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Relationship of ENSO (El Niño – Southernoscillation) and monsoon index on variability of rainfall and sea surface height in coastal city Semarang, Central Java

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ABSTRACT

The city of Semarang is one of the coastal areas in Indonesia that is prone to flooding. Flood events that often occur in the Semarang City area can be triggered by high rainfall. Variations in rainfall and sea level are closely related to global atmospheric circulation such as ENSO and regional atmospheric circulation, Monsoon. This study aims to examine the relationship between ENSO and Monsoon with the distribution of rainfall and sea level in coastal city Semarang from 2012 to 2021. Correlation and composite analysis were used to analyze the relationship and impact of ENSO and Monsoon phenomena on rainfall and sea level. The results showed the strong correlation of the ENSO index (Southern Oscillation Index) to rainfall in the JJA and SON periods. Generally, El Niño (La Niña) has an impact on increasing (decreasing) rainfall. Meanwhile, Australian Summer Monsoon Index (AUSMI) only strongly correlates with rainfall in the SON period. The westerly (eastern) wind indicated by a positive (negative) monsoon index in the SON period has the effect of increasing (reducing) rainfall. The ENSO phenomenon with sea level during the JJA period has a strong relationship. In JJA, the highest sea level (maximum tide) rises by 12.6 cm during El Niño and decreases by 0.6 cm during La Niña. Meanwhile, the lowest sea level (minimum low tide) decreased by 16.6 cm during El Niño and increased by 0.7 cm during La Niña. These results can explain the influence of global and regional atmospheric circulation on a local scale on the coast of Semarang City.

Introduction

Semarang City is one of the coastal cities in Indonesia which is very vulnerable to flooding. This city is located on the north coast of Central Java, so the threat of flooding can come from tides and rainfall. Several studies reveal that various regions of the northern coast of Java (especially Semarang City) experience land subsidence and extreme rainfall (Bott *et al*., 2021; Yastika *et al*., 2019), thereby increasing the threat of tidal flooding. Irawan *et al.* (2021) predict the flood threat of Semarang City in 2050, by considering land subsidence and sea-level rise, will expand 287%, covering 11.5 km of the city area (Irawan *et al*., 2021). The maximum daily and annual rainfall in Semarang City was also reported to increase by 2.56 mm/year and 22.64 mm/year, respectively (Suripin & Kurniani, 2016).

Rainfall is still the main factor that causes floods in Semarang City (Setyani & Saputra, 2016). Monsoon dynamics and the El Niño-Southern Oscillation (ENSO) significantly affect rainfall variability in the Indonesian region, especially in Semarang City (Hidayat et al., 2018; Haryanto *et al*., 2020). In the southern part of Indonesia, there are west monsoon and east monsoon. During the west monsoon, the wind blows to the southeast, which flows from Asia to Australia. It carries water vapor from the Indian Ocean and the South China Sea to Indonesia, therefore Semarang City occurs rainy season. Otherwise, during the east monsoon, dry air from Australian's desert was brought to Indonesia by

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a wind blowing to the northwest, it influences the dry season occurred in Semarang City (Tjasyono, 2014). ENSO, including El Niño and La Niña, causes some seasonal anomalies in Semarang City. El Niño conditions cause a negative anomaly (decrease) in rainfall, while La Niña conditions trigger a positive anomaly (increase) in rainfall (Aldrian, 2008; Supari *et al.*, 2018). In addition to rainfall, El Niño and La Niña phenomena also trigger anomalies in several sea parameters, such as temperature, chlorophyll-a, to sea level (Supriatin & Martono, 2016; Siswanto *et al.*, 2020).

Monsoon activity not only affects rainfall in the territory of Indonesia but also affects the condition of its waters. Monsoon and ENSO activities can affect water circulation, such as upwelling and downwelling, which causes sea level variations (Marpaung & Harsanugraha, 2014). Fadlan & Rosanti (2019) concluded that sea level height in the Indonesian southeast ocean relatively increased during the west monsoon and decreased during the east monsoon. Meanwhile, the northwest waters experienced a contrary phenomenon to the southeast ocean.

