The Aplication of Landsat 8 OLI for Total Suspended Solid (TSS) Mapping in Gajahmungkur Reservoir Wonogiri Regency 2016

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Abstract. Gajahmungkur reservoir is administratively located in Wonogiri Regency, Central Java, with the main function as a flood control in the upstream of Bengawan Solo River. Other functions of the reservoir are as hydroelectric power plant (PLTA), water supply, irrigation, fisheries and tourism. Economic utilization of the reservoir is estimated until 100 years, but it is begun to be threatened by the silting of the reservoir. Eroded materials entering water body will be suspended and accumulated. Suspended Material or TSS (Total Suspended Solid) will increase the turbidity of water, which can affect the quality of water and silting the reservoir. Remote sensing technology can be used to determine the spatial distribution of TSS. The purposes of this study were to 1) utilize and compare the accuracy of single band Landsat 8 OLI for mapping the spatial distribution of TSS and 2) estimate the TSS on Gajahmungkur reservoir surface waters up to the depth of 30 cm. The method used for modelling the TSS spatial distribution is the empirical modelling that integrates image pixel values and field data using correlation analysis and regression analysis. The data used in the empirical modelling are single band of visible, NIR, and SWIR of Landsat 8 OLI, which was acquired on 8 May 2016, and field-measured TSS values based on the field data collection conducted on 12 April 2016. The results revealed that mapping the distribution and the estimated value of TSS in Reservoir Gajahmungkur can be performed more accurately using band 4 (red band). The determinant coefficient between TSS field and TSS value of image using band 4 is 0.5431. The Standard Error (SE) of the predicted TSS value is 16.16 mg/L. The results also showed that the estimated total TSS of May 2016 according to band 4 is 1.087,56 tons. The average estimation of TSS value in up to the depth of 30 cm is 61.61 mg/L. The highest TSS distribution is in the northern parts, which was dominated by eroded materials from Keduang River.

Keyword: TSS, Estimation, Mapping, Landsat 8 OLI

1. Introduction
One of many problems in the maintenance of reservoir is the silting of the reservoir. Eroded materials entering the water will be suspended and accumulated. Suspended Material or TSS (Total Suspended Solid)
Solid) will increase the turbidity of water, which can affect the quality of water and silting the reservoir. Monitoring the silting process is difficult, because the reservoir area is large and the process of materials entering the reservoir cannot be seen clearly. The problem will be obvious when floods occur due to decreased capacity of the reservoir.

Currently, technology of remote sensing has been constantly evolving and can be used to sense water body. Landsat 8 OLI have a unique sensor, which can be used in sensing the condition of a body of water. Temporal resolution of Landsat 8 OLI is 16 days, freely available, and is effective to be used to monitor water conditions in reservoir continually.

Utilization of Landsat 8 OLI to monitor the sedimentation of reservoir is via the estimation of TSS in water. If the number of TSS is high, the accumulation of sediment at the base of the reservoir is also high. Besides this, the recording of Landsat 8 OLI is approximately 185 km x 185 km, it will be identified the areas with high potential occurs silting, or the area that become the potential location of entrance of sedimentary material in reservoir.

Landsat 8 has many bands used for the interpretation of various objects on the Earth’s surface. Eleven single band consisting of visible bands, infrared bands, panchromatic, cirrus and thermal band, have unique function in the interpretation of object. Based on the ability of penetration and sensitivity of each single band to interpreting the suspended materials, visible and infrared bands are the most effective. To perform the mapping and estimation of TSS in reservoir, we need to know which band has the best performance.

Gajahmungkur Reservoir was selected as the study area (Figure 1) because the Gajahmungkur Reservoir has silting reservoir problem. Based on JICA study, the average annual sediment in period of 1993-2004 amounted to 3.18 million m³[1]. Based on studies conducted by the Research Directorate of Water Problems (DPMA) 1982 [2] the erosion rate is estimated at 8.58 mm/year. In addition, Sub Center for Rehabilitation and Conversion Land of Solo (Sub Balai RLKT Solo, 1985[2]) stated that the erosion rate is estimated at 26.00 mm/year. With the erosion rate of that value, Faculty of Geography-SBRLKT Solo 1996 [2] estimated that the economic life of Gajahmungkur Reservoir is reduced from the planned use of 100 years to just 27 years.

![Figure 1. Administrative boundaries of Gajahmungkur Reservoir](image)

2. Objectives
The objectives of this study are 1) evaluate which spectral band have better accuracy in the estimation of TSS. We integrated image pixel values and TSS field data from Gajahmungkur Reservoir water of the same coordinate to perform empirical modeling. From individual field data, we performed accuracy assessment, and 2) map and estimate of distribution of TSS using spectral band with the
highest accuracy. Only the TSS in the water column up to the depth of 30 cm from the surface was estimated.

