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Developing A Model for Estimating Secchi Disk Depth using Landsat TM and ETM+ in Indonesian Lakes

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ABSTRACT

A simple data pre-processing to minimize the atmospheric effects and improve data quality was proposed to build a model for estimating Secchi Depth (SD) from Landsat TM and ETM+ data. The model intended to be simply applicable without requirement of in-situ data for both atmospheric correction and model recalibration. Rayleigh scattering effects were removed using 6S software. Median filters were applied iteratively to improve the low Signal-to-Noise Ratio. Aerosol scattering effects in visible bands were reduced using the SWIR band. The reflectance extracted from pre-processed Landsat images and corresponding in-situ SD measurements from 9 lakes collected from 2011 to 2014 (ranging from 0.5 m to 18.6 m) were used for model calibration. Other in situ SD measurements from 31 Lakes collected in 1992-1993 (ranging from 0.4 m to 20 m) were used to validate the developed model. A long-term change of SD in Lake Maninjau estimated from the model was also compared with in situ data collected from 2001-2017 for another validation. Results show that the developed model provides acceptable result and robust estimates SD for both several different lakes in 1992 and long-term change SD of Lake Maninjau with determination coefficients of 0.81(with RMSE of 2.59 m, n=31) and 0.46 (with RMSE of 1.22 m, n=17) respectively. These results indicate that the developed model is simply applicable and has a potential to fill the SD data gap for further water environment studies.

1. INTRODUCTION

Lakes are habitats of great human importance as they provide water for domestic, industrial and agricultural use as well as providing food [1]. Despite their fundamental importance to humans, freshwater systems including lakes have been affected by anthropogenic disturbances. The disturbances cause the eutrophication, acidification and contamination by toxic substances. This problem is predicted to continue to increase, especially in developing countries where the developments prioritize other than environmental conservation [1]. Monitoring the environment is necessary to ensure the management practices achieve the sustainability [2]. For effective lake management, it is essential to have long-term water quality information on a broad regional and spatial scale [3].

One of important water quality parameter is secchi depth (SD). SD is the simplest and most often used for limnological measurements because its values are easily understood [4]. Assessing the SD is one of the key issues in environmental monitoring and management, because it can affect both ecosystems and water amenities [5].

Since conventional water-monitoring methods (e.g., water sampling from a boat) are very time-, labor-, and cost-consuming, the maintenance of steady monitoring is remain challenging for local and national governments with meager financial resources, especially in developing countries [6]. As the result, the number of in situ water quality data is very limited. On the other hand, the satellite remote sensing is a powerful supportive tool for assessing the spatial and temporal variation in water quality parameter such as SD [7, 8, and 9]. Combination of in situ and remote-sensing can be used to provide comprehensive data solutions to address sustainability issues because satellite technologies have the potential to provide better spatial and temporal coverage compare with traditional field sampling [2].

In general, studies on SD estimation using Landsat TM images can be classified into two major groups. The first group used the band ratio and the second group used the combination of single band plus band ratio as the SD predictor. Further, the studies can be differentiated whether they perform atmospheric correction or not. Previous models were built based on empirical relationship. Different band and band ratio combinations that were suggested from previous research may relate with the differences in image quality or limnological condition of the water body [10].

The existing models require to be recalibrated for other image from different time or other location. This is a significant challenge for the study areas which lack of in situ SD data. Kloiber et al. [11] mentioned that, ideally a single (standard) relatively simple equation with constant coefficient values would be used to calculate SD or a phytoplankton abundance index. Their study indicated that if the atmospheric effect can be removed, then one set of coefficients can be applied for different images across time and space. However, the other challenge is the meteorological data to perform the atmospheric correction for the historical image are not always available. Therefore the objectives of this research are to develop a model for estimating SD from Landsat TM / ETM+ data, to test the model if it is simply applicable without requirement of in situ data for recalibration and to provide a showcase for long term SD estimation using the developed model.

2. METHOD

All 64 Landsat Images were downloaded from the USGS website [15] for model calibration and validation. The images were pre-processed to reduce the atmospheric effect and improve the data quality. The water bodies were extracted using the combination of Normalized Different Water Index (NDWI)[12] and Modified Normalized Different Water Index (MNDWI) [13], then area of a buffer of 150 m from the shoreline were excluded. Rayleigh scattering effects were removed using 6S with tropic atmospheric model. Median filters were applied iteratively to improve the low Signal-to-Noise Ratio. Aerosol scattering effects in visible bands were reduced using the SWIR band.

The reflectance extracted from 7 scenes pre-processed Landsat images and corresponding in-situ SD measurements from 9 lakes in Indonesia collected from 2011 to 2014 (ranging from 0.5 m to 18.6 m) were used for model calibration. Following Kloiber et al. [11] and Olmanson et al. [3] least-square multiple regressions were used to obtain the model coefficient. The model using the general form:

ln SD = a + b (single band) + c (band ratio), where a, b and c are model coefficient which can be obtained from the multiple regression analysis.

Second in-situ SD data set from 31 Lakes collected in 1992-1993 [14] (ranging from 0.4 m to 20 m) were used to validate the developed model. A long-term change of SD in Lake Maninjau estimated from Landsat using the developed model was also compared with in situ data collected from 2001-2017 for another validation.

