Sensors and Materials, Vol. 35, No. 2 (2023) 553–561
MYU Tokyo

S & M 3194

Research on Variation of Water Quality Before and After Ecological Water Supplementation in the Beijing Section of the Yongding River

Yingchun Huang,[1,2*] Pinxiang Chen,[1,2] Junsheng Li,[3,4] Ya Xie,[4,5] and Xudong Yang[1,2]

[1]Beijing Institute of Surveying and Mapping, No. 60, Nanlishi Road, Xicheng District, Beijing 100038, China
[2]Beijing Key Laboratory of Urban Spatial Information Engineering, No. 60, Nanlishi Road, Xicheng District, Beijing 100038, China
[3]International Research Center of Big Data for Sustainable Development Goals, No. 9, Dengzhuang South Road, Haidian District Beijing 100094, China
[4]Key Laboratory of Digital Earth Science, Aerospace Information Research Institute, Chinese Academy of Sciences, No. 9, Dengzhuang South Road, Haidian District Beijing 100094, China
[5]Institute of Geoscience and Resources, China University of Geosciences, 29 Xueyuan Road, Haidian District, Beijing 100083, China

(Received October 1, 2022; accepted February 7, 2023)

Keywords: water quality, ecological water supplementation, water quality parameters model, precision evaluation, Yongding River

Rapid economic and social development in the Yongding River basin has resulted in a considerable increase in water consumption, and the Beijing section of the Yongding River has been continuously cut off since 1997, causing the water ecosystem to be seriously degraded. Since 2019, an ecological water supplementation project for the Yongding River has been implemented to repair its ecosystem. Water quality changes in the Yongding River after ecological water supplementation are an important aspect of the comprehensive evaluation of the effect of the project in the Beijing section of the river. In this study, we use Sentinel2-MSI satellite remote sensing data to determine the water transparency and chlorophyll-a concentration of the Beijing section of the river in the summers of 2018, 2019, and 2020, and to analyze the spatial and temporal changes in water quality after the ecological water supplementation of the river in the spring of 2019. Compared with the values from 2018 before the ecological water supplementation, the transparency increased and the water was more limpid in 2019 and 2020 after the ecological water supplementation; the concentration of chlorophyll-a decreased, and the degree of eutrophication was reduced; variations in these water quality parameters illustrate that ecological water supplementation improved the ecotope of the Beijing section of the Yongding River.

1. Introduction

The Yongding River is a tributary of the Haihe River, one of China's seven big rivers, and its origin is the intersection between two tributaries of the Sanggan River and the Yanghe River in

*Corresponding author: e-mail: 176483135@qq.com
https://doi.org/10.18494/SAM4161

ISSN 0914-4935 © MYU K.K.
https://myukk.org/

Hebei Province. After flowing into and leaving the Guanting reservoir, it enters Beijing through the Guanting gorge and then flows into the Bohai Sea through Hebei Province and Tianjin City. The Beijing section of the Yongding River flows through Mentougou City, Shijingshan City, and the Fengtai, Fangshan, and Daxing Districts successively, for an approximate distance of 187 kilometers.(1) Rapid economic and social development in the Yongding River basin has resulted in a considerable increase in water consumption, and the Beijing section of the Yongding River has been continuously cut off since 1997, and the water ecosystem there has been seriously degraded.(2–4) Since the implementation of the Yellow River Diversion Project to Shanxi in 2019, an ecological water supplementation project has been implemented to restore the ecosystem of the Yongding River by opening the gates of the Guanting Reservoir, whose water source comes from Shanxi. The Beijing section of the Yongding River now has complete access to water as a result of implementing ecological water supplementation.(5) The ecological water implementation project has successfully enhanced the water yield in the Beijing section of the Yongding River, thereby laying the foundation for repairing its ecosystem.

What has happened to the water quality of the Yongding River after the ecological water supplementation? Because the Beijing section of the Yongding River has been cut off for a long time, the water quality data from conventional ground monitoring and spatial coverage are both limited; thus, it is difficult to carry out a comprehensive evaluation of the overall water quality status of the Beijing section of the Yongding River. However, the technique of water quality monitoring based on satellite remote sensing can cover the Beijing section of the Yongding River overall, and can be used retrospectively to determine the water quality before ecological water supplementation.(6) Therefore, in this research, we use satellite remote sensing studies to determine spatial and temporal changes in water quality before and after ecological water supplementation of the Yongding River.