Monsoon variation can be identified through the value Australian Summer Monsoon Index (AUSMI), which is the average value of the 850 hPa zonal wind in the Northern Territory of Australia covering 110° E – 130° E, 5° S – 15° S (Kajikawa *et al.*, 2010). Kajikawa also explained that the AUSMI monsoon index has an excellent performance in describing rainfall variation in the Australian monsoon region in seasonal cycles and annual, inter-annual and decadal variability. Monsoon activity can be monitored using the AUSMI index in the Java region because the monsoon index and rainfall have the same pattern with the peak phases of the rainy and dry seasons compared to other monsoon indices (Mulsandi et al., 2021). Meanwhile, the ENSO phenomenon is identified through the Southern Oscillation Index (SOI) value, which is the difference in surface air pressure between the East and West Pacific waters (Zakir *et al.*, 2009). AUSMI indicates the monsoon wind which is the main indicator of Indonesian season, while ENSO influences the occurrence of seasonal anomalies in Indonesia (Mulsandi et al., 2021; Zakir *et al.*, 2009). The pattern of rainfall and sea level variability, its relationship with the ENSO phenomenon in the Pacific Ocean and monsoon, and the effect of these phenomena (ENSO and Monsoon) on the increase or decrease in rainfall and sea level on the coast of Semarang City will be explained in this study. This relationship pattern is essential as a reference in flood disaster mitigation efforts in the city of Semarang.

Materials and Methods

Location and time of research

Locations were selected based on the areas frequently affected by floods in Semarang City. The area includes Tugu District, West Semarang, North Semarang, Central Semarang, East Semarang, Gayamsari, Genuk, and Pedurungan. The data used in this research are rainfall, sea level elevation, SOI, and AUSMI. All data were collected in the period 2012 to 2021. Rainfall data were derived by 6 rainfall stations around coastal area of Semarang City (Figure 1). Tidal data from 2012-2021 were obtained the Geospatial Information Agency (BIG) (http://ina-sealevelmonitoring.big.go.id/). SOI and AUSMI data were respectively downloaded from http://www.bom.gov.au/climate/enso/ produced by the Bureau of Australian Meteorology and https://extreme.kishou.go.jp/itacs5/ produced by Interactive Tool for Analysis of the Climate System (iTacs).

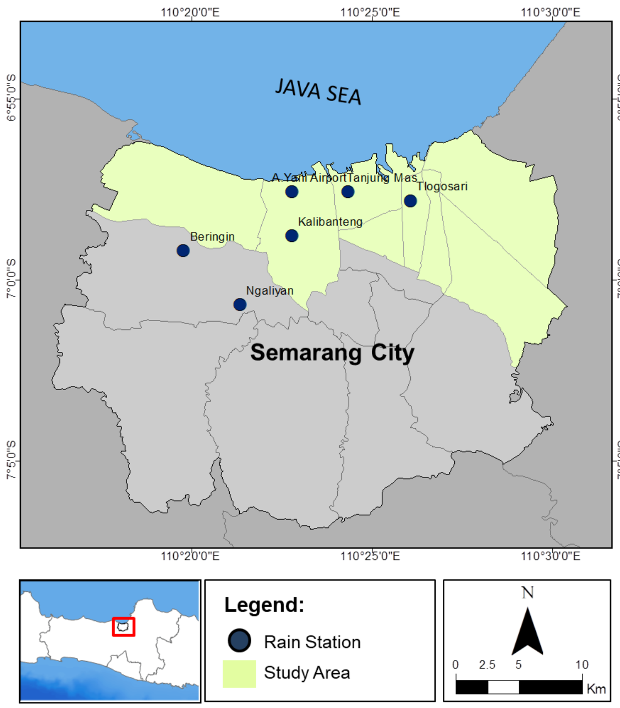

Figure 1. Location of research and rainfall observation stations on the coast of Semarang City.

Furthermore, all collected data were classified into four seasons which include the west monsoon season in December-January-February (DJF), the first season of transition from west to east monsoon in March-April-May (MAM), and the east monsoon season in June-July-August (JJA), and the the second season of transitional from east to west monsoon in September-October-November (SON).

Tidal data was processed using the least square to obtain water level elevation values, namely the mean sea level (MSL), the lowest low water level (LLWL) as the minimum sea level, and the highest high water level (HHWL) as the maximum sea level. The elevation value is obtained from the harmonic components, which include M2, S2, N2, K2, K1, O1, P1, M4, and MS4, with the equation:

$$HHWL = MSL + (M_2 + S_2 + K_2 + K_1 + O_1 + P) \quad ...(1)$$

$$LLWL = MSL - (M_2 + S_2 + K_2 + K_1 + O_1 + P) \quad ...(2)$$

Data analysis

Correlation analysis was obtained using correlation coefficients to determine the relationship between rainfall and sea level with the SOI and AUSMI indices in the seasonal period (DJF, MAM, JJA, and SON). This correlation analysis shows a high degree of relationship between the two variables (Prasetyo & Jannah, 2019). The equation can determine the correlation value:

$$r_{xy} = \frac{n\sum XY - \sum X \sum Y}{\sqrt{[n\sum X^2 - (X)^2][n\sum Y^2 - (Y)^2]}} \quad (3)$$

The confidence level used to determine the value of the correlation coefficient will be considered significant is 95%, or the considerable number is less than 0.05 (<0.05) (Sugiyono, 2014).