3. RESULTS

The atmospheric correction resulted in Rayleigh and Aerosol corrected reflectance as shown in Fig. 1. It shows that over the water surface the proposed method gave better performance compare to surface reflectance standard products [15]. The aerosol effect at the longer band (TM5 & TM7) can be mitigated pixel by pixel.

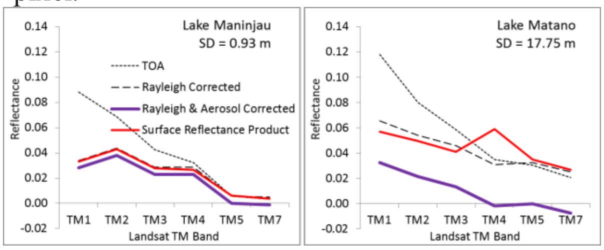

Fig. 1. Atmospherically corrected reflectance

In order to develop the model, wide ranges of in situ SD (0.5 – 18.6 m) were utilized in this research. It was limited in numbers (31 measurements from 9 Lakes), but covered a wide range of optical properties which are represent the variety of limnological conditions. The combination of filtered atmospherically corrected satellites data and the wide range in situ SD data were expected to be the optimum input for model development. All possible band combinations were tested as the result we select 6 models with best performance for further analysis, as shown in Table 1.

Table 1. Model Calibration performance

Mod-el	Band Configuration	R^2	RMSE (m)	NMAE (%)
A1	TM1 & TM1/TM3	0.987	1.17	6.41
A2	TM2 & TM1/TM3	0.981	1.17	12.01
A3	TM3 & TM1/TM3	0.993	0.57	13.15
B1	TM1 & TM1/TM2	0.958	1.29	29.13
B2	TM2 & TM1/TM2	0.958	1.40	31.36
B3	TM3 & TM1/TM2	0.959	1.27	30.30

The accuracy of the selected models (A3 and B3) were plotted in Fig.2. The estimated SD is the average value which calculated from 90% of total water pixels (due the sampling site coordinate were not available). It was observed that the over estimation of model A3 are too large especially for clear water. Model B3 provide more acceptable result.

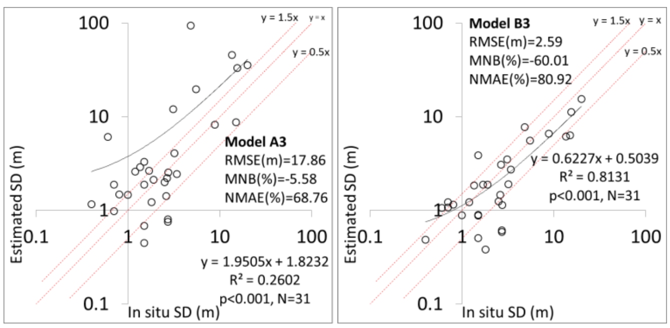

Fig. 2 Scatter plot of in situ versus Estimated SD

The water quality in lake can change over a short or long-time period. Model B3 then was used to estimate

SD of Lake Maninjau during 2001-2017 (Fig.3). The result showed that 30 years ago the average SD in Lake Maninjau was estimated around 5 m. However, starting from 2009 the SD values were steady lower than 2 m and both from measured and estimated. In-situ observation in August 2006 ranged from 2.25 m to 5.8 m, it showed that the SD in Lake Maninjau sometime was heterogeneous. From fig.3, we can also see that the estimated long-term SD from Landsat matched well with in-situ data.

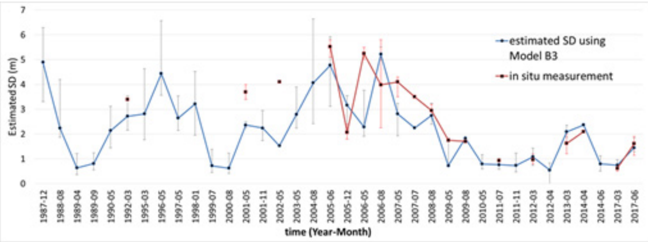

Fig 3. A showcase of long term SD estimation of Lake Maninjau using Model B3

4. DISCUSSION

The sources of estimation errors in this research are generally propagated from the time gap and the geographic location error. The validation data set 1 were collected from the field surveys conducted during 1992-1993. At those periods, the corresponding Landsat images were not always available. To make use of all in situ data we set the wider time window. Narrowing the time window into less than one month for validation data set 1, reduced the number of data which can be used into 11 data. The RMSE can be reduced to 1.21 m with the MNB = -21.23% and NMAE = 42.82%. This result indicates that a narrower time window can provide better accuracy.

The next limitation is that the sampling locations information is not available. Match-up between in situ and estimated SD from the model is not an ideal comparison. In this research, we compare the single value of in situ SD data and the average of the SD value from the whole water bodies.

5. CONCLUSION

In this study, a model for estimating SD using Landsat TM/ETM+ data has been developed. It uses TM3 and ratio of TM1/TM2 with fixed coefficient. It was proved to be consistent predictors of SD and more robust from noise.

The model can be simply applicable without requirement of recalibration on each image. Neither required atmospheric conditions information. It has been validated using two validation data set. Both estimated SD for several different lakes at the same period and time series of a lake showed reasonable result. However, the applications for another different environment such as tempered lakes in mid or higher latitude are required to be further studied.

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