Water quality parameters that can be monitored by satellite remote sensing include chlorophyll-a concentration, suspended matter concentration, transparency, the content of colored soluble organic matter, as well as other measurements.(7–10) Water transparency is the depth to which visible light can penetrate the water, and can be used to characterize the clarity of the water.(11) Chlorophyll-a concentration represents the algal biomass, which can be utilized to characterize the nutritional state of water.(12) Clarity of water and nutritional state are essential indicators for the comprehensive estimation of water quality. In this study, we use Sentinel2-MSI satellite remote sensing data to determine the water transparency and chlorophyll-a concentration of the Beijing section of the Yongding River in the summers of 2018, 2019, and 2020, and to analyze the changing spatial and temporal situation of water quality before and after ecological water supplementation.

2. Research Area Data Acquisition

2.1 Ground-based experimental data acquisition

A water surface experiment was conducted in the Beijing section of the Yongding River on July 31, 2021, and the experimental data from nine sampling sites have been acquired (Fig. 1).

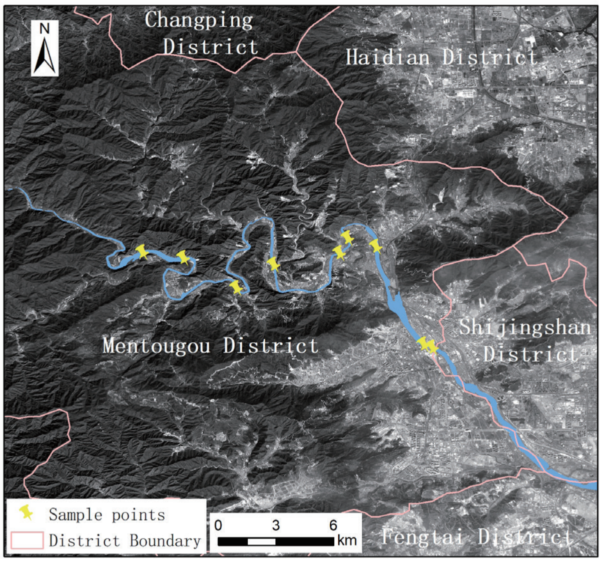

Fig. 1. (Color online) Distribution of water surface experimental sampling sites in the Beijing section of the Yongding River.

Table 1
Statistical results for typical water quality parameters measured in the surface water of the Beijing section of the Yongding River.

Parameters of water quality	Average	Standard deviation	Min	Max
Transparency (m)	1	0.4	0.4	1.6
Concentration of Chlorophyll-A (mg/m^3)	7.2	7.3	1.7	25.4

Experiments on surface water samples are twofold: (1) utilizing Seder plates to measure water transparency at the surface of the water at the site, and (2) collecting water samples at the surface, refrigerating them, and delivering them to the laboratory for measurement of the chlorophyll-a concentration using an industry-standard spectrophotometric method. The mean, standard, minimum, and maximum of the measured transparency and chlorophyll-a concentration are shown in Table 1.

2.2 Satellite image data acquisition

The satellite remote sensing data source used in this research is Sentinel2-MSI, which originated from the European Space Agency (ESA). Sentinel2-MSI has 13 wave bands: the spatial resolution of the four wave bands with central wavelengths of 490, 560, 665, and 842 nm is 10 m; that of the six wave bands with central wavelengths of 705, 740, 783, 865, 1610, and 2190 nm is 20 m; and that of the three wave bands with central wavelengths of 443, 945, and 1375 nm is 60 m.

The three advantages of Sentinel2-MSI as the data source are: (1) obtaining four wave bands with 10 m spatial resolution, six wave bands with 20 m spatial resolution, and three wave bands with 60 m spatial resolution; (2) acquiring multiple wave bands to enable the selection of suitable wave bands for inland water quality parameter inversion modeling; and (3) ESA providing the stable surface albedo production of Sentinel2-MSI and verifying its application to an inversion model of water quality parameters.(13)

The ecological water supplementation in the Beijing section of the Yongding River was carried out in the springs of 2019 and 2020. During the supplementation process, the amount of water varies greatly, which is not conducive to analyzing changes in water quality. Therefore, we chose the summer session after the supplementation to compare and analyze the water quality changes in the Beijing section of the Yongding River, comparing the summer of 2018 before the supplementation to the summers of 2019 and 2020 after the supplementation. In this research, we used the cloudless or less cloudy images of Sentinel2-MSI from the summers of 2018, 2019, and 2020, with numbers of images of 23, 20, and 10, respectively.

