INTERSEASONAL VARIABILITY IN THE ANALYSIS OF TOTAL SUSPENDED SOLIDS (TSS) IN SURABAYA COASTAL WATERS USING LANDSAT-8 SATELLITE DATA

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Abstract. The spatial and temporal capabilities of remote sensing data are very effective for monitoring the value of total suspended solids (TSS) in water using optical sensors. In this study, TSS observations were conducted in the west season, transition season 1, east season, and transition season 2 in 2018 and 2019. Landsat 8 image data were used, extracted into TSS values using a semi-analytic model developed in the Mahakam Delta, East Kalimantan, Indonesia. The TSS data obtained were then analysed for distribution patterns in each season. The sample points were randomly scattered throughout the study area. The TSS distribution pattern in the west season showed a high concentration spread over the coastal area to the off sea, while the pattern in the east season only showed a high concentration in the coastal areas. Transitional seasons 1 and 2 showed different patterns of TSS distribution in 2018 and 2019, with more varied values. The distribution of TSS is strongly influenced by the season. Observation of each cluster resulted in the conclusion that human activity and the rainfall rate can affect the concentration of TSS.

Keywords: *Rainfall Rate, Total Suspended Solids, Seasonal Total Suspended Solids, Surabaya*

1 INTRODUCTION

Technological advances have completely changed human life and work. The digital world is increasingly helping people to do many things that were previously done manually in a more practical and effective way. Such advances have also taken place in earth observation satellite technology, which is used as a vehicle for remote sensing. The use of such technology can make work efficient both in terms of time and energy, allowing observation of large areas of study. Optical remote sensing systems are often used in monitoring natural resources and waters qulity. Satellite recording technology can record electromagnetic waves outside the range of visible waves, which is very useful in distinguishing the spectral pattern of objects being recorded; for example, land and water can be distinguished easily because they have spectral differences. The spectral pattern of water in visible waves can provide extensive effective information on matter in the air (Le, Li, Zha, Sun, Huang, & Zhang, 2011), meaning that water quality observation methods, such as total suspended solids (TSS), can be performed using digital images. Improved sensor spectra and various algorithms are continuously being developed, and TSS detection parameters can be determined more accurately and quickly. The use of Landsat-based sensors has been widely used in determining TSS parameters; for example, Arief et al. (2016) employed

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Landsat-8 imagery to make TSS model estimation using a two-dimensional algorithm, with use of the green and red bands. In addition, Yanti et al. (2016) compared single Landsat-8 bands to map TSS distribution in Gajahmungkur Reservoir, Wonogiri City, Central Java, Indonesia, finding that the red band was the best to estimate TSS. Wang et al. (2017) and Jiyah et al. (2017) used QRLTSS model for TSS mapping, which used the red band and had a good ability to detect TSS with high dynamics. Using Landsat 5 TM, Landsat 7 ETM and Landsat 8, Parwati and Purwanto (2017) built a model based on one previously developed by Budhiman (2004), which also used the red band. Their results showed that TSS would increase if there was a change in land cover. Trisakti et al. (2015) also employed Landsat 8 to ascertain water clarity in Kerinci and Tondano Lakes, showing that Kerinci Lake (2m) had lower water clarity than Tondano Lake (2-3m).

TSS is the result of the reactions of heterogeneous materials, which then serve as the initial constituent material for sediment and inhibit the formation of organic substances in water (Tarigan & Edward, 2003). High TSS concentrations in water can cause other impacts, such as those found by Helfinalis et al. (2012), who demonstrated that high TSS concentrations can reduce the photosynthetic activity of marine biota, both micro and macro, which will result in decreased oxygen levels produced by plants, meaning fish will die due to a lack of oxygen. However, the level of TSS cannot determine what is happening in the water (Ainy et al., 2011; Domining et al., 2019). Waters that contain high TSS also tend to experience high sedimentation. TSS concentration measurements can be used as a determining indicator of water quality.

The coast of Surabaya is a busy area. The various activities that are conducted there show the importance of these waters. This entails the monitoring of water quality, namely the TSS content. Monitoring TSS concentrations can show the level of pollution in Surabaya waters (Hariyanto & Krisananda, 2019; Hariyanto *et al.*, 2014). Information on TSS concentration can be used as a parameter of water quality, so that action can be taken to prevent or deal with any water pollution that occurs. Pollution handling activities are conducted when the TSS content being monitored is at a dangerous level; namely, when the concentration is very high. Reducing TSS concentration can be achieved by avoided deforestation, especially of mangroves in the area around the water. Such concentration has been shown to decrease when there was an increase in the area of mangrove plants around the water (Parwati & Purwanto, 2017).

The territory of Indonesia is located in the tropics and is crossed by the equator. The pseudo motion of the sun crossing the equator cause the country experiences two seasons, namely the west season and the east season (Hutabarat, 2006). The west, or rainy season, occurs in December, January and February, while the east, or dry season occurs in June, July and August. The period between the west and east seasons, in March, April and May, is referred to as transitional season 1. While between the East Season to the West Season, in September, October and November, is referred to as transitional season 2 (Fadika et al., 2014).

In the west or rainy season, the TSS concentration (turbidity) will increase in the central area of the waters due to the high intensity of rain, which results in the process of material being moved from small rivers around the waters or from the coast to the middle of the water (deep water) (Risuana *et al.*, 2017). Meanwhile, in the east or dry season, the TSS concentration will be low in the middle part of the water, but high in the coastal area. Baseline sediment resuspension is a major factor affecting TSS concentrations during the east season (Quang et al., 2017).

