Analysis of Sedimentation Patterns Using Landsat 8 in North and West Part Coastal Area of Madura Island

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Abstract
Indonesia is a country with its sea area four times greater than its land area. Indonesia also has many islands. Therefore, Indonesia is known as a maritime and archipelagic country. Due to those conditions, coastal areas become the important part in Indonesia. Coastal area is an area of transition from terrestrial to marine ecosystems. Coastal activities can affect its physical conditions, especially sedimentation. Sedimentation pattern can be represented by Suspended Sediment Concentration (SSC) parameter. Satellite remote sensing is an effective source of information to monitor SSC in the coastal area. This study intends to analyse sedimentation patterns on the north and west coasts of Madura Island by extracting SSC values from Landsat-8 imagery. Modelling of currents and sediment transport is also performed in this study to analyse sedimentation pattern. From the analysis it was found that the value of SSC in the rainy season tended to be higher than in the dry season. The tendency of SSC is to gather in the estuary area of rivers, bays, and beaches which protected by the construction of coastal buildings. Whereas through modelling of current and sediment transport, Arosbaya Sub district is the most dynamic sub district due to the meeting of currents from and into the Madura Strait which carrying sedimentary material.

1. Introduction

Coastal areas become the important part in Indonesia as a maritime and archipelagic country. Monitoring the dynamics of coastal conditions is needed to observe accretion and abrasion caused by natural conditions, such as sedimentation. Suspended sediment is an early indicator for the presence of bed load sediment which are the natural causes of coastline morphological changes. Suspended sediments require certain time and conditions such as beach slope and grain size to subsequently settle and become bed load sediment (Dean and Dalrymple, 2002). Fugate and Friedrichs (2001) in Kironoto (2008) stated that an increase in the velocity of sediment particles to settle will be in line with an increase of Suspended Sediment Concentration (SSC).

Suspended sediments are the most affected sediments by the dynamics of oceanographic parameters such as currents, tides and winds (Carter, 1988). Interactions of oceanographic parameters with the bottom of water which occur continuously and significantly can bring material to or away from the coast. The phenomenon can causes accretion or abrasion in coastal areas. Accretion which occurs due to continuous sedimentation can have an impact on the expansion of area administrative boundaries. Yet, conversely, if erosion occurs significantly, it can erode land area and further reduce the function of facilities that have been built in a coastal area.

The north and west coast regions of Madura Island have high sedimentation activities (Putra et al., 2017). This research was conducted because the locations of the seven sub districts along the north and west coasts of Madura Island consisting of Kamal, Socah, Bangkalan, Arosbaya, Klampis, Sepulu, and Tanjungbumi have important functions to support economic activities in the Surabaya Metropolitan Area. In addition, this area is directly adjacent to the sea where differences in the characteristics of the waters in the north and south can cause different sedimentation patterns. The south side of Bangkalan Sub district and the west side of the Kamal Sub district are areas which there are the narrowest part of the Madura Strait. This condition can accelerate the sediments transport towards or into the strait. Whereas Sepulu and Tanjungbumi Sub districts near to the Java Sea have open water characteristics, thus the sediments in this area may not be as fast as the sedimentation in the area of narrow Madura Strait.

This study aims to observe the sedimentation patterns by analyzing SSC values, also by modelling currents and sediment transport in the north and west coast regions of Madura Island. The analysis was done by using Ladsat-8 multi-temporal data, along with oceanographic parameters. Landsat is a passive remote sensing image which has a 30-m spatial resolution. Yepez et al., (2017) and Kaliraj et al., (2014) utilized Landsat-8 images for SSC observations. Although included in moderate resolution images, the diversity of spectral channels and temporal resolution of Landsat images can be used to study the SSC and their impact on coastal area.

2. Methodology and Data Analysis

2.1 Study Area

The location of this study is the west and some north part of coastal area of Madura Island (Figure 1). The coastal area of Madura Island is important location to study due to its diverse and dynamic characteristics. These characteristics differ between the north part (Zone 1) and the west part (Zone 2). Zone 1 is open water and is directly adjacent to the Java Sea. Zone 2, which is located right on the strait, is a narrow area, resulting hydraulic control sections where tidal currents flow rapidly (JICA, 2007).

In 2016, the Research and Development Agency of Indonesian Energy and Mineral Resources discovered a new land or island in Zone 1. The emergence of the new land was thought to be due to interactions between the tides at the spring and extreme waves in West Monsoon. The interactions multiply the wave flux energy that reaches the shore and cause massive littoral drift. Then, the sea floor material is transported and stacked to form heaps above the reef average and become the basis of the island. Meteorological and oceanographic data also show that there was an extreme wave action at the height of the tide which was thought to have triggered extreme littoral drift and abolished the coastline of Madura Island (Research Center for Marine Geology, 2016).

Water movement in Zone 2 is different from Zone 1 (Yuanita et al., 2012). This phenomenon is due to bathymetry and strait configuration in Zone 2. When water in the Java Sea (Zone 1) is high, water enters the Madura Strait (Zone 2). In this case, the movement of water is constantly different from the western part to the eastern part of the Madura Strait. Another aspect which causes the phenomenon is the different type of tides. In the Java Sea, tides are diurnal types, while in the Madura Strait, tides are mostly semidiurnal types.

2.2 Data Acquisition

The data used in this study are Landsat-8 satellite image data path/row 118/065 in 2013, 2015, 2018 and 2019 (Table 1). In-situ data such as SSC and surface currents are acquired in April 2019 at the same day as Landsat-8 orbit time.

Table 1: Images used

No	Date	Cloud Cover (%)
1	28 July 2013	4.75
2	01 November 2013	6.13
3	16 June 2015	0.29
4	23 November 2015	3.43
5	10 July 2018	7.82
6	30 October 2018	4.11
7	18 January 2019	40.74
8	24 April 2019	23.55

2.3 Pre-processing

Image pre-processing is applied to each Landsat-8 dataset in order to focus on study area and to reduce cloud cover. First, image cutting based on Region of Interest (ROI) in study area is performed on each image scene. In this case, band 5 and natural color band 4-3-2 (red-green-blue) are used. Natural color band is useful as an interpretation of the image based on the actual appearance in the field. The images used in this study have low percentage of cloud cover. However, some clouds are remains in the images and covering some parts of study area. Thus, as the second step in pre-processing, cloud masking is applied to remove cloud cover in the images.