3. Methodology

3.1 Sentinel2-MSI data preprocessing

Satellite image data preprocessing mainly includes image resampling, study area cropping, water distribution extraction, and off-water reflection correction.

(1) Image Resampling

Utilizing the ESA-provided software Sentinel Application Platform (SNAP), we resampled the Sentinel2-MSI images, resampling the wave bands with 20 and 60 m spatial resolutions to 10 m.

(2) Study Area Cropping

The coverage area of a Sentinel2-MSI image is larger than the range of the Beijing section of the Yongding River. Therefore, on the basis of the latitude and longitude ranges of the Beijing section of the Yongding River, we cropped the images to enhance further computational efficiency and received the cropped images covering the Beijing section of the Yongding River.

(3) Water Distribution Extraction

Water quality monitoring based on satellite remote sensing first needs to extract the water body distribution from satellite images. We used Sentinel2-MSI images to compute and improve the normalized Modified Normalized Difference Water Index (MNDWI) and determined the water body recognition threshold by visual interpretation using a MNDWI gradation histogram, and finally extracted the water body distribution by threshold segmentation.(14)

(4) Off-water Reflection Correction

The surface reflection data of Sentinel2-MSI has been obtained using epicontinental aerosol correction, Rayleigh scattering correction, and cirrus correction. However, for water bodies, further correction is necessary to remove the effects of residual aerosol scattering, solar flares, and sky light reflection and finally extracting off-water reflectance. In this paper, we apply simple correction methods based on NIR and short-wave infrared (SWIR) wave bands.(15)

$$R_{rs}\left(\lambda\right)=\frac{R\left(\lambda\right)-\min\left(R_{NIR}:R_{SWIR}\right)}{\pi} \tag{1}$$

Here, $R_{rs}(\lambda)$ is the remote sensing reflectance, which is also called water separation reflectivity; $R(\lambda)$ is the surface reflectance; $\min(R_{NIR} : R_{SWIR})$ represents the minimum value of the surface reflectance of NIR and SWIR wave bands.

3.2 Water quality parameters model and precision evaluation

The sampling point data acquired from surface experiments on the Beijing section of the Yongding River are relatively few, and the range of water parameters is relatively concentrated. Therefore, these experimental data are not suitable for constructing a typical remote sensing inversion model of water quality parameters specifically for the Beijing section of the Yongding River and can only be used to test the effect of the inversion model of water quality parameters.

Considering that the distribution range of the water quality parameters of the Beijing section of the Yongding River is similar to the range of those of the Panjiakou and Daheiting reservoirs, the inversion model of water quality parameters of the Panjiakou and Daheiting reservoirs was used as shown in Table 2.

A Sentinel2-MSI transit on July 31, 2022, was synchronized with the ground experiment. We used the surface experiment to acquire measured water quality parameters from nine sampling sites and made a precision evaluation of water quality parameters from Sentinel2-MSI image inversion. The average relative errors of transparency and chlorophyll-a concentration through calculation are 28 and 38%, and the root-mean-square errors (RMSEs) are 1.67 mg/m^3 and 0.28 m, respectively. These precision evaluation indicators are in agreement with the mainstream accuracy of the typical remote sensing inversion model of water quality parameters of inland water bodies;[7] hence, we can utilize these inversion models of water quality parameters to calculate the transparency and chlorophyll-a concentration of the Beijing section of the Yongding River.

4. Results and Discussion

We applied an approved remote sensing inversion model for water quality parameters on cloudless Sentinel2-MSI images covering the Beijing section of the Yongding River obtained in the summers of 2018–2020. Calculating the mean value of the water quality parameters for each summer to analyze the changes in water quality, we acquired the averaged inversion results of typical parameters over each summer.

Table 2
Typical water parameter inversion model based on Sentinel2-MSI satellite data.

