Trends and Seasonal to Annual Sea Level Variations of North Java Sea Derived from Tide Gauges Data

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Abstract

Information of Sea level variations is very important not only for a scientific purpose also for daily and practical purposes. That information is used as a basis of management and development coastal areas, in order to improve the social welfare and disaster mitigation. The information of sea level variations of Indonesia waters is still limited, especially local sea level variations such as of the Java Island Sea, the largest population island in Indonesia. In this study, sea level variation in the seas around Java Island especially, North Java Sea was investigated based on tide gauge data from four tidal stations, namely Pondok Dayung, Semarang, Jepara and Surabaya tidal stations. The period of data was started from 1995 until 2014. The tide gauge data was corrected in the preliminary step by global test to eliminated outlier data, then shifting and scaling corrections. Identification of sea level variations was carried out using the moving average and linear trend method to detect the pattern and trends of seasonal and annual sea level variations. The results show that mean sea level rise (SLR) from 1995 to 2014 years at North Java Sea is -0,13 mm/year. The seasonal sea level variation affected by the monsoons, where sea level rise occurs at East Monsoon and West Monsoon. Then the annual sea level variation was affected by the ENSO phenomenon, where sea level down significant because of El-Nino phenomenon.

Keywords: trend; sea level variations; tide gauge data

INTRODUCTION

Indonesia consists of thousands of islands with large populations inhabiting the coastal areas. Therefore, the information of sea level variations is needed for the purposes of management and development of coastal areas and improvement of the economic condition of society. Sea level change become an important issue in coastal areas or archipelago countries in the world. Sea level change in Indonesian waters since 1993 to 2011 increased by an average 4 mm / year. Sea level can be varied at the hands of spatial and temporal conditions. Substantially, global sea level variation is different from the regional one where the later is more complex due to each region’s temperature and salinity (Bindoff and Willebrand n.d).

The research was conducted to analyze the local sea level variations around Java Island, using long period data acquired from tide gauge data. Java Island’s water was chosen by taking into consideration the fact that Java Island is the island with the densest population, of which number is up to 58% of the total Indonesia’s population, also the fact that most of its people live in coastal areas.

Sea level variations have been a matter of discussion in several coastal areas of the world, including of Indonesia, ranging from the South China Sea (Peng et al., 2013), Tropical Pacific Island (Becker et al., 2012), north west bank of the Pacific Ocean (Marcos et al., 2012), Japan Coasts (Senjyu et al., 1999), Sunda Strait (Oktavia et al., 2011) to several tide stations in Indonesia.
(Pamuji, 2009) in which the data used are those of Satellite Altimetry’s and tide gauge’s. The identification of this sea level variations usually uses long period data (Peng et al., 2013; Becker et al., 2012; Marcos et al., 2012; and Senjyu et al., 1999).

In this study tries to analyze the variations in sea level based on tide gauge data. The research areas are the North Java Sea, where there are four tidal stations, namely Pondok Dayung, Semarang, Jepara and Surabaya. Tide gauge data are obtained from the Geospatial Information Agency. The aim of the research is to determine trend, seasonal and annual sea level variations of the North Java Sea and to know tide gauge data quality in the long period.

DATA AND METHODOLOGY

Tide Gauges Data
The tide gauge data used in this research were taken from tide stations in the North Java Sea. The tide gauge data conditions can be seen in Figure 1. Based on the data analyzed sea-level rise, and seasonal and annual sea level variations of the North Java Sea. Table 1 shown the tide gauge data after check and have quality that can be used to analysis sea level variations.

Table 1: The period of tidal data every station that is used to identify variations in ocean surface waters of the North Java Sea

<table>
<thead>
<tr>
<th>No</th>
<th>Name of Tidal Stations</th>
<th>The Period of Tide Gauges Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Surabaya</td>
<td>1995 to 1997</td>
</tr>
<tr>
<td>2</td>
<td>Jepara</td>
<td>2011 to 2014</td>
</tr>
<tr>
<td>3</td>
<td>Semarang</td>
<td>2011 to August 2013</td>
</tr>
<tr>
<td>4</td>
<td>Pondok Dayung</td>
<td>2012 to 2014</td>
</tr>
</tbody>
</table>

Methodology
The research implementation consisted of several activities there are tidal data collection, control quality of tidal data, identification of sea level rises each tide gauge stations by linear regression method and analysis of variations in sea level by the moving average method.