The aim of this study is to determine the distribution pattern of TSS content in each observation season in order to establish the related TSS value range that was also matched with rainfall rate data.

2 MATERIALS AND METHODOLOGY

2.1 Location and Data

The research location was the Surabaya coastal region, East Java Province, Indonesia. Geographically, Surabaya is located to the south of the equator, at -7°9'N to -7°21'N and stretches from 112°36' E to 112°57'E. The area of Surabaya City is 52,087 Ha, 63.45% or 33,048 Ha of which is land, with the remaining 36.55% or 19,039 Ha being sea. The focus of this research is on the waters of the City of Surabaya, with the study area divided into three observation clusters, namely cluster 1 (waters of Lamong Bay Port), cluster 2 (waters around Suramadu Bridge) and cluster 3 (Wonorejo Mangrove area), as shown in Figure 2-1.

2.2 Data standardisation

Landsat 8 satellite spectral data, to be precise channels 1 to 7 in path/row 118/65, from the United States Geological Survey (USGS), were used in the process of extracting MPT concentration in water. The QGIS 3.14 and ArcGIS 10.4 open-source applications from the Environmental Systems Research Institute (ESRI) were employed to process the satellite image data. The layout of the MPT processing results used ArcGIS 10.4 tools.

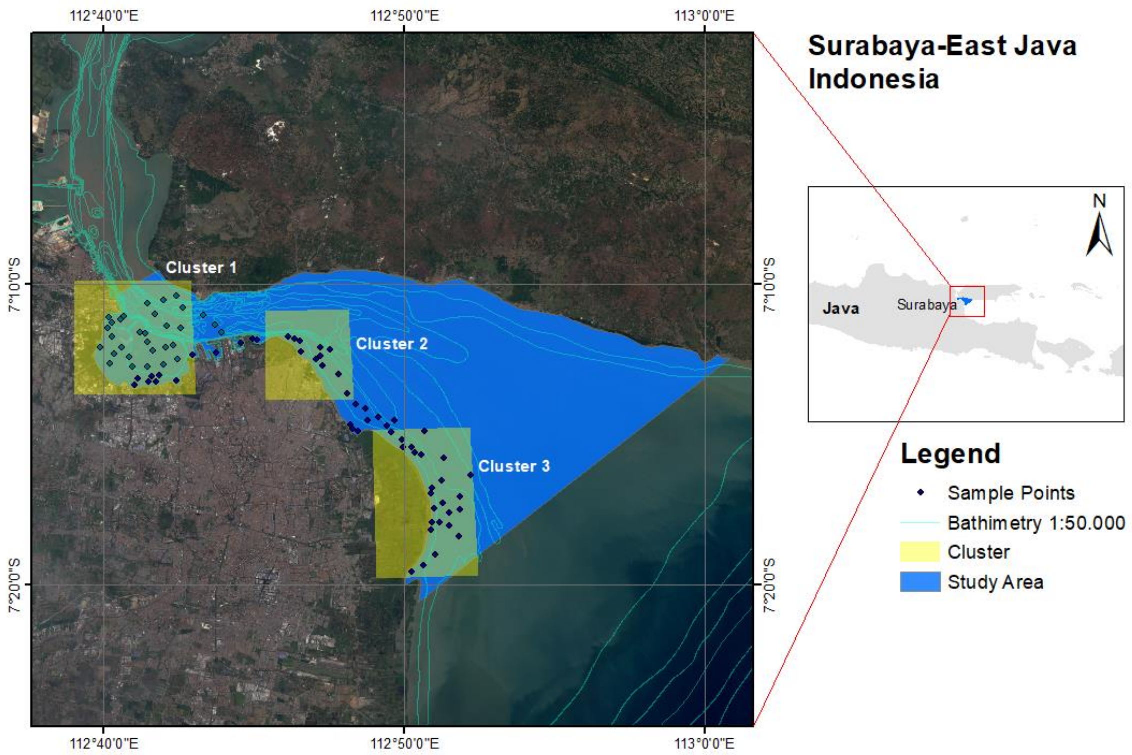


Figure 2-1. Study Area

2.3 Methods

The Landsat 8 satellite data used in the study comprised eight images representing each season: west season 2017, west season 2019 and transitional season 1, east season, and transitional season 2 in 2018 and 2019. It used data from 2017, 2018 and 2019 without any consideration of possible ENSO events during the season.

Table 2-1. Acquisition of Landsat Image Data

No.	Type of Data	Acquisition Date
1	West Season	30 December 2017
2	Transitional Season 1	7 May 2018
3	East Season	11 August 2018
4	Transitional Season 2	28 September 2018
5	West Season	18 January 2019
6	Transitional Season 1	26 May 2019
7	East Season	26 July 2019
8	Transitional Season 2	18 November 2019

The working stages in the research can be seen in the flow chart in Figure 2-2. The TSS information extraction process followed the stages described below.

