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Analysis of sea level rise and tidal components based on satellite altimetry Jason-2 and tide gauge data in 2008-2016 in Sunda Kelapa

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Analysis of sea level rise and tidal components based on satellite altimetry Jason-2 and tide gauge data in 2008-2016 in Sunda Kelapa

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Abstract. In this study, Sea Level Anomaly based on the tide gauge and satellite altimetry measurements are used to analyze Sea Level Rise (SLR) and tidal component in Sunda Kelapa Waters for 9-years. The satellite altimetry data uses data from AVISO and Tide Gauge data is obtained from BIG (Geospatial Information Agency of Indonesia). This study uses the least square analysis method to know the value of SLR, and harmonic analysis method to know the type of tidal along with tidal components value in Sunda Kelapa Waters. SLR analytic result in Sunda Kelapa based on satellite altimetry Jason-2 show increase in 0.00342 meters/ year. Sunda Kelapa Waters can be classified as having mixed single dominant tides on January- June and diurnal tides on July-December. Tidal component in Sunda Kelapa Waters with tide gauge observation resulted average value of Z0; 0.1501 m, M2; 0.0062 m, S2; 0.0086 m, N2; 0.0022 m, K2; 0.0045 m, K1; 0.0240 m, O1; 0.0093 m, P1; 0.0106 m, M4; 0.0011 m, and MS4; 0.0011 m.

1. Introduction

Sunda Kelapa is the old port of Jakarta located on the estuarine of Ciliwung River. The Port of Sunda Kelapa is a port situated in the Bay of Jakarta. This port is a port of call cruise among nations that was built in 1527 during the Portuguese administration. The current location of the Port of Sunda Kelapa has grown rapidly to become the central office, commercial, industrial, and hospitality.As the oldest port in Jakarta area that still retains its traditional hallmark, the Port of Sunda Kelapa become a leading tourist attraction. Therefore, the geographical condition of Sunda Kelapa is very important to know, one of them is about Sea Level Rise. Sea Level Rise (SLR) [1-4] is a natural phenomenon that occurs because of several factors such as tides, climate change, and global warming. SLR can leads coastal areas down. This can be observed from sea level anomaly of the tide gauge measurements and altimetry satellite recordings. Since 1990, sea level anomaly in Java Island was recorded by TOPEX/ Poseidon satellite and shows the value of SLR about 3 mm/years. In 2010, the sea level anomaly was recorded by Jason-2 satellite and shows the value of SLR about 4-6 mm/years [5]. This study not only analyzes about sea level rise in Sunda Kelapa but also determine what type of tidal and the tidal components during 2012-2015. Tidal [6-9] is a process of sea level change that is characterized by the movement up or down of the sea surface periodically which caused by the tensile force of the sun and moon.

2. Experimental Methods

This study using satellite altimetry and tide gauge data during 9 years (2008-2016). Satellite altimetry data can be obtained from AVISO *(aviso.oceanobs.com)* and the Tide Gauge data can be obtained from

BIG *(Geospatial Information Agency of Indonesia).* Satellite altimetry data used are on tracks 242 and 229, cycle 1-301. In this study using two methods, that are least square analysis and harmonic analysis method. Both methods are made linear graphs by *Origin 9.0.* The least square analysis method is used to analyze the speed of Sea Level Rise. From this method can be obtained a linear graph with this equation $y = mx + c$, where y is SLA data from the altimetry satellite and tide gauge, m is the velocity of sea level rise, and x is the period. Meanwhile, the type of tidal and the value of the tidal component in Sunda Kelapa Waters can be known from the harmonic analysis method and can be obtained two parameters (amplitude and phase). The tidal components can be determined by:

$$H_n = \sqrt{A^2{}_n + B^2{}_n} \tag{1}$$

$$g_n = arctg\left(\frac{B_n}{A_n}\right) \tag{2}$$

where H_n is amplitude and g_n is phase, two parameters will be discussed below. The type of tidal can be determined by Formzahl Number [10-11] that given based on the rasio beetwen diurnal (K_1 and O_1) and semidurnal (M_2 and S_2) amplitude constants:

$$F = \frac{AK_1 + AO_1}{AM_2 + AS_2} \tag{3}$$

where, F is Formzahl Number, AK_1 is amplitude of K_1, AO_1 is amplitude of O_1, AM_2 is amplitude of M_2, dan AS_2 is amplitude of S_2. The relation of Formzahl Number with type of Tidal:

