



IDENTIFICATION OF SEA LEVEL RISE BASED ON TIDAL DATA USING THE LEAST SQUARE METHOD

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Abstract Flood occurs when water overflows its banks due to inadequate channel capacity. Flooding typically results from too much precipitation, which prevents the channel from handling the water flow and results in a deluge. Pontianak City frequently faces severe and protracted flooding when it rains. Both high rainfall and rising sea levels, which impact the Kapuas River, might result in flooding. This argument states that this study was done to anticipate sea level rise for the next six years, which will impact Pontianak City's water flow height using tidal data from Pontianak's Climatology Maritime Station from 2016 to 2021. The average rate of sea level rise, calculated using the least squares approach, is 1.579 cm/year. With an increase rate of 0.017 cm/year, the average sea level rise forecast for the Kapuas River for the next six years is 1.789 cm. It will be necessary to reduce floods in the future to avoid the effects of water flow.	Article history: <i>Submitted 21-06-2023</i> <i>Revise on 26-11-2023</i> <i>Published on 28-11-2023</i> Keyword: <i>Sea Level Rise, Least Squares, Tidal, Kapuas Rivers</i> DOI: http://dx.doi.org/10.26418/jts.v23i4.66656
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1. Introduction

Pontianak City, West Kalimantan Province, is one of the areas that often experience flooding. Pontianak City is in a location identified for its potential to experience flooding or inundation for a long time when it rains (Danial et al., 2021) The effect of rising river levels from global warming is spreading worldwide. The causes of this phenomenon of rising sea levels are the melting of polar ice caps, extreme weather events, and land subsidence due to soil compaction.

Based on the definition and description above, the influence of ebb tides is quite significant in causing inundation flooding in the Pontianak region. It can be ascribed to the phenomenon of flooding that occurs in the Pontianak region, and if seen from the perspective of the cause, which is ebb tides, there is a chance of flooding in the future (Yoganda et al., 2019)

Long-term tidal data is essential to explain this phenomenon. The tidal data is obtained from tidal measurements conducted by Pontianak's

Climatology and Meteorological Station, West Kalimantan.

2. Materials and Methods

2.1 Theoretical Frame Work

Flooding in Pontianak City is caused by several factors, one of which is tidal. The full tides cause seawater to become high in the Kapuas River water area, so water is held back into the Kapuas River. It causes the condition of the Kapuas River water level and water caused by rainfall to enter a parallel position, which causes the water level to be inundated and not go down to the river body.

This study will use the least square method for the next five years to predict sea level rise along the Kapuas River waters so that flood mitigation efforts can be made due to the tides. The accuracy of sea level rise predictions must also be taken into account to ensure good prediction results.

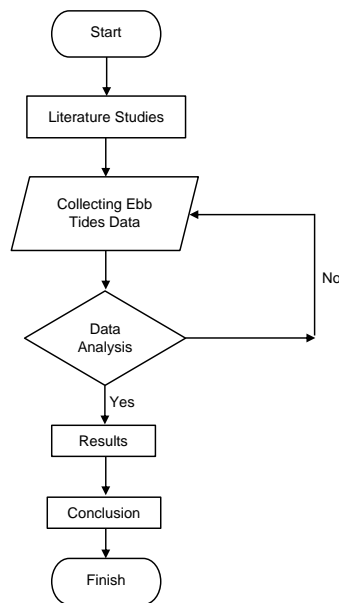


Fig 1. Framework

2.2 Research Location

The Kapuas River in Pontianak City, West Kalimantan, is the site of the research project with the title Identification of Sea Level Rise Based on Tidal Data Using the Least Square Method.

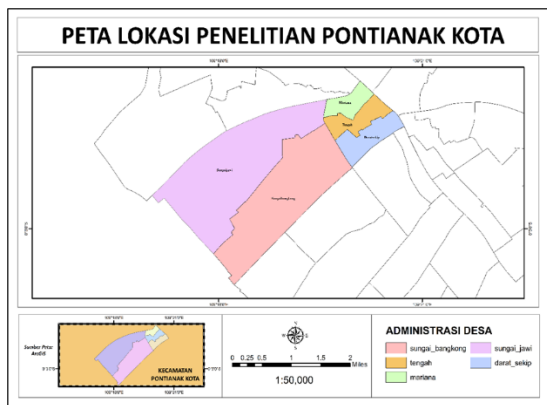


Fig 3. Research Location

2.3 Data

This research uses secondary data from agency sources/government publications that support this research obtained from the Pontianak Climatology Maritime Station. The data obtained from the institute will be processed using Microsoft Excel software and then compiled in the form of a table. The data obtained is the highest every hour for one month in 6 years, so the amount of data to be analysed is 43,800.