2.4 Radiometric and Atmospheric Correction

Radiometric correction is useful for converting data in an image in the form of a Digital Number (DN) into radiance and / or reflectance (Jaelani, 2013). Radiometric correction is done to correct errors or distortions caused by imperfect operations and sensors, the attenuation of electromagnetic waves by the atmosphere, variations in the angle of data retrieval, variations in elimination angles, reflection angles and others that can occur during retrieval, transmission and data recording. The correction is applied to each image scene using the following equation.

$$L_{\lambda} = M_{\lambda} \times Q_{cal} + A_{\lambda}$$

Equation 1

Where:

Lλ =Spectral radiance from TOA (Top of Atmosphere)

Mλ =Band-specific multiplicative rescaling factor

Qcal =Digital Number (DN)

Aλ l =Band-specific additive scaling factor

Atmospheric correction is used to eliminate atmospheric effects to obtain surface reflectance values from the processed image.

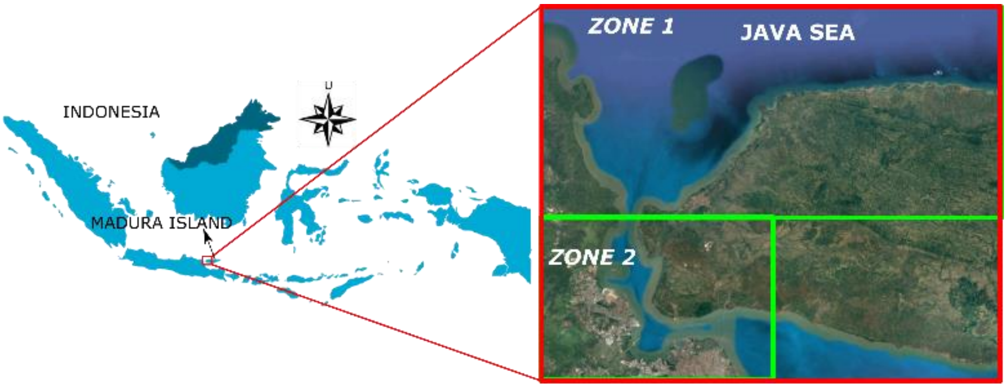


Figure 1: The study area

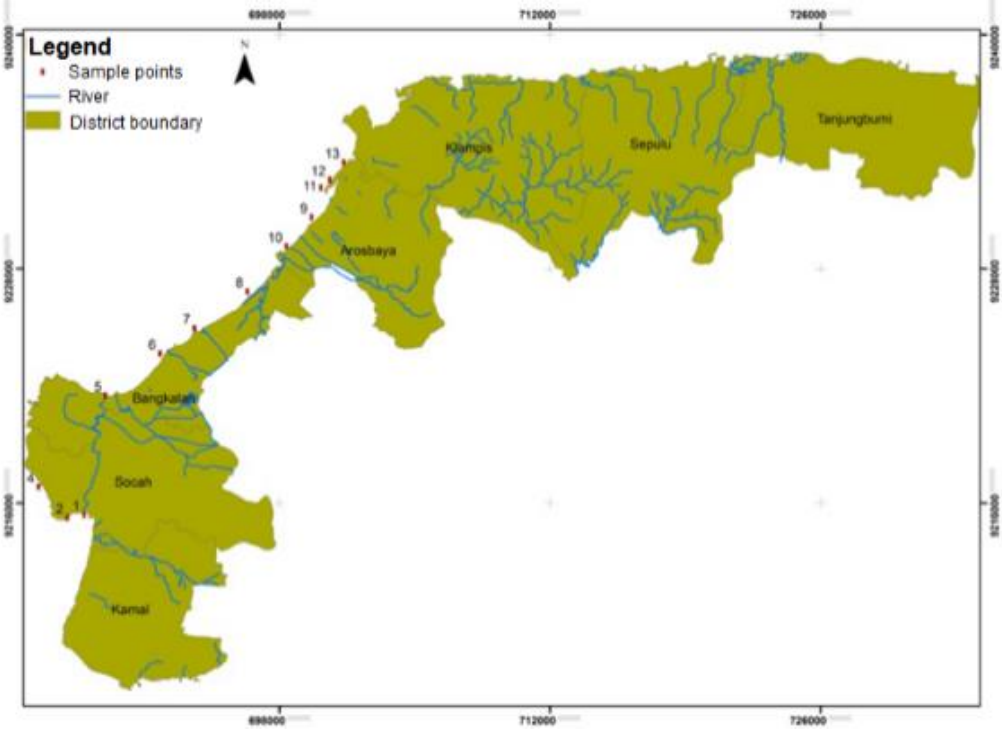


Figure 2: Location of SSC Sampling Points

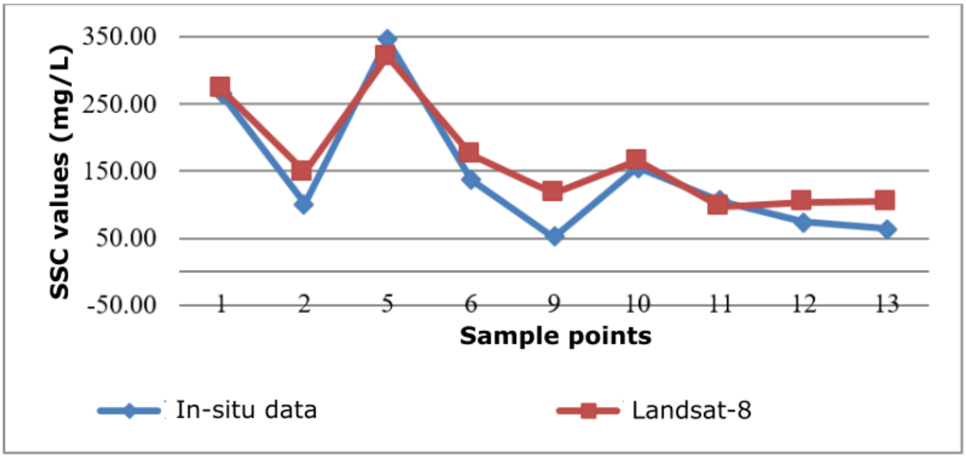


Figure 3: Comparison graph of SSC values between in-situ data and extraction from Landsat-8 image

Atmospheric correction used is the Second Simulation of Satellite Signal algorithm in the Solar Spectrum-Vector or known by 6SV (Laili, 2015). Comparison between before and after corrections are performed using 10 sample points to analyze the results.

