Geomatics & Geoinformation
Exercise 3
Handling spectral indices

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Contents

1 Analysis of damage caused by the Vaia storm using the Normalized Difference Vegetation Index

1.1 Vaia storm

The Vaia storm hits Italy on Oct. 29, 2018 causing casualties, 3 billion euros worth of damage and destroying approximately 42500 hectares[1] of forest.[6]
Specifically, the storm affected 4 regions:

- Lombardia
- Veneto
- Trentino-Alto Adige
- Friuli-Venezia Giulia

In Alto Adige a total of 6000 hectares [2] of forest were felled and razed to the ground.
The spruce[3] forests of the Latemar massif[4], of the municipalities of Nova Ponente, Nova Levante Fontanefredde and San Vigilio di Marebbe, appear to be the forest areas most affected and severely damaged [5].
The analysis will be focused on this particular area, to measure the extension of the damaged zone a remote sensing [5] technique called NDVI will be used.

Remote sensing pipeline

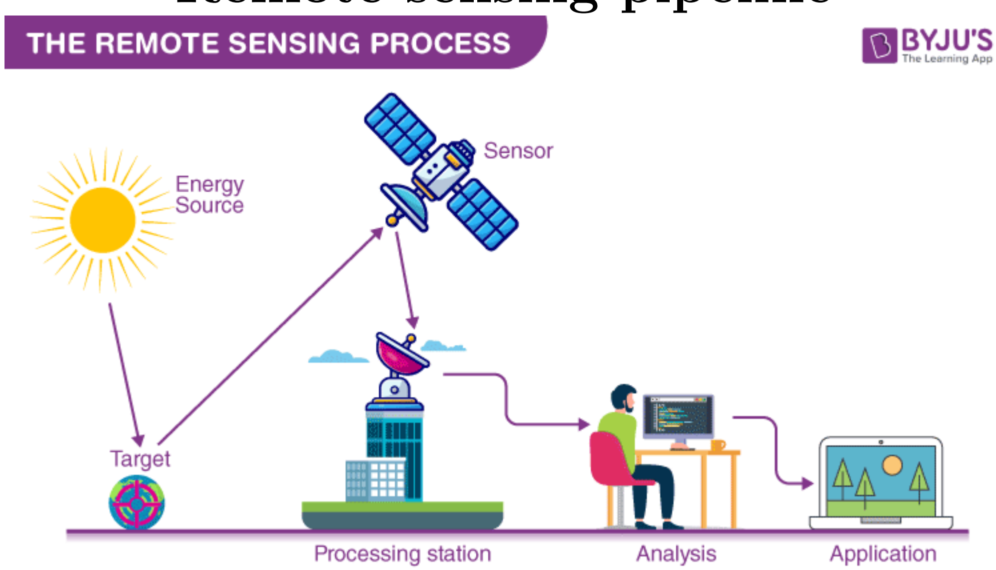


Figure 1: Image source *BYJU'S* [1]

[1] 425 km^2
[2] 60 km^2.
[3] Abete rosso
[4] Massiccio del Latemar
[5] Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance (typically from satellite or aircraft).[9]

1.2 Introduction to the NDVI

The Normalized Difference Vegetation Index is a very useful tool to quantify healthy vegetation.
It quantifies vegetation by measuring the difference between *near-infrared* (*NIR*, which vegetation strongly reflects) and *red light* (*RED*, which vegetation absorbs).

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}}, \quad -1 \leq \mathrm{NDVI} \leq 1$$

The result of this formula generates a value between -1 and +1: if a pixel has low reflectance (or low values) in the red channel and high reflectance in the NIR channel, this will yield a high NDVI value (and viceversa)[2] [8].

So briefly:

- **High NDVI** values means *healthier vegetation*
- **Low NDVI** values means *less healthy or no vegetation*

Satellite multispectral sensors like Landsat and Sentinel-2 have the necessary bands to compute the NDVI.
In practical application vegetation is considered healthy when it has an NDVI value greater than 0.3.