2.4 Analysis Method

2.4.1. Ebb Tides Definition

According to the book Coastal Engineering (Triatmodjo, 1999), ebb tides are fluctuations in sea level due to the force of attraction of celestial bodies, especially the sun and the moon, towards the mass of seawater on Earth.

2.4.2. Types of Ebb Tides

According to (Triatmodjo, 1999), ebb tides in Indonesia can be divided into four types, as described in image 1, which is:

- Semi-diurnal tides occur consecutively and regularly with two high tides and two low tides that are nearly the same height. The semi-diurnal tide is found in the Malacca Strait to the Andaman Sea.
- The diurnal tide is one in which there is one high tide and one low tide per day. The tidal period is 24 hours and 50 minutes. This type of tide occurs in the waters of the Karimata Strait.
- Semi-diurnal mixed tides are ordinary in eastern Indonesia, where there are twice as many high tides and twice as many low tides in a single day, but their height and period are different.
- The Strait of Borneo and the north coast of West Java both have mixed tides, which are diurnal tides where one tide and one low tide occur each day, but occasionally, for a short period, two tides occur, and two recede with highly different heights and periods.

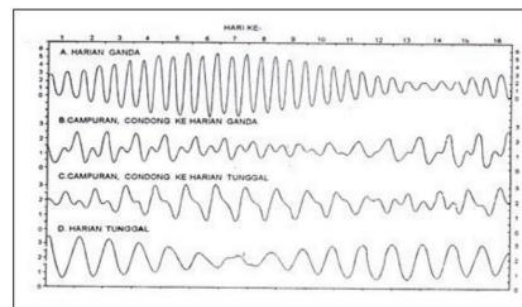


Fig 2. Types of Ebb Tides

The tidal types that will be determined using the least square method can be done by calculating the formzahl(f) number with the following provision (Lang et al., 2022):

$$F = \frac{K^1 + O_1}{M^2 + S_2}$$

F is Formzahl number. O1 is the Primary cause of amplitude, the moon's gravitational attraction. K1 is the moon's and the sun's gravitational pull, which are the primary causes of amplitude. M2 is The gravitational pull of the moon, which is responsible for the primary double component of amplitude along the z-axis. S2 is the sun's gravitational force that

catalyses the main dual component of amplitude. There also tidal classification which can be seen in Table 1 (Prayogo, 2021)

Table 1. Tidal classification types

F Value	Tidal Types
≤ 0,25	semi-diurnal tide
0,25 – 1,50	mixed tide prevailing semi-diurnal
1,50 – 3,00	mixed tide prevailing diurnal
≥ 3	diurnal tide

2.4.3. Tidal Component

The tidal component is a description of the resultant force driving the tides. The force of attraction between the earth, moon, and sun produces the resulting tidal force. These tidal components are separated into three groups. The first group comprises the semi-diurnal tide group's M2, S4, N2, and K2 components. The second group is the tides included in the diurnal tide group consisting of components K1, O1, and P1. The third group is the tidal components belonging to the Short Period group consisting of M4 and MS4 components. Each of these tidal components has a different period (T) and is calculated in units of time (hours) (Supriyono et al., 2022).

2.4.4. Water Level Elevation

Water level elevation would constantly change. Therefore, there is a need for an elevation set based on tidal data that can be used as guidelines in planning a coastal building. A few of the elevations as followed by (Arif et al., 2018):

1. HHWL (Highest high water level) is the highest water level during a full moon or full moon.
2. MHWL (Mean high water level) is the mean of high water level over 19 years.
3. MSL (Mean Sea Level) is the sea level between mean high and low water. This elevation is utilized as a benchmark for height on land.
4. MLWL (Mean low water level) is the average low water level during 19 years.
5. LLWL (Lowest low water level) is the lowest during a full moon or full moon.

Water level elevation can be calculated from the tidal component value obtained from the least square method. The following points are some equations for determining the design water level elevation (Mardika & Pratama, 2021)

HHWL = $S_0 + (M_2 + S_2 + K_2 + K_1 + O_1 + P_1)$

MHWL = $S_0 + (M_2 + K_1 + O_1)$

MLWL = $S_0 - (M_2 + K_1 + O_1)$

LLWL = $S_0 - (M_2 + S_2 + K_2 + K_1 + O_1 + P_1)$

2.5 Least Square Method

In order to apply the least square method, it is possible to predict the water level through an examination of the tidal component. While tidal components arising from astronomical factors and shallow water tides are periodic, meteorological disturbances are seasonal and sometimes momentary. Regardless of meteorological factors, tidal elevation is the sum of the components that make it up and can be expressed using the sine function as follows (Saputra et al., 2020):

$$hti = Z_0 \sum_1^a H_a \cos(\omega_a t_i + g_a)$$

ht_i is water level elevation to -i (meter). H_a is constituent amplitude to-n (meter). ω_a is angular velocity to-n (derajat/hour). g_a is amplitude constituent ke-n (meter). Z_0 is mean sea level. t is time. N is component sum

2.6 Linear Regression

In general, linear regression is a statistical method explaining the relationship patterns of two or more variables (Maghfiroh, 2021). Additionally, linear regression can measure the relations and variables or express them more as a relationship or function.