2.5 Extraction of Suspended Sediment Concentration (SSC)

The SSC value obtained from satellite imagery is an interpretation model of the reflectance values which are then recorded by satellite sensors. The algorithm used is obtained by deriving a regression model for all possible bands and the ratio of band combinations, empirically. Then, the algorithm is selected based on the highest correlation value or R^2 between the estimated SSC values from image with the measured SSC values in the field (Yepez et al., 2017).

Accuracy of model simulation is needed to determine the deviation between the values generated from image with the values obtained from field measurements (in-situ). In order to find the deviation, Root Mean Square Error (RMSE) and Normalized Mean Absolute Error (NMAE) are calculated (Yepez et al., 2017). The minimum value of NMAE for extracting water quality parameters from remote sensing data must be below 30% (Laili et al., 2015) or in the confidence interval (α) 70%.

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}(\widehat{Xi}-Xi)^2}{N}}$$

Equation 2

Where:
(Xi)ˆ = Value of modeling results
X_i = Value from in-situ measurement
N = The amount of data

$$\text{NMAE}\ (\%) = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{\widehat{X_i}-X_i}{X_i}\right| \times 100$$

Equation 3

Where:
(Xi)ˆ = Value of modeling results
X_i = Value from in-situ measurement
N = The amount of data

In this study, Near Infrared (NIR), band-5, is used to extract SSC. The determination is due to a significant suitability between the SSC values from in-situ data with the SSC value extracted from Landsat-8 images which is showed by NIR band, especially at 726-868 nm wavelengths. The suitability is indicated by R^2 value of 0.92% at a significant level of $p < 0.001$. The value is higher than R^2 from visible band (Yepez et al., 2017). From this calculation, it can be said that NIR band (band-5) is more suitable for SSC extraction than visible bands. The signal of NIR band is absorbed when it hits water body, thus, the value will be zero. For this reason the sediment concentration floating in relatively shallow waters can be extracted from this band with the assumption that the reflectance value of more than zero is a floating material which can still be acquired by the sensor. The SSC value can be calculated using the following equation (Yepez et al., 2017).

$$\text{SSC} = 1.35512\text{x}(\rho_{w5x1000}) - 2.9385$$

Equation 4

Where SSC in mg/l and ρ_{w5} in percent.

Those SCC values are then compared with in-situ data in order to evaluate the extraction results. The algorithm in Equation 4 is possible to be applied in estimating SSC values, but the specific coefficients of the model can vary due to the optical characteristics of SSC, such as particle size, shape, color, type of minerals and organic substances which can affect the optical characteristics of turbid waters. SSC in open water is greatly affected by the direction and speed of the current. The direction of the current is affected by monsoons which cause seasons change. Therefore, analyses of SSC pattern based on seasons are carried out in this study.

2.6 Analysis of Currents and Sediment Transport

As mentioned above, there are two zones of the study area in this research. Zone 1 is open water and is directly adjacent to the Java Sea. Zone 2 is located right in the Madura strait with a relatively narrow strait width. Analysis of currents and sediment transport were carried out for each zone in order to obtain the SSC pattern and its tendency based on oceanographic parameters. Build upon this analysis, we hope to answer our hypothesis about different characteristics between north and south coastal area which can influence the dynamics of shoreline changes on the west and north coast of Madura Island. The speed and direction of current used in here is the tidal current obtained from the hydrodynamic model.

3. Results and Discussion

3.1 Evaluation of Suspended Sediment Concentration (SSC) Extraction Results

SSC values extracted from Landsat-8 April 2019 image are compared with in-situ data in order to evaluate those results. Figure 2 shows the distribution location of sample points to get in-situ data of SSC. Table 2 represents the comparison between SSC values extracted from Landsat-8 image and SSC values from in-situ measurement. From Table 2, it can be seen that points 1 and 5 have SSC values of more than 200 mg/L. Those two points are located in the mouth of the Gladagpanjang River. The locations have the slowest current speed among all sample locations. It is probably due to strong turbulence in those locations which caused by the meeting of river currents with ocean currents. The meeting causes the emergence of SSC values with relatively large types of floating material in the form of silt.

In this study the correlation coefficient value was 0.944 which showed a good correlation between in-situ data and the model (extraction from Landsat-8). Even though the RMSE value reached 35.137 mg/L, which is relatively large, the SSC values patterns presented in Figure 3 show similar range of values between in-situ data and the model. In addition, the NMAE value is 15.68% which still meets the <30% requirement.