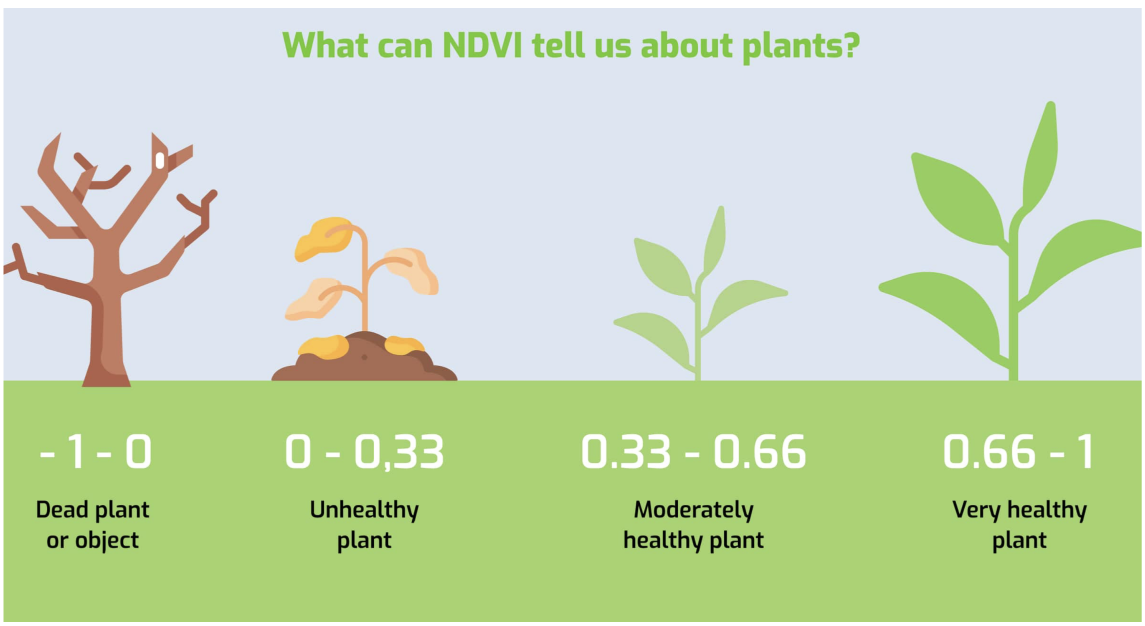


Figure 2: Image source *GeoPard Agricolture* [4]

Having a tool able to quantify the extension of areas characterized by healthy vegetation could be very useful to monitoring green areas, or even better to understand the impact of a natural disaster.
For instance could be used to understand how a fire have damaged a forest.
In this report it will be used to understand how much the *Vaia storm* has damaged the forest of Trentino Alto Adige.

1.3 Defining the pipeline

As has been said before the main tool to measure the damage that the Vaia Storm will be the NDVI, however the only use of NDVI is not enough.
The NDVI will be applied using Google Earth Engine, therefore a pipeline must be defined. To obtain the results sought the steps are multiple:

1. Define the area of interest (ROI);
2. Take the Sentinel-2 Collection, filter it as necessary;
3. Apply radiometric scaling and cloud masking[6] to the collection;
4. Select the median image, cut it out in the roi;
5. Apply NDVI masking with a selected threshold ;
6. Measure the pixels remaining after the masking and approximate the extensions of healthy vegetation area.

Those steps will be performed twice, first in a time span before the storm, then in a time span after the storm.
As final step by subtracting the extensions of healthy vegetation area after the storm to the extensions of healthy vegetation area before the storm the damaged area by Vaia will be defined.

$$\text{Area damaged by the storm} = \begin{array}{l}\text{extensions of}\\ \text{healthy vegetation}\\ \text{area before}\\ \text{the storm}\end{array} - \begin{array}{l}\text{extensions of}\\ \text{healthy vegetation}\\ \text{area after}\\ \text{the storm}\end{array}$$

In order to evaluate the two areas a function taking the following inputs will be used:

- Region of interest
- Time interval
- NDVI threshold

This function allows to compute extensions of healthy vegetation area with more easily and with less code.
The script containing the function described and all the code used to measure the damage of the Vaia storm will be the following link: `https://code.earthengine.google.com/f3c3c22b0bbfadb0808ab94c810cd4e6`.

[6] Process that consist in removing pixels that contains clouds, cloud shadow, cirrus, aerosols.
It is a fondumental step when working with certain type of band and images.

