Spatio-Temporal Distribution of Total Suspended Matter Concentration in Changdang Lake based on In-situ hyperspectral data and Sentinel-2 Images

Submitted to: Remote sensing

Submitted: 10 September 2021

Revised: October 2021

Dear Editor and Reviewers,

We sincerely appreciate your comments and suggestions regarding our manuscript. After considerable discussion and thinking, we have revised the manuscript and present our point-by-point responses below. Each of the corresponding revisions, both major and minor, are included in the revised version of the manuscript.

(Responses to the comments from the editor and reviewers are shown in green, and modified text in the manuscript is highlighted in yellow.)

Responses to Reviewe 1's comments:

This manuscript presents a regional model for TSM estimation for Changdang Lake from Sentinel-2 image data. It then analyzes the spatio-temporal patterns in TSM variability in terms of seasonality, meteorological conditions and mechanical dredging.

While the data analysis that went into the manuscript is generally sound, there are a few areas within the text that can be improved with more detail. Particular comments are listed below.

1) *Section 1: Although extensive references are made to retrieving TSM concentrations from image data acquired by various satellite sensors, there is no discussion on minimum sizes of water bodies that can adequately be analyzed from e.g. MODIS and Landsat sensors. The paragraph on P2L79-97, leads up to S2 image data as better suited for medium and small lakes but no mention is made of adjacency effects etc.*

Response: We have revised the paragraphs according to your suggestion.

a) On lines 56-66 of the manuscript, we have **added** content as follows: 'Affected

by its spatial resolution, different satellite images can detect different minimum widths of rivers and lakes. Generally, 3~5 pixels is the minimum width of water bodies that can be adequately analyzed from satellite images with less adjacency effects. Images from Sentinel-2 are more detailed than those from Landsat and MODIS sensors. For example, for rivers or lakes with a width of 1000 m, only 4 pixels can be observed in MODIS images with a spatial resolution of 250 m, 33 pixels can be observed in Landsat OLI images with spatial resolution of 30 m, but 100 pixels can be observed in Sentinel-2 images with a spatial resolution of 10 m. Therefore, Sentinel-2 images can be used to monitor the water bodies in medium and small lakes more accurately, without the influence of adjacency effect; however, there have been very few studies on using Sentinel-2 images to monitor TSM concentration in medium and small lakes.'

b) On lines 111-116 of the manuscript, we have **added** content as follows: 'Changdang Lake covers an area of 85 square kilometers. Using the Sentinel-2 images with a spatial resolution of 10 m to monitor Changdang lake, we could extract a sufficient number of pure water pixels to study the lake, without the influence of the adjacency effect. However, if we use the MODIS image with a spatial resolution of 1000 m to monitor the Changdang Lake, the area of the lake can be greatly reduced and the research results will be affected by the edge adjacency effect.'

2) *Section 2.1: The annual average water level in the lake is stated to be 1.2-1.5m. How certain are the authors that analysis was done in optically deep water? i.e. where the bottom is not affecting the spectral response measured by the satellite? This would probably not be eliminated by SWIR correction and may affect the response in the red band where light penetrates deeper into the water column.*

Response: According to your suggestions, we have modified two parts:

a) The measured transparency of Changdang Lake is ranged from 9.7 cm to 31 cm and the average water depth is about 120-150cm, which is far less than the water depth. Therefore, it can be determined that Changdang Lake is optical deep water. Therefore, SWIR correction method can be used for sentinel-2 image re-correction.

We **added** the text: 'measured transparency of Changdang Lake ranged from 9.7

to 31cm' in lines 153 and 154 of the manuscript.'

b) The statement about submerged vegetation in the study is not rigorous, it may not be necessary to appear in the manuscript. The reasons are as follows: First of all, the field experiment did not observe submerged aquatic vegetation in Changdang Lake, so there is no submerged aquatic vegetation in the centre of the lake, there may be submerged aquatic vegetation on the shore. Secondly, when extracting water from Sentinel-2 images, the edge of Changdang Lake will be eroded inward by 2–3 pixels (that is, 20–30m), which can basically eliminate the influence of submerged aquatic vegetation and adjacency effects.

We **removed** the phrase 'aquatic plants' from line 201 of the manuscript.

3) Section 2.2.1: P5L147 (equation 1): How was L_{sky} calculated?

Response:

L_{sky} refers to the downward radiance brightness of the sky, which was measured directly using ASD spectrometer in the field experiment, as shown in the following figure 1.

We **added** the text: 'which is directly measured using ASD spectrometer during the field experiment.' in lines 171 and 172 of the manuscript.