3.2 SSC Pattern based on Season

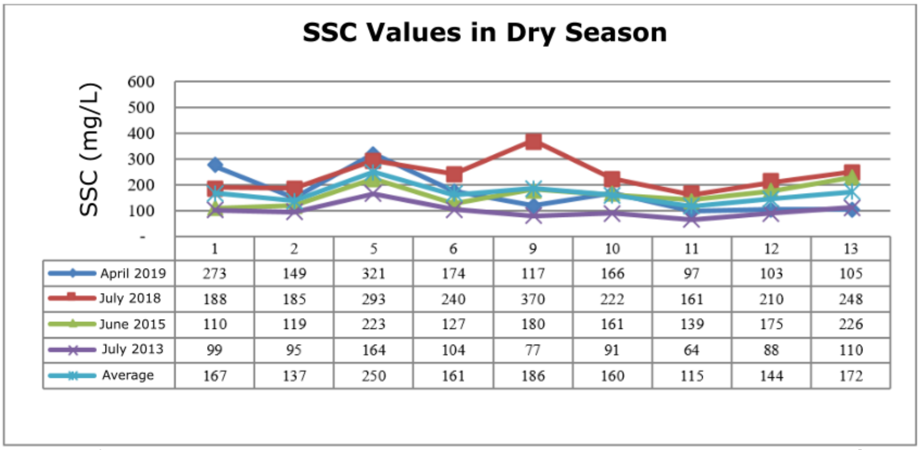
In the dry season, the images used are Landsat 8 images in July 2013, June 2015, July 2018 and April 2019. While in the rainy season, Landsat 8 in November 2013 and 2015, October 2018 and January 2019 are used. Figure 4 shows the SSC value in dry season at each sample point. The maximum value is at point number 9 in July 2018. However, on average, the maximum SSC value from each year is at point number 5. Whereas the minimum value is at point number 11. Point number 5 is located at the mouth of the Gladagpanjang River, Socah District while point 11 is in open water of Arosbaya District. Figure 5 represents a graph of the SSC value in rainy season. From the graph it appears that there is extreme value at point number 10 in 2018. This is because there are thick clouds in the image of 30 October 2018, exactly at point 10, which cannot be removed by cloud masking. For further analysis and calculations, the sample point number 10 on the image of 30 October 2018 will not be included.

Landsat-8 image on 18 January 2019 provides a relatively small SSC value in all sample points compared to other images. The minimum SSC value in the rainy season is found at sample point number 1 and 2 from the image of 18 January 2019. Both of these points are located in the Socah District, Junganyar region. Sample point number 1 is precisely located at the mouth of the Gladagpanjang River. The locations of those two points are protected by the Junganyar village in the north. It is suspected that the small SSC values are caused by the currents, which carrying SSC material from the north, moves directly towards Kamal District. However, this hypothesis needs to be further proven by involving the direction factors and the current speed at the location of the sample points.

The image of October 2018 was taken during low tide conditions which caused the water to recede to the coastline of 652 m at sample point number 1 and 145 m at sample point number 2. Therefore, SSC extracted from the image of 30 October 2018 has a very high value at all sample points (more than 300 mg/L). As a result, the average SSC value in rainy season at all years is higher than the average SSC value in dry season. Maps of SSC distribution are shown in Figures 6 and 7. From the figures, it can be seen that the SSC values increases in the rainy season and are concentrated in several regions, such as in the Districts of Kamal, Bangkalan and Arosbaya. The difference of SSC value between the rainy and dry seasons from 8 sample points is 162.13 mg/L.

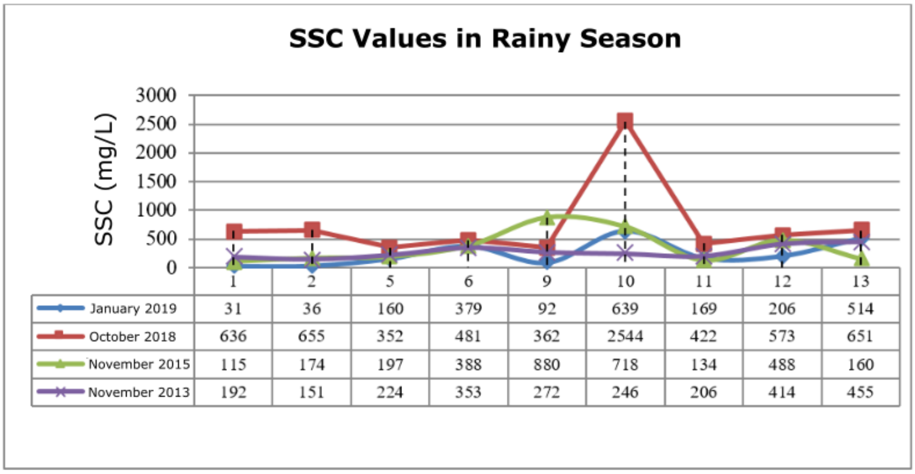
Table 2: Comparison of SSC values between in-situ data and extraction from Landsat-8 image

Point	**SSC values (mg/L)**		**Depth of Sampling (m)**	**Surface current speed (m/s)**
	In-situ	**Landsat**		
1	266,00	272,83	0,5	0,013
2	102,00	149,40	0,5	0,083
5	346,00	321,17	1	0,013
6	138,00	174,44	1	0,106
8	38,00	669,89	1	0,036
9	52,00	117,03	1	0,060
10	156,00	165,80	0,5	0,066
11	106,00	97,19	0,5	0,040
12	74,00	102,80	0,5	0,044
13	64,00	104,52	0,4	0,124



	1	2	5	6	9	10	11	12	13
April 2019	273	149	321	174	117	166	97	103	105
July 2018	188	185	293	240	370	222	161	210	248
June 2015	110	119	223	127	180	161	139	175	226
July 2013	99	95	164	104	77	91	64	88	110
Average	167	137	250	161	186	160	115	144	172

Figure 4: SSC Values in dry season extracted from Landsat-8 images



	1	2	5	6	9	10	11	12	13
January 2019	31	36	160	379	92	639	169	206	514
October 2018	636	655	352	481	362	2544	422	573	651
November 2015	115	174	197	388	880	718	134	488	160
November 2013	192	151	224	353	272	246	206	414	455