1.4 Define the parameters

1.4.1 Define the area of interest (ROI)

As a region of interest the forest area near: Nova Ponente, Nova Levante Fontanefredde and San Vigilio di Marebbe has been selected.
The area has been defined using the polygon geometry from GEE.

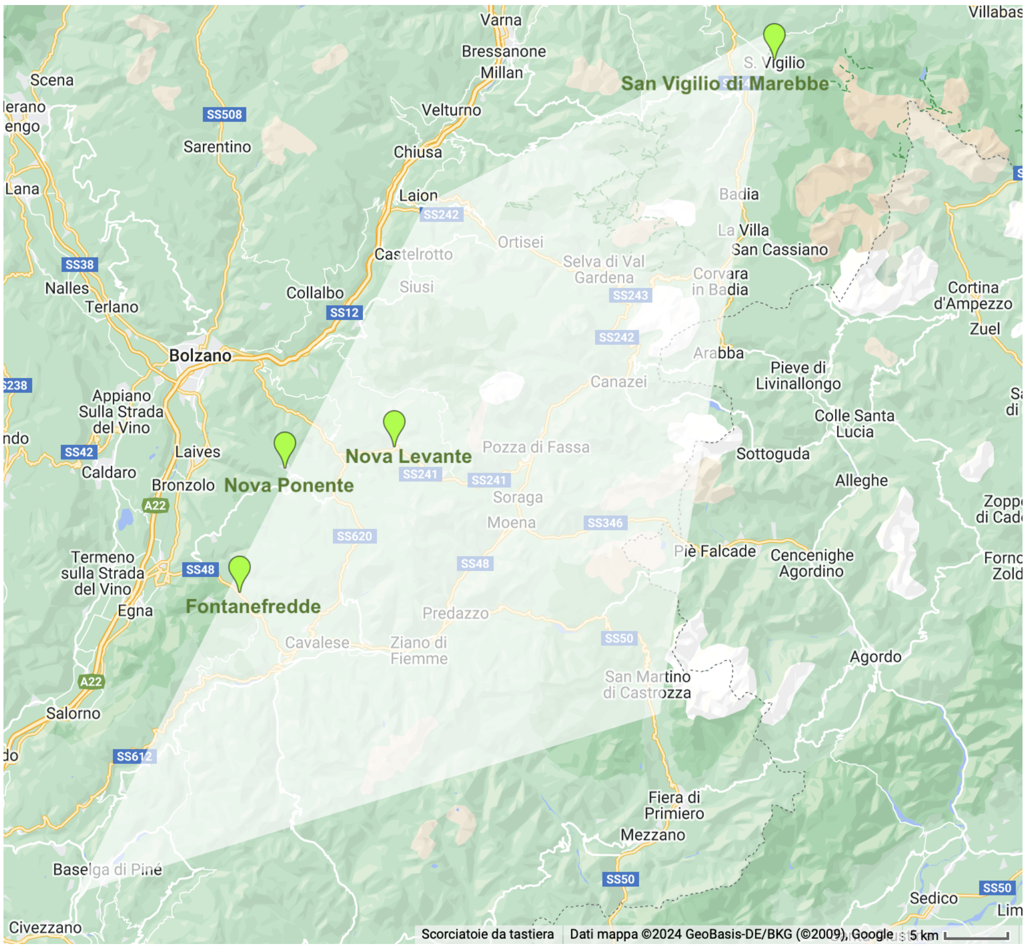
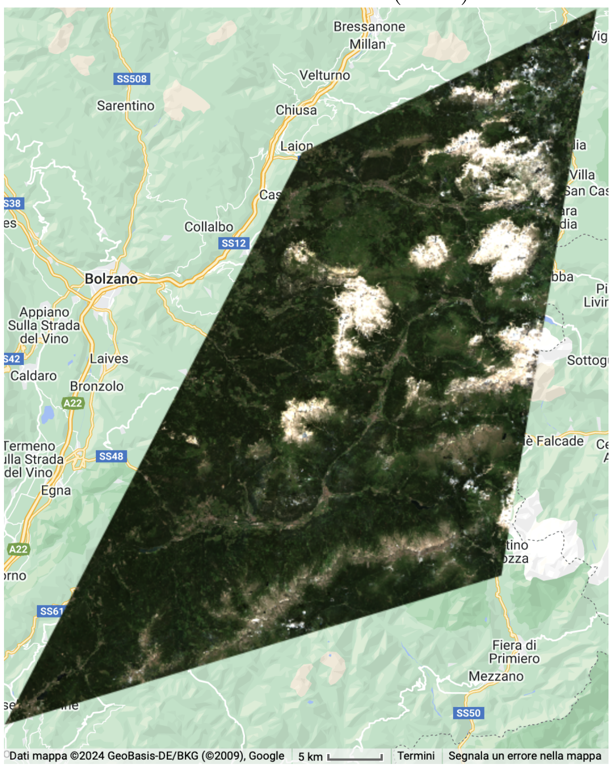


