Estimation on the concentration of total suspended matter in Lombok Coastal using Landsat 8 OLI, Indonesia

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Abstract. Total Suspended Matter (TSM) are fine materials which suspended and floated in water column. Water column could be turbid due to TSM that reduces the depth of light penetration and causes low productivity in coastal waters. The objective of this study was to estimate TSM concentration using Landsat 8 OLI data in Lombok coastal waters Indonesia by using empirical and analytic approach between three visible bands of Landsat 8 OLI subsurface reflectance (OLI 2, OLI 3 and OLI 4) and field data. The accuracy of model was tested using error estimation and statistical analysis. Colour of waters, transparency and reflectance values showed, the clear water has high transparency and low reflectance while the turbid waters have low transparency and high reflectance. The estimation of TSM concentrations in Lombok coastal waters are 0.39 to 20.7 mg/l. TSM concentrations becoming high when it is on coast and low when it is far from the coast. The statistical analysis showed that TSM model from Landsat 8 OLI data could describe TSM from field measurement with correlation 91.8% and RMSE value 0.52. The t-test and f-test showed that the TSM derived from Landsat 8 OLI and TSM measured in field were not significantly different.

1. Introduction
Sediment transport in the coastal waters influences not only the rates and types of biological and chemical processing, but also geomorphic processes constructing the landforms [1]. Land use intensification in coastal zone causes the increasing of sediment and nutrient to water bodies, which threatening water security for human and another waters organism [2]. Total Suspended Matter (TSM) is sediment particle (organic or inorganic) which suspended in water and originated from erosion and human activities. Higher concentration of sediment particles in water causes the increasing of TSM affecting water turbidity and reduce the ability of sunlight penetration into water. TSM is also one of water constituent which can be used as indicators for water quality. Monitoring of TSM concentration in Lombok coastal is necessary since its designation as tourism and business area for marine culture would affect their development [3].

Remote sensing images provide global or regional coverage of earth surface with potential monitoring platform from monthly to daily basis. Development of water quality monitoring method based on remote sensing data require information on apparent optical properties (AOP) and inherent optical properties (IOP) of water [4]. The interaction of light with sediment into water is complex because both materials scatter and absorb radiation [1][5]. The apparent upwelling radiance measured remotely a function of water and sediment properties and a function of initial solar input, atmospheric transmission of the radiation, the upwelling radiance at the water and specular reflection of water surface due to both sunlight and sky-light. The apparent upwelling is dependent on illumination geometry,
atmospheric conditions and water surface parameters such as roughness. By counting all of these parameters can determine the relationship of remotely sensed reflectance and sediment [1][5][6]. Nevertheless, IOP are defined as the optical properties which determined only by the type and concentration of substance in water and it is independent with illumination geometry [4].

The wavelength between 400 to 1000 nm are the most effective for estimating the TSM concentration in water from reflectance because the low rate of absorption by the water high rate of scattering [1]. The previous studies interpretation quantitative and qualitative of grey level pattern on images described sediment concentration in water bodies. Many studies have been carried out for development of monitoring TSM method using remote sensing for coastal waters, among others which worked on multispectral satellite data, such (SeaWiFS) MODIS, OCM, Landsat and SPOT images [1][4][5][7][8][9][10][11][12].

The objective of this study is estimation of TSM concentrations using Landsat 8 OLI (Operational Land Imager). Landsat 8 OLI is multispectral satellite which divided 433 nm to 12.5 nm wavelength into eleven band [13]. Landsat 8 OLI have three spatial resolution which are 15 meter (band 8), 30 meter (band 1-7 and 9) and 100 meter (band 10 and 11). It also has temporal resolution 16 days to capture an image from certain location. This study will apply Tassan (1994) [7] algorithm which utilise three band of wavelength bands for estimating TSM (490 nm, 550 nm and 670 nm).

2. Material and Methods

The study area of this research is located at Lombok, Indonesia with latitude 8°2’39.68” S to 9°10’6.27” S and longitude 115°42’40.19” E to 116°50’21.81” E which is shown in Figure 1. This study use Landsat 8 OLI data on September 19, 2014 with synchronized field measurement. Field measurements were conducted under different tidal, sun angle and could cover conditions at three areas: Tanjung An, Gerupuk and Awang Bay areas as seen in figure 1. Chlorophyll-a (Chl-a) and TSM concentration were resulted from laboratory analysis of water sample collected from 15 observation stations which spread from Tanjung An, Gerupuk and Awang Bay. Coastal water analysis was carried out at certified laboratory in Bogor Agriculture University.