Parameters of water quality	Inversion model based on Sentinel2-MSI
Transparency (m)	$10^{(-1.16*(R_{rs}665/R_{rs}490)+1.01)}$
Concentration of chlorophyll-a (mg/m³)	$14460*(R_{rs}560-0.6*R_{rs}490-0.4*R_{rs}665)^{1.3358}$

4.1 Water spatial distribution of the Beijing section of the Yongding River

We used the 2020 summer water quality parameters (transparency and chlorophyll-a concentration) determined by Sentinel2-MSI to analyze the water quality spatial distribution after the ecological water supplementation. The results of the transparency remote sensing inversion reveal that the water body transparency is relatively high in the area of the Zhuwo Reservoir, Luopuling Reservoir, Sanjiadian Reservoir, Yuanbo Lake, and Daning reservoir, and the water body transparency in other channel segments is relatively low (Fig. 2). This may arise because, after the reservoir intercepts the water body, the flow velocity is lower. When the water level becomes higher, the water flow does not stir up the bottom mud, resulting in higher water body transparency in both the lake and the reservoir than in other channel segments.

The results of remote sensing of chlorophyll-a concentration show that the upstream chlorophyll-a concentration is comparatively low, while the downstream chlorophyll-a concentration is relatively high (Fig. 3). This may arise because the upstream is mainly located in mountainous areas, which are less affected by human activities, whereas the downstream is located on a plain, which is more affected by human activities. Moreover, the downstream point source and surface source pollution bring more nutrient salts, which are more conducive to the growth of algae.

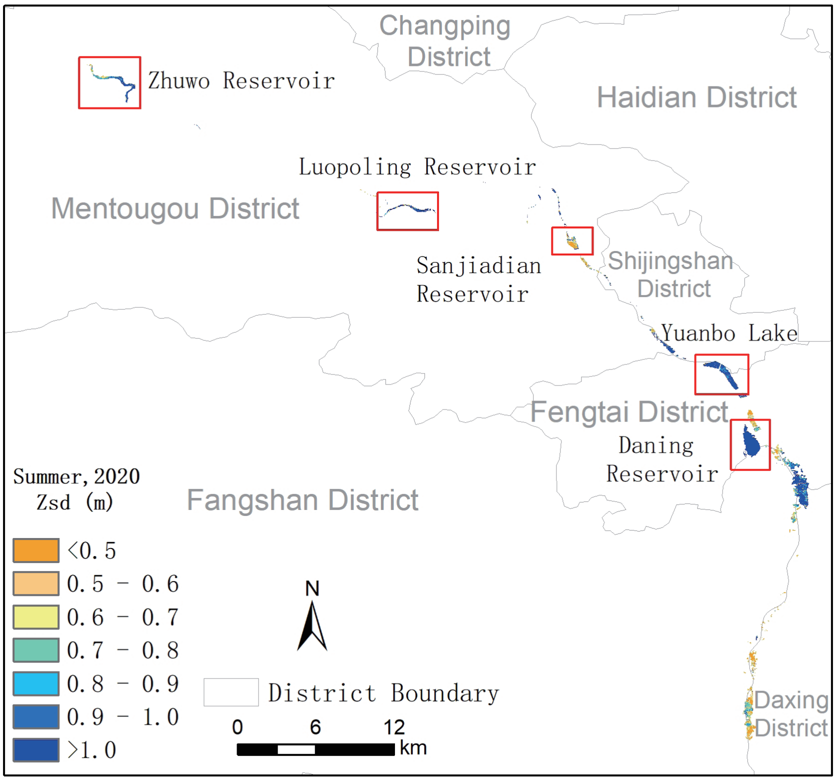

Fig. 2. (Color online) Remote sensor monitoring results of transparency in the Beijing section of the Yongding River in the summer of 2020.

