SPATIAL ANALYSIS OF TOTAL SUSPENDED MATTER DISTRIBUTION FROM LANDSAT 8 OLI IN LOMBOK COASTAL, INDONESIA

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Abstract. The presence of suspended matter in water is responsible changing the spectral composition of the water. Total Suspended Matter (TSM) are fine materials and originate from lands, plants, animals or microorganisms found on the continental shelf which made water columns becoming turbid and reduced the depth of light penetration. TSM concentration can be estimated from satellite image such as Landsat 8 OLI and the distribution could be analysis spatially. Thus the objective of this study is to analysis the distribution of TSM from Landsat 8 OLI. The research was carried out in Lombok coastal, Indonesia and the analyses was conduct by using empirical approach. The result showed that the estimation of TSM concentrations spread out near coastal Lombok and the concentration was around 0.39 – 20.7 mg/l. It was also shown that TSM becoming high when it is near coastal and low when it is far from the coast. This result has 91.8 % correlation with field measurement and RMSE value is 0.52.

1. Introduction

Coastal represent the interface between land and ocean where freshwater mixes with ocean water but the mixing occurs more widespread along the coast as opposed to transitional waters dominated by strong gradients from the freshwater source to the sea end-member (Wiser 2016). Coastal waters extending one nautical mile from land points where territorial water are measured. Coastal waters include water that has not designated as transitional water. Coastal waters also include bays and estuaries, and territorial waters from shorelines out to 12-mile limit (EPA 2016). Transitional and coastal waters is the most productive ecosystems in the world. Monitoring water quality is important to follow the changes status of water conditions, especially in Lombok coastal, since its designated as tourism and business area of marine culture (Pijar 2012).

One of water constituent which can describe water quality in coastal waters is Total Suspended Mater (TSM) concertation. TSM is concentration of particle suspended in water, which could be organic and inorganic, originates from erosion and human activities. The increasing of the sediment load in coastal waters make the water turbid and its effect reducing the ability of sunlight penetration into water. TSM could be measured by in situ (sampling-based) measurements and remote sensing technology. The remote sensing technology offers the ability to TSM mapping and monitoring for vast area nearly continuously. The remote sensing technology could cover the limitation of in situ measurements in spatial and temporal coverage.

The remote sensing technology for monitoring of coastal waters is started in 1977 when Coastal Zone Color Scanner (CZCS) was found (Gordon et al. (1983), Morel and Prieur (1977)). CZSC is the first multispectral instrument which used for ocean color measurement. Remote sensing satellite provides ocean color data for monitoring water quality such as TSM. Many study has been carried out for monitoring TSM using remote sensing for coastal waters, among others, by Kirk (1983), Tassan (1994), Budhiman (2004), Parwati,et al (2008), Parwati (2014), Putra et al. (2014), Qu (2014) and

Kumar et al. (2016). Those authors worked on developing of algorithm and applications of TSM mapping based on multispectral satellite data, such (SeaWiFS) MODIS, OCM, Landsat and SPOT.

The objective of this study are extracted and analyzed of TMS concentrations spatially based on Landsat 8 OLI (Operational Land Imager). This study is applied Tassan (1994) algorithm which has been modified based on field measurement. As one of multispectral satellite, Landsat can be used for TSM monitoring in coastal waters because Landsat have spectral bands from visible to infrared with 30-meter of spatial resolution and 16 days of temporal resolution. The present generation of Landsat satellite series is Landsat 8 OLI which has much more of spectral bands compared with the previous Landsat series. Landsat 8 OLI is replacing Landsat 7 which have problem with striped data. The specification of Landsat 8 OLI is showed in Table 1.

