Crude Waters

Landsat Image Enhancement of Oil Spills in Lake Maracaibo, Venezuela

COGS Centre of Geographic Sciences
nscc

Project Overview

Shaped like a rotund teardrop dipping south into Venezuela, Lake Maracaibo is a large tidal estuary covering an area of 13,280 square km. Since the early 20th century, the lake and its surroundings have been sites for numerous petroleum extraction wells; crude oil being the the industry that fueled Venezuela's economy for decades. Decaying transportation pipelines and derricks crisscross the lake's bottom, mainly along its eastern shore, leaking crude oil that appears on the water surface and accumulates in coastal mangrove forests.

In recent years, the Maduro government has leaned heavily on squeezing what's left of Venezuela's vast reserves at the expense of the natural environment and other industries such as fishing and aquaculture (Bloomberg News, 2020).

Using Landsat 8 imagery acquired in September 2021, this project performs image enhancement techniques in Catalyst Focus to highlight the numerous oil streaks on Lake Maracaibo's surface, as well as distinguishing them from surrounding algal blooms, sediment and clear water.

Study Area

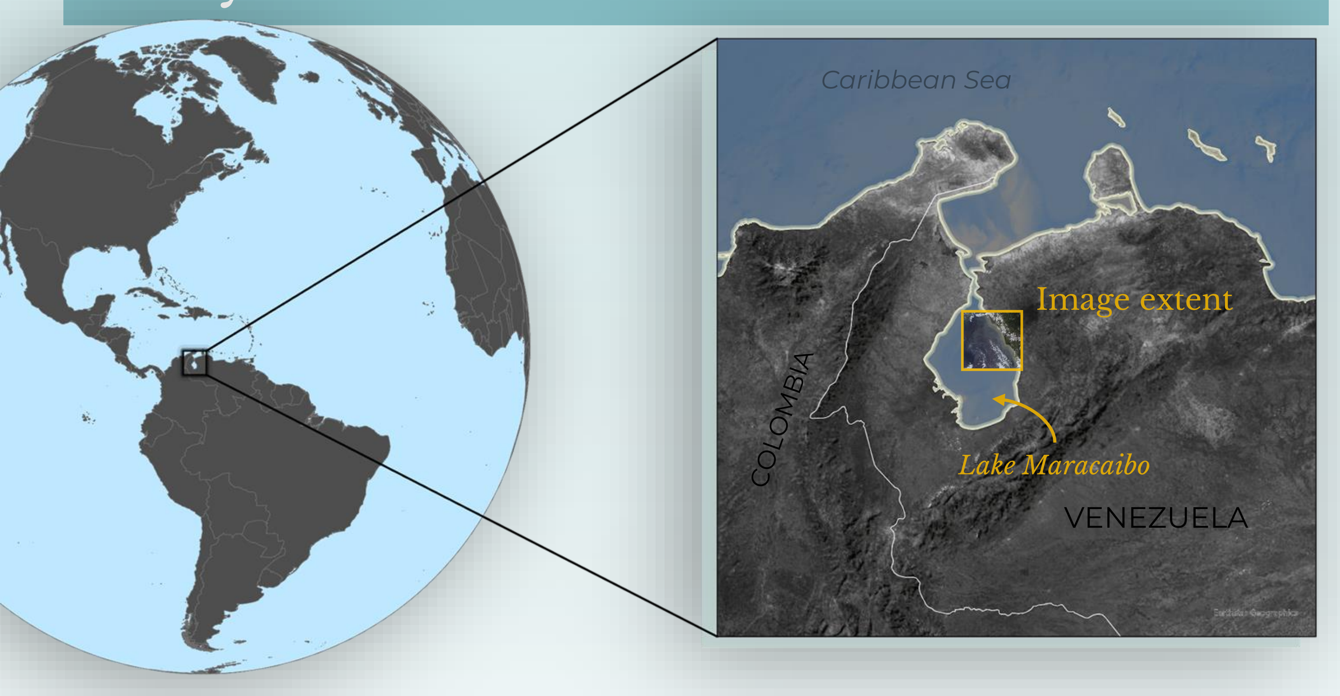

Figure 1: Locator map of the project. The project uses a subset of a Landsat 8 scene centred on the northeastern shore of Lake Maracaibo near Ciudad Ojeda, Venezuela. The image covers a square defined by the geographic coordinates:
Upper left: 71°51'31.4773"W, 10°28'18.7391"N,
Lower right: 71°00'12.2158"W, 9°38'11.9963"N. *Data: Natural Earth, Esri*

