Article

Monitoring Total Suspended Solid Distribution In Coastal Bali Area Using MODIS Satellite Data

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Abstract

Total Suspended Solid (TSS) is one important parameter for water quality. This research aims to analyze MODIS feasibility for identifying TSS, to identify TSS monthly patterns and annual patterns variability, and to analyze the TSS distribution patterns around Bali coastal area. Observation data of the wet season was observed in Benoa Bay on 2nd October 2013 and the dry season was observed in Perancak from July on 28th to July 31st, 2009. The comparison between observation data and satellite data was used to establish a new modification algorithm for suitable conditions around Bali coastal area. Based on research analysis, the feasibility of MODIS was different in each season. In the wet season, the coefficient correlation was (r) = 0.55 and in the dry season, it was (r) = 0.68. poor correlation in the wet season indicated the bottom effect of the area which has a shallow and heterogeneous depth. The TSS average in the wet season was 75.55 mg/l and 55.97 mg/l in the dry season. The highest value was analyzed in November (82.74 mg/l) and the lowest value in June (46.41 mg/l). During wet season, the stream volume and the stream flow rate increase and bring the TSS into coastal areas through the runoff process. The mapping patterns showed that the southern coastal area and western coastal area of Bali had a high value every month. The northern coastal had a high value only in the wet season. The characteristic of Bali river area, which is perennial and intermittent rivers caused this phenomenon. The population and Bali land-use area also affected the high TSS in these areas. Yearly patterns of TSS from 2009 to 2013 around Bali coastal areas were different every year. The highest TSS distribution observed in 2013 wet season is 87.75 mg/l. The lowest TSS distribution occurred in 2009 dry season with a value of 52.2 mg/l. The TSS tends to increase every year due to the changing in Bali land use. TSS patterns from 2009 to 2013 were dynamic every year. The El Nina and La Nino events also gave impact on the patterns. The MODIS feasibility in different locations was different depending on the characteristic of the physical property of water. The shallow and small area causes misinterpretation of the satellite reflectance. The TSS monthly patterns depended on the season and the mapping can be used to describe the sources of TSS pollution, the distribution, and the quantity of TSS in the coastal area.

Keywords: *MODIS; Total Suspended Solid (TSS); Water Pollution; Mapping*

1. Introduction

Total Suspended Solid (TSS) is an important parameter to know whether the water quality is good or bad (Su et al, 2008). It plays a major role in biological, chemical, and physical processes. TSS contains organic and inorganic material and is expressed as mg/l (Esquivel, 2011).

Bali is a small island yet a well-known tourism destination in the world. It is surrounded by coastal area which has high diversity of natural resources such as coral reefs, mangroves, fish, etc. The rapid development will make Bali has a potentially high risk of water pollution. It is contrasted to the environment itself. The imbalance of both environment and development will destroy Bali, especially due to water pollution such as

TSS. The effect of TSS pollution in water body can be a harmful for the environment and living organism (Ayana et al., 2015). The primary effect is reducing water's ability to penetrate the light energy and decreasing primary productivity (Usali and Ismail, 2010).

Nowdays people start to use remote sensing data as a tool for environmental management systems (Cohen and Goward, 2004). The conventional research for TSS delivers accurate data but it has a weakness. It is difficult to do monitoring in the long term, expensive, time-consuming, and can only be used for specific points. The weakness of conventional methods can be improved by remote sensing technique (Ahn et al., 2001).

One satellite data that can be used for monitoring coastal area is Moderate Resolution Image Spectroradiometer (MODIS; Kim et al., 2017). MODIS provides a good temporal resolution which is crossing one area in one to two days for monitoring purposes. Remote sensing technology has a possibility for detecting and mapping pollutant agents to better understand the spatial and temporal patterns, as well as to determine the affected areas and identify the pollution source and distribution.

The monitoring study of the TSS distribution in Bali coastal area using MODIS satellite is important for a better understanding of sediment flux and processes in the coastal environment to maintain water quality and geomorphologic balance. Effective mapping and monitoring technology for TSS will support research investigations, environmental assessments, and management efforts. This monitoring will be very helpful to identify the state, distribution, and sources of water pollution.