![Figure 1. Location of study area and observation stations which indicated by red flag symbols.](image)

In the laboratory, TSM concentration was determined using the gravimetric method based on Budhiman et al. 2012 [4] while Chl-a concentration was measured using spectrophotometer using filtered water samples referring to Budhiman et al. 2012 [4]. Coastal water transparency in field was measured by Secchi disc. Field observation sites were marked by GPS. The image processing and analysis were carried out using ER Mapper 2014, ENVI 5.0 and ArcGIS 10.1. ENVI 5.0 was used for atmospheric correction, while ER Mapper 2014 and ARGIS 10.1 was used for advanced image processing and spatial analysis. TriOS RAMSES as hyperspectral radiometer was used for reflectance measurement in the wavelength range of 400 - 700 nm with 10 nm interval. Processing for in situ reflectance from TriOS RAMSES was retrieved using MSDA_XE software and the statistical analysis was carried out using Microsoft Excel.
Empirical and analytical approach was used to estimation of TSM concentration. The empirical approach is based on AOP and the analytical approach is based on IOP [4][6]. AOP generate subsurface remote sensing reflectance based on water leaving radiance and irradiance, while IOP generate subsurface remote sensing reflectance based on absorption and scattering from each water constituent (Chl-a, TSM and CDOM). Optical measurements were conducted simultaneously with water sample collection using above water measurement technique performed with TriOS RAMSES hyperspectral radiometer.

AOP generate based on subsurface remote sensing reflectance TriOS RAMSES and compare with Landsat 8 OLI. 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 (θ = 40 deg) relative to nadir and zenith [14]. Remote sensing reflectance from TriOS RAMSES got from water leaving radiance divided by irradiance. Subsequently remote sensing reflectance (Rrs) of RAMSES is calculated as follows:

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

According to Hommersom et al. (2012) [14], water leaving radiance $L_w(\lambda, \theta)$ is measured through formula:

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

Hommersom et al. (2012) [14] mentioned that $R_{rs}(\lambda, \theta)$ spectra were corrected for possible “white light” error $\varepsilon$ to become $R_{rs}(\lambda, \theta)$ corrected. Thus, the corrected remote sensing reflectance is calculated as follows:

$$R_{rs(corr)}(\lambda, \theta) = R_{rs}(\lambda, \theta) - \frac{2.35 \times R_{rs}(780) - R_{rs}(720)}{1.35}$$

Reflectance from Landsat 8 OLI was generated from Landsat 8 OLI level 1T on September 19th, 2014 which had been radiometric and atmospheric corrected previously. Radiometric and atmospheric corrected was conducted by using ENVI FlAASH radiometric calibration. Corrected radiometric and atmospheric image would generate water leaving reflectance data. According to Danbara 2014 [15], the water leaving reflectance $\rho_w(\lambda)$ retrieved from atmospheric correction can be converted to remote sensing reflectance [15] using formula:

$$R_{rs}(\lambda) = \frac{\rho_w(\lambda)}{\pi}$$

Remote sensing reflectance below the (subsurface remote sensing reflectance $r_{rs}(\lambda)$ ) is related to above surface remote sensing reflectance $R_{rs}(\lambda)$ [16], through:

$$r_{rs}(\lambda) = \frac{R_{rs}(\lambda)}{(0.52 + 1.7 \times R_{rs}(\lambda))}$$

Inherent optical properties (IOP) was generated from subsurface remote sensing reflectance $r_{rs}(\lambda)$ of water column [4][6] [17] using formula:

$$r_{rs}(\lambda) = 0.34 \frac{0.5b_w + Bb^*_TSM}{(a_w + 0.06a^*_{chl-a}C^{0.65})(1 + 0.2 \exp(-0.014(\lambda - 440))) + (0.5b_w + Bb^*_TSM)}$$

where $b_w$= backscattering of water, $B$ = ratio between backscatter and scatter of particle, $b^*_TSM= backscattering$ of TSM, $a_w$= absorption of water, $a^*_{chl-a}$= absorption of chl-a, $C$= Chl-a concentration, and $f = 0.34$. The value of absorption coefficient of water ($a_w$) and backscattering of water ($b_w$) were taken from Mobley (1994) [18]. The scattering coefficient of TSM ($bTSM$) was taken from Kopelevich (1983) [19] formula:
\[ b_{TSM}(\lambda) = b^*_{TSM}(550) \left( \frac{550}{\lambda} \right)^\alpha \]  

(7)

where \( \alpha \) is the spectral shape exponent and \( b^*_{TSM}(550) \) is backscattering coefficient of TSM at reference wavelength of 550 nm [19].