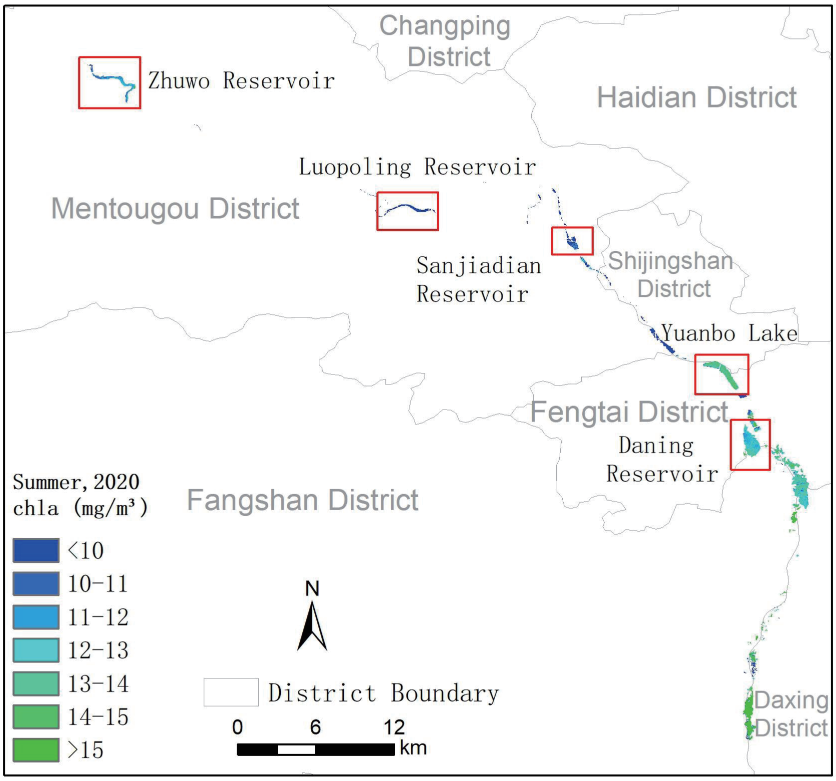

Fig. 3. (Color online) Remote sensor monitoring results of chlorophyll-a in the Beijing section of the Yongding River in the summer of 2020.

4.2 Change of water quality over time in the Beijing section of the Yongding River

We applied the water quality parameters from the summers of 2018, 2019, and 2020 (transparency and chlorophyll-a concentration) determined by Sentinel2-MSI to analyze the changes in water quality before and after ecological water supplementation.

The results from the remote sensing inversion model reveal that the transparency was higher in 2019 and 2020 after the ecological water supplementation than in 2018 before the ecological water supplementation, demonstrating that water is more limpid after the ecological water supplementation (Fig. 4). The chlorophyll-a concentrations in 2019 and 2020 after the ecological water supplementation were lower than those in 2018 before the ecological water supplementation, indicating that the eutrophication of the water bodies was reduced after water recharging. In brief, the changes in transparency and chlorophyll-a concentration illustrate that the water quality improved after the ecological water supplementation and indicate that ecological water supplementation improved the water eco-environment of the Beijing section of the Yongding River because of the increasing water volume in that section.

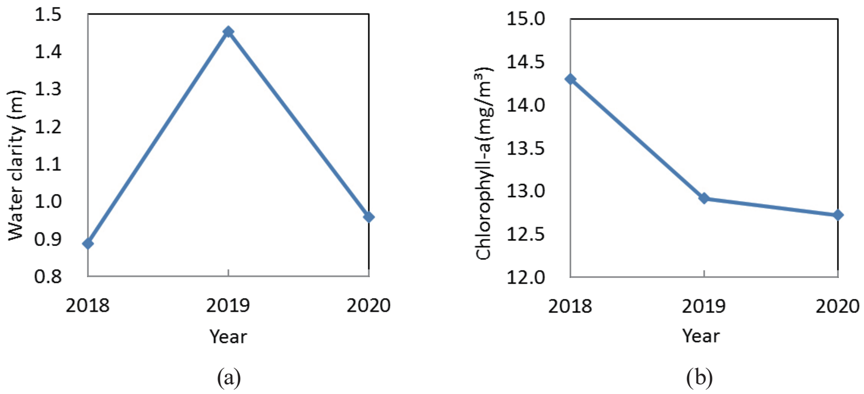

Fig. 4. (Color online) Annual variation of (a) transparency and (b) chlorophyll-a concentration in the Beijing section of the Yongding River during the summers of 2018–2020.

5. Conclusions

Utilizing satellite remote sensing data from Sentinel2-MSI, in this research, we determined the water body transparency and chlorophyll-a concentration of the Beijing section of the Yongding River in the summers of 2018, 2019, and 2020 to further analyze the changing spatial and temporal quality of water after ecological water supplementation.

In this study, we found that the water body transparency in several lakes and reservoirs in the Beijing section of the Yongding river is higher than in the other channel segments and that the chlorophyll-a concentration is lower upstream than downstream after ecological water supplementation. Compared with 2018 before ecological water supplementation, the transparency of water in 2019 and 2020 after ecological water supplementation improved and the water bodies were more fluid; chlorophyll-a concentration decreased and eutrophication was reduced. These changes in water quality parameters demonstrate that ecological water supplementation has improved the ecological environment in the Beijing section of the Yongding River.