Figure 5: SSC Values in rainy season extracted from Landsat-8 images

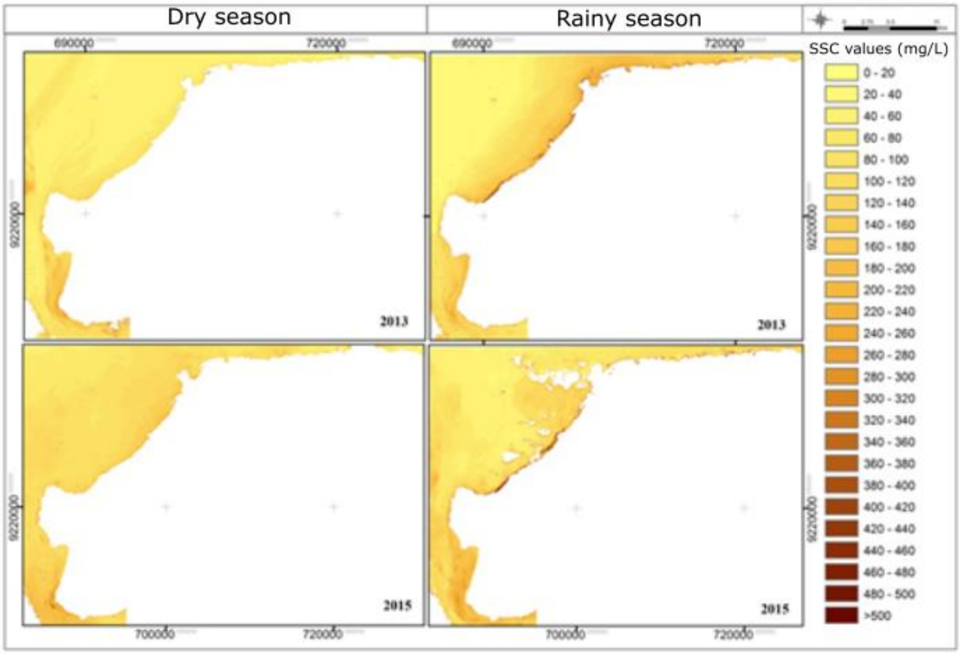


Figure 6: SSC distribution in north and west part coastal area of Madura Island (2013 and 2015)

In the dry season of 2013, the SSC is concentrated in the southern region, especially in the Kamal Sub district and is decreasing for the northern region such as Klampis Sub district to Tanjungbumi District. Whereas in the rainy season, the sediment concentration increases in the northern region increases and decreases in the southern region. This is different from the dry and rainy season in 2015 which showed SSC spread to all regions, although in the rainy season SSC values are higher than in the dry season.

The SSC value in 2018 is higher than in 2019. In the rainy season of 2018, SSC is distributed with the highest value among the other 4 periods. Kamal District, Bangkalan District and Arosbaya District are sub districts with a high concentration tendency and increase in the rainy season.

3.3 Modelling of Currents and Sediment Transport

For each zones, there are three models of currents direction and sediment transport. Those three models are based on three acquisition dates of Landsat-8: 28 July 2013, 16 June 2015 and 10 July 2018. The model for Zone 1 on 28 July 2013 at 09.34 is visualized in Figure 8 and 9. Figure 8 (a) and (b) show that the currents in Tanjungbumi, Sepulu and Klampis Sub districts moves from north to south, perpendicular to the coast and a small part of it is veered following the coastline profile. The type of sediment transport in this region is presented in Figure 9 (a) and (b) which is dominated by onshore-longshore transport (transport perpendicular to the coastline). In the bay area, the current has a small speed. The currents leading to and leaving the bay have a lower speed compared to when at the bay mouth. The same thing also happened in areas that have coastal buildings such as in the area of *PPI* Banyusangka and Telaga Biru Port in Tanjungbumi District. The existence of wharves and beach buildings blocks littoral currents, cause turbulence and bending of currents at a higher speed than in the bay.

From Figure 8, the current conditions in Arosbaya District and the northern part of Bangkalan District are dominated by littoral currents. Littoral currents can act as erosion agents and beach sediment transporters (Astawa and Pandjaitan, 2010). From Figures 8 and 9, it can be seen that the SSC moves in the direction of the current. In the estuary area, the volume of sediment transport is opposite the current speed. For example, in the Gladagpanjang River estuary, the current has small value (Figure 8), while the volume of sediment transport (Figure 9) is relatively high. The current movement and direction of sediment transport on the coast of Arosbaya District are shown in Figures 8 (c) and 9 (c). From the figure, it can be seen that the current moves from north to south. Before reaching Lajing Village in the south, the current turned to follow the profile of the island in Tengket Village. In the figure, it can be seen that the current experienced a little turbulence until it returned to normal when entering Bangkalan District.

The model for Zone 1 on 16 June 2015 at 09.35 is visualized in Figure 10 and 11. The model show that the highest current of Zone 1 are located around the coast of Bangkalan District, with the direction from north to south. In Figure 10 (a) and (b), perpendicular currents occur in the northern coastal region of Madura which is directly adjacent to the Java Sea. In Tanjungbumi and Sepulu Sub districts, the current moves from the beach to the north perpendicularly. This applies also in Klampis Sub district. But in the southern part of Klampis Sub district, the current turned south after passing Tanjung Modung on the northwest side of this sub district. The current is continuously go to the south along the coast to the District of Arosbaya. Longshore current occurs in Arosbaya District. In Figure 10 (c), it can be seen that this area is dominated by littoral currents from the south. Before entering the area of Arosbaya Sub district, the current was seen from the estuary of the Asemtantoh River towards the north along the coast at speeds below 0.48 m/s, then stopped at the end of the northern part of Tengket Village. Thus, the coastal area of Tengket Village becomes a meeting place between currents from Bangkalan and Klampis Districts. Those conditions create a quite significant turbulence in the coast of Arosbaya District, starting from Lajing Village to Tengket Village.

The volume of sediment transport on 16 June 2015 in zone 1 was less than the volume of sediment transport that occurred on 28 July 2013. However, the locations of sediment showed in Figures 11 (a), (b) and (c) did not change. This means, at these points there are continuous sediment transport. The model for Zone 1 on 10 July 2018 at 09.35 shows the maximum current in Bangkalan District with the current direction from the north to the beach. Figure 12 (b) shows the current speed around Telaga Biru Port is quite high with the direction of the current leading to the beach which is sheltered by a pier. This current then spreads to the east and west, afterwards turns and rotates at the base of the dock which close to land. In Klampis Sub district (Figure 12 (b)), the current from the bay spreads and moves to follow the beach profile.