Figure 3: Region of interest

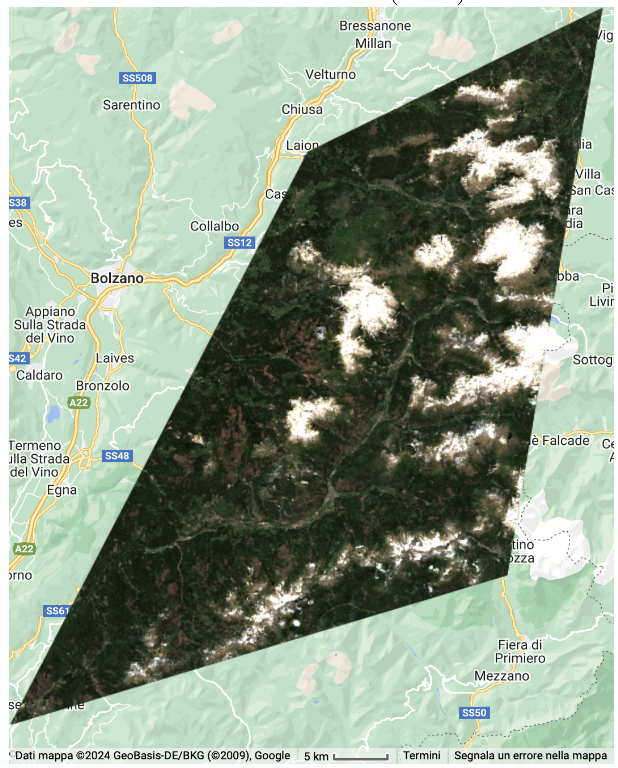
In total the area of interest is made up of 2523 km^2.

Have a look at the region of interest before the impact of the storm and after.

Roi before the storm (RGB)



Roi after the storm (RGB)



1.4.2 Filter the collection

The Sentinel Collection used is the *Harmonized Sentinel-2 MSI: MultiSpectral Instrument, Level-2A*, this collection is made up of images of all the world, in a time span that goes from **2017-03-28** to **2024-06-02**, dates are in yyyy/mm/dd format.
It goes without saying that work with all those images is computationally impossible, and also useless for the purpose of the analysis.
So what is usually done is filter the collection by region of interest and the time span desired.
Of course as **region of interest** the entire area described in 1.4.1 has been selected.
The collection is also filtered by **clouds percentage**, in particular only images with less than 50 % of cloudy pixels have been selected.
As **time intervals** were chosen the following:

- The first interval goes to the **2018-06-01** to the **2018-07-30**.
- The second interval goes to the **2019-06-01** to the **2019-07-30**.

Why the focus is on an interval that goes from june to july when the storm happened on the 30 october?
Of course the ideal would have been to collect images right before the disaster and right after but since the region of interest is often cover by clouds and snow in the winter, taking the images collection during summer can avoid those problems.
Then the two intervals were chosen at the same time for different years in order to have a less biased comparison.
The great length of the intervals is to be implied to the research of the accuracy, in fact, when selecting only a month an excessive cloud masking was disturbing the analysis.

1.4.3 NDVI threshold

As first NDVI threshold 0.3 was chosen, that is the value proposed by the literature.
However analyzing the result became clear that this NDVI threshold was not masking all the areas without trees, so it was to low.

Figure 4: Region of interest masked with NDVI threshold at 0.3

Looking the image above it is clear that a lot of brown surfaces that are damaged forest area are not being masked, so to be more precise an higher NDVI threshold, for instance 0.5, must be considered.

After applying the new NDVI threshold set at 0.5 the result was the following.