In order to estimation of TSM concentration from Landsat 8 OLI for Lombok coastal waters effectively an attempt is made to generate site specific new coefficient for Tassan (1994) algorithms, as following formula:

\[ TSM = 10^{1.6+0.23 \log((R(550)-R(670))(\frac{R(550)}{R(490)})^{-0.1})} - 10 \]  

(8)

where TSM in mg/l. According to Landsat 8 OLI band specification R (490), R (550) and R (670) are corresponding to band of Landsat 8 OLI 2, OLI 3 and OLI 4 respectively. The statistical analysis has been carried out to compare the model output with in situ measurement for TSM concentration.

The accuracy of TSM algorithms was evaluated using best fit analysis by comparing TSM in situ measured versus TSM estimation [6]. Evaluation was carried out by using error estimation, t-test, f-test and regression analysis. According to the regression analysis, the model could be accepted if error estimation is low and t-test and f test is bigger than confident level (>0.05). 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:

\[ RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (C_{\text{estimated}} - C_{\text{measured}})^2} \]  

(9)

\[ RMSRE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left( \frac{C_{\text{estimated}}}{C_{\text{measured}}} - 1 \right)^2} \]  

(10)

\[ MRE = \frac{1}{N} \sum_{i=1}^{N} \left| \frac{C_{\text{estimated}} - C_{\text{measured}}}{C_{\text{measured}}} \right| \]  

(11)

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 analysed the distribution of TSM concentration spatially based Landsat 8 OLI using density slicing classification.

3. Result and discussion

TSM concentrations in Lombok coastal waters were ranged between 10 - 21 mg/l with average concentration of 14.9 ± 3.4 mg/l. The TSM concentration was varied from off-shore to shore or coastal waters, where higher TSM concentration was located in the coastal areas near the shores. These values were similar with studies in Mahakam conducted by Budhiman et al. (2012) [4], in which TSM maximum was found in the coast and TSM minimum was in the off-shore. TSM concentrations in the coastal waters were generally influenced more by riverine inputs compare to tidal force [20]. Since TSM concentration measured in this study low then TSM dynamics in Lombok waters were influenced by tide. TSM concentrations in Lombok lower compare to Mahakam Delta (6 -182 mg/l). According Budhiman (2004) [6], Lombok coastal water can be categorized as clear waters.

The maximum Chl-a concentration (2.547 µg/L) was found in the coastal area of Awang Bay and the minimum was in Tanjung An (0.086 µg/L) with average 1.255 µg/L. The concentration of Chl-a has decreasing trend from near river mouth to the sea. Chl-a in Lombok coastal water was lower than Mahakam delta which have Chl-a concentration 1.3 to 29.9 µg/L [6]. 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) [4] studied, the transparencies increased from the on-shore to the off-shore in each transect.

The AOP measurement in Lombok coastal water show in subsurface reflectance. Subsurface reflectance in situ measurement from TriOS RAMSES was obtained by using equation (1) to (5). The subsurface reflectance in situ and water colour 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. Based on colour of waters, values of transparency and spectra reflectance showed that clear water which have high transparency and low subsurface reflectance value while the turbid waters have low transparency and high subsurface reflectance.

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 (Figure 3). Based on statistical analysis, the coefficient of determination ($R^2$) and RMSE are found to be 0.79 and 0.23 respectively. This analysis indicates that subsurface remote sensing reflectance of OLI 2, OLI 3 and OLI 4 are in close agreement with in situ observations and can be used to estimation the TSM concentrations effectively.