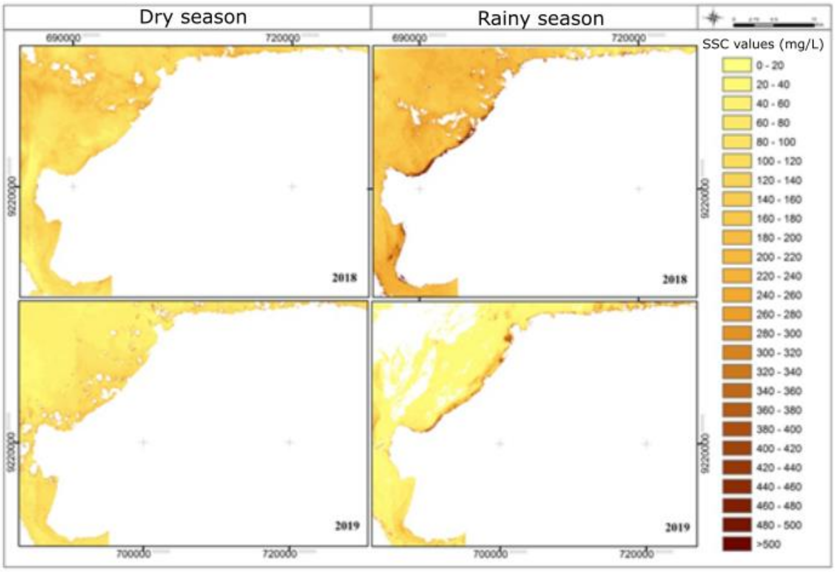


Figure 7: SSC distribution in north and west part coastal area of Madura Island (2018 and 2019)

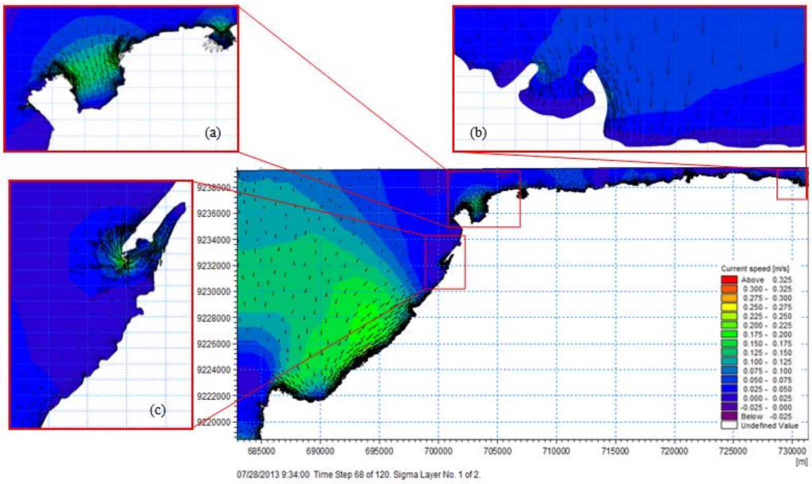


Figure 8: Direction and speed of currents in Zone 1, modelling 28 July 2013 at 09.34

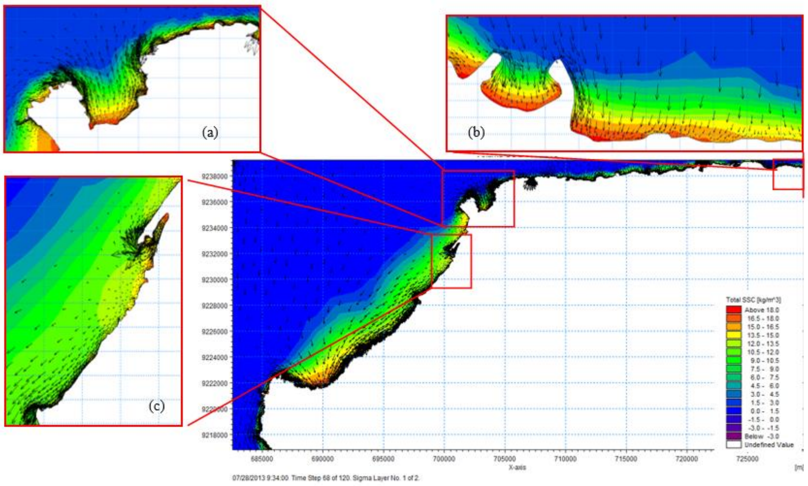


Figure 9: Sediment Transport in Zone 1, modelling 28 July 2013 at 09.34

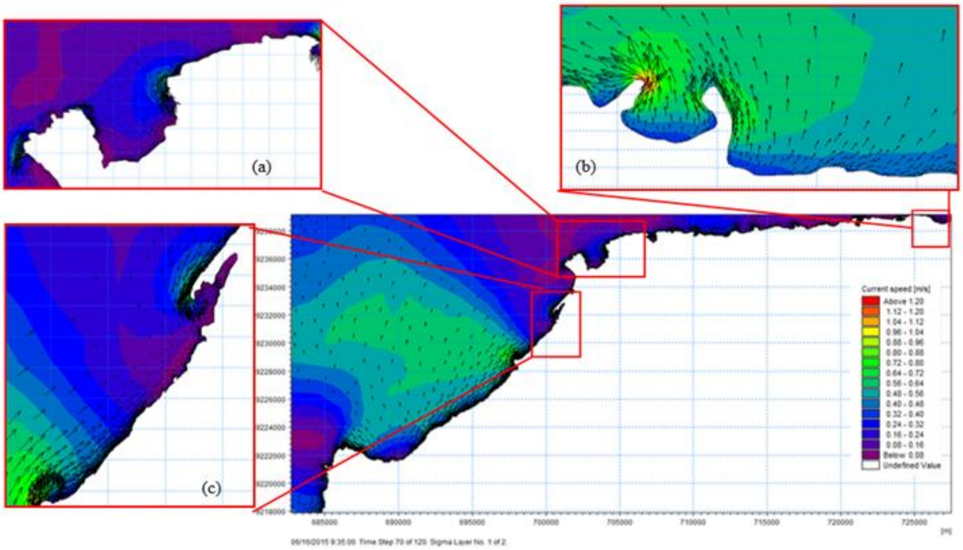


Figure 10: Direction and speed of currents in Zone 1, modelling 16 June 2015 at 09.35