Table 1. The band specification of Landsat 8 OLI (USGS 2016)

Band	Specifications
Band1	Coastal/Aerosol, (0.433 – 0.453 µm), 30 m
Band2	Blue, (0.450 – 0.515 µm), 30 m
Band3	Green, (0.525 – 0.600 µm), 30m
Band4	Red, (0.630 – 0.680 µm), 30 m
Band5	NIR, (0.845 – 0.885 µm), 30 m
Band6	SWIR 1, (1.560 – 1.660 µm), 30 m
Band7	SWIR 2, (2.100 – 2.300 µm), 30 m
Band8	Pan, (0.500 – 0.680 µm), 15 m
Band9	Cirrus, (1.360 – 1.390 µm), 30 m
Band10	LWIR 1, (10.3 – 11.3 µm), 100 m
Band11	LWIR 2, (11.5 – 12.5 µm), 100 m

2. Methodology

The study area is located at Lombok coastal, Indonesia with latitude $8^0$2'39.68" S to $9^0$10'6.27" S and longitude $115^0$42'40.19" E to $116^0$50'21.81" E (Figure 1). Landsat 8 OLI data on September 19, 2014 was used in this study. Field data were collected under different tidal, sun angle and could cover conditions. Field measurement covered the Tanjung An, Gerupuk Bay and Awang Bay. In situ measurement of reflectance and TSM concentration based on laboratory measurement was carried out synchronous to Landsat 8 OLI passed over Lombok island. TSM concertation measured at Bogor Agriculture University Faculty of Fisheries Laboratory based on water samples which is collected from 15 observation stations at Lombok coastal which spread from Tanjung An, Gerupuk Bay and Awang Bay (Figure 1). TSM concentrations of laboratory were determined using the gravimetric method based on water filtered through pre-weighed filters (Whatman GF/F filters, pore size of 0.45 µm) which dried and reweighed (Budhiman et al. 2012).

