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Analysis of Inundation Area as an Impact of Sea Level Rise in Dumai City, Riau Province

Analisis Genangan Rob Akibat Kenaikan Muka Air Laut di Kota Dumai Provinsi Riau

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Abstract

This research was carried out in December 2021-January 2022 in Dumai City District, Riau Province. The purpose of this study is to determine the rate of sea level rise based on analysis of tide data from 2001-2021 and to predict inundation areas in the next 20 years. This research method is a descriptive survey using remote sensing as an additional tool to show the results. Acquisition needs are in the form of primary data (land use and tide data) and secondary (slope data, elevation, land use, and tide data). These parameters are processed and analysed to describe the extent of the inundation by displaying a map of the City of Dumai. The results showed that the waters of Dumai City have a Formzhal number of 0.5, which means that the water area is classified as a mixed tide, semi-diurnal prevalence, with a sea level rise of 2.003 cm/year. Then, the numbers used to predict the height of sea level rise in the next 20 years are 0.973 m each. Furthermore, sea level height was analyzed to obtain the inundation area for the next 20 years, it turns out that the inundation area each year is 11.89 ha.

Keywords: Inundation Area, Sea Level Rise, Dumai City

Abstrak

Penelitian ini telah dilaksanakan pada bulan Desember 2021- January 2022 di Kabupaten Kota Dumai, Provinsi Riau. Tujuan dari penelitian ini adalah untuk mengetahui laju kenaikan muka air laut berdasarkan analisis data pasut dari tahun 2001-2021 dan untuk memprediksi daerah genangan pada 20 tahun kedepan. Metode penelitian ini adalah survei deskriptif dengan menggunakan penginderaan jauh sebagai peralatan tambahan untuk menunjukkan hasilnya. Kebutuhan akuisisi berupa data primer (data tata guna lahan dan pasang surut) dan sekunder (data kemiringan lereng, elevasi, tata guna lahan, dan pasang surut). Parameter-parameter tersebut diolah dan dianalisis untuk menggambarkan luas genangan dengan menampilkan peta Kota Dumai. Hasil penelitian menunjukkan bahwa perairan Kota Dumai memiliki angka Formzhal 0,5 yang artinya wilayah perairan tersebut tergolong tipe pasang surut campuran condong harian ganda (*mixed tide, prevaling semi diurnal*), dengan nilai kenaikan muka air laut mencapai 2,003 cm/tahun. Kemudian, angka yang digunakan untuk memprediksi ketinggian kenaikan muka air laut pada 20 tahun kedepan, masing-masing adalah 0,973 m. Selanjutnya tinggi muka air laut dianalisis untuk mendapatkan luas genangan pada 20 tahun kedepan, ternyata luas genangan tiap tahun masing-masing menjadi 11,89 ha.

Kata kunci : Kenaikan Muka Air Laut, Kota Dumai

1. Introduction

Dumai City is one of the cities located in Riau Province and based on geographical position of Dumai City is located, at 10° 51' 30"- 10° 59' 8" North latitude and 114° 24'-114° 34' East longitude with an area of 1,772.38 km². The topographic conditions in Dumai have an altitude of about 3 metres above sea level (Petrus & Aryajaya, 2015). The topographical condition of Dumai City which is quite sloping can also increase the level of danger of Dumai City against tidal inundation disasters. Dumai City is located in the coastal area / north Coast of Sumatra Island which has relatively large waves (Samulano & Mera, 2011). The coastal dynamics of Dumai City are strongly influenced by strong Indian Ocean waves reaching the coast and the process of abrasion and coastal erosion dominantly occurs along the coast. The process of land erosion also continues to occur in the upstream area characterized by the high supply of sediment carried by river flow to the sea (Rifardi, 2008). In addition to the abrasion process, Dumai City is also prone to tidal floods and tsunamis (Sukri, 2015). Dumai City is developed as an industrial area, settlement, harbour, plantation and shipping lane. These activities have an impact on changes in coastal morphodynamics and hydrodynamics of the Rupat Strait waters. Rifardi et al. (2015) argue that the land use change in Dumai City has caused the mangrove area to be greatly reduced.

Based on the above problems, Dumai City has considerable potential for tidal inundation due to sea level rise. The coastal condition of Dumai City which is directly adjacent to the Rupat Strait will affect changes in the characteristics of coastal areas. One of the efforts that can be done is to estimate the vulnerable areas through the analysis of tidal inundation parameters (in this case elevation, slope, and land use) to sea level rise. This research provides an overview of the influence of tides on the extent of tidal floods formed in Dumai City through the creation of tidal flood inundation maps by analysing sea level rise through periodic tidal data and utilising remote sensing data and Geographic Information Systems (GIS) to determine the extent of areas experiencing tidal flood inundation in Dumai City, Riau Province. This is important to determine disaster mitigation and prevention measures as well as future spatial planning.