In addition to correlation analysis, composite analysis was used in this study to determine the impact of the ENSO phenomenon on rainfall and sea level. The composite analysis is a sampling technique that may be based on the average state of the same specific phenomena. The results usually represent the estimated time indicated by the spectacle (Rustiani, 2014 in Prasetyo & Pusparini, 2018; Aditya *et al.*, 2021). The composite value is obtained by calculating rainfall anomalies and sea levels for seasonal periods during El Niño and La Niña for an average of 10 years. Rainfall anomaly is presented in the form of percentage distribution in the year the phenomenon occurred to the standard using ArcGIS 10.4

Results

Rainfall Variability

The seasonal average rainfall on the coast of Semarang City is shown in Figure 2. Variations in seasonal rainfall influenced by ENSO and monsoons can be shown in Figure 3. From 2012 to 2021, the highest average monthly rainfall was in the DJF period, between 201 to 400 mm, while the lowest monthly rainfall was in the JJA period, 21 to 50mm (Figure 2). Based on the data series (Figure 3), the highest average monthly rainfall in DJF is 495.7 mm in 2020/2021. On the other hand, the lowest average monthly rainfall was 4.41 mm in the 2019 JJA period.

Sea level variability

The variation of the average maximum and minimum sea level influenced by ENSO and the monsoon period from 2012 to 2021 is shown in Figure 4. The highest maximum sea level (highest tide conditions) in the 2019 MAM period was 0.719 m (71.9 cm) of the Mean Sea level (MSL). While the lowest minimum sea level (lowest low tide) in the 2015 JJA period was -0.89 m (-89 cm) from MSL.

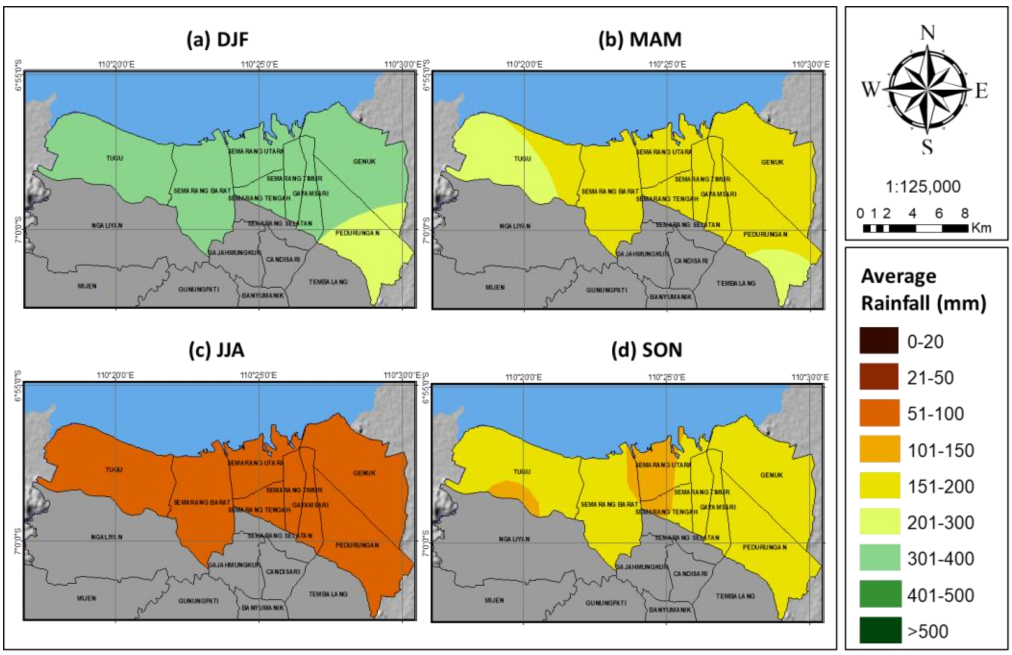

Figure 2. Distribution of the average seasonal rainfall in the Semarang City Coast from 2012 to 2021.