Table 1. Classification of tidal

Formzahl number	Type of tidal
F≤ 0.25	Double daily
0.25<F≤ 1.5	Mixed (double dominant)
1.5<F≤ 3	Mixed (single dominant)
F>3	Single daily

The area of this study can be seen in the following figure:

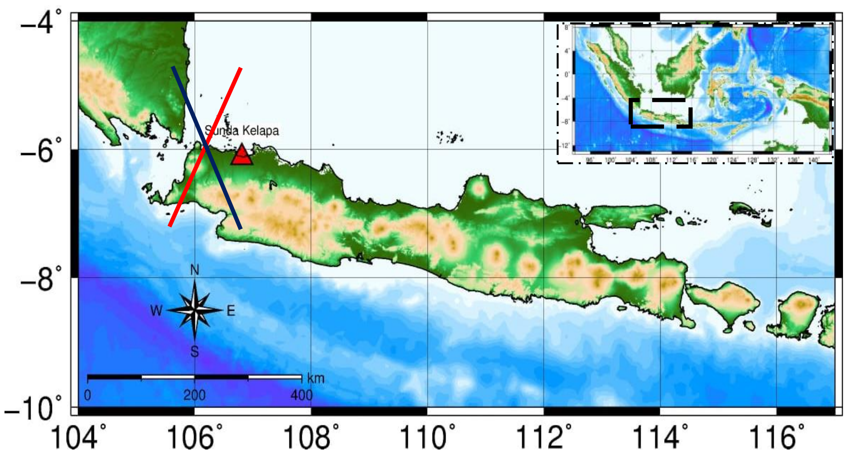

Figure 1. The location of Sunda Kelapa Waters in Indonesia

3. Result and Discussion

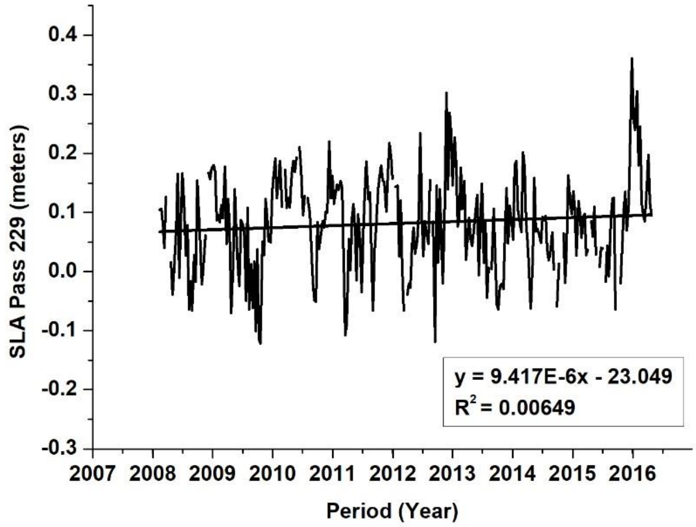

Figure 2 Graph SLR in Sunda Kelapa Waters from Satellite Altimetry Data in Pass 229

