River Color in the Greater Pittsburgh Region

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Rationale

Pittsburgh has numerous water quality issues such as combined sewer overflow and acid mine drainage, making the rivers unsuitable for many human uses. Yet, Pittsburgh's rivers provide 90% of Allegheny County residents with drinking water. There is a need for simple metrics of water quality to detect changes and identify water quality events. Satellite observations of river color may offer a simple approach for quantifying changes in water quality but has yet to be tested at a local scale.

Approach

Landsat imagery from 1984-2020 was used to measure river color, as the human eye perceives it, across all large rivers in the Ohio River Basin. Color, as quantified by the dominant wavelength, is a value between 400-700 nanometers corresponding to the visible spectrum. Water quality events and sites of concern were investigated in the satellite record.

Questions

We used satellite observations of river color to answer the following questions:

- What color are Pittsburgh's rivers?
- Can satellite observations of river color be used to detect past water quality events?

Abstract

Pittsburgh's rivers provide an important economical and recreational backbone for a city built on steel and coal. To characterize the present status and past responses of the region's rivers to water quality events, we built a database of river color from Landsat imagery captured between 1984 and 2020. We found that 1) the expected color of Pittsburgh's rivers is green, and the regions rivers have similar colors on average; 2) river color observations over time and space can be associated with water quality events under the right conditions.

Findings

What color are Pittsburgh's rivers?

We grouped the Allegheny, Monongahela, and Ohio Rivers by pool and found that their differences in expected color, measured as dominant wavelength within the visible color spectrum, are minimal. Overall, the average color of Pittsburgh's nearest rivers is 536 nm with a standard deviation of 27 nm. To the human eye, this appears as green (figure 1).

Figure 1. The modal color of Pittsburgh's rivers (left) and an image of the Monongahela River (right). Color is subjective; notice how the river's color appears different in the shadow and the light.

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What are the pros and cons of using Landsat imagery?

Landsat imagery offers the longest continuous set of orbit-based observations of Earth. Thus, it provides an abundant and centralized database of optical measurements from which long-term trends in river color can be observed; the color database built for this research contains over 2.7 million observations.

Although there is an abundance of observations, there are various reasons a site or event may not be visible at a certain point in time. Cloud cover, river ice, and hill shadow can all block observations of rivers. Landsat also has a periodicity of 8-16 days. Additionally, it is difficult to observe river color from rivers less than 60 meters wide as Landsat has a pixel resolution of 30 meters.

What is AMD?

Acid mine drainage (AMD) occurs when iron sulfides, such as pyrite, weather and release into waterways. Pittsburgh's extensive coal-mining history has exposed many of these chemical compounds to air and water, thus leading to the deterioration of surface– and ground–water quality.

Additionally, variability of river color was measured by pool. The Allegheny River steadily increases in variability towards Pittsburgh while the Monongahela River increases and decreases from pool to pool. The most variable pool is the Pike Island pool, which is approximately 130 kilometers from Point State Park on the Ohio River.

Can satellite observations of river color be used to detect past water quality events?

We performed two case studies to determine if distinct colors were observed at the time and place of water quality events.

St. Michael Acid Mine Drainage (AMD) Treatment Plant Opens, 2013
The Conemaugh River begins in Johnstown, PA where two rivers meet; the Little Conemaugh River and Stonycreek River. 20 kilometers upstream the Little Conemaugh River is the St. Michael AMD Treatment Plant, which began operations in mid-July of 2013. Prior to the plant's opening, AMD discharge from the St. Michael mine shaft accounted for around a third of the total AMD input into the Little Conemaugh River. We observed color over time at the confluence of the Little Conemaugh River and Stonycreek River and found that the Conemaugh River has been become less orange since January, 2000. This change has accelerated since the opening of the plant (figure 2).