1. The data collection required for the study was that of Landsat 8 imagery representing each season. At this stage, the number and distribution of the research sample points was also determined.
2. Performance of a cloud masking process. This was done manually using the QA channel on Landsat 8, which contains information about the quality of Landsat 8 images (USGS, 2013). The range of values in the QA channel detected as cloud will be eliminated, so the clouds in the scene image will disappear.
3. Image pre-processing, including radiometric correction, sun angle correction, and atmospheric correction using the DOS1 (Dark Object Substraction) method. This process was performed using the pre-processing tools in QGIS 3.14 to produce surface reflectance data, the bottom of atmosphere reflectance.
4. Performance of the process of separating land and sea by running the normalized difference water index (NDWI) algorithm (McFeeters, 1996) with the equation:

$$NDWI = (A-B)/(A+B) \quad (2\text{-}1)$$

A : reflectance Green band
B : reflectance NIR band

5. Calculation of the TSS content using a semi-analytic model. This model was used as Afgatiani et al. (2020) showed that it produced lower error than the empirical model. The semi- analytic model of Budiman (2004) was employed, which has previously been used in the Porong River area (Budianto & Hariyanto, 2017; Indeswari et al, 2018) and has a high regression value, with the following formula:

$$MPT\ (mg/L) = X * (\exp(Y * Z)) \quad (2\text{-}2)$$

X : 8.1529
Y : 23.704
Z : reflectance Red band

6. Extraction of the TSS value with a predetermined sample point on all the images resulting from the MPT processing. The sample point MPT data were used in the process of evaluating the MPT value in each cluster.
7. The rainfall rate used was based on data from the JAXA Global Rainfall

Watch (GSMaP). It was calculated according to each season.
8. Secondary data for validation were obtained from other papers and reports, as there are no in situ data.
9. Analysis of the TSS distribution data for each season, and analysis of the TSS sample data in each cluster by adding the rainfall rate and secondary data.

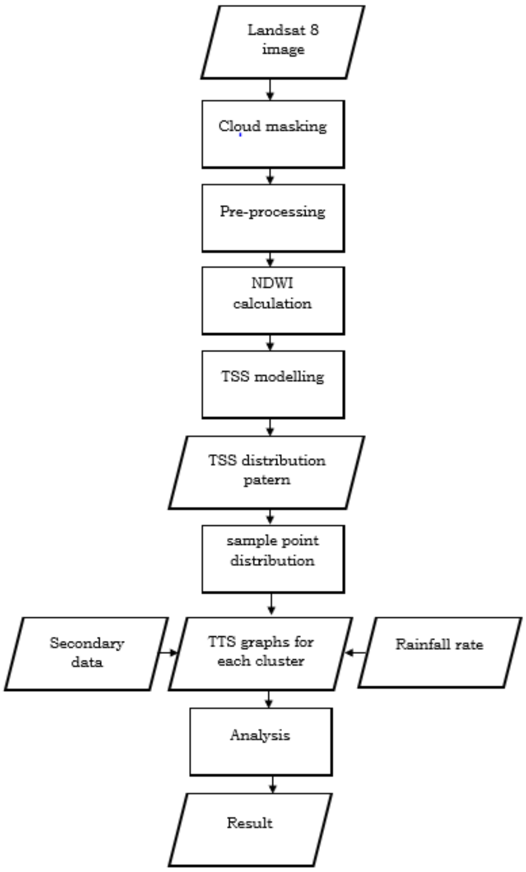


Figure 2-2. Flow diagram of data processing and analysis

3 RESULTS AND DISCUSSION

The TSS distribution shows dynamic fluctuations from season to season; that of 2018 can be seen in Figure 3-1. The distribution in the 2018 west season, which has a TSS concentration of 60.5 – 692.6 mg/L, indicates a high TSS concentration in the coastal (shallow) to middle (deep) waters. Transitional season 1 2018, with a TSS concentration of 29.6 – 97.2 mg/L, shows that the level had decreased in the coastal and mid-water areas. East season 2018 had a TSS concentration of 45.9 – 144.9 mg/L, with high concentrations spread along the coastal area, while levels in the middle of the TSS waters experienced a decline. Transition Season 2 2018 had TSS concentrations of 35.6 – 281.6 mg/L, with high concentrations scattered in the middle of the water, while in the coastal areas the TSS concentration fell.

The distribution of TSS in the 2019 west season, with a concentration of 24.9 – 807 mg/L, indicates high TSS concentrations in the coastal to middle waters. The levels in transitional season 1 2019, with TSS concentrations of 23.8 – 115.4 mg/L, show that TSS with a high concentration decreases in both the coastal and middle water areas. The 2019 east season, with TSS concentrations of 34.2 – 122.9 mg/L, experienced a decrease in TSS concentrations in all the study areas, with no visible distribution of TSS at high concentrations. TSS concentrations in the coastal areas are higher than those in the middle of the water. Transition Season 2 2019 had TSS concentrations of 30.3 – 163 mg/L, with high concentrations scattered in the middle of the water, while in coastal areas the TSS concentration fell.

The distribution of TSS in the 2018 and 2019 west seasons shows high concentrations spread over the coastal area to the middle area. On the other hand, the distribution of TSS in transitional season 1 2018 and transitional season 1 2019 shows a decrease in concentration from the west season, both in the coastal and in mid-water areas. Regarding TSS distribution in east seasons 2018 and 2019, TSS distribution in the coastal areas shows a higher TSS concentration than in the middle water area, while the distribution of TSS in transitional seasons 2 of 2018 and 2019 shows an increase in the TSS value from the east Season in the mid-water areas, but a decrease in coastal areas.

The distribution pattern of TSS in transitional seasons 1 and 2 does not show particular patterns, as is the case for the west and east seasons. TSS in each season in Surabaya displays the same pattern as in previous studies by Risuana et al. (2017) and Quang et al. (2017), with west season TSS concentrations high from the coastal area to the middle of the water. On the other hand, in the east season, TSS concentrations will be high in the coastal areas but will decrease in the middle of the water. Moko and Wiweka (2012) showed that the TSS concentration range in the east season was 24 – 402 mg/L. However, the resulting values from the image processing in the east season in both 2018 and 2019 were lower (34.2 - 144.9 mg/L) than in situ. Guntur et al. (2017) showed in situ data in transition season 1 of 9.9 - 131.7 mg/L. These values are almost similar to the TSS estimation results from the images of the 2018 and 2019 transition seasons, of 23.8 – 115.4 mg/L. Ma'arif and Hidayah (2020) found in situ data in the west season of 250 – 470 mg/L.