3. Methods

3.1. Image Data
Two images of Landsat 8 OLI used in this study were acquired in February 18th, 2016 and May 8th, 2016. The Landsat 8 OLI (path 119 row 65) covers the whole Gajahmungkur Reservoir. Landsat 8 OLI acquired on February 18th, 2016 was used to determine the distribution of sample location before field survey, while Landsat 8 OLI acquired on May 8th, 2016 was to perform the modeling and mapping.

3.2. Field Data
Field survey was conducted on April 12th, 2016 using speedboat and GPS handheld to get to each sample point based on field survey plan map. The date of field survey and image acquisition has difference of two months. It was because only in this date of acquisition the image has the smallest cloud cover before field survey conducted. The difference had little influence, because this image was only used to see the pattern of TSS prior to field survey. Water was sampled up to the depth of 30 cm from the surface. Total samples obtained are 49 out of 54 planned samples, which consist of 25 sample points and 24 of validation points. The sampled water were measured on April 14th, 2016 in the Laboratory of Hydrology and Water Quality of the Faculty of Geography, Universitas Gadjah Mada by using SNI-06-6989.3-2004 Gravimetry method.

3.3. Radiometric Correction
Radiometric image correction is required to improve the quality of the image and improve the pixel values that do not correspond to the value of the spectral reflectance of the actual object [3]. Radiometric corrections conducted in this study are a correction Top of Atmosphere (ToA) and Dark Subtraction (DOS). Correction to ToA changed the pixel values of the image into the reflectance values by normalizing the angle and intensity of solar energy, while the DOS correction intended to remove atmospheric path radiance. DOS correction assumes that there is a pixel containing 0% reflectance [4].

3.4. Classification
Classification was done to get the water turbidity classes by Landsat 8 OLI acquired in February 18th, 2016. Classification was done by density slice method based on spectral reflectance histogram. That was because the peak of the histogram represent one type of water turbidity. Density slice is one method of classification that can be done by selecting the brightness level of the entire value of existing pixels in the image. Danoeodoro [3] has the assumption that every object in the image of a particular channel has a brightness value of a certain range, the range of brightness values of 0-255 can be sliced into several intervals that describe the appearance of the object in general. The classification process resulted in nine different classes with clear water on the first class and the most turbid water is in the ninth (Figure 2). The range of water turbidity level are as follow: The Ith has a density range of -0.0244 to -0.0032, IIth has a density range of -0.0032 to -0.0008, IIIth has a density range of -0.0008 to 0.0020, IVth has a density range of 0.0020 to 0.0075, Vth has a density range of 0.0075 to 0.0106, VIth has a density range of 0.0106 to 0.0145, VIIth has a density range of 0.0145 to 0.0259, VIIIth has a density range of 0.0259 to 0.0393, IXth has a density range of 0.0393 to 0.0758. From these nine classes of turbidity, we determined the distribution of modeling and validation samples.
3.5. Correlation Analysis

Pixel values of Landsat 8 OLI acquisition May 8th, 2016 was extraction based on actual coordinate points of field survey. Correlation analysis was done between pixel value of image and TSS field value of laboratory measurement result.
For 25 samples, the significant threshold at 95%CL is 0.396. Table 1 shows the correlation analysis of 25 data between TSS field data and the pixel value. The $r$ of band 1, band 5, band 6 and band 7 was <0.396 and not the relationship is not significant, which can be caused by several factors. Field survey conducted on April 12, 2016 has a difference of ±1 month from the date of acquisition of the image on May 8, 2016. This affected the distribution of TSS pattern in the water reservoir. The intensity of the rainfall that occurred during the one month is also quite high, so the spatial distribution of TSS can change. The field TSS values which not correspond to the image condition need to be repaired via contextual editing.

Table 1. Correlation analysis between TSS values in the field with the pixel values of band 1 - band 7 before contextual editing. The $r$ value with mark (*) is significant.

| Band          | Modeling samples | Accuracy assessment samples |
|---------------|------------------|-----------------------------|
|               | Coefficient ($r$) | Coefficient of Determination ($R^2$) | Coefficient ($r$) | Coefficient of Determination ($R^2$) |
| Band 1 – Ultra-blue | 0.361 | 0.130 | 0.278 | 0.077 |
| Band 2 – Blue | 0.413* | 0.170 | 0.297 | 0.088 |
| Band 3 – Green | 0.449* | 0.201 | 0.289 | 0.083 |
| Band 4 – Red | 0.459* | 0.211 | 0.283 | 0.080 |
| Band 5 – NIR | 0.365 | 0.133 | 0.340 | 0.115 |
| Band 6 – SWIR 1 | 0.349 | 0.122 | 0.307 | 0.094 |
| Band 7 – SWIR2 | 0.357 | 0.127 | 0.325 | 0.105 |