2. Material and Method

2.1. Time and Place of Research

This research was conducted from December 2021 to January 2022, located in the waters of Rupat Strait, Dumai City, Riau Province. The research location can be seen in (Figure 1).

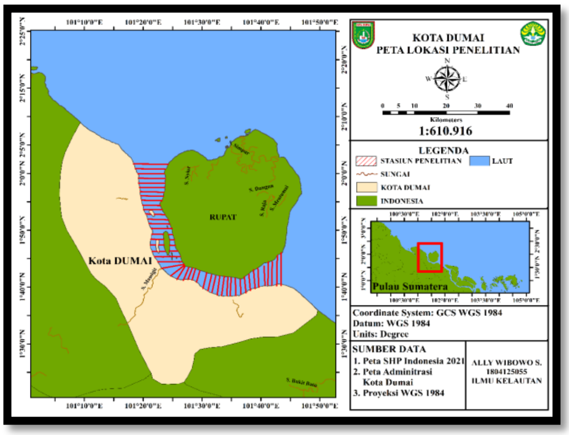

Figure 1. Research location map

2.2. Research Methods

This research was conducted using descriptive quantitative and survey methods, through remote sensing systems. Quantitative descriptive analysis was conducted to examine the effect of average sea level rise on seawater runoff that inundates the coastal areas of Dumai City. The research was divided into several stages, namely literature study, data collection (including primary and secondary data) and parameter data processing for tidal inundation analysis in Dumai City.

2.3. Research Procedures

2.3.1. Data Collection

Data collection was carried out in primary and secondary ways. Primary data were obtained from field surveys, tidal measurements began with the determination of benchmarks or measurement tie points. Measurement of tides using tide bars for 15 days every 1-hour interval. Secondary data is obtained by downloading on sites that provide data needs and government agencies. Secondary data required include slope, land use, elevation, and tides.

2.3.1.1. Tidal

Data from the recording of tides in the field were analysed using the Admiralty method to obtain tidal harmonic constants, namely M2, S2, K2, N2, K1, O1, P1, M4, and MS4. Tidal harmonic constants can calculate MSL, HHWL and LLWL levels. The tidal harmonic constants also obtained Formzahl number (F) which shows the type of tides in the study area. The first stage carried out is to process tidal data in the waters of Dumai City in 2011-2020 so that the values of tidal constants are obtained. 9 main components of tidal harmonic constants are used, namely: M2, S2, K2, N2, K1, O1, P1, M4, and MS4. According to Rempengan (2013) after obtaining the values of M2, S2, K1 and O1 then obtained a Formzahl number, for each month by following the formula applied, as follows:

$$F = (k1+O1)/(M2+S2)$$

Description:

F = Formzahl number
K1, O1 = Main single daily tidal constants
M2, S2 = Main double daily tidal constant

Furthermore, the value of sea level rise is obtained by linear regression method using the following equation:

$$Y = ax + b$$

Finally, the value of the annual upward trend can be found with the equation used by Cahyadi et al. (2016):

$$\text{Trend per year} = \frac{\text{Ymax-Ymin}}{\text{Length of year of Observation}}$$

2.3.1.2. Land Use

GCP (Ground Check Point) to know the condition of coastal areas affected by flooding is determined randomly and thoroughly at the observation station by considering the number of clusters / spatial data classification results in all coastal areas of Dumai City. Land Use of the coastal area of Dumai City is processed using sentinel imagery through the website https://earthexplorer.usgs.gov/. Classification of areas in the image is carried out using the supervised classification method using maximum likelihood classification. In processing land use data, an accuracy test is carried out, including:

$$\text{Overall Accuracy } = \frac{D}{N} \text{ x } 100\%$$

Description:

D = Total correct row values that have been added diagonally
N = Total correct values in the error matrix

$$\text{Producer's accuracy} = \text{xii/xi+ x } 100\%$$

Description:

Xii = Total correct cell values in the class (column)
Xi+ = Sum of cell values in the column

$$\text{User's accuracy} = \text{xii/xi+ x } 100\%$$

Description:

Xii = Total correct cell values in the class (row)
Xi+ = Sum of cell values in the row

$$\text{Kappa accuracy} = \frac{\text{(TS x TCS)- } \sum \text{(Column count x amount on line)}}{\text{TS2- } \sum \text{(Column count x amount on line)}}$$

Description:

TS = Total number of samples (97)
TCS = Number of correct samples in the whole class

2.3.1.3. Elevation

Obtaining elevation values using DEM data obtained from BIG (www.tides.big.go.id/DEMNAS) to know the height of the land.