Figure 5: Region of interest masked with NDVI threshold at 0.5

The improvement was evident, the damaged forest area have been masked and now their measurement would be more accurate.

1.5 Results

Using different **NDVI** threshold the amount of damage caused by the Vaia Storm identified by the model is different.

NDVI threshold 0.3	
Area of interest before the storm	2523.6 km^2
Healty vegetation before the storm	2268.2 km^2
Area of interest after the storm	2523.7 km^2
Healty vegetation after the storm	2175.8 km^2
Damaged area	92.4 km^2

NDVI threshold 0.5	
Area of interest before the storm	2523.6 km^2
Healty vegetation before the storm	2107.1 km^2
Area of interest after the storm	2523.7 km^2
Healty vegetation after the storm	1890.9 km^2
Damaged area	216.2 km^2

Using **NDVI threshold 0.3** the damaged found is of 92.4km^2 of forest, that correspond to 9240 hectars.
This damage is more or less similar to the 6000 hectars of damage indicated by the articles, considering that the precise area in which the authors have made their evaluations and it extension is unknown so the result obtained seems good.
However analyzing the masked image with the NDVI threshold fixed at 0.3, Figure 4, the result doesn't appear great, so another NDVI threshold was considered.

Using **NDVI threshold 0.5** the damaged found is of 216km^2 of forest, that correspond to 21600 hectars.
This damage is much more that the 6000 hectars damaged indicated by the articles cited at the beginning of this report, but considering that the total extension of the area subject of the analysis in the articles is unkown and looking at figure 5 the final results seems correct.

In the end it is clear that both of the analysis have their issues, but the goodness of the tool has been proven.
For sure with the help a particular machine learning technique and some fine tuning the results of this procedure can be improved, refuted or confirmed.

2 Modified Normalized Difference Water Index

2.1 Lake Mead National Recreation Area and Las Vegas urban growth

Lake Mead National Recreation Area is a U.S. national recreation area in south eastern Nevada and north western Arizona, and it is big water basin near Las Vegas.
Over the years reduction of this water basin has been noticed [3], and this reduction is due to the massive Las Vegas urban growth [7].

Given that the analysis will be focused on this particular area with the intent to build a time series of the last ten years in order to understand how much the Lake Mead National Recreation Area has been damaged.
To build this time series the Modified Normalized Difference Water Index (MNDWI) will be exploited.

2.2 Modified Normalized Difference Water Index

The **Modified Normalized Difference Water Index** (MNDWI) uses green (G) and Short Wave Infrared (SWIR) bands for the detection of water.
This tool can be used to detect and to quantify the extension of areas covered by water through the analysis of the less cloudy optical image (Landsat 8 TOA Reflectance Tier 1) collected in a given area of interest (ROI) for a temporal period of interest.
In this report it will be used to understand the impact of the massive urban growth of Las Vegas over the Lake Mead National Recreation Area.

2.3 Define the pipeline

In order to measure the damage that the growth of Las Vegas caused the idea is to measure the area covered by the water over the years and then analysing the resulting time series.
To measure the area covered by the water for a pipeline has been defined, the pipeline can be describe as follows.
First the area of interest (ROI) must be defined, this area will be the same for each annual detection.
Then for each year in which the analysis is carried out the following steps can be performed:

1. Take the Landsat-8 Collection, filter it as necessary;
2. Among those images select the less cloudy;
3. Apply MNDWI masking;
4. Measure the pixels remaining after the masking and approximate the extensions of water area;
5. Store this measure.

By applying this procedure to a time span from 2013 to 2023, that is as far away as the Landsat 8 collection permits, a time series will emerge.

[7] Las Vegas has seen its population expand from 273,000 in 1972 to 2,204,079 in 2017. [7]

To make this pipeline simpler a function that needs the following inputs:

- Region of interest
- Interval

has been created. Iterating over this function specifing the rights periods will create the time series.

The script containing the function described and all the code used to measure the extension of the lake during the years will be found at the following link: `https://code.earthengine.google.com/9da12547feede6214d3a4dcd4bc24703`.

2.4 Define the parameters

2.4.1 Region of interest

As region of interest of course Lake Mead National Recreation Area has been selected.
This was possible using the **polygon** geometry from GEE, in fact, the entire perimeter of the lake was selected in order to have a better estimate.