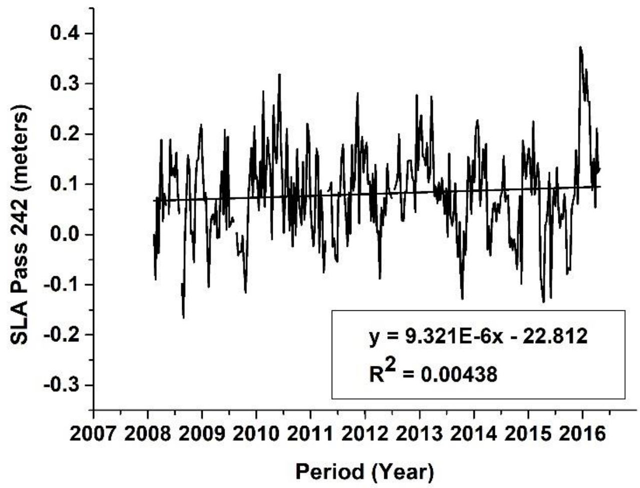

Figure 3 Graph SLR in Sunda Kelapa Waters from Satellite Altimetry Data in Pass 242

From **Figure 2** and **Figure 3** can be seen that in 2008-2016 had a positive trend with their respective values. SLR results can be seen in the following **Table 2**:

Tabel 2 SLR Value of each pass

Pass	Gradient (meters/day)	SLR (meters/years)
229	9.417×10^{-6}	0.00344
242	9.321×10^{-6}	0.00340
Average	9.369×10^{-6}	0.00342

In Table 4.1. it can be seen that the SLR values obtained on each pass are not much different. The SLR value shows that the sea level at Sunda Kelapa during the period 2008 to 2016 has increased by 0.00342

meters/year. When compared with the SLR research conducted by Wuriatmo in 2012 about SLR in Java, more precisely in the Jakarta area which was worth 0.0020 ± 0.0002 m / year, the value of SLR at Sunda Kelapa in the period 2008-2016 increased by 0, 00342 meters/year. And when compared with the value of SLR globally which is worth 0.0032 ± 0.0001 (Cazenave, 2013), SLR in Sunda Kelapa is categorized as having almost the same value. The increase in SLR value is because it is influenced by several factors such as the existence of data errors, NaN data, and the occurrence of natural phenomena that occurred in Sunda Kelapa during the period 2008-2016. Natural phenomena that occur in Sunda Kelapa during the period 2008-2016 are the El-Nino and La-Nina phenomena. El-Nino is a dramatic increase in the temperature of seawater in the Pacific Ocean along the equator from its average value (24˚C) within a certain period. At the time of El-Nino, the seawater temperature reaches 28˚C-30˚C. In the period 2008-2016, El-Nino occurred in September 2012 with an index of 0.52 and 0.73 in August 2012. La-Nina is the opposite of El-Nino. At the time of La-Nina, the seawater temperature reached 19˚C-22˚C. In the 2012-2015 period, La-Nina occurred in January 2012 (-1), February 2012 (-0.8), March 2012 (-0.6), January 2013 (-0.54), and February (- 0.53).
The type of tidal in 2012-2015 can be classified as having single or diurnal tidal because of the Formzahl Number between 3.01-4.50. In January until June, the Formzahl Number between 1.50-3.00, so can be classified to mixed single dominant tidal. And in July until December have Formzahl Number ≥3.00, so can be classified to the diurnal tide. Form this result, Sunda Kelapa can be classified as having mixed single dominant. This result is in accordance with the analysis from Pariwono (1985) that the Western Part of Indonesia is dominated by a diurnal tidal type [6].A tidal component in Sunda Kelapa Waters with tide gauge observation resulted in an average value that shown in the following table:

Table 3. Average value of amplitude the tidal component

Tidal component	Amplitude (meters)	Phase (°)
Z_0	0.1501	-
M_2	0.0062	185.7918
S_2	0.0086	271.4210
N_2	0.0022	216.1110
K_2	0.0045	160.0688
K_1	0.0240	212.7371
O_1	0.0093	183.4308
P_1	0.0106	219.0829
M_4	0.0011	201.2194
MS_4	0.0011	191.0263

4. Conclusion
This study can be concluded that sea level rise in Sunda Kelapa for 2008-2016 based on satellite altimetry Jason-2 data has increased at 0.00342 meters/ year and having the diurnal tide for 2013-2015.

5. Acknowledgment
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