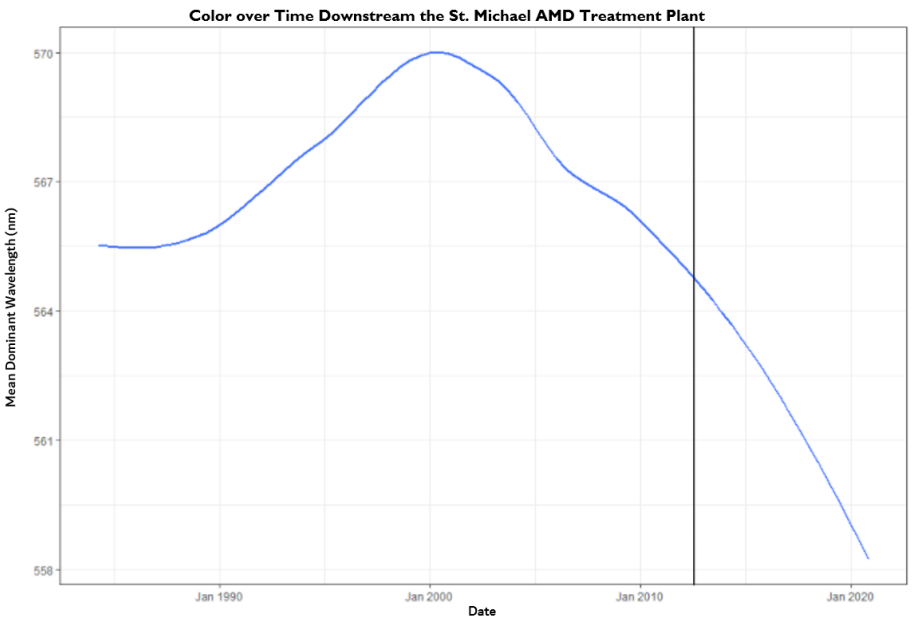

Figure 2. The Conemaugh River has become less orange at the nearest observable downstream point to the St. Michael AMD Treatment Plant. Although dominant wavelength has continuously fallen since January 2000, the rate at which it is decreasing has accelerated after the plant opened.

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What is a river pool?

River pools are section of rivers in-between locks and dams designated by the Army Corps of Engineers. On the Allegheny River, pools are named by number since the locks are as well. However, the pool within downtown Pittsburgh is often referred to as both the Emsworth Pool and the Pittsburgh Pool.

What is dominant wavelength?

Dominant wavelength (DW) is a quantitative measurement of color in nanometers (nm) which describes the dominant hue based on colors in the visible spectrum (400 to 700 nm). A lot more can be said about color by numerically interpreting trends, shifts, and distributions rather than visually.

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Ashland Oil Spill, 1988

Approximately 1 million gallons of diesel were released into the Monongahela River on January 2nd, 1988 when a holding tank near West Elizabeth collapsed. The slick was up to 15 centimeters thick and traces were observed over 150 kilometers downstream.
Color was observed to be unique during the spill, but that uniqueness continued upstream of the origin. This should not have occurred since the oil could not travel against current. It is likely that the only observations available, which were made one week after, captured clean-up efforts and/or mixing had displaced much of the oil from the surface (figure 3).

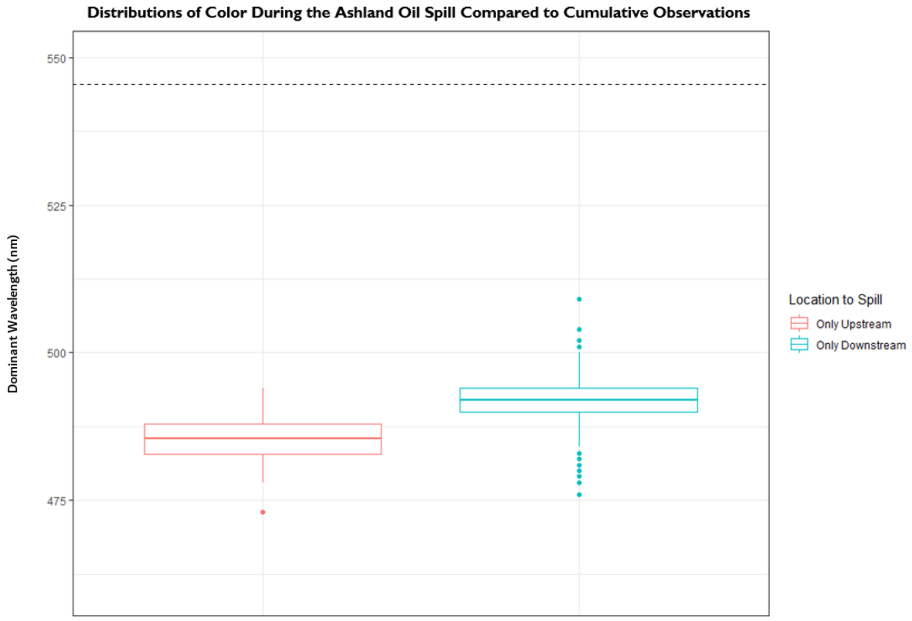

Figure 3. Observations of color downstream and upstream are significantly different from the mean color of the river during the spill (horizontal line). However, they are both below 500 nm; this would not be the case if the spill, were the cause of the low values.

Implications

- Expected river colors help understand how a river should look
- Water quality events and interventions could be observable in long-term color trends
- Color is very dynamic near manmade structures and influences; what is the relationship between color and other long-term human influence (e.g. population)?

Landsat data provides an understanding of expected river color and color is an indicator of large water quality events.