By observing the variation in the TSS distribution in each season, it is clear that the distribution of TSS is strongly supported by the changing seasons, especially in the west and east seasons. In these seasons, the surface currents move in the direction of the monsoon wind. Surface currents in the west and east seasons are greatly influenced by the wind that blows over the season. In transition seasons 1 and 2, surface currents in the water are not dominated by the influence of the wind. This is because the wind speed above the sea level is too low. It is suspected that the surface currents that occur are caused by tidal influences (Fadika et al., 2014). Surface currents in water also affect the distribution and value of TSS; according to Fathiyah et al. (2017), strong surface currents affect the direction of TSS distribution, which will follow the direction of the sea surface currents. Krisna et al. (2012) also found that the direction of TSS distribution will be in the same direction as that of the wind in the area. Wind direction is also influenced by the seasons.

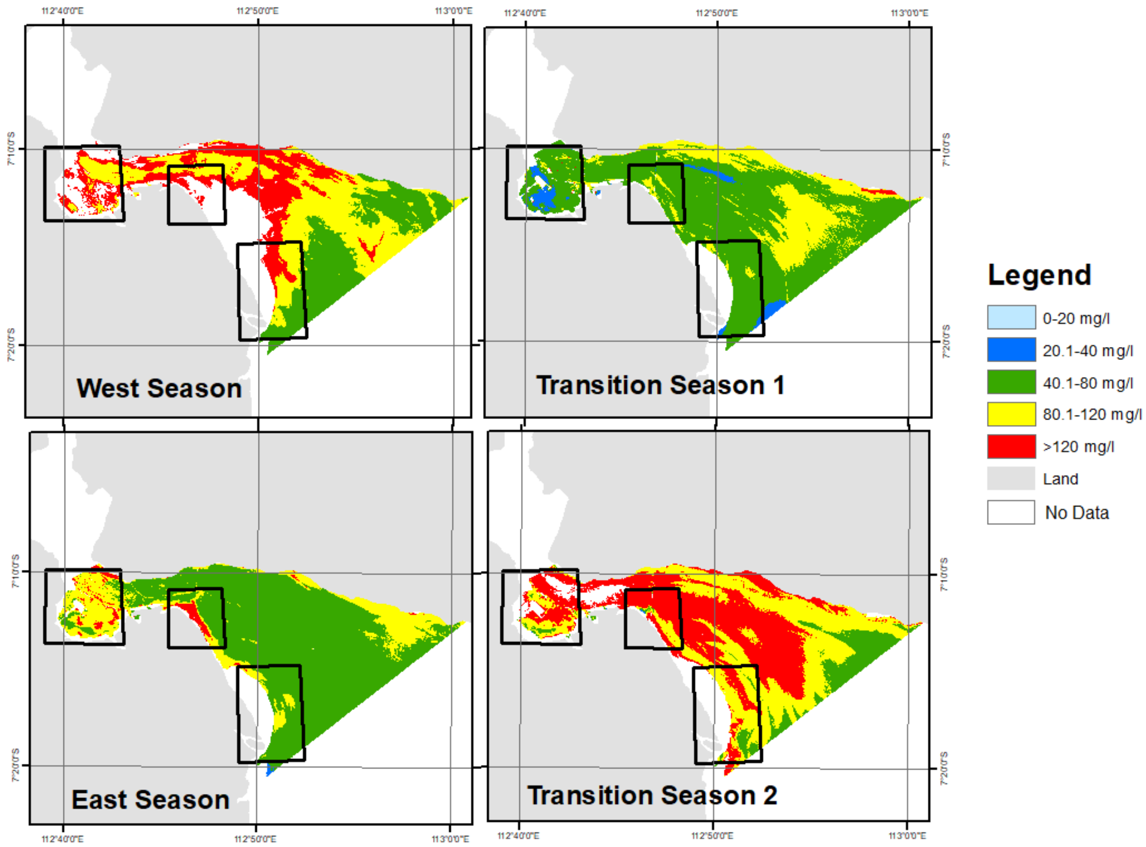


Figure 3-1. TSS distribution in 2018

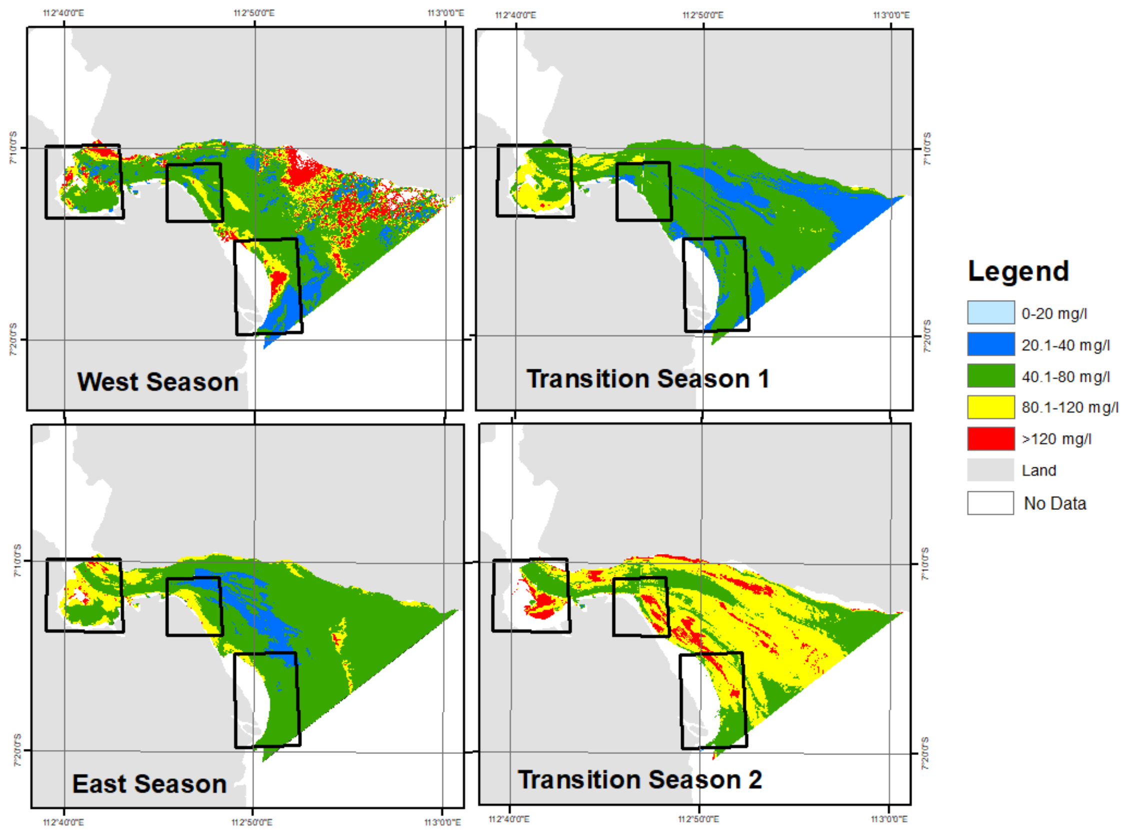


Figure 3-2. TSS distribution in 2019

Evaluation of the TSS values in each cluster was made by using six sample points. The selection of these took into account spatial distribution and avoided outlier values, as can be seen in Tables 3-1 to 3-3, which show the TSS values at each sample point. Figures 3-3 to 3-5 show the fluctuation of each sample in each season.

Cluster 1 was located in the Lamong Bay Port area, where the TSS values varied considerably from season to season, can be seen in Figure 3-3. Starting from the west season in 2018, the TSS value was relatively high, in the range of 100-200 mg/L, while in transition season 1 2018, the value dropped drastically. It increased again in east season 2018 and transitional season 2 2018. In west season 2019, the TSS value fell again, before successively increasing in transitional season 1 2019, east season 2019 and transitional season 2 2019. The average TSS value in cluster 1 was above 50 mg/L, which means that its concentration was quite high.