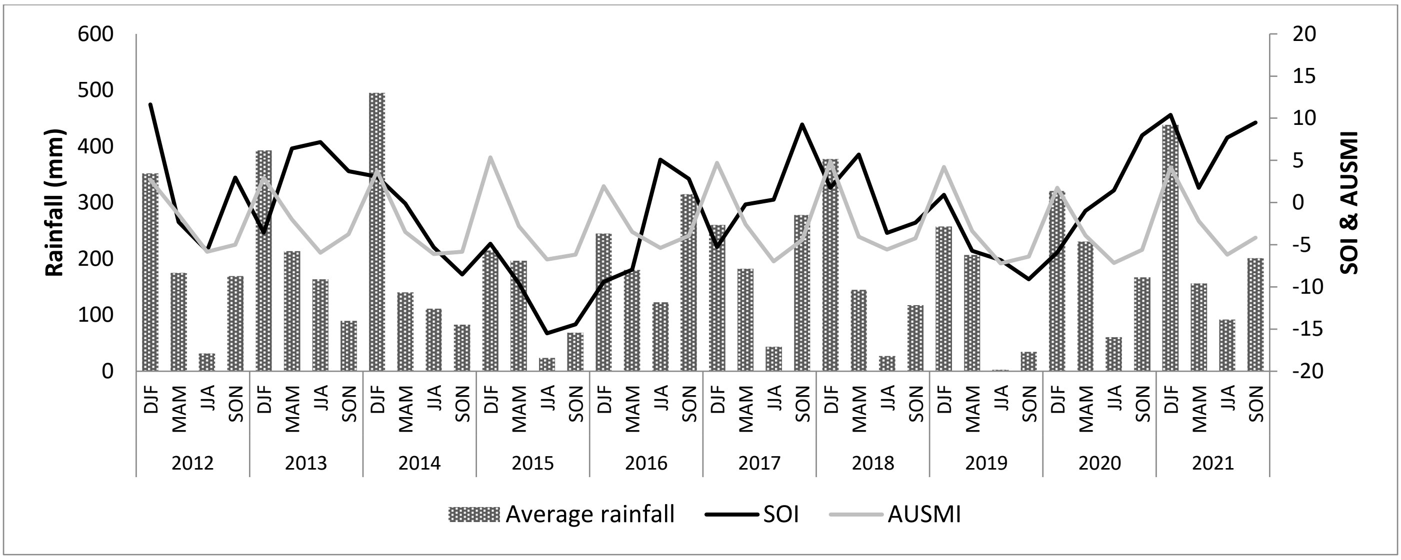

Figure 3. Seasonal rainfall variations for 2012 to 2021, whereas the dark line being the Southern Oscillation Index (SOI) value indicating the ENSO condition and the light line being the Australian Summer Monsoon Index (AUSMI) indicating the monsoon conditions.