Risen sea level can be identified from the MSL (Mean Sea Level) value obtained from calculating the harmonic component Z0 of tidal processing results using the least squares method. Every month, the Z0 value is graphed using Microsoft Excel and then analyzed using linear regression analysis to determine the increase in sea level by looking at the relationship between sea level and time using the following equation (Cahyadi et al., 2016):

$$Y = a + bx$$

x is time and variable. y is sea level, meanwhile is the off coefficient, and b is the increasing rate. Then to calculate the annual upward trend can be found using the following equation (Maghfiroh, 2021):

$$Tren \text{ peryear} = \frac{\text{maksimum value} - \text{minimum value}}{\text{value during observation year}}$$

2.7 Matrix Computation

1. Calculate the angular velocity of each component with the equation:

$$\omega_a = \frac{2\pi}{T_i}$$

2. Observation Matrix Computation (L)
3. Assembling coefficient matrix (A)

The following is the design matrix in the harmonic analysis of tides using the least squares method (Saputra et al., 2020).

$$A = \begin{bmatrix} 1 & \cos(\omega_1 t_1) & \sin(\omega_1 t_1) & \dots & \cos(\omega_n t_1) & \sin(\omega_n t_1) \\ 1 & \dots & \dots & \dots & \dots & \dots \\ 1 & \cos(\omega_1 t_1) & \sin(\omega_1 t_1) & \dots & \cos(\omega_n t_n) & \sin(\omega_n t_n) \end{bmatrix}$$

$$X = \begin{bmatrix} S_0 \\ A_1 \\ B_1 \\ \vdots \\ A_9 \\ B_9 \end{bmatrix}$$

$$L = \begin{bmatrix} L_1 \\ L_2 \\ \vdots \\ L_n \end{bmatrix}$$

A is Coefficient matrix (design), B is Tidal component matrix, and L is Observation matrix (observation).

2.8 Calculating Components and Standard Deviation

Standard deviation is calculated to see if the least square estimation results can be trusted in the calculation using the following equation (Arif et al., 2018):

$$\sigma = \sqrt{\frac{v \cdot v}{r}}$$

σ is standard deviation. r is residual ($n - u$). v is correction matrix. n is number of observation data. u is number of parameters

2.9 Calculating The Amplitude and The Phase of Each Component

1. Calculating the mean sea level value, Z0. In this calculation is the constant value that is first obtained (Prayogo, 2021):

$$Z_0 = A_a$$

2. Calculating the constant value of each tidal constant

$$H_a = \sqrt{A_a^2 + B_a^2}$$

3. Calculating the phase of each component

$$g_a = \arctg\left(\frac{B_a}{A_a}\right)$$

2.10 The Upward Trend Per Year

To calculate the trend of sea level rise using the equation : (Cahyadi et al., 2016).

$$Y = a + bx$$

3. Result and Discussion

The tidal data obtained are processed and analyzed using the Least Squares method. This analysis is carried out to obtain tidal components and predicted sea level rise elevations in the Kapuas River waters. Based on data obtained from 2016 - 2021 for six years obtained from the Maritime Climatology Station

can be seen in the appendix. The data is used to get nine harmonic constants and tidal types.

3.1 Standard Deviation of Tidal Component

The values of tidal parameters that have been generated previously are then tested for accuracy. It can be seen in the standard deviation calculation results in Table 2.

Table 2. Standard Deviation Value

Data input	Standard Deviation
2016	0,499
2017	0,199
2018	0,640
2019	0,136
2020	1,040
2021	0,520

3.2 Tidal Component

The calculated tidal components are the amplitude and phase values for the component types (Ayuningsih et al., 2021).

Table 2. The Results of Tidal Component (ω)

No	Symbol	Period (hour)	ω (der/hou)	ω (rad/hou)
1	M2	12,421	28,984	0,505
2	S2	12,000	30,000	0,523
3	N2	12,658	28,440	0,496
4	K2	11,967	30,082	0,525
5	K1	23,935	15,041	0,262
6	O1	25,819	13,943	0,243
7	P1	24,066	14,959	0,261
8	M4	6,210	57,968	1,011
9	MS4	6,103	58,984	1,029

3.3 Tidal Component Amplitude and Phase Values

The amplitude and phase values of the resulting tidal parameter values are then calculated. The following equations are used to compute the amplitude and phase values (Saputra et al., 2020):

$$H_a = \sqrt{A_a^2 + B_a^2}$$

$$g_a = \arctg\left(\frac{B_a}{A_a}\right)$$

3.4 Formzahl Number

Formzahl number (F) is a number that divides tides into several types. The F value represents the type of tides at the review location. The formula used is as follows (Rosida et al., 2022):

$$F = \frac{AK_1 + AO_1}{AM_2 + AS_2} = \frac{0,00656 + 4,73068}{0,00012 + 0,00043} = 0,428 \text{ cm}$$

According to the computations, the average value of the F-number in the tide data is 0.57 cm, which indicates that there are two tides and two ebbs per day on average, while periodically, there is only one tide and one ebb with a different height and time (Hamuna et al., 2018).