The tidal data of North Java Island’s water were acquired from Geospatial Information Agency (Badan Informasi Geospasial) by submitting first a data use proposal. The tidal data obtained from BIG still contain errors such as spike or outlier data, the offset data, and the value of tide riding is too small or big. The tidal data used to analyze sea level variations have to be free of outlier errors, offset error (tides data at certain periods which have different references), and tides’ steep anomaly. The outlier mistakes can be omitted through global testing the initial data with level of significant 99%. Meanwhile, the offset mistakes can be corrected through shifting, which is referring the tides data deemed incorrect to the tides data references deemed correct. Last, mistakes in the tides’ steep anomaly can be corrected through a scalling process.

Sea level rise is identified through linear regression method to find out its tendency based on tidal data. Based on the research conducted by Nicholls (2003); Kahar (2008); Cazenave et al. (2010); and Marcy et al. (2012) in Putra (2013) on sea level rise, the phenomenon of said rise tends to be linear. Therefore, identifying it would need to use linear regression analysis. Its equation here is shown in Equation (1) (Nawari, 2010 and Ebdon, 1985 in Putra, 2013 and Bapennas, 2010).
Fig. 1. Display data conditions of tidal stations Surabaya (1), Jepara (2), Semarang (3), and Pondok Dayung (4)

\[ y = a + bx \]  

where,

- \( y \): sea level
- \( x \): time
- \( a \): offset points
- \( b \): the rise degree (slope, trend)
The value of regression constant can be calculated use Equation (2) and (3) (Nawari 2010 and 1985 Ebdon in Putra 2013).

\[
b = \frac{\text{\(\sum xy\)-n\(\sum y\)}}{\text{\(\sum x^2\)-n\(\sum x\)^2}}
\]

(2)

\[
a = Y - bX
\]

(3)

Where,

- \(X\) : mean value of x variable
- \(Y\) : mean value of x variable

Identifying sea level variations of tidal data can be done by data smoothing use moving average method (Senjyu et al., 1999). Technically, the identification process of sea level variations can be carried out by changing the window/period of the data smoothing. Here is the moving average equation as shown in Equation (1) (Van Onselen, 2000).

\[
F_{t+1} = \frac{X_t + X_{t-1} + \ldots + X_{t-n+1}}{N}
\]

(4)

Note:

- \(F_{t+1}\) : period to t+1 prediction
- \(X_t\) : period to t real points
- n : moving average range of time
- N : the number of observations used in calculating the moving average

RESULTS AND DISCUSSION

Quality of Tide Gauges Data

Based on the results of plotting the data for each tidal tide stations (Figure 1) shows the presence of empty data, offset error and the value is too large tidal riding (riding the tidal anomaly). Data can be caused by tidal empty endless paper used for data recording tide (tide manual recording devices), endless power supply, or an error during installation tool, so that data is not recorded tide (Widyantoro 2014). Offset error occurred due to systematic error such as breakdown of the data recording process.

Data tide which has offset error in need of correction shifting. Offset error is an error because the reference of reference during data recording tidal offset correction is done by equating the value of the reference data group that is considered one of the sets of data are assumed to be true. The determination of the reference value or sets of data are assumed to be true is to look at the tidal data patterns in the period before and after. The nature of periodic ups and downs, then it should have a reference value low tides are not too dissimilar significantly.

Correction scaling conducted on the tide which has a value of tidal anomaly riding riding the tide is too big or too small. At a certain period in the same tidal station, riding a tidal values did not differ significantly. Scaling correction process is done by calculating the value of the multiplier scale of the data that is assumed to be true, then multiplied against the tide of data experienced a stable range tidal anomalies (Widyantoro 2014). Tide graph visualization of data that has been corrected can be seen in Figure 2.
Fig. 2. Data conditions of tidal stations Surabaya (1), Semarang (2), Pondok Dayung (3) that corrected shifting and scaling

**Trends of North Java Sea**

Sea level rise of each tidal station is calculated based on tide gauge data. The result of sea level rise at each tide station is shown in Table 2.