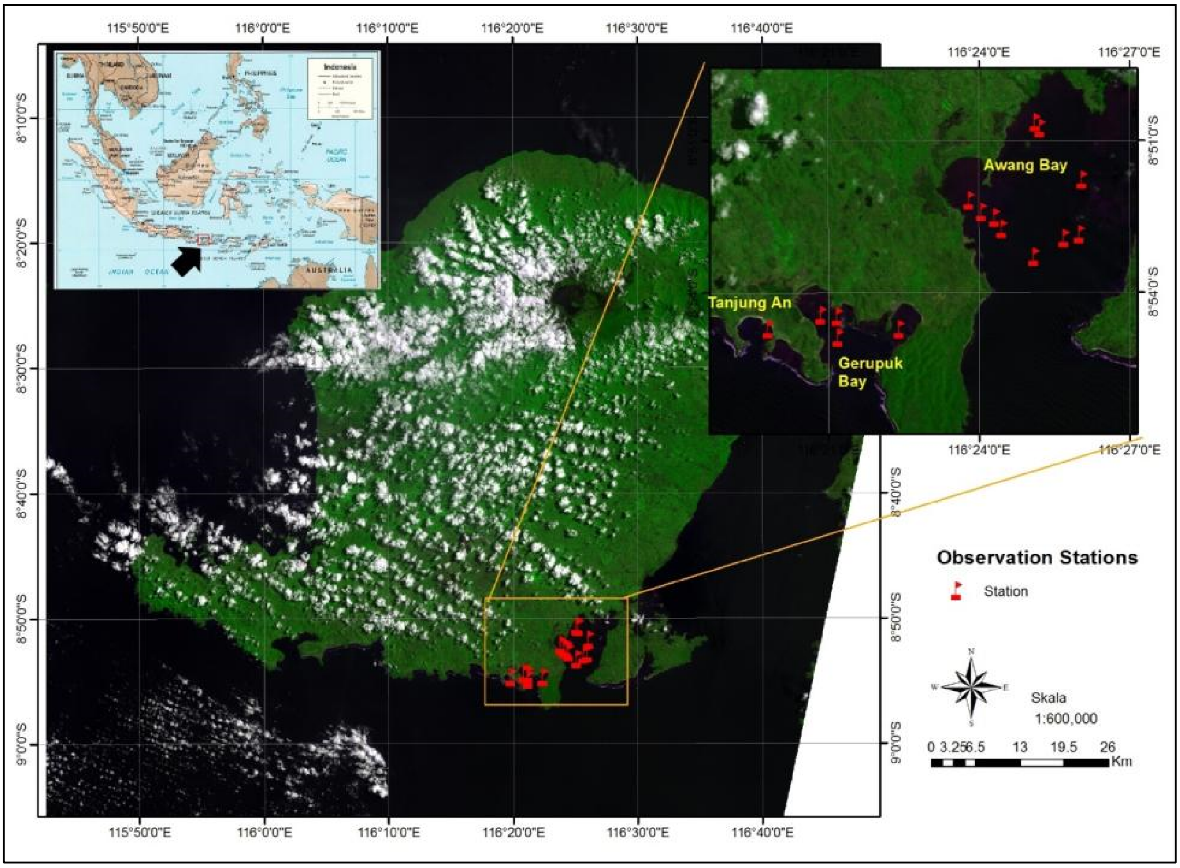

Figure 1. Study area and observation stations which indicated by red flag symbol

The transparency is measured by Secchi disc, while position of water samples collection was measured by GPS. Furthermore, the image processing and analysis was carried out using ER Mapper 2014, ENVI 5.0 and ArcGIS 10.1. Processing for in situ reflectance from TriOS RAMSES was retrieved using MSDA_XE software and the statistical analysis is carried out using Microsoft Excel.

Optical measurements were conducted simultaneously with water sample collection using above water measurement technique performed with TriOS RAMSES hyperspectral radiometer. This study was used for reflectance measurement in the wavelength range from 400 to 700 nm with 10 nm interval. TriOS RAMSES consists of three sensors which are irradiance sensor for Ed and two radiance sensors for Lsky (sky radiance) and Lu (upwelling radiance) measurement. The measurements were taken at 40 deg ($\theta = 40$ deg) relative to nadir and zenith (Hommersom et al. 2012). According to Hommersom et al. (2012), water leaving radiance $L_w(\lambda, \theta)$ is measured through formula:

$$L_w(\lambda, \theta) = L_u(\lambda, \theta) - 0.028 \times L_{sky}(\lambda, \theta) \quad (1)$$

Subsequently remote sensing reflectance (Rrs) of RAMSES is calculated as follows:

$$R_{rs}(\lambda, \theta) = \frac{L_w(\lambda, \theta)}{E_d(\lambda, \theta)} \quad (2)$$

Hommersom et al., (2012) mentioned that $R_{rs}(\lambda, \theta)$spectra were corrected for possible "white light" error ε to become $R_{rs}(\lambda, \theta)$ corrected. Thus the corrected remote sensing reflectance is calculated as follows:

$$R_{rscor}(\lambda,\theta) = R_{rs}(\lambda,\theta) - \frac{2.35\times Rrs(780) - Rrs(720)}{1.35} \quad (3)$$

Reflectance from Landsat 8 OLI was generated from Landsat 8 OLI level 1T on September 19, 2014 which had been radiometric and atmospheric corrected previously. Radiometric and atmospheric corrected was conducted by using ENVI FlAASH radiometric calibration. Radiometric and atmospheric corrected generates water leaving reflectance. According to Danbara (2014), the water leaving reflectance $\rho_{w(\lambda)}$ retrieved from atmospheric correction is converted to remote sensing reflectance using formula:

$$R_{rs}(\lambda) = \frac{\rho_{w(\lambda)}}{\pi} \quad (4)$$

Remote sensing reflectance below the surface or which is called subsurface remote sensing reflectance $r_{rs}(\lambda)$ is related to above surface remote sensing reflectance $R_{rs}(\lambda)$ (Lee et al.,2005), through:

$$r_{rs}(\lambda) = \frac{R_{rs(\lambda)}}{\left(0.52 + 1.7\, R_{rs}(\lambda)\right)} \quad (5)$$

This study used algorithm provided by Tassan (1994) which has modified based on field measurement for retrieved of TSM concentration from Landsat 8 OLI.

$$TSM = 10^{1.6+0.23\log\left(\left(R(5\ 5)-R(67\ 0)\right)\left(\frac{R(550)}{R(4\ 9)}\right)^{-0.1}\right)} - 10 \quad (6)$$

where TSM in mg/l. According to Table 1 R(490), R(550) and R(670) are corresponding to OLI 2, OLI 3 and OLI 4 respectively.