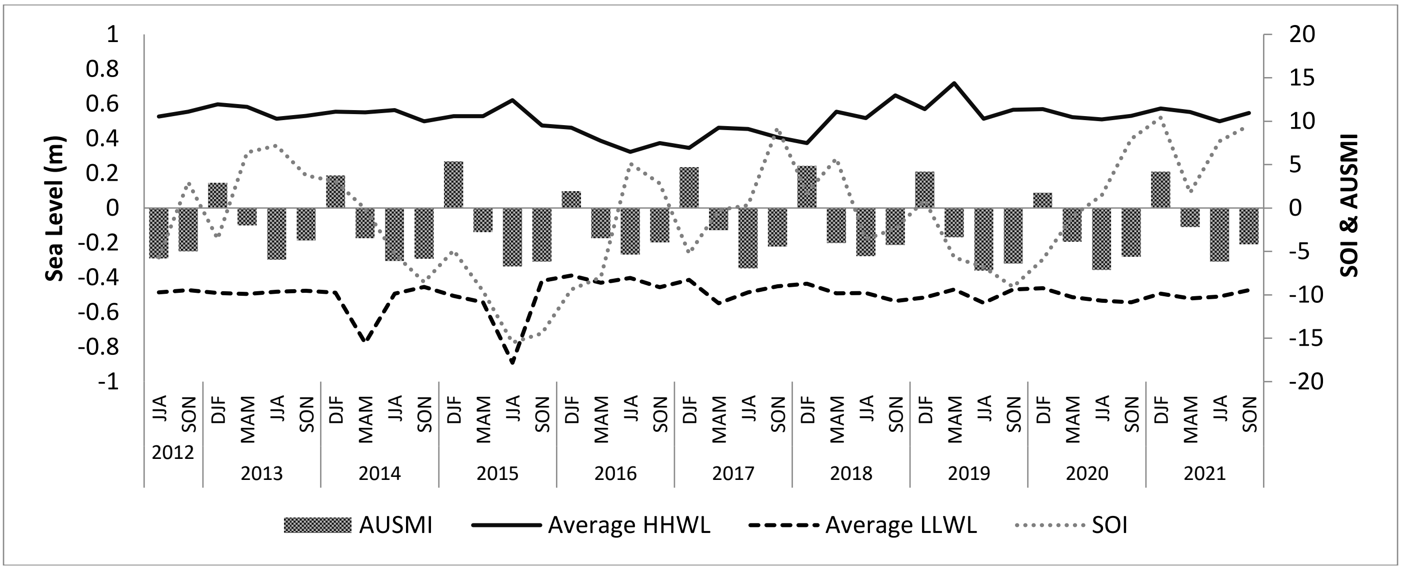

Figure 4. The variation of the maximum and minimum sea level for the period 2012 to 2021, whereas the dark line is the Southern Oscillation Index (SOI) value indicating the ENSO condition, and the light line is the Australian Summer Monsoon Index (AUSMI) indicating the monsoon conditions.

Figure 3 and 4 showed that the positive value of AUSMI only occurred in DJF period, therefore the west monsoon was released only in DJF period. DJF 2015 experienced the highest AUSMI value which was at 5.36. Other periods showed negative values, meaning the east monsoon was dominant in these periods. This study found that the lowest AUSMI value during 2012-2021 was -7.21 which was conducted at JJA 2019.

The SOI value shows dynamics that are pretty fluctuating each season. Based on Figure 3, from 2012 to 2021, the El Niño phenomenon occurred twice, namely in MAM period in 2015, the SOI value reached -15.5 to -7.97 until MAM period in 2016, and in MAM until DJF periods in 2019/2020, the SOI value reached -9.1 to -5.7, it related to decreasing in rainfall. At the same time, La Niña occurred four times, namely MAM until JJA periods in 2013 with SOI value of 6.4 to 7.17, SON period in 2017 with SOI value of 9.27, SON until DJF periods 2020/2021 with SOI value of 7.97 to 10.4 then in the middle until the end of 2021 SOI values of 7.7 on JJA periods and 9.5 on SON periods. The JJA and SON periods are the most frequent La-Nina periods compared to other seasonal periods in 2012-2021.

The relationship between ENSO and AUSMI on rainfall

The relationship between the SOI Index and the average rainfall on the coast of Semarang City from 2012 to 2021 (Table 1) were a moderate to high

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positive correlation in the DJF, JJA, and SON periods with correlation values of 0.495, 0.709, and 0.779. The significant effect of ENSO on rainfall was found only in the JJA and SON periods. Only the MAM period showed a weak negative correlation between SOI and rainfall and did not have a significant relationship. In contrast to SOI, only the SON period showed a significant AUSMI correlation with rainfall. The influence of AUSMI is not expected to be significant enough on rainfall in the city of Semarang.

The composite analysis of rainfalls are shown in Figures 5 and 6. El Niño affected the decrease in average rainfall (Figure 5). The negative anomaly of rainfall in the coastal area of Semarang City was observed in the JJA, SON, and DJF periods. Rainfall anomalies in that period varied from 0 to -80% of the average, with the lowest percentage of anomalies between –80 to -60% in SON covering most areas of North Semarang, West Semarang, and Central Semarang, as well as a small portion monument area. In contrast to the JJA, SON, and DJF periods, MAM shows favorable anomaly variations of rainfall up to 20% of the average in most coastal areas of Semarang City. The percentage of the negative anomaly of rainfall was -20% of the average in El Nino when MAM covered the North Semarang, Pedurungan, and a small part of the Genuk area.