3.6. Regression Analysis

Regression analysis was used to obtain resultant regression function to model the TSS (Figure 3 – Figure 9). The Independent Variables are pixel value and the Dependent Variables are TSS field values. Regression analysis used was linear equation model. The basic formula for the resultant regression function is as follow:

$$Y = A + BX$$  \hspace{1cm} (1)

Explanation:
- $Y =$ The dependent variable (field TSS)
- $A =$ The constants
- $B =$ The slope of regression
- $X =$ The independent variables (pixel values)
3.7. Contextual editing
Contextual editing is a process to eliminate, modify data or information that was less relevant. Contextual editing applied in this study is to eliminate the TSS samples that are not relevant with the pixel values. Irrelevant data adversely affected the correlation analysis. The process of elimination was done based on the visualisation of pixel value and the corresponding TSS value in the field. The assumption used is if the pixel is bright, then the value of TSS is also higher. This is because the pixel values of the water will be more reflective if the content of TSS is high.

There are five samples removed for modelling samples and four samples removed from validation samples. As seen on Table 2, contextual editing significantly improved the correlation coefficients.
Table 2. Correlation analysis between TSS values in the field and the pixel values of band 1 - band 7 at sample locations after contextual editing

| Band         | Modeling samples | Accuracy assessment samples |
|--------------|------------------|----------------------------|
|              | Correlation Coefficient (r) | Coefficient of Determination ($R^2$) | Correlation Coefficient (r) | Coefficient of Determination ($R^2$) |
| Band 1 – Ultra-blue | 0.739 | 0.546 | 0.536 | 0.287 |
| Band 2 – Blue   | 0.750 | 0.563 | 0.581 | 0.337 |
| Band 3 – Green  | 0.742 | 0.550 | 0.593 | 0.352 |
| Band 4 – Red    | 0.736 | 0.543 | 0.601 | 0.361 |
| Band 5 – NIR    | 0.691 | 0.477 | 0.625 | 0.390 |
| Band 6 – SWIR 1 | 0.667 | 0.445 | 0.630 | 0.397 |
| Band 7 – SWIR2  | 0.680 | 0.463 | 0.647 | 0.419 |

3.8. Accuracy Assessment

Accuracy assessment was done to understand the error of prediction between modeled TSS with field TSS as a reference. Accuracy test was done on each band. The equation for the calculation of error value is:

$$SE = \sqrt{\frac{\sum \text{error}}{n-2}}$$  \hspace{3cm} (2)

Explanation:
SE = Standard error of estimate (mg/L)
\(\sum \text{error}\) = Total of error of prediction on each band
error = The calculation of error at one point (TSS in the field – TSS of image)^2
n = The number of sample

SE value shows the deviation between TSS in the field and modeled TSS in mg/L. High SE can be interpreted that the TSS of image are highly overestimated or underestimated from the actual TSS in the field.

3.9. Estimation of Total Sediment Content

The calculation of total sediment has been done by calculate the TSS of image from applying the regression equation every single band. TSS value being modelled has a unit of mg/L. The unit needs to be converted to g/m³. The conversion was done by multiplying each pixel value of TSS with the number of occurrences of pixels and also the depth of measurement. The estimation was only performed on a model with the lowest SE. It is considered that the total estimate of TSS of the most accurate model represents the actual TSS value in the field.

3.10. Research flowchart

The research flowchart is shown in Figure 10.
4. Discussion

4.1. Distribution of TSS
The spatial distribution of TSS from each band is generally almost similar, but the estimated value of TSS is different. It is due to the difference spectral reflectance properties of each band on water. The water reflectance values can illustrate the condition and quality of the water. TSS turbidity level became one of the factors of the spectral properties of water. Turbid water will have higher reflectance values than clear water [6]. Band 1 and band 2 showed that the northern part of the reservoir has > 70 mg/l, which higher than the other bands. That was because band 1 (0.43-0.45 μm) and band 2 (0.45 – 0.51 μm) have high the capability to penetrate the water. According to Butler et al. [5], blue (0.45 μm - 0.52 μm) and green energy (0.52 μm - 0.60 μm) has the best water column penetration ability. Water penetration capability will decrease with the increasing turbidity of water column. Band 1 and band 2 can reflect the materials of TSS on the deeper water column. Thus, the detection of TSS in the water column by band 1 and band 2 is more detail than other bands. Just note that band 1 has lower ability...
than other visible bands to reflecting the material of TSS in the water, but more sensitive to clear water. This is evident in the minimum value in the estimation of the band 1 or band 2, which produced lower minimum value of the estimated TSS compared to the other bands. In this case, it is because this energy can penetrate deeper into the water column but unable to strongly return the signal to the sensor in large quantities, because the lack of sensitivity to the material of TSS in the water.

