Spatiotemporal variability of turbidity water in tidal areas of Perak River, Malaysia, based on field survey and Sentinel-2 image analysis

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Abstract. In the Perak River, which flows into Malaysia, a tidal zone extends approximately 40 km from the mouth of the river, and turbid water is always present. Therefore, a detailed field survey is necessary to reveal the dynamical phenomenon of turbid water associated with the tidal zone. However, it is efficient to specify the survey area and conditions by clarifying the rough spatiotemporal variability characteristics in advance. In this study, water sampling and turbidity measurements were conducted in the tidal sensitive area of the Perak River during the satellite Sentinel-2 transit. An equation to estimate turbidity from surface reflectance at near-infrared wavelengths was experimentally developed using fine sand collected from the Perak River, and this equation was applied to past Sentinel-2 images to clarify the spatiotemporal variability characteristics of turbidity in the tidal zone. The results showed a large longitudinal variation in turbidity in the 20 km section from the mouth of the river, and a convergence zone of suspended sediment was identified when turbidity was relatively high.

1 Introduction

Turbid water in rivers degrades water quality by interfering with photosynthesis of aquatic organisms and causing loss of biodiversity. Estuarine turbidity maximums can occur in estuaries with high tidal movement. This location in particular affects water quality, including oxygen depletion. This phenomenon has been reported worldwide, including in the Chesapeake Bay estuary [1] and the Kowloon estuary [2].

In the Perak River, which flows into Malaysia, the water is always turbid, and the tidal zone extends approximately 40 km from the mouth of the river. Therefore, a detailed field survey is necessary to reveal the dynamical phenomenon of turbid water during rising and falling tides, but it is more efficient to identify the scope and conditions of the survey by clarifying rough spatiotemporal variation characteristics in advance.

One method for understanding the distribution of turbidity over a wide area is to use an equation that relates the near-infrared wavelengths of satellite images to water surface reflectance, which is highly correlated with turbidity. However, to obtain this equation, field data under various turbidity conditions are required. The authors propose a simple method to

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obtain the equation by measuring turbid water of various turbidity levels made from fine sand collected in the river using a small multispectral camera with the same wavelength as the satellite (Sentinel-2) [3]. This technique was applied to characterize the spatiotemporal variability of turbidity in the Pella River tidal estuary from satellite imagery.

2 Experiments on spectral characteristics of turbid water in the Perak River

2.1 Sampling of fine sediment in the Perak River

The Perak River is a 400-km-long river located in the state of Perak in the western part of the Malay Peninsula and flows into the Gulf of Perak in the Strait of Malacca from its source near the border with Thailand. On March 8, 2024, with the assistance of the Teluk Intan Office of the Department of Irrigation and Drainage, Jabatan Pengairan dan Seriran (JPS), which manages the Perak River, we collected fine sediment deposited on the river bottom at the inner bank of the bend of Teluk Intan shown in point 4 of Figure 1. The turbidity of the water surface was measured with a turbidity meter (JFE Advantech Co., Ltd.: INFINITY-Turbi), and was about 80 FTU.

Figure 2 shows the November 2023 tidal changes measured at Bagan Datoh at the mouth of the Perak River. The figure shows that the tide level difference is about 1 m at low tide and up to about 3 m at high tide.

Fig. 1. Satellite imagery of the lower Perak River and estimated turbidity sites.

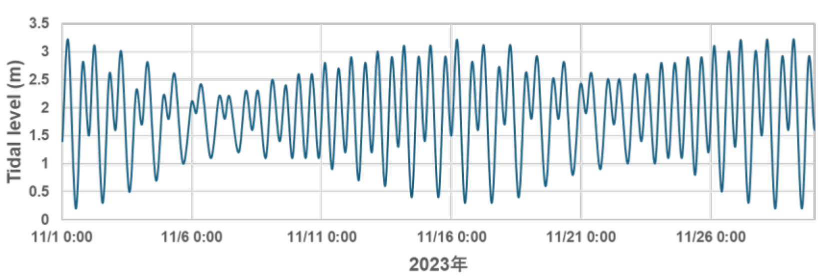


Fig.2. Tidal level at the mouth of the Perak River at Bagan Datoh (November 2023).

 https://doi.org/10.1051/e3sconf/202560301011

2.2 Experiments on measuring turbid water using a multispectral camera

The fine sand collected from the Perak River was dried in a drying oven for one day, crushed into fine particles, and then sieved to remove dust and other debris using a 100-µm sieve. The particle size distribution was measured using a laser diffraction particle size analyzer (SHIMADZU SALD-2200), and as shown in Figure 3, the representative particle diameter d50 was 50 μm.