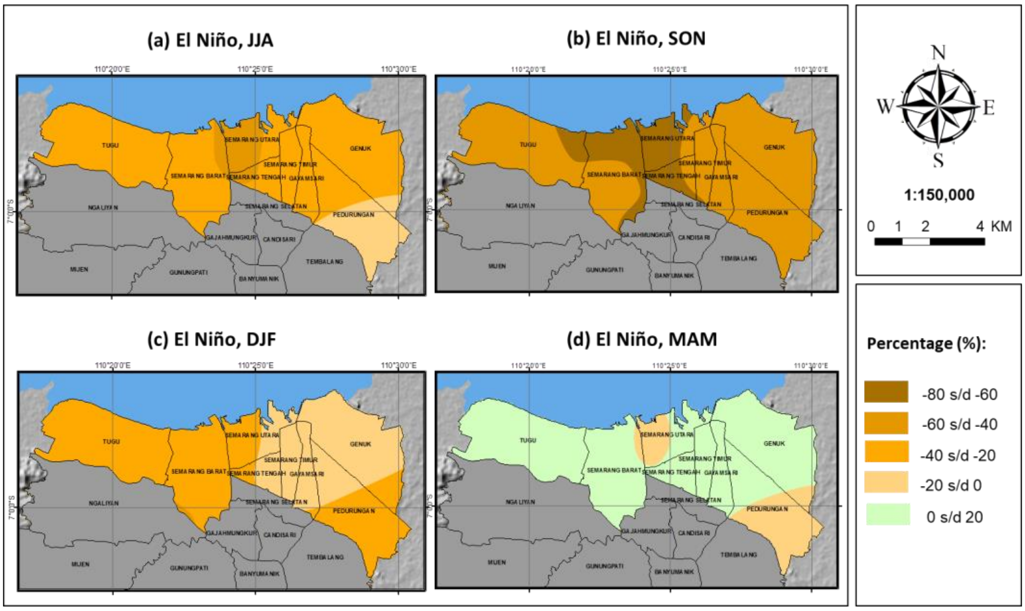

Figure 5. Distribution of Rainfall Anomaly percentages in El Niño phase on (a) JJA, (b) SON, (c) DJF, and (d) MAM from 2012 to 2021.

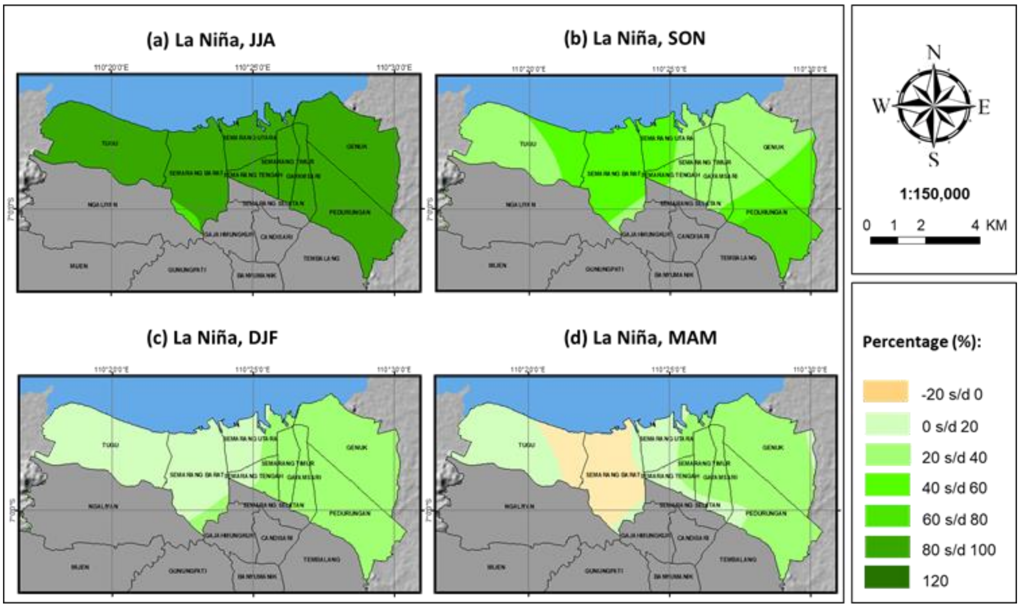

Figure 6. Distribution of Rainfall Anomaly percentages in La Niña phase on JJA(a), SON (b), DJF (c), and MAM (d) from 2012 to 2021.

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Table 1. Correlation of rainfall with SOI and AUSMI indices (2012 to 2021).

Periods	SOI		AUSMI	
	r	P-Value	r	P-Value
DJF	0.495	0.085	0.344	0.249
MAM	-0.106	0.731	-0.067	0.827
JJA	0.709	0.007	0.24	0.43
SON	0.779	0.002	0.595	0.032

Table 2. Correlation of average maximum sea level with SOI and AUSMI indices (2012 to 2021).

Periods	SOI		AUSMI	
	r	P-Value	r	P-Value
DJF	0.213	0.555	-0.455	0.187
MAM	0.17	0.639	0.037	0.919
JJA	-0.646	0.044	-0.351	0.32
SON	-0.147	0.686	-0.119	0.744

Table 3. Correlation of average minimum sea level with SOI and AUSMI indices (2012 to 2021).