2. Method

2.1 Study Area

The study area is located in Bali coastal area (Figure 1). The coordinate location is -7.97 - -8.90 S and 114.37 - 115.79 E. This research was conducted in wet season (from October to March) and dry season (from April to September), from 2009 to 2013. In situ data for wet seasons were collected on 2nd October 2013 at Benoa Bay Area (Southern Bali) with 30 points of sample locations. Meanwhile, in situ data for dry seasons were collected from July 28th to July 31st, 2009 at Perancak Area (Western Bali) with 29 sample points.

2.2 Research Materials and Instruments

The materials of this research are Satellite Images MODIS Terra (250 m spatial resolution) from 2009 to 2013 (NASA, 2014) and TSS in situ data from Benoa bay and Perancak in 2009. Research instruments used in this study are ENVI 4.7, ArcGIS 10, and Microsoft Excel 2003.

2.3 Preprocessing Data

Satellite data from Terra MODIS Level 1B (L1B) is needed to be processed before extraction to TSS algorithm. The methods of preproccesing data were:

- Geometric and Bow Tie correction

Georeferencing is the processes of scaling, rotating, translating and deskewing the image to match a particular size and position. To georeference is to define location in physical space and is crucial in the making of aerial and satellite imagery useful for mapping. With ENVI 4.7, World Geodetic System 1984 (WGS 84) used as the DATUM map. The MODIS L1B data set contains calibrated and geolocated at aperture radiances for 36 discrete bands covering the part from 0.4 µm to 14.4 µm of the electromagnetic spectrum. Bow Tie correction needs to be set at Terra Level 1B due to the distortion caused by the characteristic of the MODIS sensor and the Earth's curvature.

- Digital Number to Reflectance

The digital number was converted to reflectance value using Envi 4.7 with the algorithm from MCST, 2012.

$$\rho = ref\_scalesB(SI - ref\_offsets) \tag{1}$$

Where ρ is reflectance value; ref_scales is reflectance scales from the satellite attribute file; ref_offsets is reflectance offsets from the satellite attribute file; and SI is a digital number of band 1 from satellite data