The accuracy of TSM algorithms was evaluated by comparing TSM in situ measured versus TSM estimation (Budhiman et al.,2012). Evaluation was carried out by using error estimation, t-test, f-test and regression analysis. The Root Mean Square error (RMSE) is absolute mean square error which describes the magnitude of difference between in situ measured and estimated concentrations. Root Mean Square Relative Error (RMSRE) and Mean Relative Error (MRE) are relative error in terms of error percentage relative to the measured concentrations. RMSRE and MRE are dimensionless. The RMSE, RMSRE and MRE are defined as formula bellow:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Ci_{estimated} - Ci_{measured})^2} \quad (7)$$

$$RMSRE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{Ci_{estimated}}{Ci_{measured}} - 1\right)^2} \quad (8)$$

$$MRE = \frac{1}{N}\sum_{i=1}^{N}\frac{\left|Ci^{estimated} - Ci^{measured}\right|}{Ci^{measured}} \quad (9)$$

where N is the number of measurement. TSM in Lombok coastal waters was mapped using Landsat 8 OLI based on site specific algorithm. This study was analyzed the distribution of TSM concentration spatially based Landsat 8 OLI using density slicing classification.

3. Result and Discussion

TSM concentrations of water samples collected in 15 stations which measured at Laboratory were ranging from 10 to 21 mg/l with average 14.9 mg/l and standard deviation 3.4. The TSM concertation measured were varied from off-shore to on-shore where the higher TSM concentration located at on-shore. These values were similar with Mahakam studied by Budhiman et al. (2012), which mention the maximum of was found in on-shore and the minimum of TSM concentrations was found in off-shore. The TSM concentrations in the waters influenced by tide are low (20-30 mg/l), while are high when influenced by river (Dutrieux, 1991). Since TSM concentration measured at this study are low then it is influenced by tide. Water transparencies result from Secchi depth (Sd) at field measurement varied from 0.5 m to 7 m. the minimum Sd value located on Awang Bay near port which actual depth was 3.9 m. The maximum value located on middle of Awang Bay which actual depth 31.9 m. Similar with Budhiman et al. (2012) studied, the transparencies increased from the on-shore to the off-shore in each transect.

The subsurface reflectance of in situ measurement using TriOS RAMSES and water color are presented in Figure 2. This subsurface reflectance's were developed from water leaving radiance which dominated by absorption and backscattering from water molecule and particulate matter. Generally, the reflected energy in blue region is low. The reflectance spectra start increasing up to 490-570 nm and decreasing after 570 nm till 670 nm. From 670-690 nm the reflectance spectra are increasing again and degreasing after that. The subsurface reflectance of each stations are varied from 0.006 to 0.18. Based on color of waters, values of transparency and spectra reflectance showed that clear water which have low transparency value have low subsurface reflectance while the turbid waters have high subsurface reflectance.