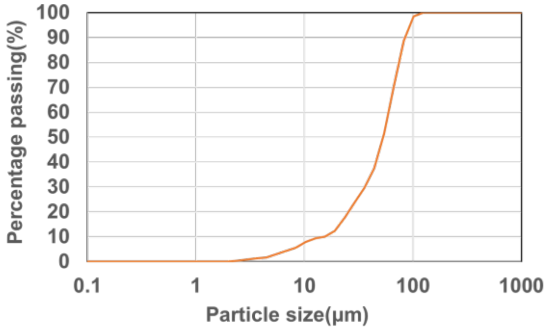


Fig. 3. Particle size accumulation curve of fine sand collected from the Perak River.

In this study, first, turbid water of various turbidity levels was created using fine sediment collected in the field, and these were photographed by a small multispectral camera (RedEdge-MX by MicaSense) and corrected based on the results of solar radiation meter measurements to calculate the water surface reflectance ρ_w at near-infrared wavelengths. The relationship between the values of water surface reflectance and measured turbidity was applied to Equation (1) [4], which is generally used to estimate turbidity by remote sensing, to obtain an equation for estimating turbidity T.

$$T = \frac{A_t \rho_w}{1-\rho_w/C} \tag{1}$$

where A_t: calibration coefficient, C: wavelength-dependent coefficient, and C is the value corresponding to each wavelength proposed by Nechad et al. [5]. A_t is calculated from the relationship between ρ_w and T by the least-squares method. Figure 4 shows the situation of turbid water imaging by multispectral camera and reflectance of turbid water surface at near-infrared wavelengths at turbidity 63 FTU.

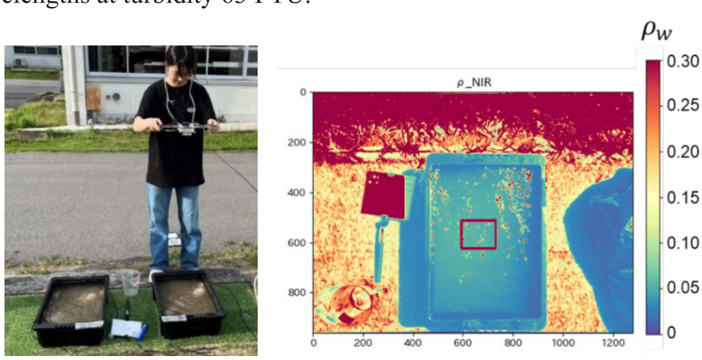


Fig. 4. Turbid water imaging by multispectral camera and near-infrared wavelength reflectance of turbid water surface at turbidity 63 FTU.

The measurement experiments were conducted under clear sky conditions with cloud cover ranging 0. Here, a cloud cover of 1 or less (cloud cover is less than 10% of the sky) indicates “clear sky,” a cloud cover of 2 to 8 (cloud cover is 20% to 80% of the sky) indicates “sunny,” and a cloud cover of 9 or more (cloud cover is 90% or more of the sky) indicates “cloudy. The turbidity of the turbid water was set to nine cases ranging from 50 to 400 FTU, based on the 80 FTU measured during the field survey, and the reflectance of the water surface was calculated.

The relationship between water surface reflectance at near-infrared wavelengths and turbidity obtained from the experiment is shown in Figure 5. Here, the data used in the turbidity estimation equation and the data used to check the accuracy of the estimation are divided 7:3. The approximate curve in the figure is the turbidity estimation equation, and a positive correlation was confirmed as in previous studies. The accuracy of the obtained turbidity estimation equation is shown in Figure 6. In this case, the coefficient of determination was 0.74, confirming good estimation accuracy.