This high TSS value was due to the relatively high activity at Lamong Bay Port; moreover, the port is also near the other big port of Tanjung Perak. This directly increases the activity in cluster 1 waters. High activity in the waters causes considerable material to be carried into the waters, resulting in a high TSS value (Handoyo et al., 2017).

Cluster 2 in the Suramadu Bridge area also shows a variation in TSS values from season to season, as can be seen in Figure 3-4. Evaluation of the TSS values of the selected six cluster 2 sample points is shown in Table 3-2. The selection of sample points in each cluster must be free from clouds in each season so that the TSS value selected represents the actual situation.

Starting from the west season 2018, the TSS value was quite high, in the range of 100-200 mg/L, while in transition season 1 2018, it dropped drastically. The west season has the highest TSS value. This period is the peak of the rainy season at Indonesia, especially in the southern equator regions, such as Sumatra, Java, Bali and Nusa Tenggara. The amount of rainfall in the season is generally above 250 mm/month (Mulyana, 2002). This means there will be increasingly more water containing residue running off the land, resulting in an increment in TSS. The transition season is a time when there is a change from the west to the east seasons. In this season, the TSS values are irregular due to the changing wind direction (Siregar et al., 2017).

In east season 2018 and transitional season 2 2018, the TSS values increased again, then decreased in 2019 west and intermediate 1 season, before once again rising in 2019 east season and decreasing in transitional season 2 2019.

In the 2018 west season, 2018 east season, and transitional season 2 2018, the TSS value was in the range of 100-200 mg/L, with a high concentration. Meanwhile, for other seasons the TSS value was below 100 mg/L. In transition season 2 2019, four sample points had no TSS data because the areas were covered by cloud. Overall, the TSS value in cluster 2 was below that of cluster 1, which was because the activity in the waters around Surabaya Bridge was not as dense as that of Lamong Bay Port (cluster 1). Environmental factors such as wind speed, wind direction and tides have a relatively minor effect on increasing TSS concentrations compared to human activities in water areas (Noel et al., 1995). However, this paper does not include wind data.