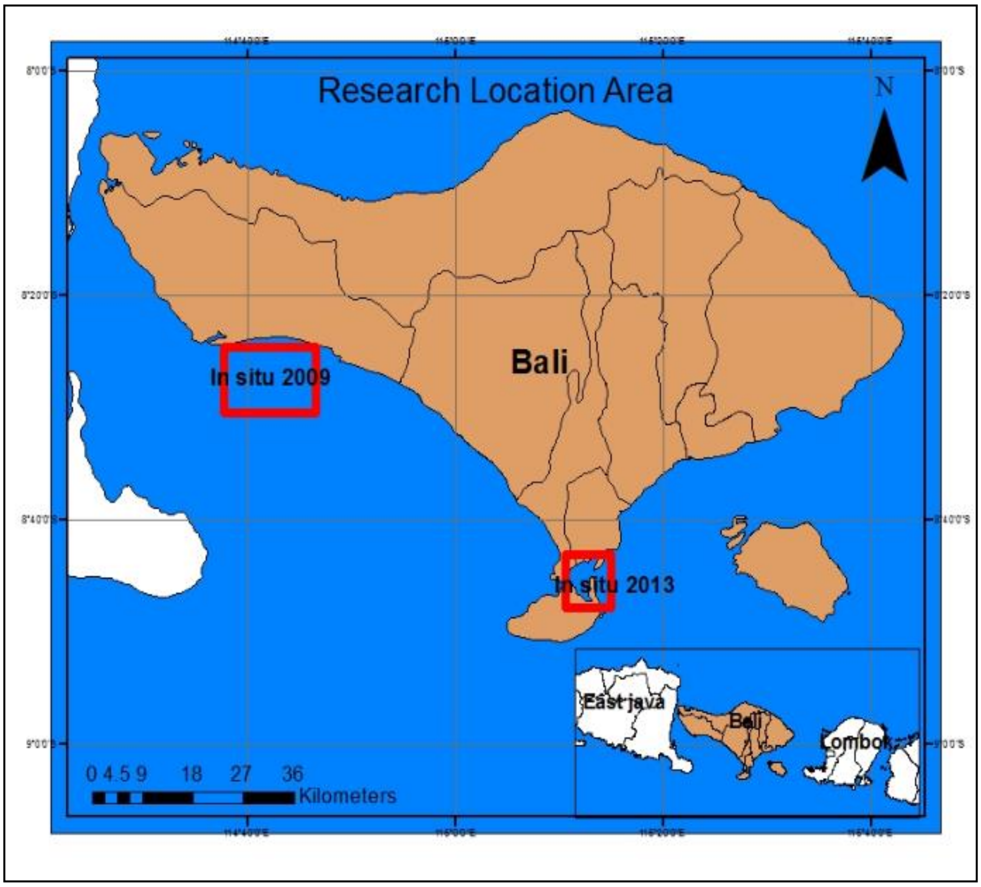

Figure 1. Location of Study Area

- Resize and Masking

Resize satellite is used to make the limitation of study area in the same coordinate location. Masking area is important to make separation between land, cloud and sea. The threshold value of near infrared reflectance is used for masking process.

- Atmospheric Correction

The atmospheric correction method used Dark Object Subtraction (DOS). DOS is a simple method which assume that the darkest object in reflectance value for near infrared band should be zero in the deepest water. The dark subtract of atmospheric correction consisted in the selection of the darkest value in band 2 and subtracting it to all band 1 data. This value was manually identified on each image and then defined in the "User Value" option of this routine.

2.4 Extracting TSS Data

Estimation of TSS from satellite data in the coastal Bali area used the algorithm by Miller and McKee (2004):

$$TSS(mg/l) = (1140.25\, b1) - 1.91 \tag{2}$$

Where TSS (mg/l) is a TSS extraction from modis satellite data and b1 is reflectance value from band 1.

2.5 Statistical Approach

In order to examine the relationship between in situ TSS data and TSS from satellite observation data, we use statistical approach of correlation coefficient. The formula of correlation coefficient is as follows:

$$r = \frac{n\sum xy - \left(\sum x\right)\left(\sum y\right)}{\sqrt{n\left(\sum x^2\right) - \left(\sqrt{x}\right)^2}\sqrt{n\left(\sum y^2\right) - \left(\sum y\right)^2}} \tag{3}$$

Where r is a correlation coefficient value; n is the number of sample; x is TSS from in situ measurement and; y is TSS from in situ measurement.

3. Result and Discussion

3.1 MODIS Feasibility

The wet season was observed in Benoa bay at the morning of 2nd October 2014 when the MODIS satellite passed the study area. After preprocessing, there were 13 points of sample data used in this study. The reflectance value in Benoa Bay during wet season ranged from 0.07 to 0.12 and the TSS satellite value started from 77.99 mg/l to 136.77 mg/l. The TSS detection from satellite data was very high compared with in situ data which ranged from 24 mg/l to 57 mg/l (Table 1).

Table 1. In situ TSS data and satellite TSS data during wet season

No	Latitude	Longitude	TSS in situ (mg/l)	Reflectance	TSS satellite (mg/l)
1	-8.75	115.19	57.00	0.10	110.15
2	-8.75	115.20	39.00	0.10	111.95
3	-8.75	115.20	42.00	0.09	98.67
4	-8.75	115.21	39.00	0.09	98.39
5	-8.75	115.21	39.00	0.12	136.77
6	-8.75	115.21	39.00	0.07	77.99
7	-8.74	115.21	33.00	0.08	94.97
8	-8.75	115.22	43.00	0.07	78.66
9	-8.76	115.21	34.00	0.09	103.93
10	-8.76	115.20	42.00	0.10	109.59
11	-8.77	115.20	39.00	0.09	95.47
12	-8.77	115.21	45.00	0.10	110.27
13	-8.75	115.20	24.00	0.09	101.86

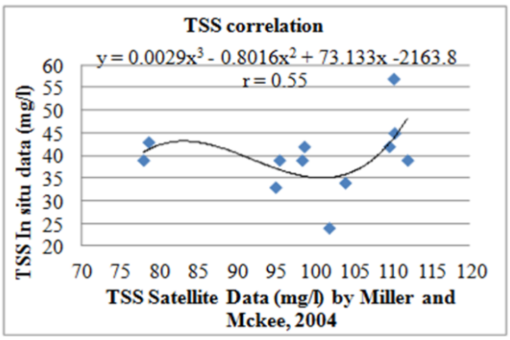

Figure 2. The coefficient correlation between TSS in situ and Miller and McKee in wet season

The correlation coefficient was 0.55 in polynomial power 3 correlation. The equation was $0.0029x^3 - 0.8016x^2 + 73.133x - 2163.8$ (Figure 2).