Acknowledgments

Our research was supported by a science and technology project of the Beijing Institute of Surveying and Mapping, the ‘Study on the Ecological Environment Change of Yongding River in Beijing’. We also express our respect and thanks to the anonymous reviewers and the editors for their helpful comments in improving the quality of this paper.

References

1 H. F. Shao, J. M. Liu, P. B. Liu, J. Hu, X. C. Yao, and J. J. You: Water Resour. Hydropower Eng. **52** (2021) 62 (in Chinese). https://doi.org/10.13928/j.cnki.wrahe.2021.07.007
2 W. Y. Cui, D. Y. Liu, S. T. Liang, P. Y. Zhang, and F. Q. Kong: J. Hydroecol. **41** (2020) 23 (in Chinese). https://doi.org/10.15928/j.1674-3075.2020.02.004
3 X. Y. Zhang, J. Li, Y. J. Su, C. Z. Pan, Y. J. Huang, and M. Yin: Environ. Eng. **40** (2022) 117 (in Chinese). https://doi.org/10.13205/j.hjgc.202205017

4 Y. J. Lin: Water Wastewater Eng. **47** (2021) 206 (in Chinese). https://doi.org/10.13789/j.cnki.wwe1964.2021.S2.038
5 Y. Du, C. Wan, G. Z. Du, L. M. Wang, P. P. Miu, W. He, and Y. Gao: Water Conserv. Plann. Des. **7** (2020) 14 (in Chinese). https://doi.org/10.3969/j.issn.1672-2469.2020.07.004
6 B. Zhang, J. S. Li, Q. Shen, Y. H. Wu, F. F. Zhang, S. L. Wang, Y. Yao, L. N. Guo, and Z. Y. Yin: Natl. Remote Sens. Bull. **25** (2021) 37 (in Chinese). https://doi.org/10.11834/jrs.20210570
7 J. S. Li, M. Gao, L. Feng, H. L. Zhao, Q. Shen, F. F. Zhang, S. L. Wang, and B. Zhang: IEEE J. **12** (2019) 3769. https://doi.org/10.1109/JSTARS.2019.2936403
8 Z. Y Yin, J. S. Li, Y. Liu, F. F. Zhang, S. L. Wang, Y. Xie, and M. Gao: Opt. Express **30** (2022) 22572. https://doi.org/10.1364/OE.454814
9 Y. Liu, J. S. Li, C. C. Xiao, F. F. Zhang, S. L. Wang, Z. Y. Yin, C. Wang, and B. Zhang: IEEE Trans. Geosci. Remote Sens. **60** (2022) 4206714. https://doi.org/10.1109/TGRS.2022.3161651
10 Y. M. Zhou, J. S. Li, Q. Shen, F. F. Zhang: Spectrosc. Spect. Anal. **35** (2015) 1015 (in Chinese). https://doi.org/10.3964/j.issn.1000-0593(2015)04-1015-05
11 S. L. Wang, J. S. Li, B. Zhang, Z. P. Lee, E. Spyrakos, L. Feng, C. Liu, H. L. Zhao, Y. H. Wu, L. P. Zhu, L. M. Jia, W. Wan, F. F. Zhang, Q. Shen, A. N. Tyler, and X. F. Zhang: Remote Sens. Environ. **247** (2020) 111949. https://doi.org/10.1016/j.rse.2020.111949
12 F. F. Zhang, J. S. Li, Q. Shen, B. Zhang, L. Q. Tian, H. P. Ye, S. L. Wang, and Z. Y. Lu: Int. J. Appl. Earth Obs. Geoinf. **74** (2019) 138. https://doi.org/10.1016/j.jag.2018.07.018
13 Y. L. Zhao, S. L. Wang, F. F. Zhang, Q. Shen, and J. S. Li: Remote Sens. **13** (2021) 2260. https://doi.org/10.3390/rs13122260
14 H. Q. Xu: Int. J. Remote Sens. **27** (2006) 3025. https://doi.org/10.1080/01431160600589179
15 S. l. Wang, J. S. Li, B. Zhang, Q. Shen, F. F. Zhang, and Z.Y. Lu: Int. J. Remote Sens. **37** (2016) 6076. https://doi.org/10.1080/01431161.2016.1256508