar Sub-district, with just 2 houses.

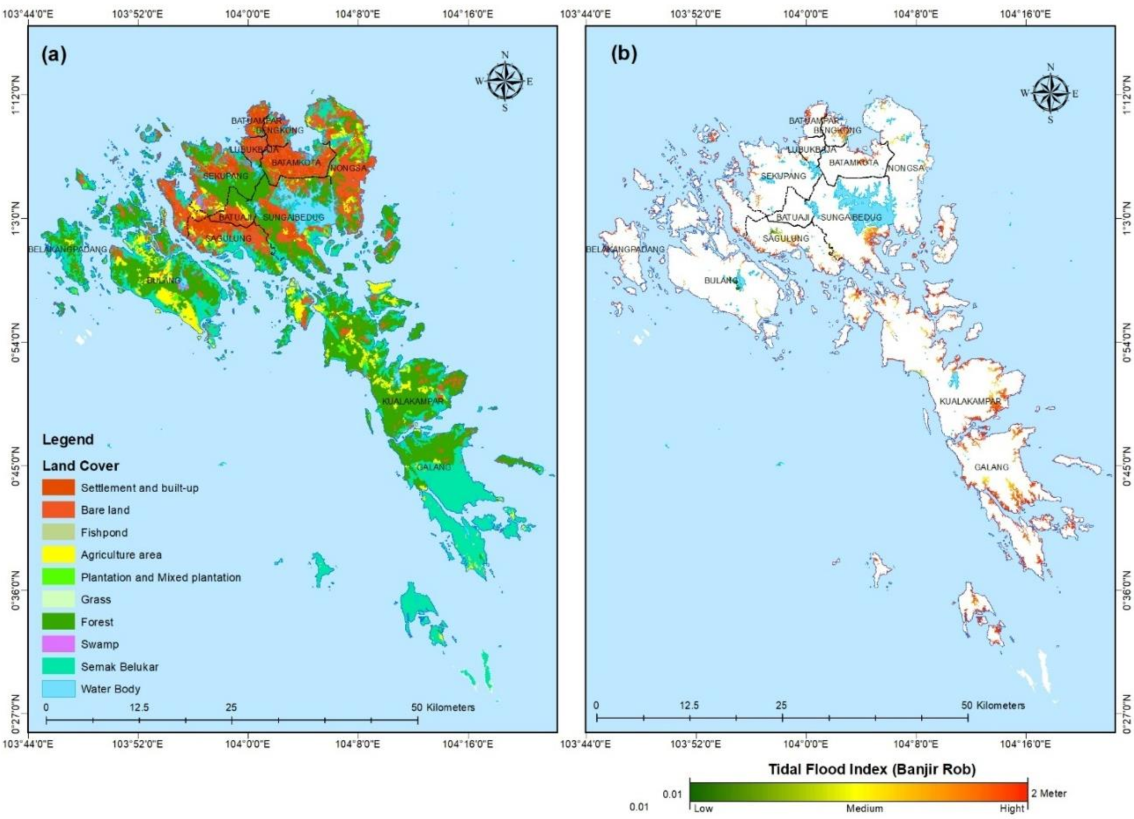

Figure 2. Land cover and tidal flood hazard on the Batam City

Table 2. Impact of tidal flood on the land cover

No	Land cover	Large (Ha)
1	Water body	1036,5
2	Fish pond	35,1
3	Forest high density	794,2
4	Plantation and Mixed plantation	75,5
5	Settlement and built-up	553,8
6	Swamp	225,0
7	Shrub	6405,2
8	Bare land	1505,7
9	Agriculture area	287,2
	Total	10918

In Table 2, we observe the areas affected by flooding with various types of land use. The land type that suffered the most substantial impact from flooding was shrubs, covering an area of 6,405.3 hectares, while the land type least affected by flooding was ponds, with an area of 35.1 hectares. Additionally, settlements and active areas experienced flooding impacts over an area of 553.8 hectares. The table 3 provides a comprehensive overview of the impact of tidal flood on buildings. It reveals that a total of 12,681 buildings were affected by the flooding, signifying the scale of the issue. Among these affected buildings, Bengkong sub-district stood out with the highest number, totaling 3,758 units. In contrast, the sub-district of Kuala Kampar experienced the least impact, with only 2 buildings affected.

Table 3. Impact Tidal Flood (*Banjir Rob*) on settlement

No	District	Unit building	Inundation (Ha)
1	Batam Kota	921	256,36
2	Batuaji	183	313,45
3	Batuampar	1.092	193,11
4	Belakangpadang	551	866,02
5	Bengkong	3.758	529,26
6	Bulang	298	1.221,54
7	Kuala Kampar	2	1.568,49
8	Lubukbaja	1.093	61,21
9	Nongsa	780	1.129,86
10	Sagulung	726	545,29
11	Sekupang	1.356	366,48
12	Sungaibedug	1.921	528,58
13	Galang	0	3.396,11
	Total	12.681	10.975,76

The table 3 reveals the extensive impact of flooding is evident as it covered a substantial area of 10,975.76 hectares. Notably, Galang District endured the greatest extent of flooding, with a vast area spanning 3,396.11 hectares. In sharp contrast, Lubuk Baja District experienced the least flooding impact, affecting a relatively small area of 61.21 hec-tares. These findings underscore the pressing need to address the challenges posed by coastal flooding in these regions, emphasizing the urgency of mitigation and preparedness measures.