The general appearance of the visualization TSS from band 3 (0.51 – 0.59μm) is quite different from other bands. The northern part of the reservoir was dominated by a TSS class of 60-70 mg/l. It was just that the estimated maximum value of TSS from band 3 is quite high compared to the band 1 and band 2, but the estimated minimum value of the TSS in the image is the lowest of all. That was because band 3 has a lower water penetration capability but is better capable of reflecting TSS in the water. The estimated minimum value of band 3 is the lowest, it is because the ability of reflecting the water with less material of TSS is lower then other band.

The appearance of the band, 5, 6 and 7 is generally similar and not much different from the band 1 and 2. Those bands have maximum estimated TSS value quite high compared to bands 1, 2 and 3. In general, the ability to penetrate water of band 4, 5, 6 and 7 are lower than bands 1, 2 and 3. Thus, they only detect TSS based on the information on water surface. It is just the sensitivity of these bands to TSS is higher than bands 1, 2 and 3. This made the estimated minimum value in band 4, 5, 6 and 7 is higher than bands 1, 2 and 3.

Table 3. The result of TSS estimation (mg/l) from each band

| Band  | Maximum | Minimum | Mean  |
|-------|---------|---------|-------|
| Band 1| 120.94  | 37.18   | 56.29 |
| Band 2| 140.87  | 36.24   | 56.47 |
| Band 3| 170.41  | 33.17   | 57.03 |
| Band 4| 270.38  | 40.50   | 61.60 |
| Band 5| 289.66  | 44.80   | 56.30 |
| Band 6| 269.41  | 45.47   | 56.05 |
| Band 7| 205.79  | 44.94   | 55.84 |
4.2. Accuracy Test

The accuracy assessment indicates that band 4 has the smallest deviation in the estimation of TSS image with ±16.16 mg/l. Meanwhile, band with the highest deviation in estimating TSS is band 6 with SE of ±17.21 mg/l. This can be caused by the penetration ability and susceptibility to materials of TSS or object of water.

| Band       | Total Error | SE (mg/l) |
|------------|-------------|-----------|
| Band 1 – Ultra-blue | 5289.89     | 17.14     |
| Band 2 – Blue     | 5202.18     | 17.00     |
| Band 3 – Green    | 5093.80     | 16.82     |
| Band 4 – Red      | 4702.81     | 16.16     |
| Band 5 – NIR      | 5262.05     | 17.10     |
| Band 6 – SWIR 1   | 5334.28     | 17.21     |
| Band 7 – SWIR2    | 5151.07     | 16.92     |
4.3. Mapping

Information of TSS spatial distribution were presented using continuous symbol at 1: 60,000 map scale (Figure 12). Based on that map, Gajahmungkur Reservoir was dominated by waters with TSS value of 40.50 mg/l - 60.50 mg/l and the there are many variations in the water with TSS value of >120.50 mg/l. TSS value >90.503 mg/l concentrated in the northern and southern ends of the reservoir. The northern part is the estuary area of Keduang river, which contributes the highest sediment of all seven sub-watershed to Gajahmungkur Reservoir. The southern part of the reservoir is a community fish cage area and the river estuary of Temon sub-watershed and Alang sub-watershed. TSS value <90.503 mg/l to >60.503 mg/l is uniformly dispersed in most of the northern parts of the reservoir, especially in the northwestern parts of the pier and community fish cages activities. TSS value <60.50 mg/l to 40.50 mg/l are distributed in middle of the reservoir towards the eastern part of the reservoir. Based on field observations, the eastern parts of the reservoir have more vegetation than the western parts.

![Map of TSS distribution based on Band 4](image)

**Figure 12.** Map of TSS distribution based on Band 4
4.4. Estimation
According to the extraction of statistical data of modelled TSS based on band 4, the lowest TSS value is 40.5 mg/l and the highest value is 270.39 mg/l. The mean values of TSS modelled by band 4 is 61.61 mg/l. The total value of TSS in the reservoir is 1087.56 tons. This value means that there are 1087.56 tons of suspended solids in Gajahmungkur Reservoir up to the depth of 30 cm on May 2016.

5. Conclusion
This research shows that Landsat 8 OLI band 4 has the best accuracy with SE of \pm 16.16 mg/l. The distribution of TSS in Gajahmungkur Reservoir on May, 2016 based on band 4 of Landsat 8 OLI has an estimated value of TSS as follow: 1) the lowest is 40.50 mg/l, 2) the highest is 270.39 mg/l, and 3) the average value is 61.61 mg/l. The TSS is high in the northern and southern parts of the reservoir, especially in the estuary of the river. The estimated TSS in the Gajahmungkur Reservoir up to the depth of 30 cm modelled from band 4 of Landsat 8 OLI is 1087.56 tons.

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