**Table 2**: The value of sea level rise of each tidal stations in North Java Sea

<table>
<thead>
<tr>
<th>Tidal Stations</th>
<th>The period</th>
<th>Sea Level Rise Value (mm/tahun)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pondok Dayung</td>
<td>1995 s.d 2005</td>
<td>3,3</td>
</tr>
<tr>
<td></td>
<td>2007 s.d 2014</td>
<td>0,8</td>
</tr>
<tr>
<td>Semarang</td>
<td>1997 s.d 2014</td>
<td>5,4</td>
</tr>
<tr>
<td>Jepara</td>
<td>1995 s.d 2014</td>
<td>0,3</td>
</tr>
<tr>
<td>Surabaya</td>
<td>1995 s.d 2003</td>
<td>1,7</td>
</tr>
<tr>
<td></td>
<td>2004 s.d 2008</td>
<td>7,5</td>
</tr>
<tr>
<td></td>
<td>2013 s.d 2014</td>
<td>-19,9</td>
</tr>
</tbody>
</table>
Mean value of sea level rise of Pondok Dayung tidal station from 1995 to 2014 years was 2.05 mm / year. Then, the average of sea level rise of Semarang tidal station from 1997 to 2014 years was 5.4 mm / year. Mean sea level rise value from 1995 to 2014 years of Jepara tidal stations was 0.3 mm / year, and the mean value of sea level rise in Surabaya tidal stations of Surabaya data from 1995 to 2014 was -3.5 mm / year. Sea level change of Surabaya tidal stations for 20 years showed a decrease trend, because sea level decrease dramatically on 2013 to 2014 reach -39.8 mm. The decrease of sea level on 2013 to 2014 years may be due the strongly El-Nino phenomenon in 2014 years. El Niño events cause a reduction in the mass of water flowing from the Pacific Ocean to the Indian Ocean so that the waters in Indonesia has decreased. This is consistent with the results of research Riyadi (2015) that the El-Nino phenomenon that occurred in Indonesian waters characterized by the presence of sea surface down and vice versa La-Nina phenomenon is characterized by sea level up. The other factors that influence sea level rise except ENSO Phenomenon are the movement of the plates, land subsidence and earthquakes (Senjyu et al, 1999; Fenoglio-Marc et al, 2012; Marcos et al, 2012). Based on the research of Senjyu et al (1999), land subsidence causes excessive pumping of groundwater.

The mean value of sea level rise from four tidal stations of 1995 to 2014 years was -0.13 mm / year. The average value of sea level rise negative because sea level decrease dramatically in Surabaya tidal station in 2013 to 2014. This suggests the existence of a significant effect on tidal data period are used for analysis of sea level rise.

**Seasonal Sea Level Variations of North Java Sea**

Seasonal sea level variations of North Java Sea were identified based on smoothing every three months period of tidal data. Results seasonal variations in sea level are presented in Figure 3.

![Visualization of seasonal sea level variation of North Java Sea](image)

**Fig. 3.** Visualization of seasonal sea level variation of North Java Sea (Tidal Stations of Surabaya, Semarang, Pondok Dayung and Jepara)

The pattern of seasonal sea level variations in Semarang and Jepara tidal stations in 2011 to 2012 years, showed the same (showed by blue box in Figure 3). It's just not the same time occurrence, it can due to the phase difference of the waves. Moreover, the event of sea level rise and fall occur periodically in certain months. The identification results are presented in Table 3.

<table>
<thead>
<tr>
<th>Sea Level Conditions</th>
<th>The period</th>
</tr>
</thead>
<tbody>
<tr>
<td>up</td>
<td>July and August</td>
</tr>
<tr>
<td>Down</td>
<td>October, November dan December</td>
</tr>
</tbody>
</table>
Sea level up occurred in July and August or on East Monsoon and sea level down in October, November and December on a transitional season. This indicates the influence of Monsoon of the sea level up on seasonal variations in sea level.