The dry season data were observed from 28th to 31st July, 2009 by Badan Observasi Kelautan (The Marine Observation Research) at Perancak in western Bali. The number of data after preprocessing were 15 samples (Table 2)

Table 2. In situ TSS data and satellite TSS data during dry season

No	X	Y	TSS in situ (mg/l)	Reflectance	TSS satellite (mg/l)
1	-8.41	114.58	43	0.03	35.77
2	-8.42	114.58	63	0.04	45.58
3	-8.44	114.58	59	0.03	32.42
4	-8.41	114.59	106	0.05	57.21
5	-8.42	114.60	99	0.04	42.10
6	-8.38	114.55	68	0.04	41.21
7	-8.39	114.55	22	0.03	34.93
8	-8.39	114.57	49	0.03	35.42
9	-8.42	114.57	63	0.03	33.41
10	-8.41	114.70	24	0.02	20.09
11	-8.44	114.70	53	0.01	11.50
12	-8.43	114.71	81	0.02	25.63
13	-8.44	114.61	47	0.03	29.34
14	-8.42	114.65	38	0.03	28.67
15	-8.44	114.67	41	0.03	29.04

The reflectance value in the dry season ranged from 0.01 to 0.05. The TSS ranged from 11.50 mg/l to 57.21 mg/l. The in situ data value ranged from 22 mg/l to 106 mg/l. The coefficient correlation value was 0.68 at Polynomial power 3 correlation with the equation of $-0.0007x^3 + 0.1172x^2 - 4.1599x + 84.264$ (Figure 3).

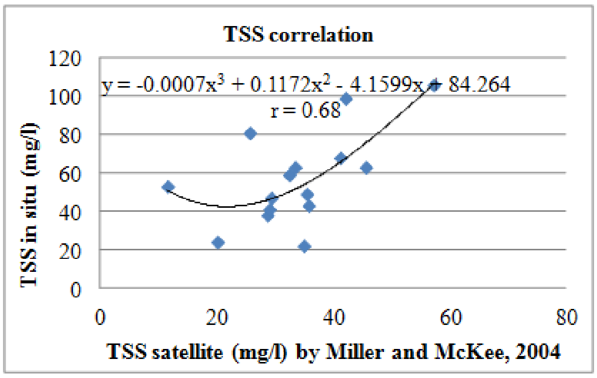

Figure 3. The coefficient correlation between TSS in situ and Miller and McKee in dry season

The MODIS feasibility to identify TSS distribution was based on the comparison between in situ data and satellite data by Miller and McKee algorithm. In wet season, the difference between in situ TSS and TSS satellite is significant. The coefficient correlation in wet season was 0.55 and in the dry season was 0.68. The coefficient correlation in dry season showed good value compared to the wet season.

In situ data during wet season was taken in Benoa bay which has unique characteristics such as shallow and small area and heterogeneous in depth area. In the dry season the in situ data was observed from Perancak which had large areas and homogeneous in depth. The low coefficient correlation in the wet season because of the satellite had wrong interpretation due to the strong reflectance from the bottom area in Benoa bay. The shallow area and the heterogeneous in depth impact to reflectance value. Rong-Rong et al. (2003) mentioned that the sediments and shallow waters provided such unaccounted high reflectance. Guzmán and Fernando (2009) showed sometimes in situ and the satellite data founded not good in correlations because of the presence of sea bottom effect signal.

The relationship between in situ data and TSS satellite data found curvilinear (polynomial power three correlation). It is the same as some past research, between suspended sediment and radiance or reflectance has curvilinear because the reflectance and radiance tends to saturate as suspended sediment concentration increase (Ritchie et al, 1976; Curran and Novo, 1988; Mobasheri, 2003).

3.2 TSS monthly patterns

In wet season, the average value started from 64.15 mg/l to 82.74 mg/l. The average TSS during wet season was 75.55 mg/l. In dry season the TSS value started from 46.41 mg/l to 69.08 mg/l with average value was 55.97 mg/l. The TSS in wet season was higher than in dry season. The highest TSS occurred in November (TSS = 82.74 mg/l) and the lowest in June (TSS = 46.41 mg/l). It is shown at Table 3 and Figure 4 as a following

Table 3. TSS monthly value in 2009

Season	Month	TSS (mg/l)
Wet	January	73.05
	February	76.93
	March	64.15
	October	80.87
	November	82.74
Dry	April	57.91
	May	57.93
	June	46.41
	July	46.49
	August	57.97
	September	69.08