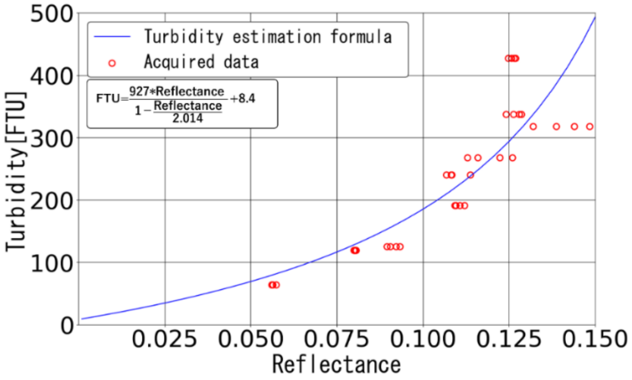


Fig. 5. Relationship between water surface reflectance and turbidity at near-infrared wavelengths.

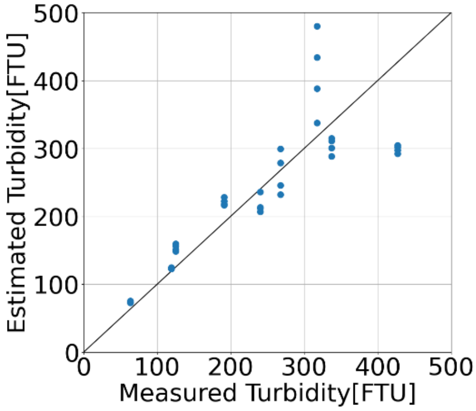


Fig. 6. Accuracy of experimental turbidity estimation equations for the Perak River.

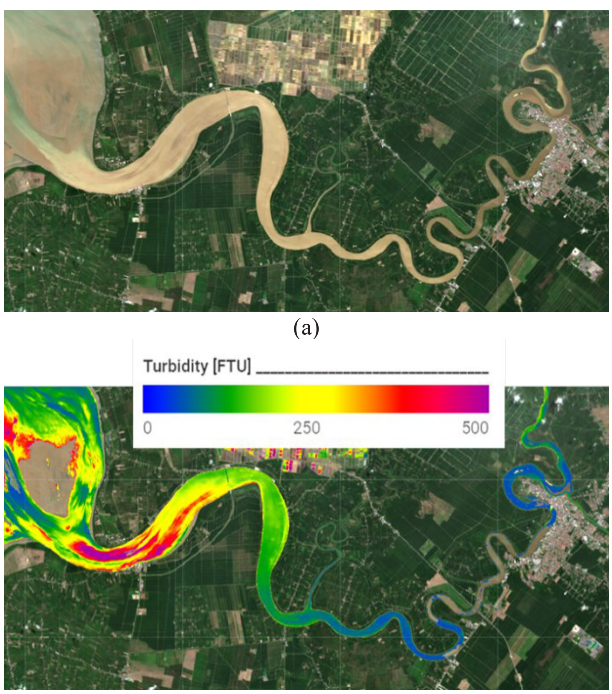
3 Spatiotemporal variation characteristics of turbid water in the Pella River based on Sentinel-2 satellite image analysis

Although the Sentinel-2 satellite data used in this study are optical sensor data and therefore can only be used for observations made during clear skies, the observation frequency is 5 days higher than other free satellite data. Furthermore, The Band 8 data (wavelength: 833 nm, bandwidth: 106 nm, resolution: 20 m), which is close to the near-infrared wavelength (wavelength: 842 nm, bandwidth: 57 nm) of the multispectral camera used in this study, is useful for turbidity estimation.

In this study, we use Google Earth Engine, a satellite data analysis platform, to obtain reflectance data from the Sentinel-2 satellite and apply the turbidity estimation equation obtained from the experimental results in Chapter 2 to examine the spatiotemporal variation characteristics of turbidity in the lower Perak River watershed.

The Sentinel-2 satellite takes images of the Perak River basin at around 11:50 a.m. each time, and cloud-free Seninel-2 images were available only ten times from May 1, 2023, to April 22, 2024. Therefore, the acquisition rate of analysable images with low cloud cover in the lower Perak River basin is not very high, about 10-20%.