Periods	SOI		AUSMI	
	r	P-Value	r	P-Value
DJF	-0.562	0.091	0.014	0.968
MAM	-0.066	0.856	0.042	0.908
JJA	0.722	0.018	0.428	0.218
SON	-0.398	0.255	-0.187	0.604

During the La Niña phase (Figure 6), a positive rainfall anomaly was observed in almost all periods, except for MAM. Positive rainfall anomalies vary to 120% of the average, with the highest percentage of anomalies in the JJA period, which is between 100 to 120% in almost all coastal areas of Semarang City. The La Niña phenomenon also affects increasing rainfall in the SON period with a percentage increase of between 20 to 80% of the average. The percentage of rainfall anomaly is lower than in the previous period. In DJF, there is only an increase of 0 to 40% from the average. However, the MAM period is different from other periods in the La Niña phase. Apart from an increase in rainfall in most coastal areas of Semarang City, there is a decrease in rainfall with anomaly percentages between -20 to 0% in the West Semarang area and a small part of the Tugu area.

The relationship between ENSO and AUSMI on sea level

The correlation between SOI and AUSMI indices with the average maximum and minimum sea level is shown in Table 2 and 3. The maximum sea level correlates very weakly with the SOI index in the DJF, MAM, and SON periods with correlation values of 0.213, 0.17, and -0.147 (Table 2). It means that the ENSO phenomenon does not too influence the maximum sea level. However, there is a significantly strong correlation in the JJA period which is the peak of the dry season, with a correlation value of -0.646. So it can be interpreted that the ENSO phenomenon significantly affects the maximum sea level variation in the JJA period. The negative correlation value indicates an inverse relationship between the maximum sea level and the SOI index.

The relationship between ENSO and the minimum sea level was observed to have a very weak correlation in the MAM and SON periods, with correlation values of -0.066 and -0.398 (Table 3). In contrast, the DJF correlation is quite solid but insignificant, with a correlation value of -0.562. The same thing with maximum sea level, minimum sea level also has a strong and significant correlation with JJA. However, the SOI index has a positive correlation with the minimum sea level. Its means that if the positive SOI index increases, the minimum sea level also increases. Tables 2 and 3 also show no significant correlation between the AUSMI index, both the maximum and minimum sea level, in all periods.

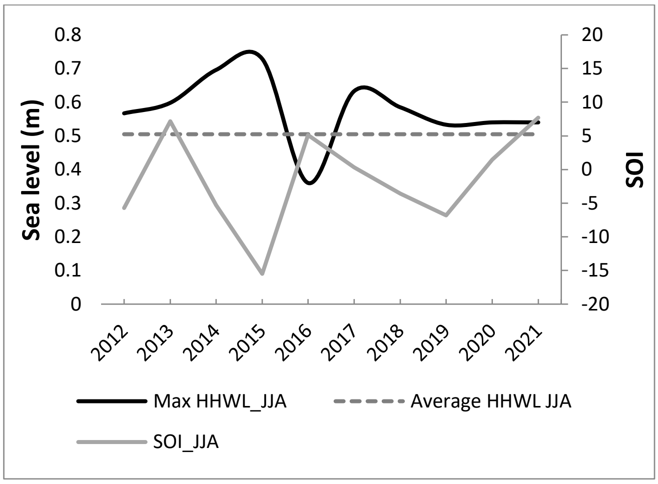

Figure 7. Maximum sea-level of the ENSO phenomenon for the JJA period.

The correlation analysis shows a strong correlation between the maximum and minimum sea level with the SOI index only in the JJA period. Figures 7 and 8 illustrate respectively the variation trends of maximum and minimum sea level during each ENSO phenomenon in JJA. During El Niño, the maximum sea level increased by 0.126 m (12.6 cm) to its maximum mean. Meanwhile, the minimum

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sea-level decreased by 0.166 m (16.6 cm) from the minimum average. It can be interpreted that in the El Niño phase, on the coast of Semarang, the tides are 12.6 cm higher than the average, and the tide is 16.6 cm lower than the average. Then in the La Niña phase, the maximum sea level decreased by 0.006 m (0.6 cm) to its maximum average. Meanwhile, the minimum sea level rose by 0.007 m (0.7 cm) from the minimum average.

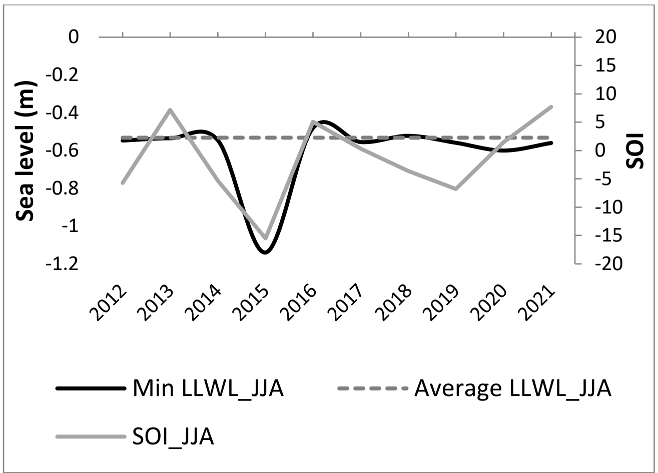

Figure 8. Minimum sea level of the ENSO phenomenon for the JJA period.