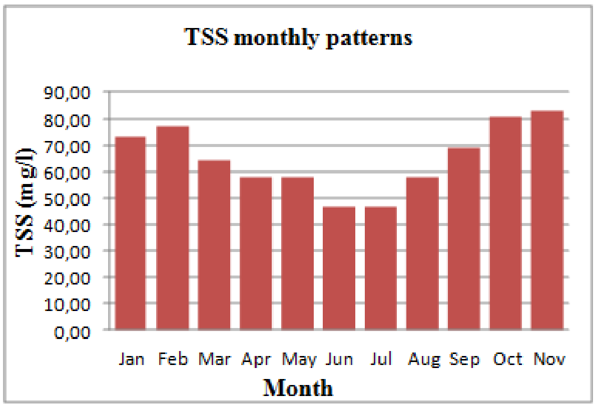

Figure 4. TSS monthly patterns in 2009

Remote sensing is an effective tool for monitoring large area and simultaneously. The distribution of TSS in Bali coastal area can be described through monthly mapping by remote sensing analysis. Figure 5 shows monthly mapping of TSS.

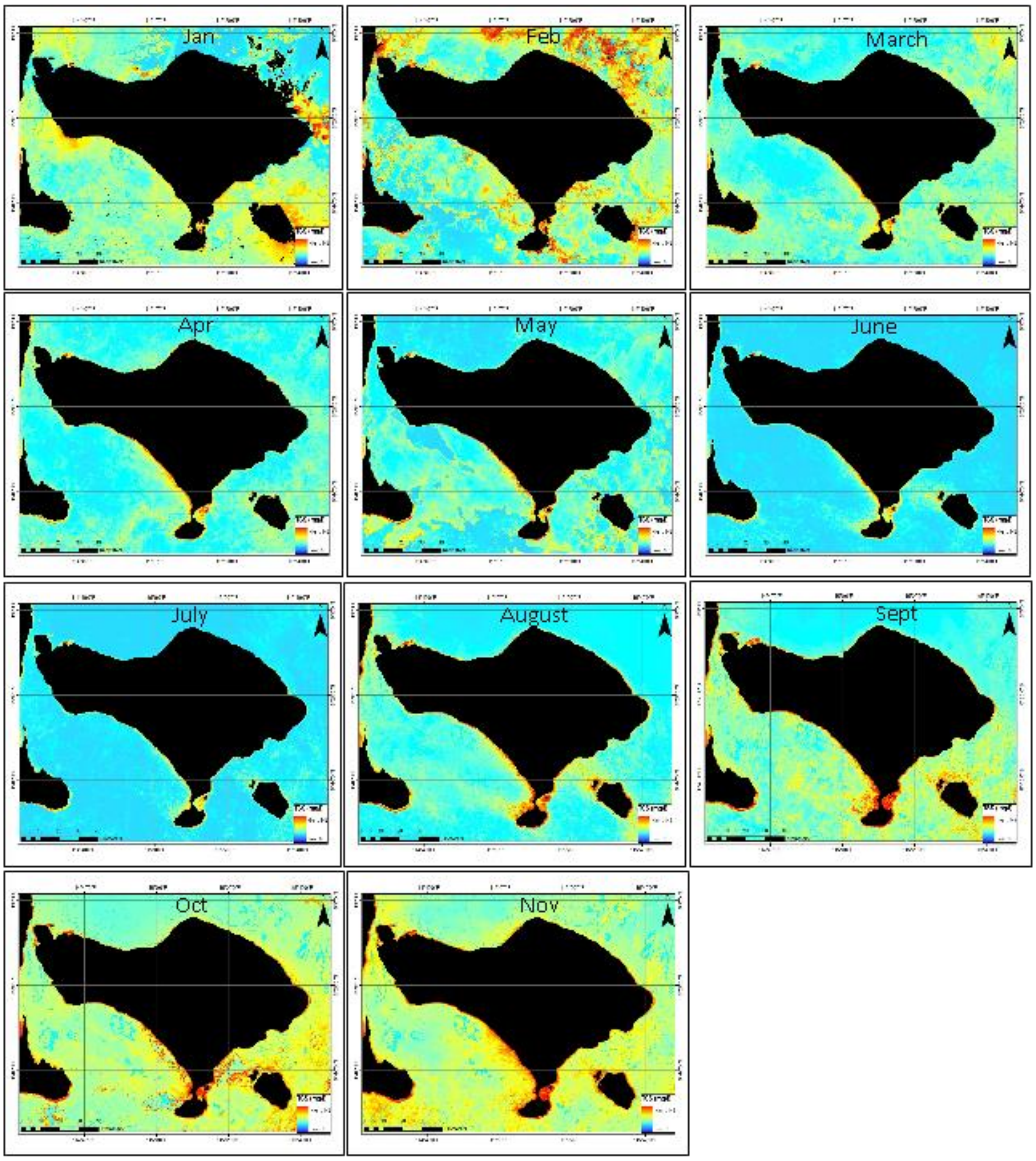

Figure 5. The TSS distribution patterns in 2009

TSS has high value during wet season. It was indicated by the dominance of yellow color on the map. The distribution of TSS shows the south Bali coastal area has a high TSS every month and tends to increase especially in wet season. While, the north Bali coastal area shows small value. TSS monitoring is very important because it is one important parameter for water pollution indicator. Based on current study, the TSS distribution and its sources are predominantly come from the south and west area and the lowest value is shown in the north area. It is probably due to the characteristic of some rivers in Bali area. There are two characteristics found in Bali area; perennial river and intermittent river. Perennial rivers with high water debit can mostly be found in the south and west area with high debit water. BLH Bali Province (2009) found that the highest river debit potential is in the south area which is 29.09 m^3/s. The north area of Bali is delineated by an intermittent river (Figure 6).