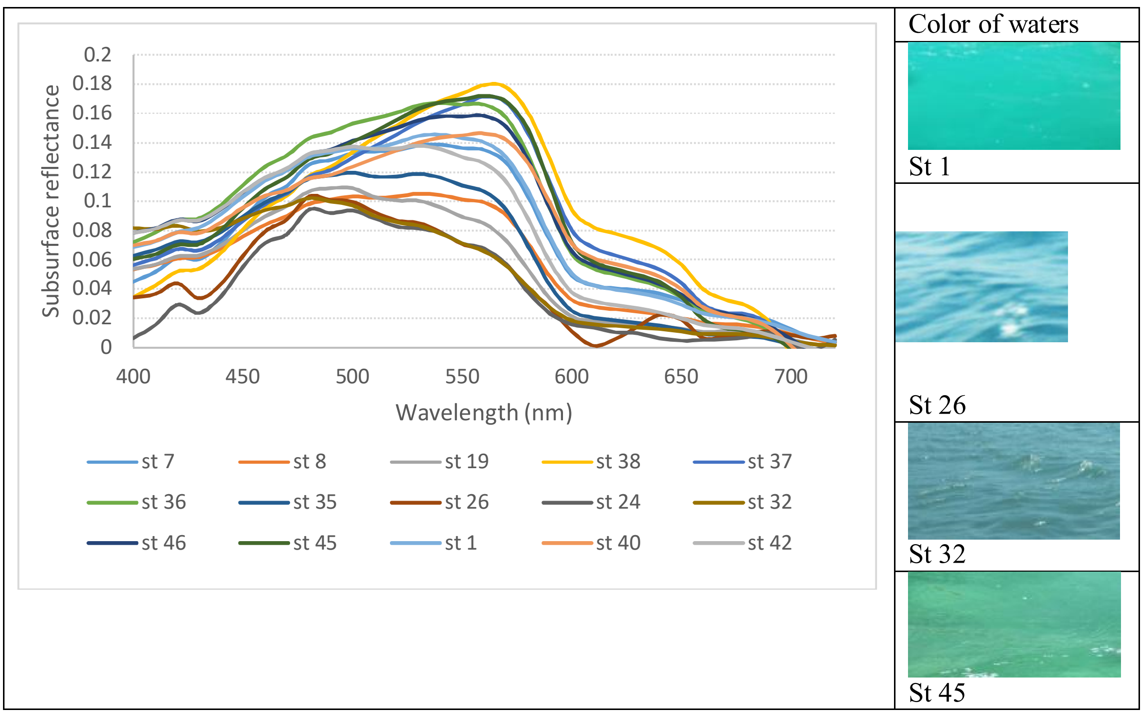

Figure 2. Subsurface reflectance of in situ measurement were resulted by TriOS RAMSES and water color in field

The Landsat 8 OLI data was used to generate TSM concentration map which subsurface remote sensing reflectance just below the surface is determined using equation (5) and the corresponding images are presented in Figure 3.The reflectance of TriOS RAMSES measurements at 490 nm, 550 nm and 670 nm corresponds to Landsat 8 OLI 2, OLI 3, and OLI 4 respectively. The subsurface remote sensing reflectance spectra obtained from Landsat 8 OLI and TriOS RAMSES has been compared in Figure 3. Overall comparison of these spectra indicates that both the reflectance values are closer to each other.