2.3.1.4. Slope

The acquisition of slope values uses DEM data obtained from BIG (www.tides.big.go.id/DEMNAS) to know the slope of the land. According to Arsyad *in* Yumai et al. (2019), the criteria for land slope classification can be seen in Table 1.

Table 1. Land Slope Classification

Class	Slope (%)	Clarification
1	0-8	Flat
2	8-15	Ramps
3	15-25	Slightly steep
4	25-45	steep
5	>40	Very steep

2.4. Data Analysis

The processing of sea level rise in this study uses tidal data measured by the BIG agency from 2011 - April 2020. The data was processed using the Admiralty method to obtain the mean sea level (MSL) value for each month. A linear regression test was then conducted to determine the relationship between sea level and the length of tidal observations. The average rate of sea level rise (MSL) obtained from the calculation of linear regression results is then processed to determine the trend value of sea level rise for 10 years by processing using equations 3.2 and 3.3 for 10 years. The resulting average rate of sea level rise is in units of time per year. The results of the sea level rise values that have been obtained are then used to predict sea level rise for 20 years (The year 2040). The calculation was done by:

$$\text{Predicted Year n} = \text{Trend per year} \times \text{Year to be predicted (n)}$$

$$\text{Inundated Area} = \text{"DEM"} \leq \text{SLR}$$

$$\text{Inundated Area} = \text{Con("DATA"<Criteria, } \textit{True, False}\text{)}$$

Description:
Con = conditional function
DATA = Raster screen

The analysis method used to obtain spatial data of the puddle area uses Logical Operator. The use of the logical operator method is carried out based on ArcGIS with the raster calculator tool function. Analysis related to the identification of affected areas uses 2 data used as input, namely SLR (Sea Level Rise) trend data and DEM (Slope and elevation). In the analysis process, the coastline used is based on administrative boundaries in Dumai City.

SLR and DEM data are analysed with the Raster Calculator tool which will display the output in the form of a raster. The raster analysis used with Raster Calculator aims to determine the inundation area of sea level rise in Dumai City. The equation used in the analysis of the inundation impact area of sea level rise is to use the mathematical logic function a<b which shows that the DEM value is smaller than the value of sea level rise. The process of correcting raster data into polygons so that the area of inundated areas can be determined, then Overlay and identification of areas, this stage combines land use data and inundation area data to determine the extent of inundation distribution on each study land cover.

3. Result and Discussion

3.1 General Conditions of Research Area

Geographically, Dumai City is located at 10^o 51' 30"- 10^o 59' 8" North latitude and 114^o 24'-114^o 34' East longitude with an area of 1,772.38 km^2. Dumai City is the city with the third largest administrative area in Indonesia based on its status as an intermediate city, the average height of Dumai City is 3 metres above water level. Dumai City has a tropical climate with rainfall between 100-300 cm and an air temperature of 24-30^{o}C with peaty swamp soil conditions. The land area of Dumai City is 1,727 km^2 of the land area of Riau Province.

Administratively, it is bordered to the north by the Rupat Strait, to the east by Bukit Batu Subdistrict, Bengkalis Regency, to the south by Mandau Subdistrict and Bukit Batu Subdistrict, Bengkalis Regency, to the west by Tanah Putih Subdistrict and Bangko Subdistrict, Rokan Hilir Regency. The coastal area of Dumai City is directly adjacent to the Rupat Strait so it has moderate waves despite the presence of Rupat Island, the changes that occur in Dumai City, especially the coastal area, are strong.

3.2. Land Use of Dumai City

The results of the land use analysis of Dumai City based on field data, are classified into 5 classes (Table 2).

Table 2. Land use class

No.	Class	Description
1.	Forest	Trees
2.	Garden	Similar Vegetation
3.	Building	Building, Factory, Residential
4.	Non-Agricultural Vegetation	Shrubs, Grass
5.	Fields	Mixed Vegetation

The results of processing sentinel imagery in 2020 with supervised classification using the maximum likelihood classification method using ArcGIS software. This method produces an accurate classification accuracy value for the separation of each class (Septiani et al., 2019). The results of the supervised classification of sentinel imagery spatial data were validated using a confusion matrix that provides information on values in accuracy testing, such as user's accuracy (UA), producer's accuracy (PA), overall accuracy (OA), and kappa accuracy (KA). The accuracy test values are presented in Table 3.