Another source which might affect high TSS in the south and west of Bali coastal area is the population number. The southern area is known to have high population numbers alng with the rapid urban development (As-syakur, 2011). It has a positive correlation with an input of water pollution in coastal areas. Based on P3E MOEF (2015), the density population growth in Badung (South Bali) is 4.62% each year. The Bali area land use is shown at Figure 7. The concentration of particulate matter and therefore the intensity of scattering in estuarine water is strongly influenced not only by the nature but also by the land use (Kirk, 2011). The southern region is the center of tourism development in Bali, especially in coastal and marine tourism there are fisheries, aquaculture, port and shipping, industries and tourism (PEMSEA and Bali PMO, 2004).

Figure 6. The rivers map in Bali area (BLH Bali Province, 2009)

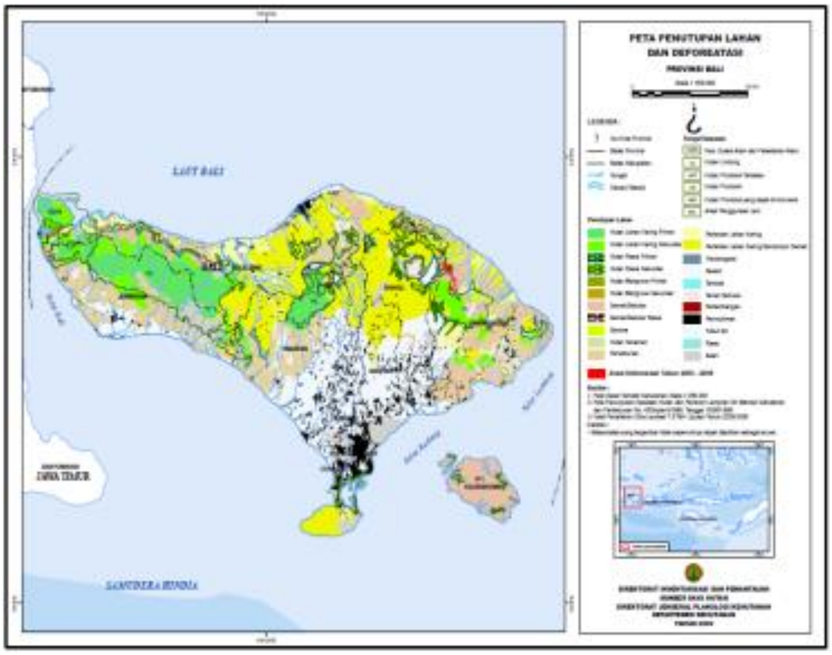

Figure 7. The map of Bali land use (P3E MOEF, 2015)

3.3 TSS annual patterns

TSS in the Bali coastal area is changing every year and the graphic shows that the TSS tends to increase. TSS patterns from 2009 to 2013 in dry season and wet season is shown in Table 5.4 and Figure 5.5 as follows.