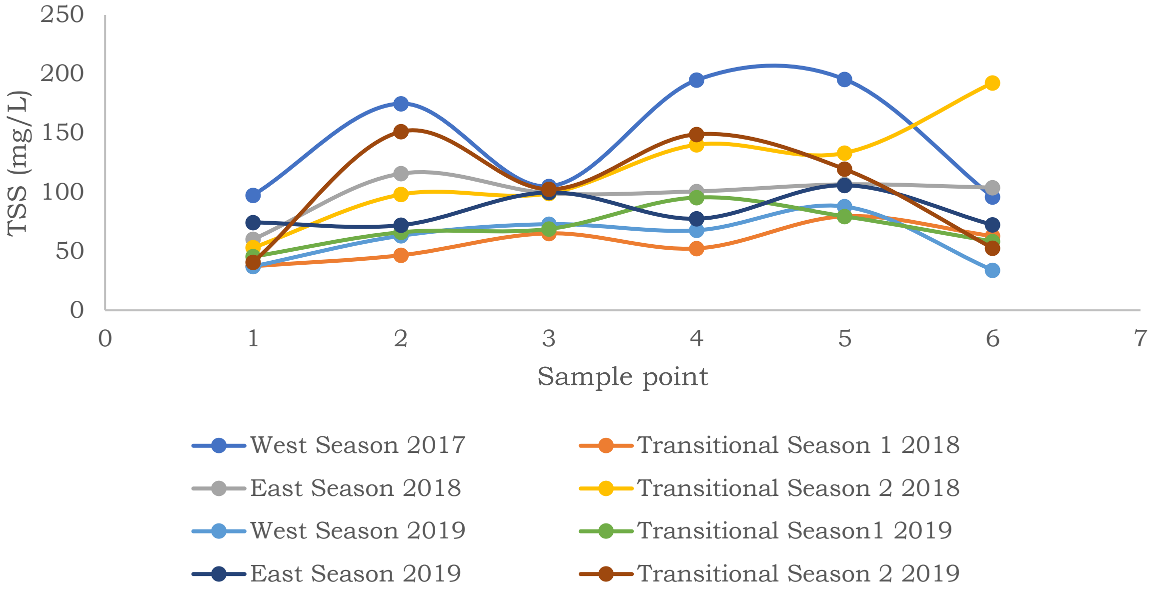


Figure 3-3. Graph of TSS values in cluster 1 (Lamong Bay Port).

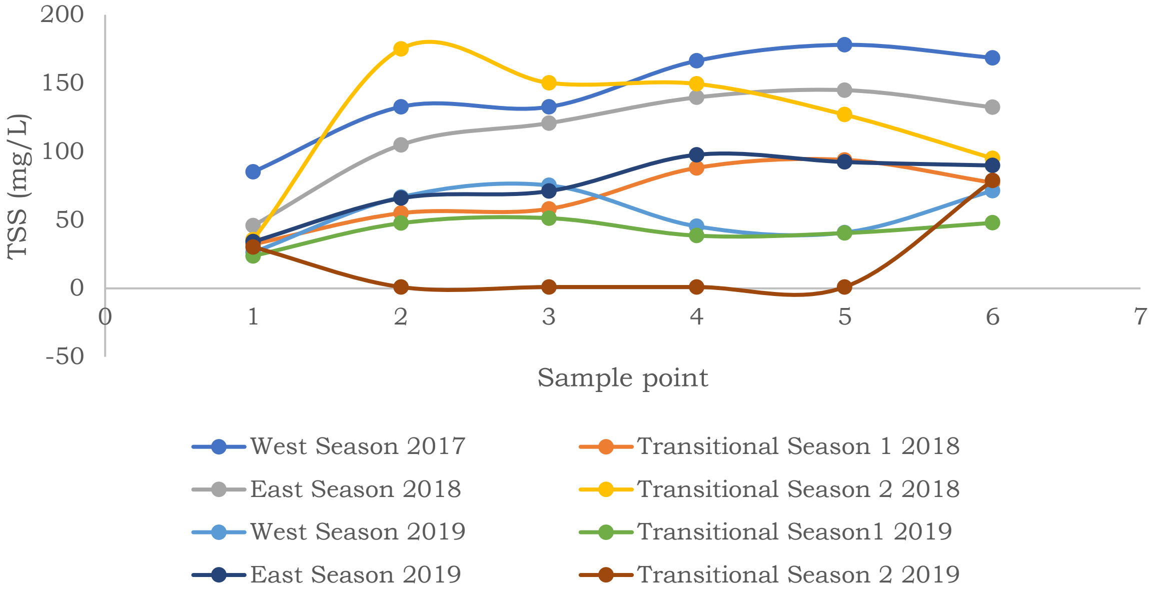


Figure 3-4. Graph of TSS values in cluster 2 (around Suramadu Bridge).