According Wyrtki (1961) the condition of the waters of Indonesia depends on the condition of the waters of the Pacific Ocean and also Arlindo. Based on research Safitri et al (2012), Arlindo influenced by monsoons where transport Arlindo maximum occurs in the east monsoon and then transport Arlindo minimum occurs in the west monsoon. Arlindo transport carrying water masses from the Pacific Ocean to the Indian Ocean. When transport Arlindo maximum, it brings a lot of water masses from the Pacific Ocean, as well as west monsoon will bring water masses more than the transitional season. This can affect the condition of the Java island waters, where when the transport Arlindo on the east and west monsoon can add to the mass of water in the Java island waters. In addition, the position of tidal station is located in shallow waters, causing the mass water trapped in the waters North Java so that the sea level will up.

**Annual Sea Level Variations of North Java Sea**

Annual sea level variations of North Java Sea were identified based on smoothing the tidal data with a 12 months’ period. The annual sea level variation is a changes phenomenon the rise and fall of sea level over one-year period. The longer the period of sea level data used to identify variations, the phenomenon can be identified on annual sea level variations more clearly. The results of the identification of annual sea level variations in North Java waters is presented in Figure 4.

![Annual Sea Level Variations of North Java Sea](image)

**Fig. 4.** Display annual sea level variations of North Java Sea (Surabaya, Semarang, Pondok Dayung and Jepara Tidal Stations)

Based on Figure 4, the annual sea level variations in 2013 in Semarang tidal station, Pondok Dayung and Jepara equally indicate a sea-level rise, although wave size are different. This shows that the condition of waters each tidal stations have the same pattern of sea level variations.

Khasanah (2015) have identified annual sea level variations of the Java Island waters based on multi-satellite altimetry data. Based on his research, the annual sea level variations are influenced by the El-Nino and La-Nina phenomenon. The annual sea level variation of Java island waters can be seen in Figure 5.
Based on Figure 5, it can be seen that there is a decrease in sea level dramatically in 1997 year and early 1998 year and then in 2011 year there was an increase in sea level. In 1997 years and early 1998 year occur the El-Nino phenomenon (aviso.oceanobs.com). El-Nino phenomenon in 1997 year is the most powerful ever happened. At the El-Nino phenomenon, mass volume of water that flow from the Pacific Ocean to the Indian Ocean is reduced so that the mass of water in the Indian Ocean waters decreased, including in Indonesia, especially Java island waters. Sea level rise in 2011 due to the La-Nina phenomenon. This is supported by the results of research Gordon (1996) in Safitri et al (2012) that transport Arlindo larger during La-Nina phenomenon and weakened when the El-Nino phenomenon. If the flow of Arlindo is large, the flow of water masses of the Pacific to the Indian Ocean more so that the mass of water in Indonesia will increase.

The annual sea level variation of tidal data based on this research were related to the El-Nino and La-Nina (ENSO) phenomenon too. However, the influence of the phenomenon of La Nina and El Nino are not yet clearly visible, because the period of tidal data is used for identification is short and does not coincide with the ENSO phenomenon. According to the research Safitri et al (2012), Arlindo transport increased in the La-Nina phenomena and decreased in the El-Nino. When there El-Nino phenomenon, water masses flowing from the Pacific Ocean to the Indian Ocean is reduced so that the mass of water in Indonesian waters is reduced and cause the sea level dropped. This is consistent with the research of Wuriatmo (2012) that in the event of El-Nino sea surface waters of the Java island waters down.

CONCLUSIONS
The mean value of sea level rise in the North Java Sea based on tidal data at each tidal station from 1995 to 2014 years was -0.13 mm / year. Seasonal sea level variations of North Java Sea related by the Monsoons, where at East Monsoon the sea level will increase and at the transitional seasons sea level will decrease. Annual sea level variations of North Java Sea caused by the ENSO phenomenon where at El-Nino phenomenon, the waters of the North Sea Java decrease and at La-Nina phenomenon, sea level of North Java Sea increase.

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