Data Preparation

Data was downloaded as a Level-1 raw data GeoTIFF file from the USGS website GloVis. The image was captured by the Landsat 8 Operational Land Imager (OLI) on September 10, 2021. Because of the 24% cloud-cover in the image, an atmospheric correction was applied to the image and a cloud mask was exported to the project folder. The image was clipped to the desired extent and subsetted to only include bands 5 (Near-infrared), 3 (Green) and 2 (Blue).

Choice of Spectral Bands

Spectral signatures from the image prior to clipping and subsetting reveal stark differences in reflective response from three areas of water within the lake: the oil streaks, the algae blooms/sediment, and open water. Band 5 (Near-Infrared), band 3 (Green) and band 2 (Blue) were chosen for the enhancement. As seen in Figure 3a, the oil spill streak delivers a high spectral response in band 5 and is quite distinct from the other areas. SWIR bands were also a good option, but NIR has been used previously in remote sensing research for assessing oil streaks on water (Fingas and Brown, 2017). The inclusion of the green and blue bands allow for additional enhancement of the algal blooms present in the lake, made clear by the spike of its spectral response in the green band (3), while blue provides reflection for the water and gives the scene a natural semblance.

Standard Enhancement

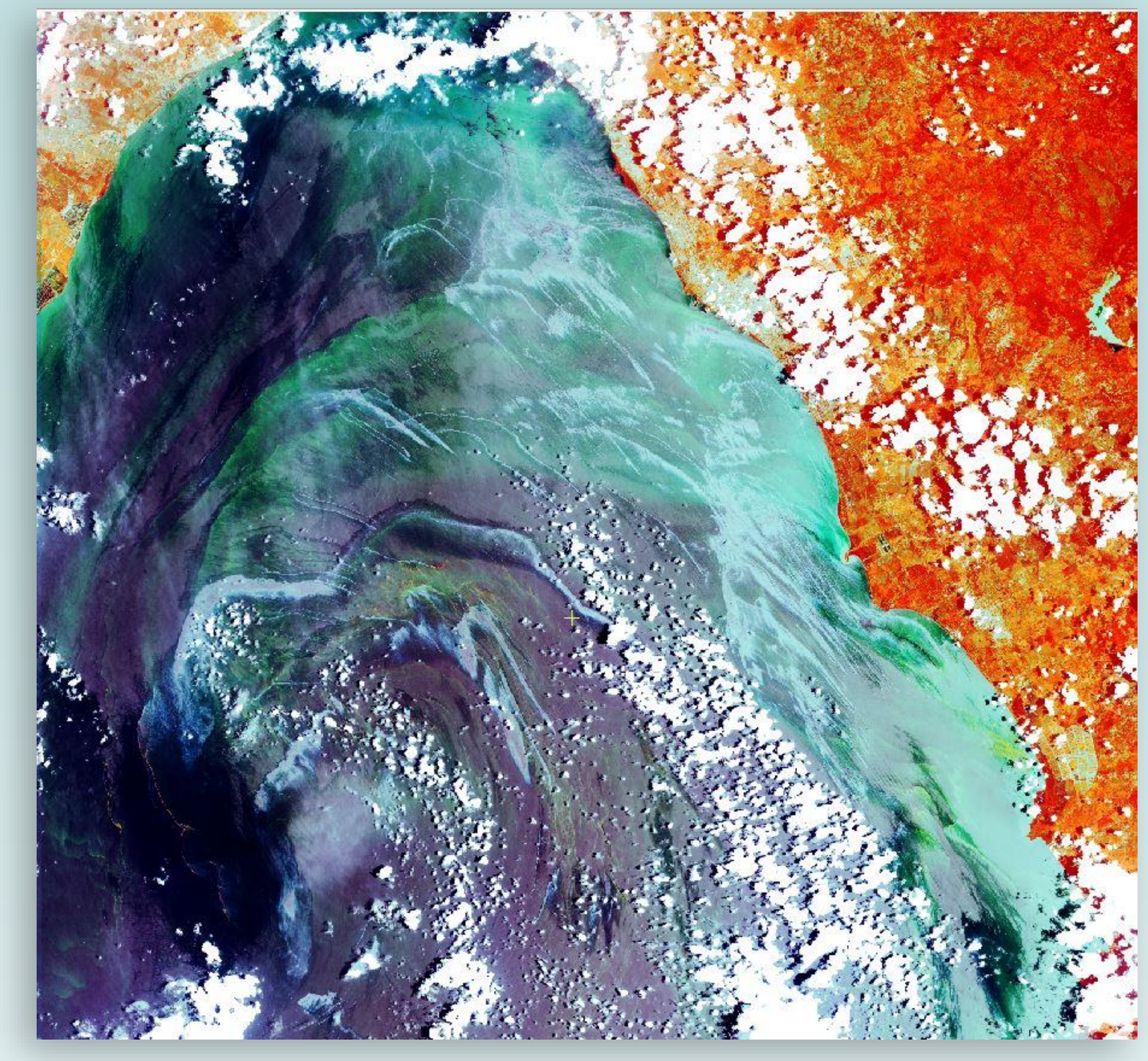

Figure 2: A histogram equalization stretch type was used for the standard enhancement method .

Using the 532 false-colour composite, a histogram equalization enhancement was used as an initial visualization (Figure 2). This enhancement allows DN values of the image to be proportionally stretched along to full radiometric range based on the frequency of occurrence of each value (Lillesand et al., 2015, p. 504). The resulting image stretches proximate valued pixels to better distinguish differences in between. Lake Maracaibo's water property features are made highly visible and more distinguishable between open water (navy blue), algal blooms/suspended sediment (turquoise) and oil streaks (light blue). The stretch also efficiently delineates the land from the lake. However, despite the increased enhancement of separate values, features are still hard to completely differentiate within the same general hue.