Discussion

Rainfall is still the main factor causing flooding in Semarang City, considering that Semarang often experiences flooding during the rainy season (Buchori *et al.*, 2018). This study shows a relatively weak AUSMI correlation with rainfall in Semarang City from 2012-2021. However, the AUSMI value is usually used as an indicator for determining monsoon winds in the Southeast Asia region. Several previous studies also showed that the AUSMI monsoon index could not describe the inter-annual variation of monsoon rains in the Indonesian region (Mulsandi *et al.*, 2021). AUSMI's correlation with rainfall increases only in the DJF and SON periods (Satyawardhana & Yulihastin, 2016). The increase in the AUSMI value in the DJF and SON periods was marked by an increase in the west monsoon winds that brought water vapor from the South China Sea, which triggered an increase in rainfall in Semarang City. In contrast, the MAM and JJA periods were marked by a decrease in the AUSMI value (Figure 2). The increase in rainfall in the MAM and JJA periods may occur from the influence of local winds and the ENSO phenomenon, considering that Semarang City is in North Java which has relatively higher rainfall than the southern region of Java under normal conditions (Pandia *et al.*, 2019).

ENSO variations (El Niño and La Niña) affect variations in monsoon winds in the equatorial region, causing seasonal changes in specific years (Trujillo & Thurman, 2011). This study shows that the effect of ENSO on rainfall in Semarang City is higher and more significant than AUSMI. El Niño causes a decrease in rainfall in Semarang City in almost all seasons, as happened in 2015, 2016, and 2019. The reduced rainfall can be attributed to a change in the Walker circulation, which moves east during the El Niño phase, thereby strengthening the easterly wind (Aldrian *et al.*, 2003; Satyawardhana & Yulihastin, 2016). Rainfall is indicated to increase almost every season in the La Niña period, such as 2013 and 2021. The western Pacific region gets more solar heat than the eastern Pacific during the La Niña period (Trujillo & Thurman, 2011). This condition will undoubtedly increase the evaporation of sea vapor in the territory of Indonesia. Finally, Semarang City will receive additional water vapor carried by the equatorial wind from the West Pacific Waters.

The ENSO phenomenon also affects tidal propagation in coastal waters (Handoko *et al.*, 2018). Figures 7 and 8 show that the El Niño phenomenon tends to increase the highest tide and decrease the lowest tide on the coast of Semarang City during the JJA period. It forms a relatively high difference in sea level amplitude, so it relatively increases water currents (Wisha *et al.*, 2018). The current increase triggers the possibility of tidal flooding around the Semarang coast (Marfai *et al.*, 2008). However, this result was contrary to the water area of West Sumatra, which experienced a sea-level rise during the La Niña and a sea-level decline during the El Niño (Khasanah & Sastra, 2017). The influence of ENSO is decreasing as it moves towards the west of Indonesia, considering that this phenomenon is an interaction between the eastern and western Pacific Oceans (Oktaviani *et al.*, 2014).

Conclusion

The ENSO phenomenon has a strong relationship with rainfall variations on Semarang City's coast during the dry season (JJA) and second transitional season (SON). El Niño events significantly impact rainfall in the SON period by reducing rainfall by 60 to 80% of the average. In comparison, La Niña in the JJA period can increase rainfall by 100 to 120% of the average. Monsoon activity represented by the AUSMI index only affects rainfall in the SON. Furthermore, the ENSO phenomenon is only strongly correlated with the maximum and minimum sea level in the JJA period. As for the relationship between the AUSMI index and the maximum and minimum TML, there is only a reasonably strong correlation in JJA but not significant. A negative correlation indicates an inverse relationship between the SOI index and sea level. During the El Niño phase (negative SOI) in the JJA period, the maximum sea level (highest tide) increased by 0.126 m (12.6 cm) to its maximum average, and the minimum sea level (lowest tide) decreased by 0.166 m (16.6 cm) from the average the minimum. Meanwhile, during La Niña (positive SOI), the maximum sea level decreased by 0.006 m (0.6 cm) to its maximum average. Meanwhile, the minimum sea level increased by 0.007 m (0.7 cm) from the minimum average.

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