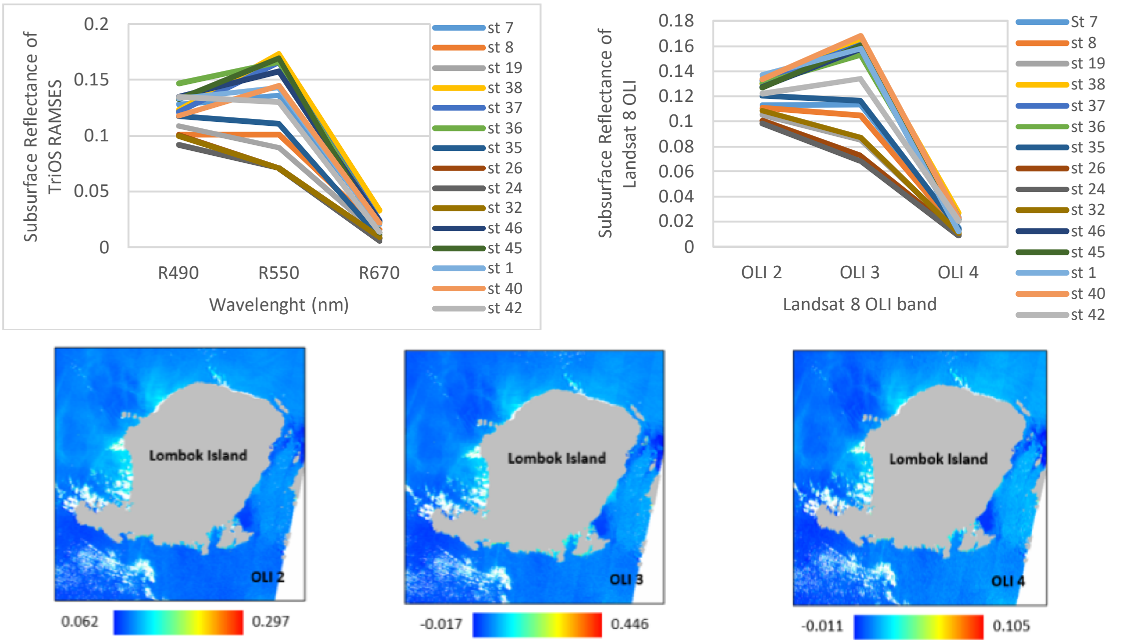

Figure 3. Subsurface remote sensing reflectance spectra of TriOS Ramses vs Landsat 8 OLI (above) and distribution of subsurface remote sensing reflectance from OLI 2, OLI 3 and OLI 4 (below)

The statistical analysis has been carried out to find out the closeness of Landsat 8 OLI subsurface remote sensing reflectance with TriOS RAMSES observed subsurface remote sensing reflectance for each band and the results are presented in Figure 4. The statistical that the coefficient of determination (R^2)for each OLI bands with RAMSES observation is greater than 0.57, while error analysis (RMSE) show and the TriOS RAMSES is below 0.04. The scatter plot of subsurface remote sensing reflectance of Landsat 8 OLI 2, OLI 3 and OLI 4 with TriOS RAMSES observed corresponding subsurface remote sensing reflectance data is presented in Figure 4. The coefficient of determination and RMSE are found to be 0.79 and 0.23 respectively. This analysis indicates that 4 subsurface remote sensing reflectance of OLI 2, OLI 3 and OLI are in close agreement with in situ observations and can be used to map TSM map effectively.

The TSM concentrations are determined using the in situ observed subsurface reflectance values and modified algorithm presented in equation (6). The statistical analyses have been carried out to compare the estimated of TSM concentrations with the TSM measured. The coefficient of determination (R2), RMSE, and p-value of t-test have been provided in Figure 5. The coefficient of determination is found to be 0.918 with RMSE =0.52 and p-value from t-test and f-test is greater than 0.05 ($p(T<=t)$ =0.39 and $p(F<=f)$ = 0.37. It is means that the modified algorithm can described TSM concentration very good. The f-test indicated the variances of TSM estimated and TSM measured were not significant different while t-test indicated the distribution of TSM estimated and TSM measured were not different either.