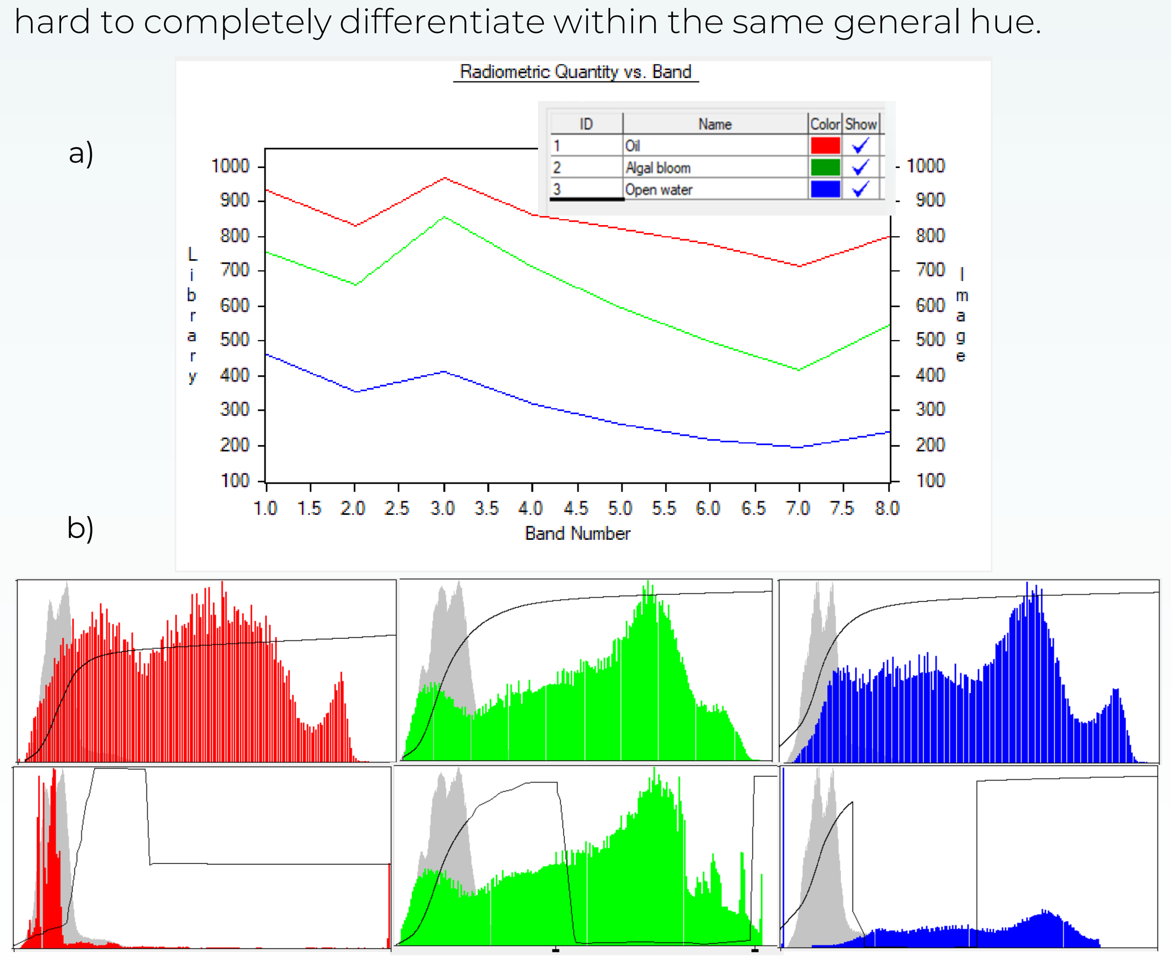

Figure 3a: A plot showing spectral responses of three water areas of the lake.
Figure 3b: Histograms of a masked area of water that included all three water area types. Above are the NIR, Green and Blue histograms of the standard enhancement and below are the custom enhancement histograms.