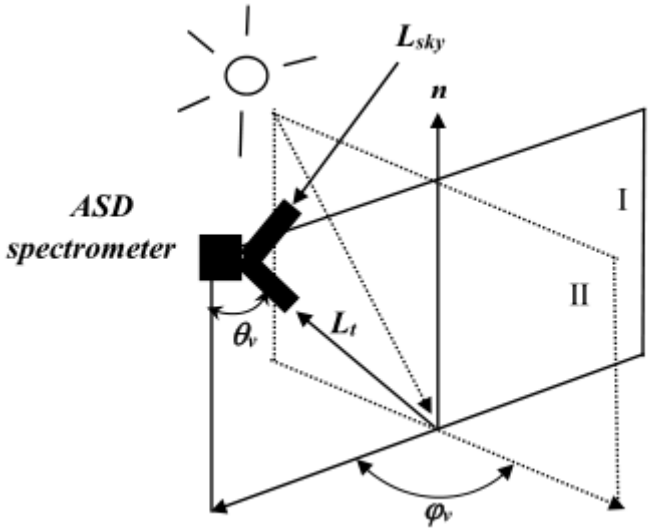

figure 1. The best observation geometry of the measurement method above the water surface of the spectrometer

4) *Section 2.3.2: Equation 4: Is this a real linear relationship? Or does it appear linear because most of the samples have a moderate TSM concentration? There may be an increasingly under estimation of TSM in waters with high TSM concentration and in very clear waters, the TSM concentration may become over-estimated.*

Response:

It is the linear relationship obtained from the real TSM concentration data. It is precisely because the measured TSM concentration range is moderate and hence we can get this better linear model.

The TSM concentration model constructed in this study is more suitable for Changdang Lake where the TSM concentration is in the range of 30-120mg/L. However, few over-estimations or under-estimations may be observed in high concentration and very clear waters, which is related to the measured data obtained at present.

5) *Section 3.1: How was the spectra collected from the 03/05/2020 S2 image to do the validation for the image re-correction and the TSM retrieval accuracy?*

Response:

First, we extracted the remote sensing reflectance from the Sentinel-2 image on May 3, 2020, according to the longitude and latitude information of the sampling points during the field experiment. Subsequently, we compared the measured remote sensing reflectance with the remote sensing reflectance after the re-correction of the Sentinel-2 image to verify the re-correction of the Sentinel-2 image. The established TSM concentration inversion model was applied to the B8/B4 band combination of Sentinel-2 images, and the predicted value of TSM concentration on Sentinel-2 image was thereby obtained. The accuracy of TSM concentration inversion can be verified by comparing the predicted value with the measured value of TSM concentration.

We have **revised** the description of the relevant content in lines 330-341 and 344-347 of the manuscript. To ensure the accuracy of the article, we **checked and updated** Table 2 and Figure 6.

We **revised** lines 330-341 as follows: ‘According to equation (2), the Sentinel-2

image was re-correction in this study. In order to evaluate the effectiveness of the Sentinel-2 image re-correction method, according to the longitude and latitude of the sampling points in the field experiment, we extracted the remote sensing reflectance of each band from the Sentinel-2 image, and compared the measured remote sensing reflectance with the Sentinel-2 image reflectance before and after re-correction. MRE and RMSE of Sentinel-2 image before and after re-correction can be obtained.' **and** 'The re-correction method of Sentinel-2 image could improve the accuracy of TSM concentration inversion in Changdang Lake to some extent.'

$$R_{rs}^{r}(\lambda) = \frac{R(\lambda) - \min(R_{\mathrm{SWIR}})}{\pi} \quad (2)$$

We **revised** lines 344-347 as follows: 'The TSM concentration inversion model of Changdang Lake is established according to equation (6). The model is applied to the B8/B4 band combination of Sentinel-2 image on May 3, 2020. Furthermore, the predicted value of Sentinel-2 image inversion was obtained.'

After the update, the revised Table 2 showed a slight difference in value compared with the original Table 2, which demonstrates the effectiveness of the re-correction method.

Table 2. Comparison of Sentinel-2 data errors before and after re-correction.

Band/band combination	Before and after image re-correction	MRE (%)	RMSE (sr^{-1})
B4 (665 nm)	Before re-correction	25.57	0.0056
	After re-correction	8.51	0.0020
B8 (842 nm)	Before re-correction	80.31	0.0088
	After re-correction	40.81	0.0045
B8/B4	Before re-correction	43.67	0.2200
	After re-correction	33.51	0.1700

Owing to the change in the inversion model of TSM concentration, the inversion accuracy results of TSM concentration verified by synchronous images were also updated. The result of this correction is shown in revised Figure 6 (instead of Figure 5).