Table 3. Accuracy test values on 5 land use classes

Class	User Accuracy (%)	Producer Accuracy (%)	Overall Accuracy (%)	Kappa
HT	90,91	97,56		
KB	62,5	33,33		
BA	100	100	140,20	0,67
VA	68,75	91,66		
LD	44,44	57,14		

Land use classification in spatial data interpretation of processing results using remote sensing with overall accuracy> 75%, these results are suitable for use as the final accuracy. This is based on the guidelines for processing satellite data for classification compiled by LAPAN *in* Asma (2018) that image classification is considered correct if the results of the Confusion Matrix calculation are >75%. The extent of land use classification data in Pariaman City is presented in Table 4.

Table 4. Land use of Dumai City

No.	Class	Description	Area (ha)	Percentage (%)
1	Forest	Trees	271.8	41.12
2	Garden	similar vegetation	1481.3	15.04
3	Building	Building, Factory, Residential	848.05	11.69
4	Non-Agricultural Vegetation	Shrubs, Grass	1.404	22.29
5	Fields	Mixed vegetation	621.7	9.86
	Total		1,727	100.00

The results of land use classification using Sentinel Image in 2021 show that the total area of Dumai City is 1,727.38 ha with the percentage of each class namely Forest 41.12%, Garden 15.04%, Building 11.69%, Non-agri vegetation 22.29%, Field 9.86%.

3.3. Elevation

Dumai City has varying altitudes. Based on the processing, the elevation ranges between 0-75mdpal. 60.04% of the Dumai City area is at an elevation of 0-15m which is in the coastal area (more details can be seen in Table 5). This elevation can determine the potential for an area to be inundated. This is because the higher the presence of an area, it will minimise the area experiencing inundation (Sostrodarsono, 2005).

Table 5. Elevation area of Dumai City

No.	Elevation (m)	Area (ha)	Percentage (%)
1	0-15	278,39	60,04
2	15-30	1,293,57	20,30
3	30-45	862,83	13,91
4	45-60	302,73	3,25
5	60-75	68,74	2,5
	Total	1,727,38	100.00

3.4. Slope

Dumai City is dominated by slope values between 0-3% with an area reaching 72.69% of the total area. The area is located in the coastal area of Dumai City (more details can be seen in Table 6.) Areas with a slope of 0-3% are categorized as flat areas (Arsyad, 1989). This will expand the potential for inundation to occur, because the flatter the land, the greater and wider the potential for inundation and vice versa.

Table 6. Calculation of Slope Value of Dumai City Area

No.	Slope (%)	Relief	Area (ha)	Percentage (%)
1	0-3	Flat	4.652.5	72,69
2	3-8	Ramps	1.072.5	18,23
3	8-15	Slightly Tilted	461.10	5,78
4	15-30	Tilted	192.01	3,10
5	30-45	Slightly Steep	10.96	20
	Total		1727.3	100.00

3.5. Tidal Conditions in the Waters of Dumai City

Based on the results of processing shows that the value of the formzhal number waters Dumai City is 0.5. The value is based on bakosurtanal (2007) including the category of mixed tide type inclined double daily (mixed tide, prevailing semi-diurnal) is a tide that occurs twice the tide and twice the ebb in a day but sometimes there is one tide and one ebb with different height and time. After analyzed using the admiralty method then performed linear regression test to determine the value of the relationship between the lengths of the observation year when processing with the value of MSL.

Sea level rise based on MSL data processing every month is obtained at 2.003 cm/year with the value of high water used as the process of calculating the difference between the highest high water level (HHWL) and the average Water Level (MSL) for 20 years the value of sea level rise is then used to determine the height of sea level rise in 2040 (20Th). The predicted value of sea level rise in 2040 is 0.973m.

3.5. Rob Inundation in 20401

Predictions of ROB inundation due to sea level rise in 2040 show that Dumai City will experience an inundation of 11.89 ha. ROB inundation in 2040 (20th) can be seen in Figure 2.

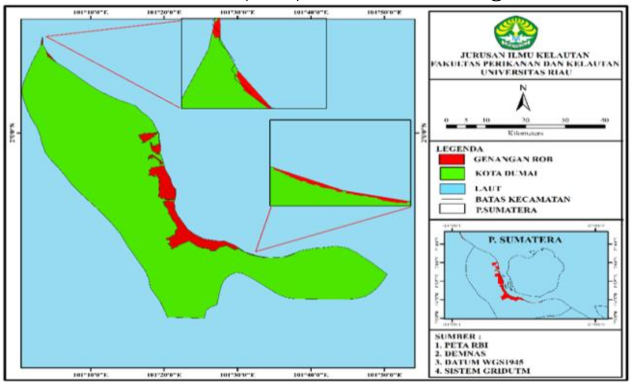

Figure 2. Rob Inundation Distribution Map in 2040 (20 years)