Custom Enhancement

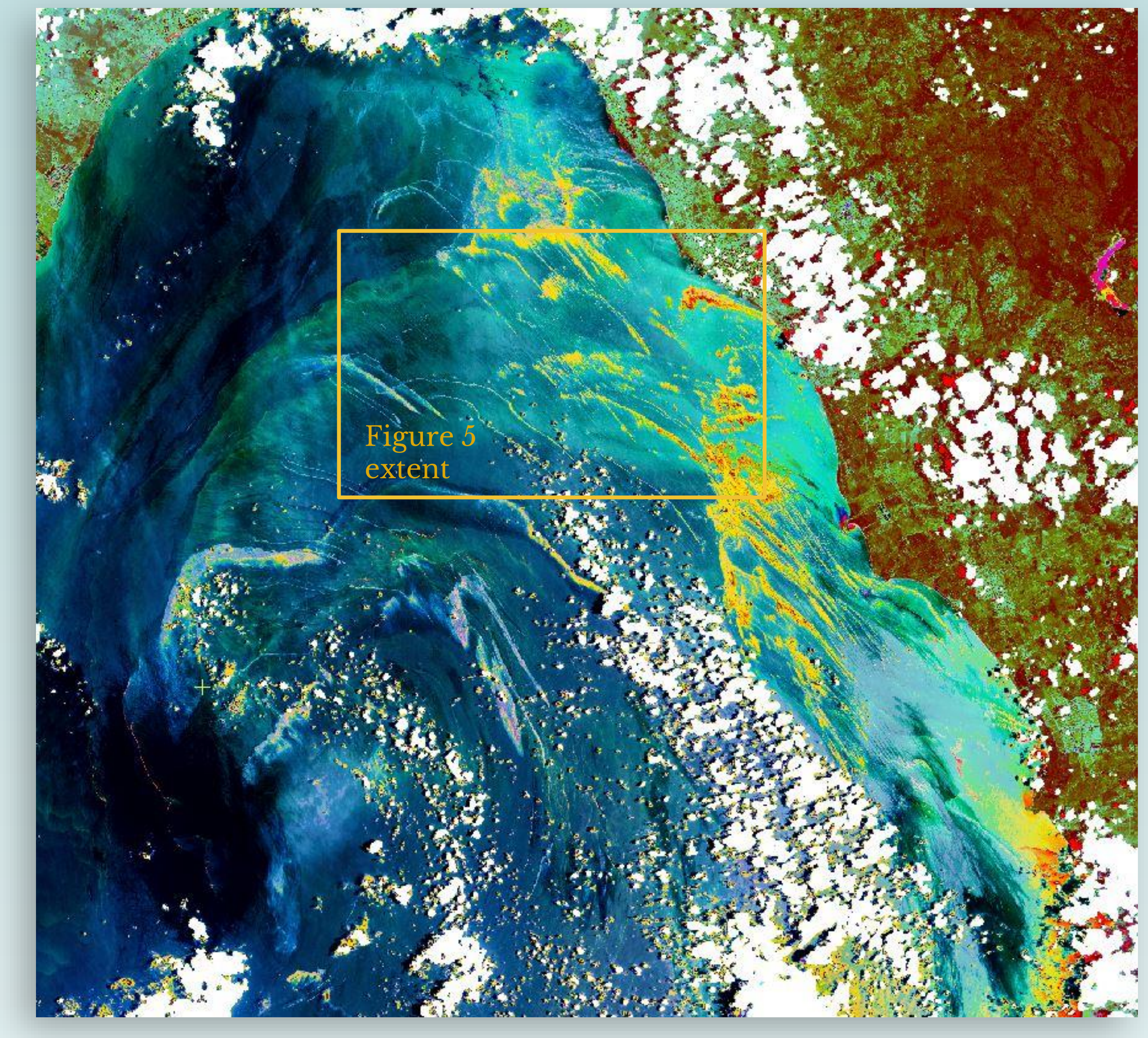

Figure 4: A custom enhancement using manual histogram manipulation methods.

A custom enhancement (Figure 4) was applied to further the delineation between the oil streaks and surrounding water. The custom enhancements were made by editing the look-up tables (LUT) and altering histogram stretches using limited ranges and manual manipulation.

The red histogram, carrying the near-infrared band was limited to a range from 8500.0 to 10,000.0 (x), and then the histogram equalization stretch was reapplied within the new x range. This range of values follows the approximate range of near-infrared DN values in the location of observed oil streaks.
The limits were then reset to the minimum of the image extent and a manual spike was drawn in between the same range of values (8500-10000).

The green band (band 3) was customized by toggling the histogram equalization stretch first. This method allows a diverse range of green values, such as the cyanobacteria in the algal blooms to be stretched and distinguished.
The minimum x was set to 11,000 and the maximum to 13,500. A manual dip was drawn from the between these values with a slight angle towards the right on the descend. By dropping the green in this range, the portions of the oil streaks with higher DN values revert to red, while the main range of the oil streak stays yellow because of the combination of the high reflectance in the infrared and green bands (red + green = yellow).

The blue band customization also started with applying the histogram equalization stretch.
Then a manual dip was drawn with the aid of setting min/max limits between 11,000 and 14,000, a range that corresponds with the total range of DN values observed in the oil streak areas for the blue band. The dip (lack of blue values) in this range allows the oil streaks to have their bright yellow/orange colour, helping them stand out from the dark blue and turquoise of the other water areas.

Credits & Disclaimer

This poster is produced by Becket Osterland (November 2021) as part of the course REMS 5001 Fundamentals of Remote Sensing.

Discussion

Both enhancements deliver more punctuated detection of oil spills and algal blooms within the image. The standard histogram equalization stretch (Figure 2) brightens the overall scene, especially within the lake area. Because the lake occupies such a large swath in the image, the high-count water DN values in this area are stretched farther along the radiometric range. While the histogram equalization helps improve the brightness of features, the delineation between water types is still somewhat unclear because all water features are within the same general hue of blue. The similarity in colour (light-blue) between the oil spills and urban areas on the shore is also a shortcoming of this enhancement that could cause confusion.