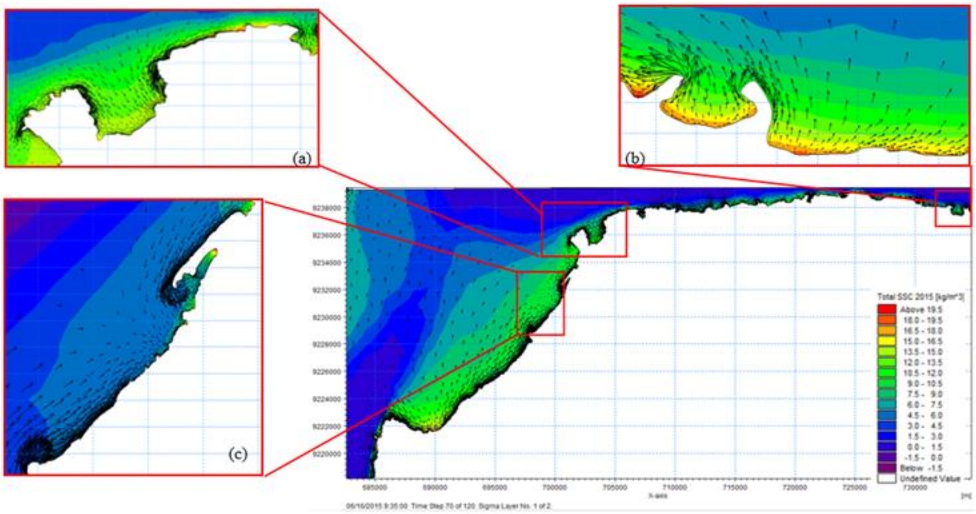


Figure 11: Sediment Transport in Zone 1, modelling 16 June 2015 at 09.35

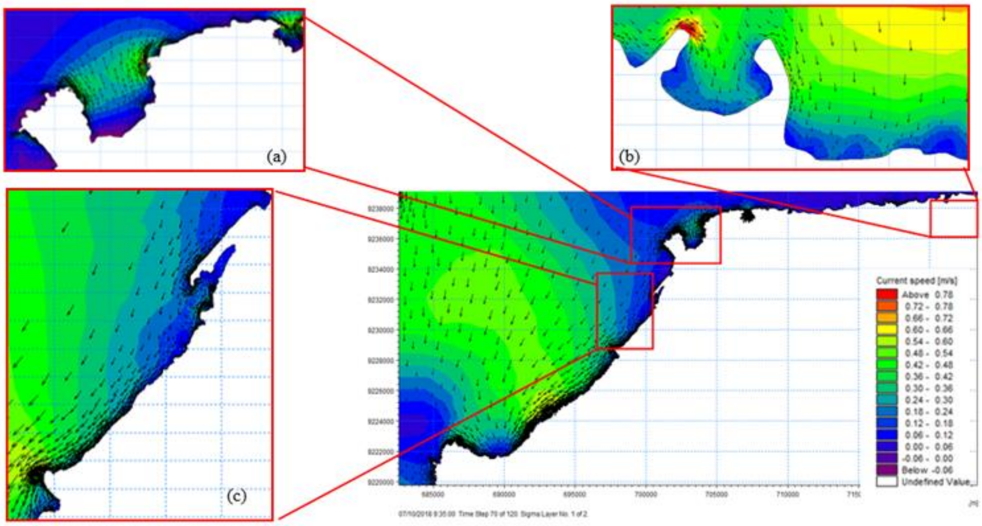


Figure 12: Direction and speed of currents in Zone 1, modelling 10 July 2018 at 09.35