Figure 7 and Figure 8 show the turbidity distribution estimated from satellite RGB images taken on May 8 and November 4, 2023, respectively, and reflectance at near-infrared wavelengths. These two cases were selected out of the 10 cases analyzed, when the estimated turbidity was the highest and lowest. However, although the water level at Bagan Datoh at the mouth of the river was about 1.3 m in both cases when these two satellite images were taken, the turbidity appears to be higher on May 8 in Figure 7 when the RGB images are compared.



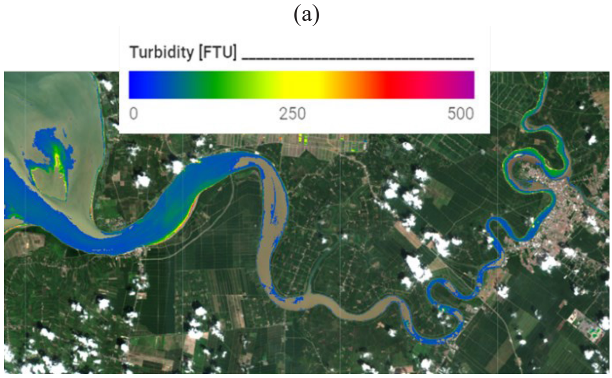
(a)

(b)

Fig. 7. Satellite RGB Image (a) and turbidity distribution estimated from near-infrared water surface reflectance (b) (Date of shooting: May 8, 2023).

In fact, the turbidity estimated from the reflectance at near-infrared wavelengths was higher closer to the mouth of the river in Figure 7 and was estimated to be up to 800 FTU. Furthermore, As shown in Figure 7(b), ETM may be occurring between points 1 and 2, where turbidity is extremely high. On the other hand, in Figure 8, the estimated turbidity was less than 100 FTU over the entire analysis range, and there was no significant difference in the estimated turbidity between the upstream and downstream areas.

(a)



(b)

Fig. 8. Satellite RGB Image (a) and Turbidity distribution estimated from near-infrared water surface reflectance (b) (Date of shooting: November 4, 2023).

The longitudinal distribution of estimated turbidity from point 1 downstream to point 5 upstream for the 10 cases analyzed is shown in Figure 9, corresponding to the points in Figure 1. From this figure, it can be understood that the estimated turbidity is less than 100 FTU in all cases at the Teluk Intan near Point 4, where fine sand was collected for the experiment in March 2024. The turbidity measured by the turbidity meter during the field survey was 80 FTU, which is in general agreement with the estimated results. The longitudinal variation of turbidity was found to be larger in the section where the river width is wider than the upstream section up to about 20 km from the river mouth.

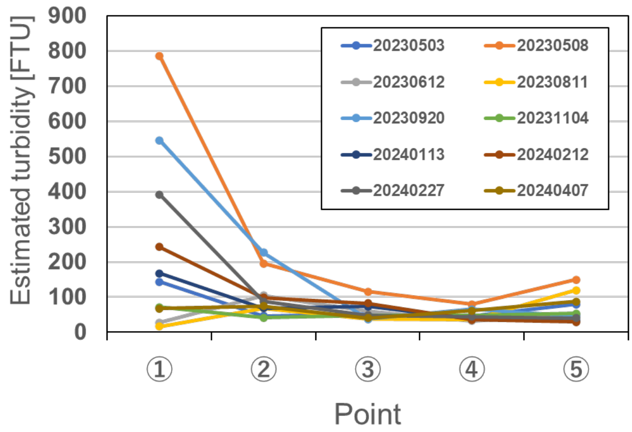


Fig. 9. Longitudinal changes in turbidity estimated from images under cloud-free conditions for the period May 1, 2023 to April 30, 2024.

4 Conclusion

In this study, an experiment using fine sand collected in the field and satellite image analysis was conducted to characterize the spatiotemporal variability of turbidity in the tidal reach of the lower Perak River in Malaysia. The results show that turbidity tends to be higher in a 20-km section near the mouth of the river than in the upstream section, and that longitudinal variation is also greater. It is possible that ETM is occurring in this range.

In the future, detailed topographic and longitudinal water level variation over time around that reach, in addition to flow studies, as well as measurements of water quality such as turbidity, salinity, and dissolved oxygen, will allow us to confirm whether ETM is occurring and to discuss the dynamics of this phenomenon.

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