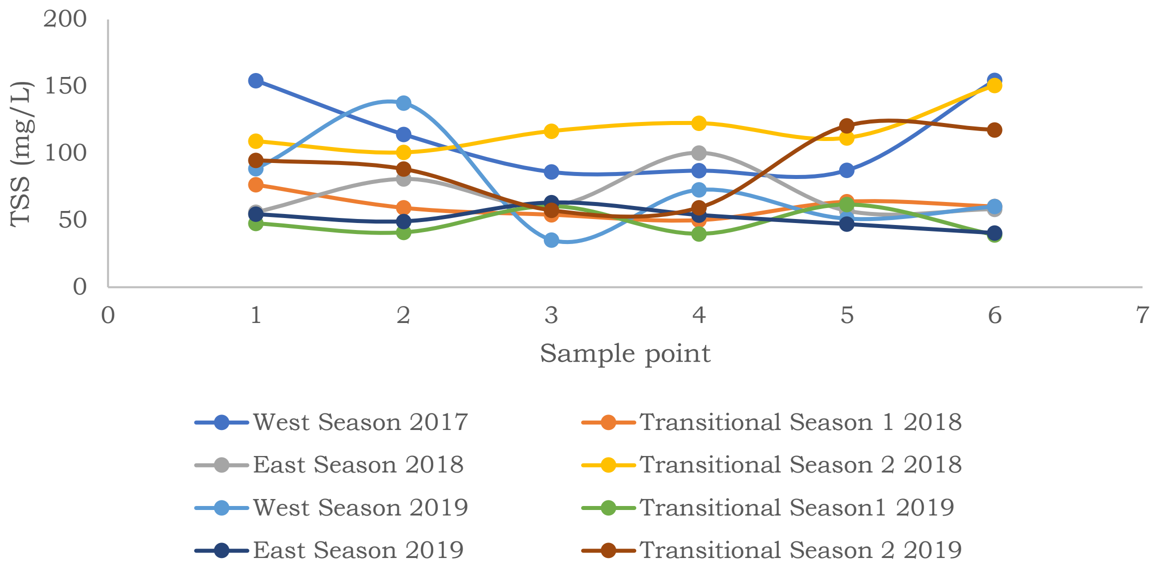


Figure 3-5. Graph of TSS values in cluster 3 (Wonorejo Mangrove area).

Table 3-1. TSS values (mg/L) of sample points, cluster 1

West Season 2018	Trans Season 1 2018	East Season 2018	Trans Season 2 2018	West Season 2019	Trans Season1 2019	East Season 2019	Trans Season 2 2019
97.4	37.4	60.1	53.0	37.2	45.4	74.4	40.8
175.0	46.6	115.7	98.0	63.1	66.1	72.1	151.2
105.0	65.2	99.2	99.0	72.9	68.9	99.8	102.5
195.0	52.4	100.7	140.2	67.7	95.5	77.5	149.0
195.5	79.6	106.6	133.2	87.8	79.5	105.9	119.5
95.9	62.8	103.9	192.5	34.0	58.2	72.4	52.7

Table 3-2. TSS values (mg/L) of sample points, cluster 2

West Season 2018	Trans Season 1 2018	East Season 2018	Trans Season 2 2018	West Season 2019	Trans Season1 2019	East Season 2019	Trans Season 2 2019
97.4	37.4	60.1	53.0	37.2	45.4	74.4	40.8
175.0	46.6	115.7	98.0	63.1	66.1	72.1	151.2
105.0	65.2	99.2	99.0	72.9	68.9	99.8	102.5
195.0	52.4	100.7	140.2	67.7	95.5	77.5	149.0
195.5	79.6	106.6	133.2	87.8	79.5	105.9	119.5
95.9	62.8	103.9	192.5	34.0	58.2	72.4	52.7

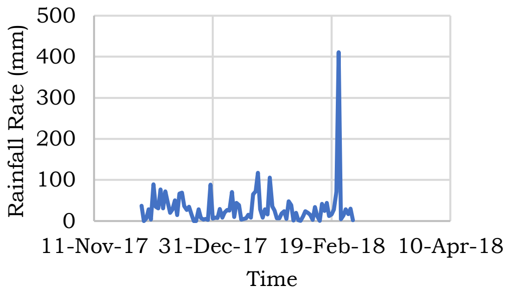
Table 3-3. TSS values (mg/L) of sample points, cluster 3

West Season 2018	Trans Season 1 2018	East Season 2018	Trans Season 2 2018	West Season 2019	Trans Season 1 2019	East Season 2019	Trans Season 2 2019
154.4	76.6	56.1	109.1	88.6	47.7	54.5	94.9
114.2	59.3	80.9	100.7	137.5	41.0	49.2	88.3
86.1	54.2	60.6	116.6	35.4	60.5	63.3	57.5
87.1	50.1	100.4	122.6	72.7	39.9	54.0	59.5
87.4	63.9	57.1	111.6	51.2	61.8	47.2	120.6
154.5	60.3	58.3	150.8	60.3	39.0	40.5	117.6

Cluster 3 was located in the Wonorejo Mangrove area, which shows that the TSS value varies from season to season, as seen in Figure 3-5. Evaluation of the TSS values for the selected six sample points in cluster 2 are shown in Table 3-3. The TSS values decreased between the 2018 west season and transition season 1 2018. In east season 2018 and transition season 2 2018, the TSS values then increased respectively. In west season 2019 and transitional season 1 2019, the values fell, before increasing again in east and transitional season 2 2019.

The monsoon season will affect rainfall. The rainfall data are shown in Figure 3-6, with the highest TSS values occurring in transition season 2 2018, with a concentration higher than 100 mg/L. On the other hand, in other seasons the value is below 100 mg/L. However, rainfall in this season tends to be high at the end of the period. Even though west and transition seasons 1 experience high rainfall with relatively high intensity, TSS levels are no higher than in transition season 2. Rainfall can affect TSS concentration; however, there is no correlation between first-flush loads of TSS and rainfall characteristics (He et al., 2010). Therefore, it is likely that the end of transition season 2 will be a seasonal first flush event. Seasonal first flush is the release of a bigger mass off contaminants or higher concentration, compared with storms later in the season (Strenstrom & Kayhanian, 2005). Rainfall can be a medium for the transport of pollutants from the surface (Shehane et al., 2005). TSS variation is influenced by seasons, and any season can affect rainfall.

Based on the TSS value sample points in cluster 3, it can be said that cluster 3 has a lower level when compared to cluster 1 and cluster 2. The waters of cluster 3 have activities that are not as busy as cluster 1 or cluster 2. The cluster 3 area is used by fishermen- small fishermen from the surrounding area, not the center of large activity. Hasyim et al. (2009) explained that this area is dominated by *Euthynmus spp.*, *Decapterus spp.*, *Ratsrellinger spp.*, *Trichiurus spp.* and *Sardinella lingiceps* during all seasons. Therefore, the TSS value is not too high when compared to the other two clusters. Human activities in and near coastal waters have great potential to increase TSS concentration (turbidity) in water (Nurjaya et al., 2019).