The custom enhancement improves on the delineation of oil spills, offering a clear contrast between the yellow-red streaks, the blue-green algal blooms and dark blue open water. The issue of similarly displayed urban areas is also mostly corrected for the oil spills, but still has some competition with algal blooms areas. This could possibly be improved be further limiting ranges of all terrestrial features to bring the lake features to the foreground. This could also be corrected by simply adding a vector layer of land overtop of the image.
The gradual ascent of the histogram stretch line for the NIR band (Figure 3b bottom-left) creates an apparent transition from bright yellow to red to green in the streaks which could indicate oil spill thickness and add another level of potential analysis to the project. NIR has been used before in remote sensing studies to indicate spill thickness (Fingas and Brown, 2017).
The visuals of open water versus areas with algal blooms is not necessarily improved between the standard and custom enhancements, although this could be done if the analysis goal was more favoured towards this area.

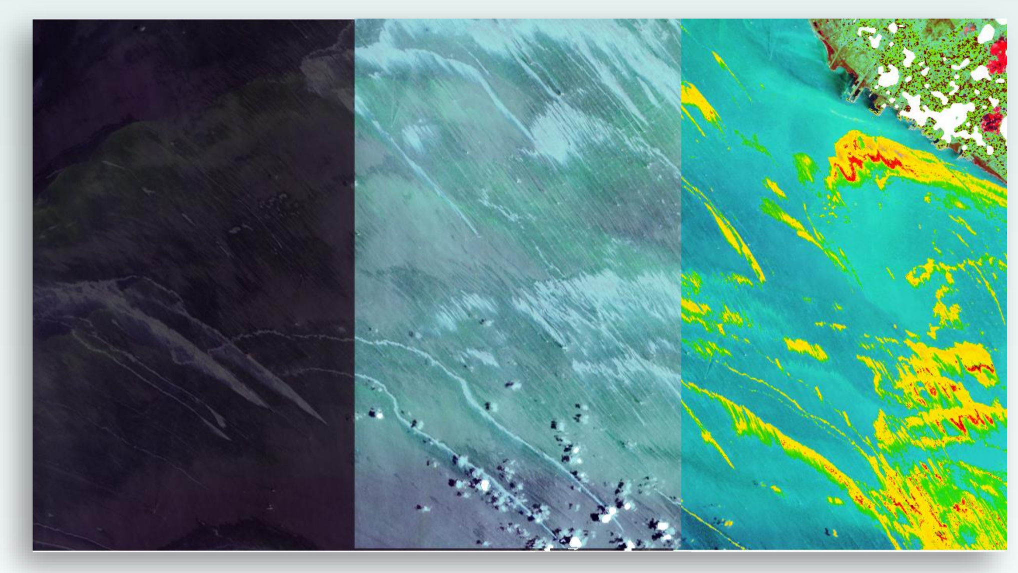

Figure 5: A clipped area of interest showing the differences between a true-colour adaptive enhancement image, the 532 composite histogram equalization enhancement and the custom enhancement.

References

Bloomberg News (2020, December 15). *Toxic Spills in Venezuela Offer a Bleak Vision of the End of Oil*. Bloomberg Green. https://www.bloomberg.com/news/features/2020-12-15/oil-spills-in-venezuela-offer-bleak-vision-of-what-lies-ahead

Fingas, M., & Brown, C. E. (2017). *A Review of Oil Spill Remote Sensing*. Sensors (Basel, Switzerland), 18(1), 91. https://doi.org/10.3390/s18010091

Thomas Lillesand, Ralph Kiefer, & John Chipman. (2015). *Remote Sensing and Image Interpretation* (7th ed.). John Wiley & Sons.

Figure 6: An oil refinery bordering Lake Maracaibo in 2020.
Photographer: Adriana Loureiro Fernandez for Bloomberg Green.

Image specifications

Platform: Landsat 8
Sensor: OLI
Scene ID: LC80070532021253LGN00
Date: September 10, 2021
Projection: UTM Zone 19
Datum: WGS84
WRS Path: 7
WRS Row: 53
Source: USGS GloVis