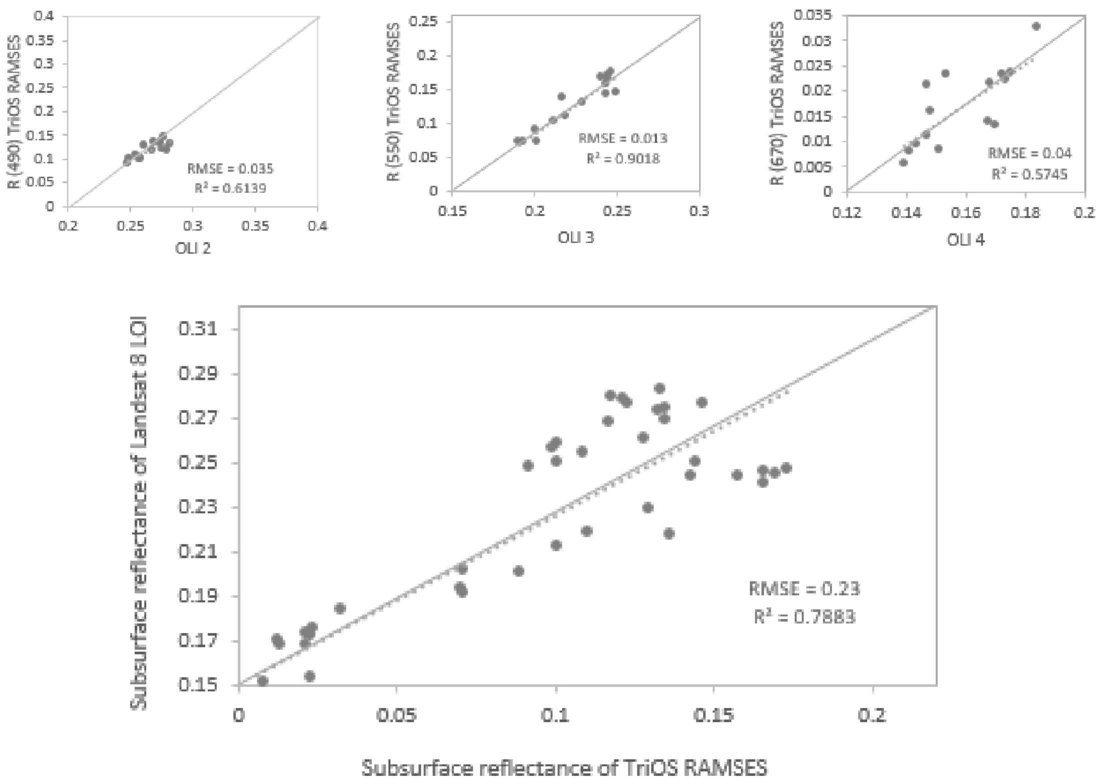

Figure 4. Accuracy of subsurface remote sensing reflectance each band of Landsat 8 OLI vs TriOS RAMSES and scatter plot between Landsat 8 OLI vs TriOS RAMSES subsurface remote sensing reflectance

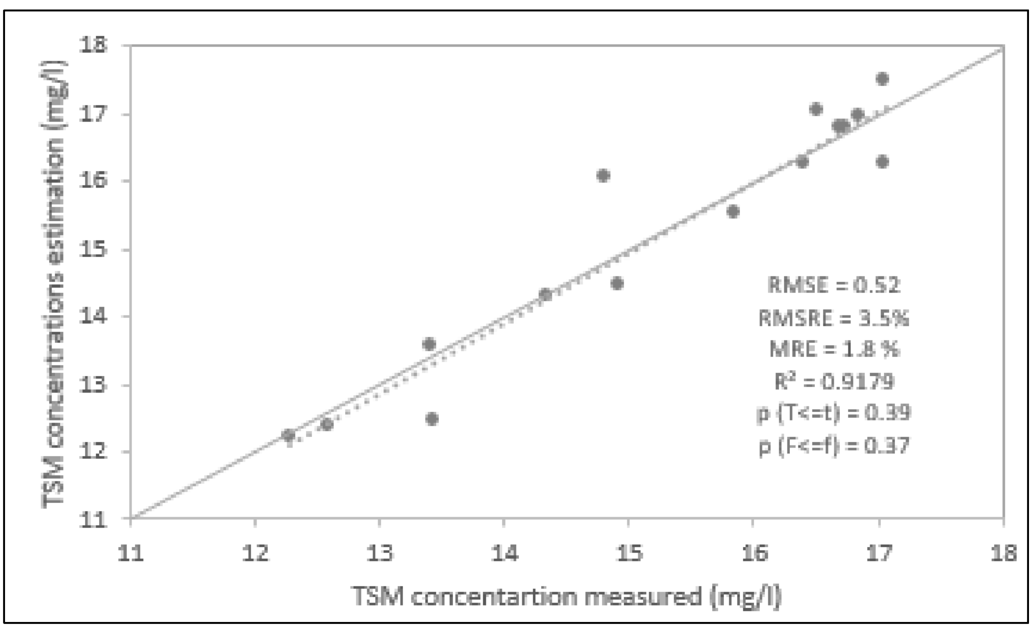

Figure 5. The comparison between estimated of TSM concentrations with TSM measured.