Turning our attention to table 4, it provides details regarding the calculation of financial losses for the restoration of the built environment in flood inundation areas. The estimated budget losses pertain to buildings, settlements, and infrastructure resulting from coastal flooding under the maximum coastal flooding scenario.

Table 4. Budget lost cause the impact of tidal flood

No	Unite	Long (Km)	(IDR)	(USD)
1	Arterial	0,02	178.276.800	11.592,98
2	Collector	0,02	225.191.400	14.643,75
3	Local	0,47	4.781.403.000	310.925,07
	Total	0,51	5.184.403.000	337.131,36

In summary, the cost calculation is based on the RAB (budget-based planning), and the development budget plan has effectively estimated the budget required for restoring the physical environment. The total losses incurred for public facilities, including roads, amounted to Rp. 5,184,403,000, which is equivalent to approximately 337,131.36 USD. This estimation considers an asphalt price of Rp. 1,000,000 per cubic meter with a total area of 0.51848712 hectares or 5184.8721 cubic meters. Based on this report, it can proactively anticipate and estimate the necessary budget allocations for disaster management efforts. These costs can then be compared with the expenses associated with managing tidal flood-prone environments, such as con-structing embankments. This comparison aids in minimizing the overall expenses and determining the priority of disaster management strategies, particularly those related to the physical construction of disaster management infrastructure.

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Figure 3. The impact of tidal flooding on residents' housing conditions (a) and residents' efforts to build houses with stilt houses to mitigate sea water rise.

Field observations have yielded insights into how the local community adapts to geographical challenges, primarily through construction practices. Many mitigation efforts have been undertaken, such as the construction of flood-protecting embankments. These tidal flood embankments function effectively in minimizing seawater runoff onto land and reducing the extent of inundation. However, some embankments have been intentionally damaged to allow water to flow into low-lying areas during high tides. In several locations, we've noted that the community has adapted by developing housing infrastructure designed for flood-prone regions. Houses in floodplain areas are constructed on stilts to prevent submersion during flooding. To facilitate community access, simple bridges connect these raised housing complexes to the surrounding area. It's worth mentioning that, based on the community's capacity, these stilt houses typically utilize concrete foundations for the walls.

According to the information gathered, it's clear that the community has adjusted to the elevation and physical condition of this city. This adaptation is evident in the houses built on stilts with concrete foundations, connected by elevated walkways made of concrete and wood, as depicted on the tidal inundation modeling results map. Furthermore, from the flood map has identified green areas, particularly along the coastline, which are situated at a relatively higher elevation above the tidal zone. Mitigation efforts in these areas involve raising the ground level through soil filling and then constructing house foundations atop the fill. However, it's important to note that these houses are safeguarded against floodwaters reaching a height of up to 1.5 meter. When sea water levels rise beyond 2.5 meters, both houses and buildings in these areas become susceptible to coastal flooding.

The results of this research have provided very clear information that the tidal dynamics on the Batam coast are semi-diurnal. Prayogo [15] This semi-diurnal tide will cause sea levels to rise in the morning and evening, so two floods that will occur in the coastal area [6]. In this tidal condition it has already flooded several areas in Batam City. In the maximum flood scenario of 2.5 meters, many floods and many building units and road infrastructure will be affected. By referring to the value of losses, it is necessary to carefully consider the management of coastal areas in an effort to mitigate coastal flood disasters [12]. However, the coastal flood disaster conditions may become more severe in the future due to the contribution of global warming which causes an increase in sea surface height [14], and weather anomalies resulting in various hydrometeorological disasters in coastal areas [3,4].

4. Conclusion

The research findings reveal that the coastal flooding in the studied area primarily occurs around the estuary and along both sides of the river. This region is characterized by relatively flat and low topography, with geomorphological features resembling tidal swamps. Among the sub-districts within the study area, Galang Sub-district stands out as having the highest potential for flooding impact, covering an extensive area of 3,396.11 hectares due to its coastal location. Conversely, Lubuk Baja Sub-district is the least susceptible to flooding, with an area of 61.21 hectares. Regarding residential areas, Batu Aji Sub-district experiences the most significant impact from flooding, encompassing a vast area of 95,933 hectares. In contrast, Batam Kota Sub-district is the least affected, with a minimal area of 3.46 hectares. In terms of building impact, Bengkong Sub-district has the highest number of affected houses, totaling 3,758, while Kuala Kampar Sub-district is the least affected, with only 2 houses fac-ing flooding. Some tidal flood affected on village including building associated to transportation infrastructure supporting community accessibility. The estimated cost for restoring the infrastructure in response to the flood disaster amounts to Rp. 5,184,403,000 or approximately 337,131.36 USD. It is crucial for the government to be prepared to allocate budget resources for emergencies and to facilitate disaster management mitigation efforts when necessary.

Acknowledgement

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Research Statement

This research was carried out with contributions from each author based on their respective capacities. There is no conflict of interest in writing this scientific work.

Data Availability

Tidal dynamic from Balai Riset dan Observasi Laut Indonesia, access on this website http://118.97.27.100/imro-ofs/index.php#show_form . Peta penggunaan lahan dan DEM NAS diperoleh dari Badan Informasi Geospasial Indonesia access on this web-site http://tanahair.indonesia.go.id

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