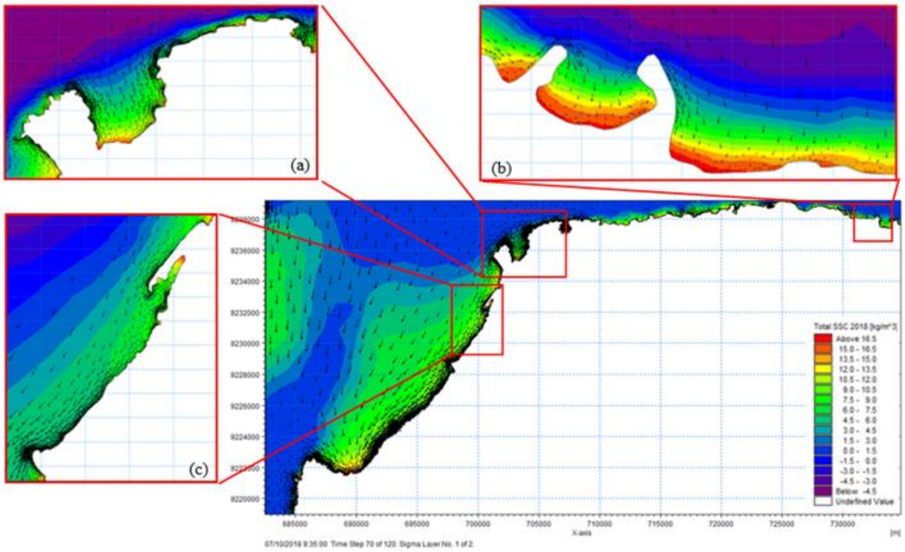


Figure 13: Sediment Transport in Zone 1, modelling 10 July 2018 at 09.35

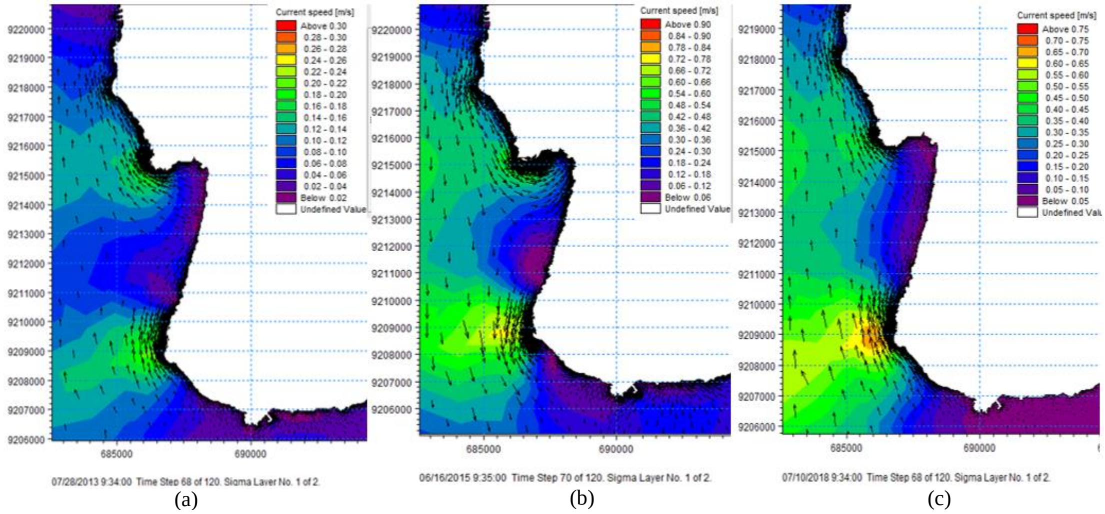


Figure 14: Direction and speed of currents in Zone 2, modelling on (a) 28 July 2013 at 09.34, (b) 16 June 2015 at 09.35, (c) 10 July 2018 at 09.35

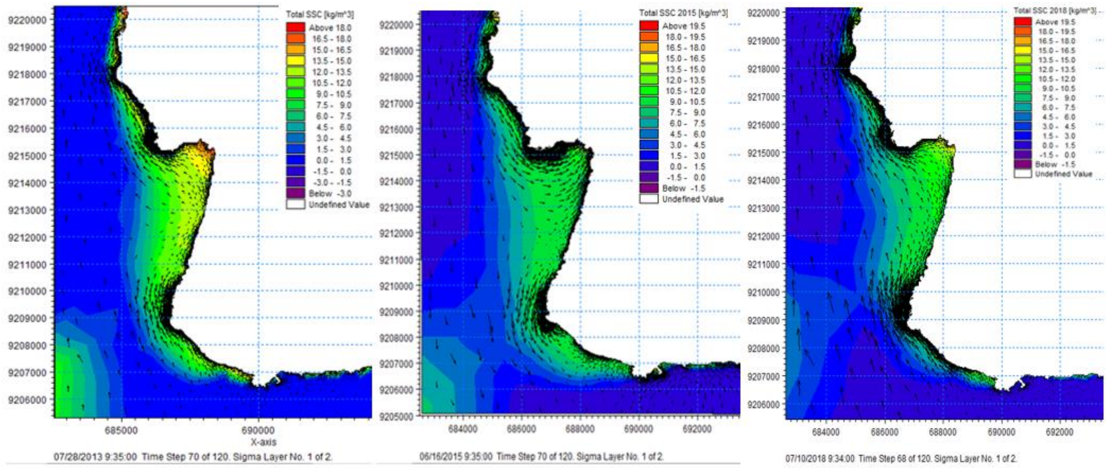


Figure 15: Sediment Transport in Zone 2, modelling on (a) 28 July 2013 at 09.34, (b) 16 June 2015 at 09.35, (c) 10 July 2018 at 09.35

In the northwestern part of this sub district, precisely after passing Tanjung Modung, the current rotates before finally moving towards the south towards Arosbaya District. This flow of rotation can also be seen in Figure 12 (c) at the mouth of Asemtantoh River and on the land around Tengket Village. Sediment transport on 10 July 2018 has almost identical pattern with sediment transport on 16 June 2015. Around the Telaga Biru Port as shown in Figure 13 (b), sediment transport is relatively high and thicker when approaching land. Figure 13(c) show sediment transport in Arosbaya District which rotates in Tengket Village has increased, with the highest volume being found at the edge of the land fold of Tengket Village. In Bangkalan Sub district, the largest volume of transport is found at the mouth of the Asemtantoh River and Gladagpanjang River.

Modeling for Zone 2 of the three different dates is shown in Figures 14 and 15. Figure 14 (a) and (c), for modeling on 28 July 2013 and 10 July 2018, show that currents move along the coast from south to north. The direction of currents from Kamal Sub district continues to north along Gili Barat Village, Tellang and Bulluh to Junganyar Bay, then turn to the Junganyar Selatan Coast to Penarjuh Village until Bangkalan District. Maximum current speed is found on the coast of Junganyar Selatan Village, Socah District and Gili Barat Village, Kamal District. The sediment transport indicated in Figure 15 (a) and (c) show the same direction of motion as currents on that date. The largest volume of sediment transport is in Socah Sub district Junganyar Village. In the model of 16 June 2015 (Figure 14 (b) and 15 (b)), it can be seen that sediment transport moves with the current, parallel to the coastline from north to south. In Junganyar Selatan Village, the direction of the current is divided into two: turn towards the bay and then enter the estuary area of the Gladagpanjang River in the District of Socah and the remainder moves towards Kamal District. The maximum current speed is found on the coast of Junganyar Selatan Village, Socah District and Gili Barat Village, Kamal District.

4. Conclusion

The result of this research indicates that the physical condition of coastal area can be monitored by analyzing sedimentation patterns. Sedimentation patterns are observed using SSC value also modelling of currents and sedimentation transport. SSC values extracted from Landsat-8 images in 2013, 2015, and 2018 showed good results. The RMSE value is 35.137 mg/L and NMAE reaches 15.68% or less than 30%. On the north and west coastal areas of Madura Island, the SSC values tend to be higher in the rainy season than in the dry season. The highest SSC value (250 mg/L) of dry season is found in the Gladagpanjang River Bangkalan District, while the lowest SSC value (115 mg/L) is in Tengket Village, Arosbaya Sub district. In the rainy season, the highest SSC value (445 mg/L) is found at point 13 and the lowest (233 mg/L) is at point 11.

From the modelling, currents speed and direction can be observed. In addition, direction of sediment transport and its value can also be monitored. All sub districts in this study which are directly adjacent to the Java Sea have a perpendicular currents pattern toward the coastal area. Another sub districts which have parallel currents pattern are experienced a significant dynamics of coastal conditions. A strong current will transport sediment material following the current direction and stop when it encounters an estuary or a barrier which can cause turbulence then settles in a quieter current condition. Based on the results of this study, in the future the dynamics of shoreline changes can be observed. This is because, factors which can determine the dynamics of shoreline changes are oceanographic conditions including the direction of currents and sediment transport.

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