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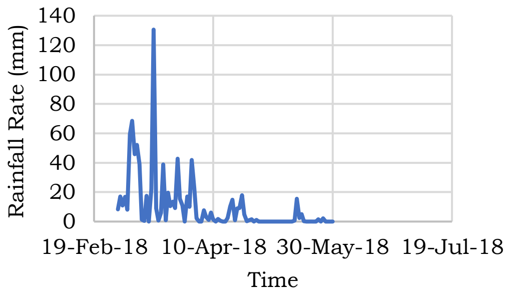

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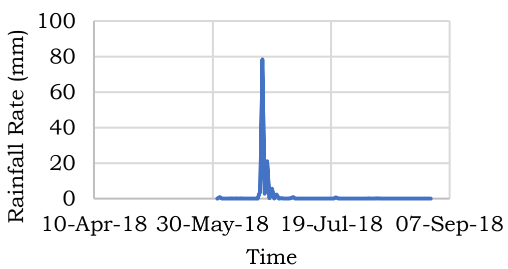

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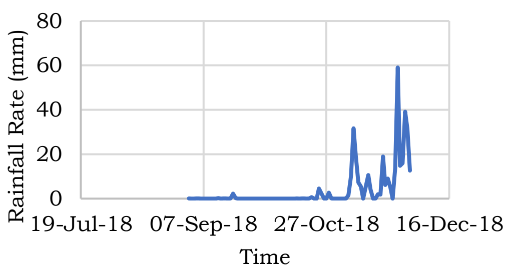

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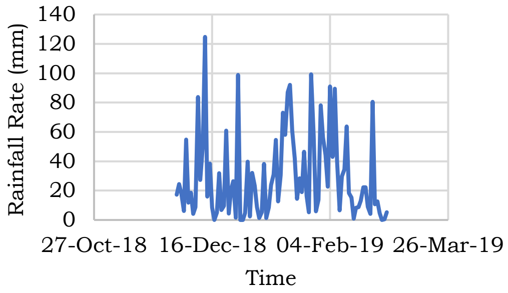

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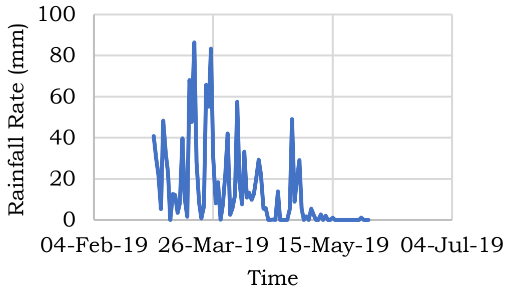

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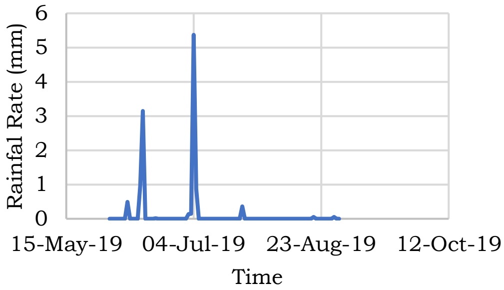

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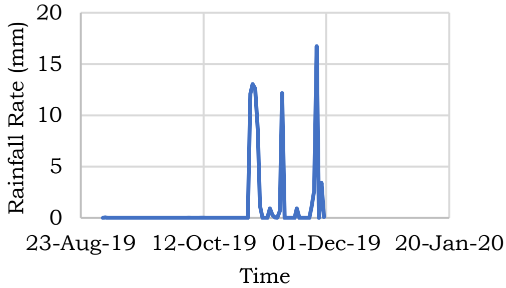

h.

Figure 3-6. Rainfall Rate in Each Season: a. Rainfall Rate West Season 2018; b. Rainfall Rate Transitional Season 1 2018; c. Rainfall Rate East Season 2018; d. Rainfall Rate Transitional Season 2 2018; e. Rainfall Rate West Season 2019; f. Rainfall Rate Transitional Season 1 2019; g. Rainfall Rate East Season 2019; h. Rainfall Rate Transitional 2 Season 2019

4 CONCLUSION

TSS distribution is highly influenced by the seasons. In the west season, TSS values with high concentrations will be scattered in the middle of the waters (deep waters), while in the east season they will only be seen in coastal areas. During transition seasons 1 and 2, the distribution of TSS is not influenced by seasons, only by tides, so that the distribution is more varied. Overall, TSS values in the west season will be higher than in the east season because of the higher rainfall.

As for the TSS values in the observation clusters, cluster 1 (Lamong Bay Port) shows different TSS distribution compared to the other locations. One of the factors that influences the distribution of TSS is seasonality.

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AUTHOR CONTRIBUTIONS

Interseasonal Variability in The Analysis of Total Suspended Solids (TSS) in Surabaya Coastal Waters Using Landsat-8 Satellite Data. Lead Author: Bela Karbela, Co-Author: Pingkan Mayestika Afgatiani and Ety Parwati. Author contributions are as follows:

1. Bela Karbela: image processing, map layouting, results analysis and prepare draft manuscripts
2.Pingkan Mayestika Afgatiani: Provision, writing and editing
3. Ety Parwati: Editing

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