In dry season, TSS ranges from 52.2 mg/l to 70.73 mg/l. In wet season the value of TSS is higher than dry season ranging from 76.96 mg/l to 87.75 mg/l. The highest TSS value recorded in 2013 during the wet season (TSS = 87.75 mg/l). The lowest TSS recorded in dry season of 2009 (TSS = 52.2 mg/l).

Table 4. The TSS value from 2009 to 2013

No	Year	Dry season TSS (mg/l)	Wet season TSS (mg/l)
1	2009	52.20	76.96
2	2010	57.30	86.44
3	2011	59.79	81.16
4	2012	54.36	81.16
5	2013	70.73	87.75

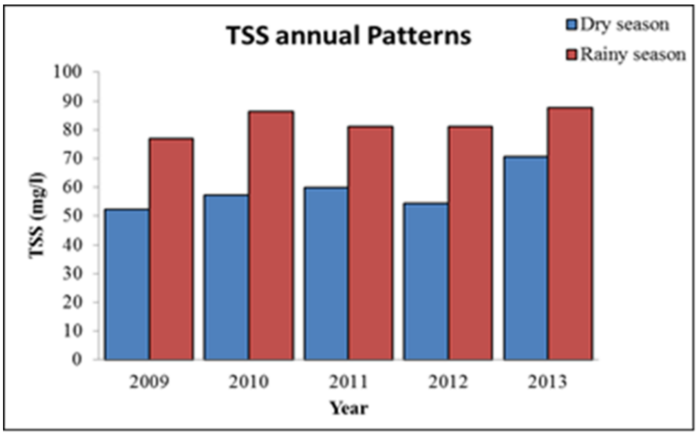

Figure 8. The TSS concentrations from 2009 to 2013

Suspended solids refer to organic and inorganic fine solid particles suspended in seawater. It includes contributions from biological components like plankton and the excretion and remains of marine organisms. Other natural sources include eroded soil and rocks that are carried to the sea by runoff. TSS patterns from 2009 to 2013 were dynamics every year (Table 4 and Figure 8). The patterns of TSS are related to El Nina and La Nino phenomenon. The TSS values are dynamics every year and tend to increase. The TSS values were increased significantly in 2010 but decreased in 2011 and 2012. Strong La Nina was occurred in 2010 and it changed the intensity and quantity of the rainfall. La Nina affects the pattern of rainfall, atmospheric pressure, and global atmospheric circulation. La Niña is characterized by lower-than-normal air pressure over the western Pacific. These low-pressure zones contribute to increased rainfall (JanNull, 2014). The high TSS recorded in 2010 was due to the high intensity and quantity of rainfall.

The highest TSS was observed in 2013 and was anticipated to increase in the next year. Bali is known for its rapid urban development among other regions in Indonesia because of its tourism potential. It leads to significant impact on the natural environment especially water pollution. In 2004, PEMSEA and Bali PMO found that the suspended solids come from river flows, the run-off from the surrounding areas, and domestic waste discharges. It is also sourced from land-use practices in the watershed sand along the coast such as land reclamation projects, aquaculture, agricultural activities, and mining activities.

4. Conclusions and Suggestions

4.1 Conclusions

The conclusions of this research are as follows:

1. The MODIS feasibility in different locations can differ depending on the characteristic of physical property of water. The shallow and small area can give misinterpretation of the satellite reflectance. Benoa Bay is unsuitable area for remote sensing application to TSS detection because the area is too shallow, small, and has heterogeneous depth.
2. The TSS monthly patterns depend on the season. The increasing of TSS value starts in the beginning of wet seasons, reaches the peak in the middle of wet season and decreases in dry season. TSS value in wet season is higher than dry season. The El Nino and La Nina phenomenon followed by the TSS annual pattern from 2009 to 2013
3. The distribution of TSS in southern and western coastal area is higher than in the north of Bali coastal area.

4.2 Suggestions

The suggestions from the authors are as follows:

1. To provide good analysis, the research needs many samples from different locations in order to get a new accurate equation, especially in wet season. Ideally, the research requires wide and homogeneous area characteristic for minimising the sea bottom effect.
2. The research needs to apply different atmospheric correction besides the Dark Object Substrate correction as comparison.

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