The IOP in Lombok coastal water described based on Chl-a absorption coefficient at 440 nm and backscattering coefficient of TSM at 50 nm. They retrieved from AOP measurement by inverting optical model using formula (6) and (7). Table 1 show summarizes of the absorption and backscattering result. The result indicates low variation of the IOP due to low standard deviations of all IOP. The low standard deviation related to the low variation of Chl-a and TSM concentration from 15 station observations. We used three sensors at the same time for AOP measurement so there is not time different between water, sky and irradiance measurement in one cloud conditions. It may have impact on the IOP result.
Table 1. IOP parameters values of Lombok coastal waters

| IOP     | $a_{\text{chl}}$ (m$^{-1}$) | bTSM (m$^{-1}$) |
|---------|-----------------------------|-----------------|
| Maximum | 0.377                       | 0.582           |
| Minimum | 0.07                        | 0.214           |
| Mean    | 0.18                        | 0.352           |
| Standard deviation | 0.11                      | 0.106           |

Figure 4 show the average of $a_{\text{chl}}$ (m$^{-1}$), $a_w$ (m$^{-1}$), bTSM (m$^{-1}$), which calculated using formula (6) and (7) respectively. It is seen that the absorption of Chl-a highly contributes in 400-570 nm. Absorption of water highly contributes in 610-720 nm. Backscatter of TSM value is bigger than water and Chl-a absorptions in 400-600 nm and lower than water absorption but bigger in Chl-a absorptions in 610-720 nm. The depression of TSM backscatter due to pigment of absorption can be seen, especially at high Chl-a concentration as shown in Figure 4. Compare with Mahakam delta turbid water had absorption of Chl-a 0.21 to 0.79 m$^{-1}$ [6], Lombok coastal water have low absorption of Chl-a. the absorption of Chl-a in Lombok coastal water is near similar with Nha Phu Estuary, Vietnam [21].

Figure 4. The average IOP of the optically active water constituent which consist of absorption of water, absorption of chl-a and backscattering of TSM in Lombok coastal waters.

The TSM concentrations were determined using the in situ observed subsurface reflectance values and modified algorithm presented in equation (8). The statistical analyses have been carried out to compare the estimated of TSM concentrations with the TSM measured (Figure 5). The coefficient of determination is found to be 0.918 with RMSE = 0.52, RMSE=3.5 %, and MRE = 1.8%. Furthermore, p-value from t-test and f-test is greater than 0.05 ($p(T<=t)$ = 0.39 and $p(F<=f)$ = 0.37. Thus, this modified algorithm resulted low error estimation and can describe TSM concentration in Lombok coastal waters 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 5. The comparison between estimated of TSM concentrations with TSM concentrations 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
The mean of TSM concentration is 11.78 mg/L with standard deviation 2.3. Furthermore, the high TSM concentration mostly distributed along on-shore waters which the values are more than 15 mg/L especially in south part of Lombok such as Gerupuk and Awang Bay. The high value of standard deviation indicates that there is high variation of TSM concentration in Lombok coastal waters. However, the analysis indicates that Lombok coastal waters are clear water due to TSM concentrations are 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 [4] and Dutrieux 1991 [20]. According to Dutrieux 1991 [20] the low value of TSM concentrations in Lombok coastal waters can be categorized as influenced by tide.

![Figure 6. TSM concentration map in Lombok coastal waters derived from Landsat 8 OLI data.](image)

4. Conclusion
The TSM concentration in Lombok coastal waters were analyzed using Landsat 8 OLI based empirical and analytical approach. The statistical analyses showed a coherent pattern between Landsat 8 OLI and in situ observation with $R^2$ and RMSE 0.79 and 0.23 respectively. It is suggested that Landsat 8 OLI can be used effectively to retrieved TSM concentrations of Lombok coastal waters. According to color of waters, values of transparency and spectra reflectance, the clear water have high transparency and low subsurface reflectance values while the turbid waters have low transparency and high subsurface reflectance values.

An attempt was made to estimated TSM concentrations in Lombok coastal waters and the site-specific algorithm resulted $R^2$ and RMSE 0.918 and 0.52 respectively with p-value from t-test and F-test is greater than 0.05. Thus, the modified algorithm was very well described TSM concentration in Lombok coastal water. 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 on coast and low when it is far from the coast (off-shore). Since this research only used fifteen samples, there is a wide scope to improve the site-specific algorithm which statistically representative.

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