The TSM concentration map in Lombok coastal waters derived from Landsat 8 OLI data is presented in Figure 6. The minimum of TSM concentration is 0.39 mg/L and the maximum is 20.7 mg/L. The mean of TSM concentration is 11.78 mg/L with standard deviation 2.3. Furthermore, the high TSM concentration mostly the distributed along on-shore waters which the values aremore than 15 mg/L especially in south part of Lombok such as Gerupuk and Awang Bay (Figure 6). However, the analysis indicates that TSM concentration in Lombok coastal waters is low. The map also showed that TSM concentrations becoming high when it is near coast (on-shore) and low when it is far from the coast (off-shore). The result is similar with field measurement and others studied which conducted by Budhiman et al. (2012) and Dutrieux (1991). According to Dutrieux (1991) result then the low value of TSM concentrations in Lombok coastal waters influenced by tide.

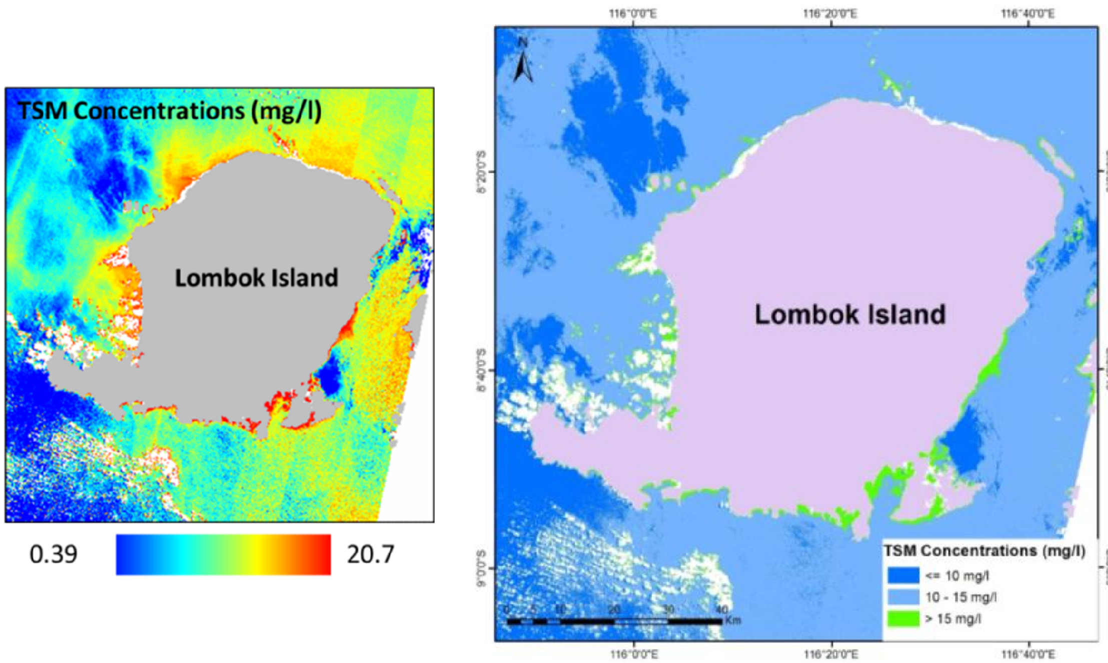

Figure 6.TSM concentration map in Lombok coastal waters derived from Landsat 8 OLI data

4. Conclusion

The subsurface remote sensing reflectance from Landsat 8 OLI bands are compared with in situ measured subsurface remote sensing reflectance. The statistical analyses showed that there is a close agreement between Landsat 8 OLI and in situ observation with coefficient of determination R2 and RMSE are found to be 0.79 and 0.23 respectively. These analyses suggest that Landsat 8 OLI can be used effectively to retrieved TSM concentrations of Lombok coastal waters.

Retrieval of TSM concentrationby using modified algorithm in Lombok coastal waters, Indonesia using Landsat 8 OLI were studied. The algorithm estimated TSM concentration with coefficient of determination R^2= 0.918 with RMSE = 0.52. Thus the modified algorithm was very well described TSM concentration in Lombok coastal water, Indonesia. The distribution of TSM concentration in Lombok coastal waters are between 0.39 to 20.7 mg/l with mean value 11.78 mg/L.The analysis indicates that TSM concentrations becoming high when it is near coast (on-shore) and low when it is far from the coast (off-shore).

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