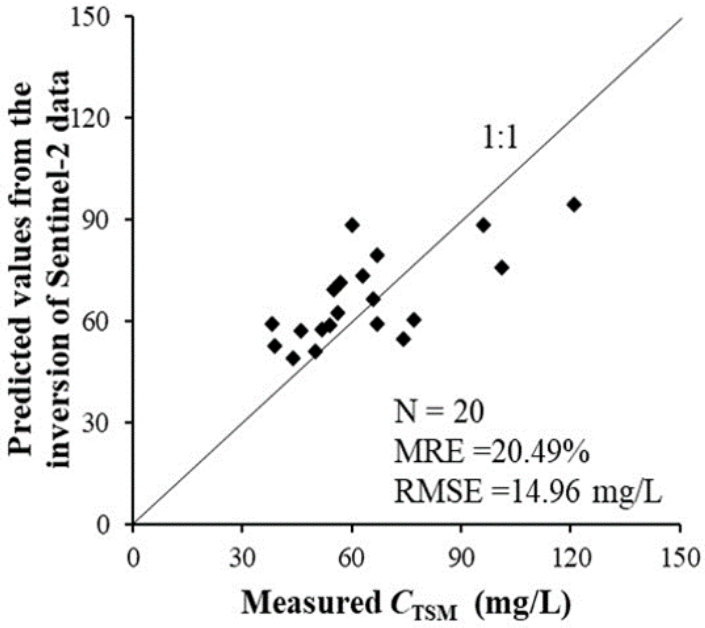

Figure 6. Comparison between the measured TSM concentration and predicted values based on the inversion of Sentinel-2 data

6) *Section 3.4：The average seasonal TSM concentration for each year was reported but not the spatial variability. A measure of the range and/or standard deviation added to Figure 9 would be useful in addition to the seasonal mean.*

Response:

Thank you very much for your suggestion. We have **added** the standard deviation to Figure 10 (instead of Figure 9) and updated Figure 10 was added to line 463 of the manuscript. We **revised** lines 460 and 462 as follows: 'The estimated average and standard deviation of TSM concentrations in winter, spring, summer and autumn were 59.69±15.52 mg/L，69.58±20.78 mg/L, 72.55±18.44 mg/L and 57.43 ±18.74mg/L'; and we **added** the text: 'the average and standard deviation of' on line 456 of the manuscript. The modified Figure 10 is shown below:

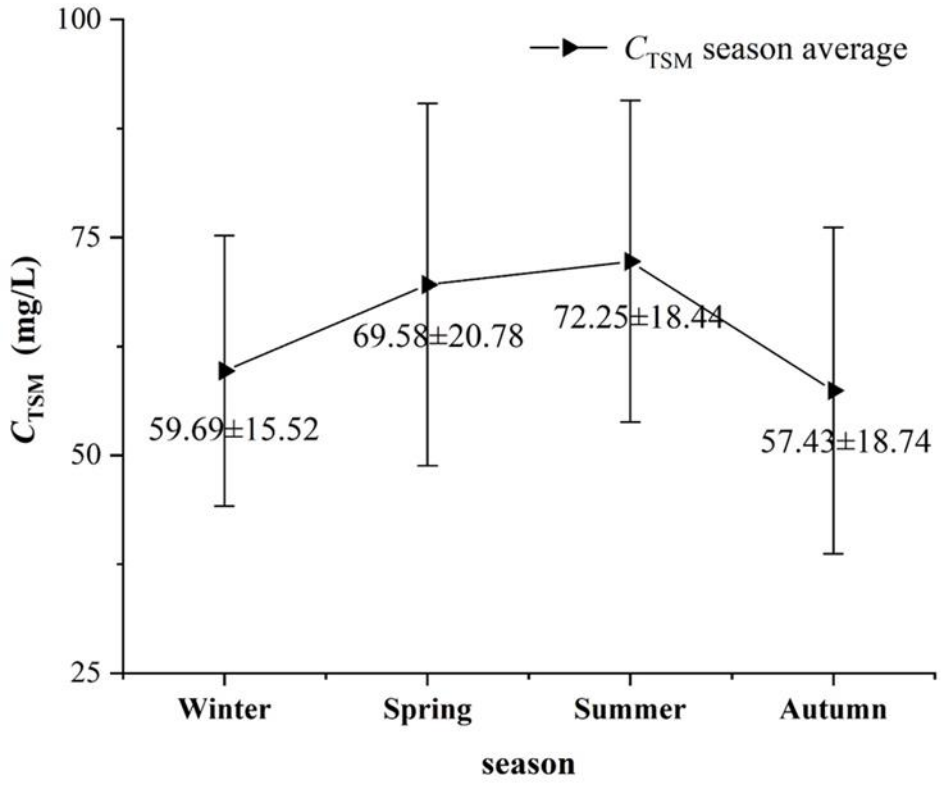

Figure 10. Average and standard deviation of TSM concentration in Changdang Lake in four seasons.

We appreciate your warm work earnestly and hope that the corrections will meet with approval. Once again, thank you very much for your comments and suggestions.

Yours sincerely.

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