3.5 Trend in Sea Level Rise

The trend of sea level rise needs to be analysed using a linear regression method to determine sea level rise. The tidal data used ranges from 2016 to 2021 (6 years). The value of sea level rise will be computed from the data, and it can then be used to examine the trend of sea level rise.

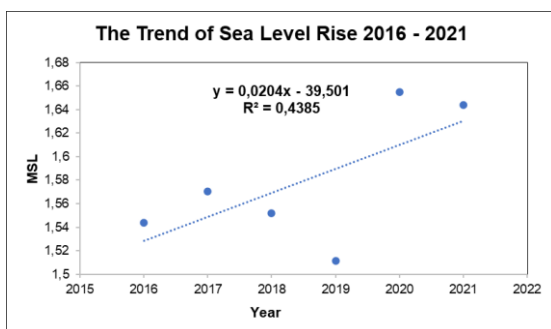


Fig 4. Sea Level Rise 2016-2021

Prediction of sea level rise using the equation $y = 0,0204x - 39,501$ (for $x =$ time function (years) and $y =$ water level rise (cm). This equation can predict the increase in water level (cm). Therefore, the equation can predict the rise of sea levels for 2022 - 2027.

Table 3. MSL Prediction of Kapuas River Waters

Year	MSL (cm)
2022	1,747
2023	1,768
2024	1,788
2025	1,809
2026	1,829
2027	1,849

The findings of tidal data processing in the Kapuas River waters obtained the rate of sea level rise each year, as well as the most significant tidal value (HHWL) that occurs in the Kapuas River waters of Pontianak City District, where the annual increase reaches 0.017 cm/year. Based on that, the growth rate will be 0.102 cm/year during the following six years.

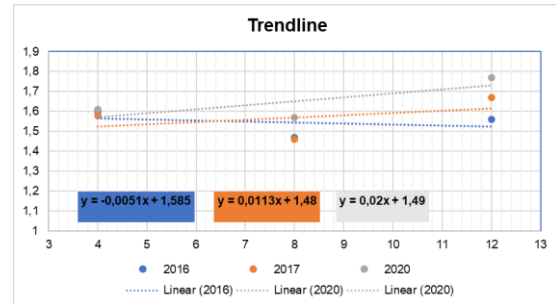


Fig 5. Sea Level Rise per 1 quarter for 3 years

In the graph above, the value of sea level increase each year can be observed based on the results of the tides calculation from year to year. The trend of sea level rise in the third quarter in months 9–12 is larger than the 2nd quarter in months 5-8. The increase is caused by excessive rainfall and global warming; land subsidence has not impacted the average rise of 1.65 cm in sea level.

4. Conclusion

Based on the findings and analyses, it is possible to draw the following conclusions:

1. The harmonic components of tides in the Kapuas River waters were analyzed using the Least Squares method, which yielded nine harmonic components: M2, S2, N2, K2, K1, O1, P1, M4, and MS4 with annual values for amplitude and phase.
2. The F value in this study reaches the tidal classification of 0.57, meaning that tidal conditions in one day occur twice the tide and twice the ebb in a day, but sometimes there is one tide and one ebb with different heights and times.
3. The average predicted value of sea level rise in the Kapuas River in 2022-2017 was 1.747 cm with an increase rate of 0.017 cm/year.

5. Acknowledgement

I would like to begin by conveying my appreciation to my parents and sister for their steadfast support, which enabled me to successfully complete my education. I am incredibly grateful to Dr.Eng Mochammad Meddy Danial, S.T., M.T., IPM. and Arfena Deah Lestari, S.T., M.Eng., who have provided direction, guidance, and motivation to me in completing this research so that it can be of benefit to everyone. I would also like to thank the Jurnal Teknik Sipil (JTS) UNTAN Team, who have agreed to publish the results of this study so that it can become a valuable reference for everyone.

6. Author's note

This article's whole, which describes my study with Mr. Mochammad Meddy Danial and Mrs.

Arfena Deah Lestari, is entirely original. The contents of this article have been reviewed in a thesis defense at the Department of Civil Engineering, The University of Tanjungpura, in October 2023 by Jassisca Meirany S.T., M.T. and Asep Supriyadi, S.T., M.T.

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