Effectiveness in land use planning greatly affects the condition of the surrounding environment. The causes of flooding are generally influenced by changes in land use structure, the use of watersheds as residential and industrial areas, damage to watersheds, and others. The acceleration of development that occurs due to high growth rates causes an increase in the urbanisation process, especially in coastal areas that are designated as residential areas and tourist destinations. One of them is land use changes that do not pay attention to the carrying capacity of the land and will affect environmental conditions and even tend to degrade such as the intrusion of seawater into the land (Diposaptono, 2009). Land use change will affect the level of soil permeability, so that when it rains, the area whose surface has been covered by buildings, the dynamics of the coastal area of Dumai City are influenced by waves from the waters of the Rupat Strait, coastal areas have strategic waters while being vulnerable to environmental changes, one of which is rising sea levels (Kaly et al., 2004). The impact of rising sea levels can cause tidal inundation.

Based on the land use map, the coastal area at the research location is used as a residential area. This will have a major influence on the acceleration of land subsidence (Prasetyo, 2014) as one of the factors causing an area to be potentially affected by tidal flooding (Cahyaningtias, 2018). Based on spatial analysis using ArcGIS software, the most inundated land use is the Open Land class, more details can be seen in Table 7.

Table 7. Distribution of Rob Inundation in Dumai City in 2040 (20th)

No.	Class	Area (ha)
1	Forest	5,08
2	Garden	0,8
3	Building	4,78
4	Non-Agri vegetation	0,67
5	Fields	0,56
	Total	11,89

Other factors such as altitude and slope of an area also influence determining the extent of inundated areas due to sea level rise. Based on analysis using DEM obtained from the website *www.tides.big.go.id/DEMNAS* managed by BIG, the elevation value of the Dumai City area varies between 0-75 mdpal with 60.04% of the area at an elevation of 0-15 m located in the Coastal City of Dumai. Relatively low elevations will be affected by sea level rise events because if the height of sea level rise is more or equal to the height of the area, the area will be inundated. Diposaptono (2009) states that one of the vulnerability factors of an area to the impact of sea level rise is the height of the area. The value of the slope class in the analysis according to Arsyad (1989) with the acquisition of 72.69% of the Dumai City area is on a flat slope around 0-3% located in the western part of Dumai City which is a coastal area. This condition will increase the possibility of potential inundation in the coastal area of Dumai City.

The dynamics of the coastal area of Dumai City are influenced by waves from the waters of the Rupat Strait, coastal areas have strategic waters while being vulnerable to environmental changes, one of which is rising sea levels (Kaly et al., 2004). The impact of rising sea levels can cause tidal inundation. Rob inundation is an event that occurs in coastal areas due to sea level rise which results in changes in daily average sea level elevation as a result of sea level rise (Dewi, 2020). Rob that occurs by high daily tides can reach land. Inundation that occurs in an area depends on the elevation, slope, and land use in the area (Sudirman et al., 2017).

Flooding due to tides is also influenced by the position of the Earth against the moon and sun. The phenomenon of tidal flooding is also inseparable from the cyclical events of the moon's motion that can cause the rise and fall of sea levels, commonly known as full and high tides. Both tide have specific characteristics when viewed from the cycle of the moon's motion towards this event. Tidal inundation can occur every month following the highest tidal cycle of each month. Areas that are very vulnerable to this event are coastal plains in low coastal areas and relatively flat slopes. This tidal inundation/flooding will be exacerbated by the intensity of rainfall that occurs in an area (Kodoatie et al., 2002).

4. Conclusions

Dumai City has a type of mixed tide, prevailing semi diurnal is a tide that occurs twice the tide and twice the ebb in a day but sometimes there is one tide and one ebb with a different height and time with a Fromzhal number value of 0.5. The acquisition of tidal data that has been analysed from the calculation of linear regression of tidal data 2001-2021 shows the value of sea level rise in Dumai City of 2.003 cm/year. The distribution of tidal inundation in 2040 (20th) shows that in that year, the sea level rise was 0.973 m with an inundation area of 11.89 ha.

5. Suggestion

Rob inundation is a phenomenon that occurs following the lunar cycle. This event occurs when the seawater experiences the highest tide. Factors that cause tidal inundation are land subsidence, sea level rise, climate, and rainfall. This research only considers one of the causal factors, namely sea level rise. Therefore, it is expected that further research to pay attention to the effects of other factors such as land subsidence and climate to obtain more concrete information and be used as a planning effort to overcome the occurrence of tidal inundation.

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