Retrieval of chlorophyll-a (Chl-a) concentration from remote sensing data is still a challenge in optically complex inland waters. Recently, several algorithms, which are based on remote sensing reflectances at red and near-infrared wavelengths (hereafter denote as NIR-red algorithms), have been developed to address the above issue. However, the performances and applicability of these algorithms have not been sufficiently evaluated, and thus it is still unknown which algorithm should be selected for a given inland water. The objectives of this study were (1) to further test the performances of recently developed NIR-red algorithms by using data collected from several Asian lakes; (2) to propose a remote-sensing-based classification method for selecting the most appropriate algorithm for each site. For the above objectives, (1) remote sensing reflectances were collected from five Asian lakes using a FieldSpec HandHeld spectroradiometer (42 sites in Lake Erhai, China; 28 sites in Lake Dianchi, China; 10 sites in Lake Biwa, Japan; 8 sites in Lake Suwa, Japan; and 46 sites in Lake Kasumigaura, Japan); (2) water sampling was simultaneously carried out to measure Chl-a in laboratory using a Shimadzu UV-1700 spectrophotometer; (3) seven NIR-red algorithms were selected for testing the performances (three 2-band-index-based and four 3-band-index-based algorithms, which respectively proposed by Gitelson et al., 2011, Gilerson et al., 2010, Gurlin et al., 2011, and Yang et al., 2011, named as NR2-Git11, NR2-Gil10, NR2-Gur11, NR3-Git11, NR3-Gil10, NR3-Gur11, and SAMO-LUT hereafter); (4) the maximum chlorophyll index (MCI), which is a measure of reflectance/radiance peak at 709 nm in water-leaving reflectance/radiance, was employed to select the most appropriate algorithm for each site. Accuracy for each algorithm was evaluated by comparing the estimated Chl-a with the measured Chl-a. Results showed that (1) all NIR-red algorithms failed for Lake Biwa (oligotrophic lake), Japan, with the root-mean-square error (RMSE) and normalized root-mean-square error (NRMS) larger than 5.90 mg m^{-3} and 130.6%, respectively; (2) for Lake Suwa, Japan (eutrophic lake) and Lake Erhai, China (eutrophic lake), the 2-band-index-based NIR-red algorithms outperformed all 3-band-index-based NIR-red algorithms (the RMSE of 2.93-3.69 mg m^{-3} vs. 2.62-4.19 mg m^{-3} and the NRMS of 12.8%-16.3% vs. 23.8%-35.1% for Lake Suwa, and the RMSE of 3.06-3.79 mg m^{-3} vs. 3.88-5.61 mg m^{-3} and the NRMS of 14.2%-17.4% vs. 21.2%-31.8% for Lake Erhai); and (3) in contrast, for Lake Kasumigaura, Japan and Lake Dianchi, China (both are hypertrophic lakes), the performances of 3-band-index-based NIR-red algorithms are better than those of
2-band-index-based NIR-red algorithms (the RMSE of 12.98-14.83 mg m\(^{-3}\) vs. 15.46-22.11 mg m\(^{-3}\) for Lake Kasumigaura, and 7.39-14.61 mg m\(^{-3}\) vs. 22.75-35.93 mg m\(^{-3}\) except for the NR3-Gur11, which yielded larger RMSE of 16.98 mg m\(^{-3}\) and 41.26 mg m\(^{-3}\) for Lake Kasumigaura and Lake Dianchi, respectively). These findings indicate that (1) no any algorithm was available for the whole lakes; (2) different algorithm should be selected for different lakes to promise a higher accuracy for Chl-a estimation. In this study, the MCI, which can be estimated from remote sensing reflectance at 665 nm, 709 nm and 753 nm, was proposed to achieve this selection. Two thresholds of MCI were empirically determined according to our datasets and boundary values for trophic categories. According to the above MCI thresholds, the whole dataset was divided into three groups (MCI≤0 corresponding with waters from ultra-oligotrophic to mesotrophic, 0<MCI≤0.0016 corresponding with eutrophic waters, and MCI>0.0016 corresponding with hypertrophic waters). Accuracy for each algorithm was reevaluated by comparing the estimated Chl-a with the measured Chl-a. Results showed that (1) all NIR-red algorithms cannot be used for the first group (N=10) because of less phytoplankton information at these wavelengths (RMSE >5.90 mg m\(^{-3}\) and NRMS>130.6%). However, if a blue-green algorithm (OC4E) was used, the RMSE and NRMS can be largely reduced to 0.30 mg m\(^{-3}\) and 12.3%, respectively; (2) for the second and third groups (N=33 and N=91, respectively), the NIR-red algorithms can be used, and 2-band-index-based NIR-red algorithms were more appropriate for the second group (RMSE of 3.48-3.87 mg m\(^{-3}\) for 2-band-index-based vs. 4.04-6.19 mg m\(^{-3}\) for 3-band-index-based) while 3-band-index-based NIR-red algorithms were more appropriate for the third group (10.29-12.26 mg m\(^{-3}\) for 3-band-index-based vs. 16.61-25.15 mg m\(^{-3}\) for 2-band-index-based, except for the NR3-Gur11). These findings indicate a possibility for the combined blue-green and NIR-red algorithms to estimate Chl-a in most inland waters, and MCI can serve as an indicator to select the most appropriate algorithm. The RMSE and NRMS were reduced from 8.83 mg m\(^{-3}\) and 71.7% (the smallest ones among the seven NIR-red algorithms) to 8.63 mg m\(^{-3}\) and 16.5%, respectively, if the hybrid method was used.

Development of an operational algorithm for remotely estimating chlorophyll-a concentration in lakes

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