Measurement of CDOM Using Smartphone Cameras

Introduction

The distinguishing feature of CDOM, its color, means it absorbs light at selective wavelengths in the visible range. CDOM light absorbance increases quasi-exponentially with decreasing wavelength, with low absorbance above ~ 500 nm (see graphic in the "Background on CDOM" page).

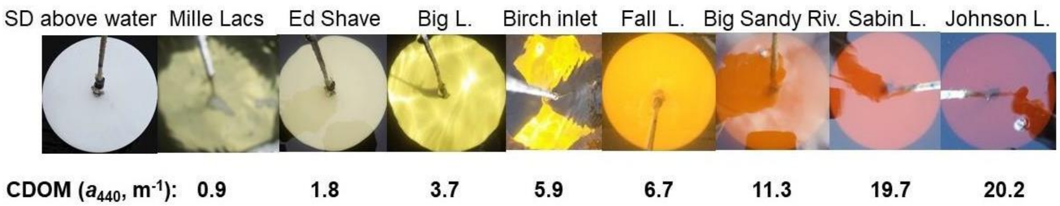
Smartphones collect images using sensors that respond to the light reflected on surfaces in the red, green, and blue (RGB) regions of the visible spectrum. The distribution of RGB intensities for each pixel reproduces the colors we observe. Digital imagery from smartphone cameras can be analyzed to extract the intensity of R, G, and B signals. This process is analogous to the way satellite sensors are used to measure CDOM in water images; i.e., "bands" in the satellite sensors collect data on light intensity reflected from a land or water surface back to the satellite. The sensor bands collect data in specific wavelength ranges across the visible spectrum. Today, most satellite sensors collect data in more than three visible bands, including the near infrared, and the bands of satellite sensors have varying bandwidths. Nonetheless, the analogy between satellite sensor and digital camera measurements applies. Algorithms developed to extract CDOM data from satellite imagery typically rely on band-ratio models, involving the red/green or red/blue bands.

The above background information led us to conclude that we could measure CDOM levels in lakes by extracting the RGB information from digital imagery of smartphone cameras. This led to the idea that an app could be developed to enable citizens to measure CDOM in lakes using smartphones and thus contribute to water quality monitoring. Here we describe our efforts under the sponsorship of an NSF "citizen science" supplement to our CDOM grant to evaluate the feasibility of using smartphones to measure CDOM, with the goal of developing an app as a simple tool to increase citizen involvement in water quality monitoring.

The basic idea

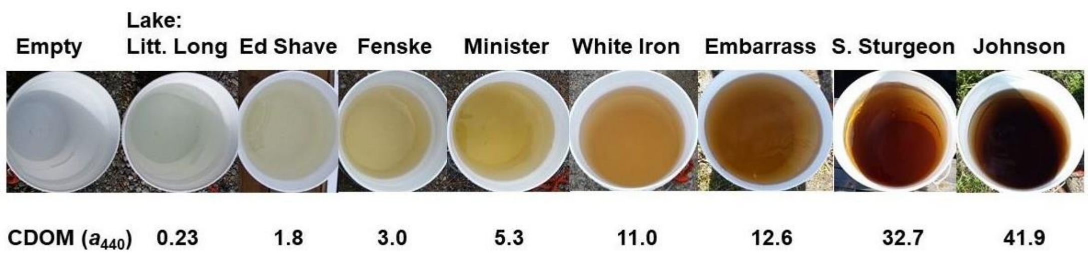
We evaluated two approaches to measure CDOM using smartphone cameras. The first involved images of a Secchi disk held at a fixed depth (1 ft.) in a water body; the second involved photos of a white bucket filled with lake water. Photos were cropped to include just a portion of the white surface of the disk or a portion of the water surface in the bucket. CDOM, expressed as a_{440}, was obtained from RGB data extracted from the cropped photos. To account for variations in light conditions, photos of the Secchi disk just above the water surface or the empty bucket were taken at the same time and under the same light conditions as the below-water disk or full bucket images.

Secchi disk approach



Above: smartphone pictures of Secchi disks at 1-foot depth in waters with increasing a_{440}. Blurry images (Mille Lacs and Birch L.) were caused by wave activity and cloud reflections (Big Sandy River and Sabin L.) and can complicate data analysis.

White bucket approach



Above: smartphone photos of a 2-gallon white bucket filled with lake waters with increasing a_{440} left to right.

Advantages and disadvantages of the two approaches:

The Secchi disk method requires no equipment aside from the disk, which persons involved in state lake water clarity programs like Minnesota's Citizen Lake Monitoring Program (CLMP) already have. This method is more prone to produce blurry images because of wave activity from wind or boat activity. The bucket method provides more stable and consistent conditions for image taking (it can be done on land), but it requires a white 2-gal. bucket. Cloud reflections, especially under calm conditions can affect image quality for both approaches.

Quantifying CDOM (a_{440}) from smartphone images

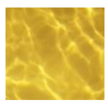
Photos were cropped to contain a part of the disk or bucket bottom that is relatively homogeneous in hue (see photos above). RGB intensities of cropped images were extracted using the public domain program, ImageJ; other readily available software, including Matlab, also could be used. RGB intensities were normalized to account for variations in ambient light quality by dividing the RGB values for water-based images by corresponding data from above-water or empty-bucket images taken under the same sun/shade/ambient light conditions. We found strong relationships between ln a_{440} and ratios of R and G intensities extracted from cropped images of buckets filled with colored lake water or Secchi disks suspended at 1-foot depth in colored waters. A typical best-fit equation for bucket data is shown below:

$$\ln(a_{440}) = 0.009 + 1.44(R^*/G^*) - 1.18(B^*)$$

$R^2 = 0.89$; RMSE = 0.39; N = 34.

* indicates RGB values for a water-filled bucket normalized to values for an empty bucket under the same light (sun/shade) conditions; e.g., $R^* = R_{full\ bucket}/R_{empty\ bucket}$; R is Intensity of the cropped image in red range of the spectrum.

Example: bucket data for Birch Lake, Minnesota

R	G	B		
214	219	225		Full bucket, sun
213	176	53		Empty bucket, sun
R*	**G***	**B***		
0.9953	0.8036	0.2355		R*/G* = 1.238

Using the above best-fit equation the calculated CDOM is: $\boldsymbol{a_{440} = 3.6\ m^{-1}}$

versus a measured value of: $\boldsymbol{a_{440} = 4.5\ m^{-1}}$.

Further studies with a single model of smartphone showed generally high R^2values for best-fit equations with a SD and bucket photos from lakes with a wide range of CDOM levels. However, when we used this approach with a range of smartphone models from various manufacturers, we found that images for the same lake water varied greatly in hue, and results based on the calibration equation from a single smartphone model were not reliable. It is possible that this issue could be resolved by saving the images from different models of smartphones as “raw” images, but this feature is not available on all phones.

Conclusions

Although image acquisition is sensitive to environmental conditions, smartphone cameras can measure water color quickly, and the approach can be reasonably accurate under appropriate conditions. However, calibration equations need to be developed for the specific model smartphone used to take the lake water images.