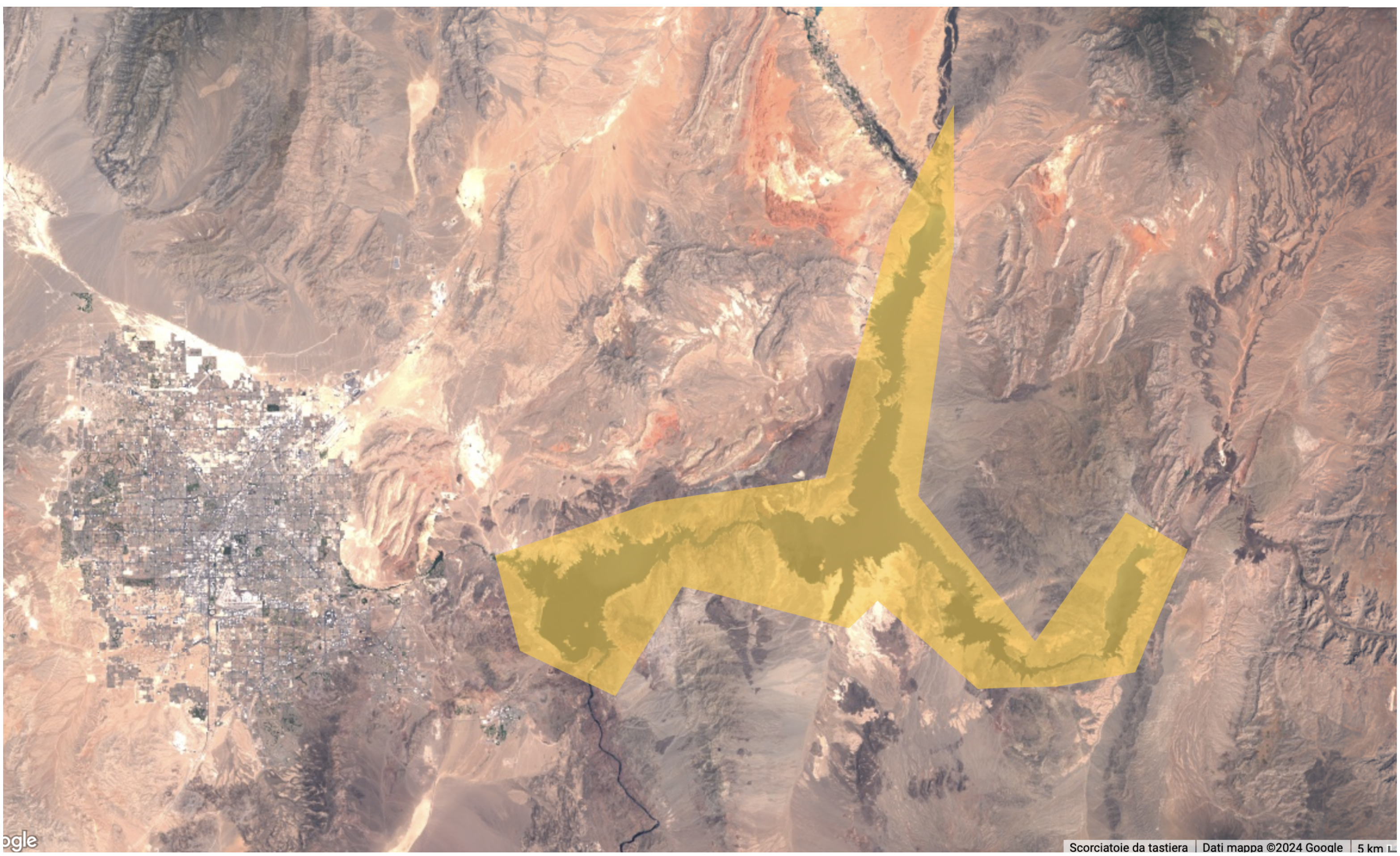


Figure 6: Region of interest (RGB)

Looking at the image below of Lake Mead National Recreation Area it is understandable why a polygon must be specified, without it would be included in the analysis areas that are not of interest and the analysis would have suffered
In fact all the whites areas in the picture are consider as water, narrow the analysis with the polygon for sure increase the precision of the study.

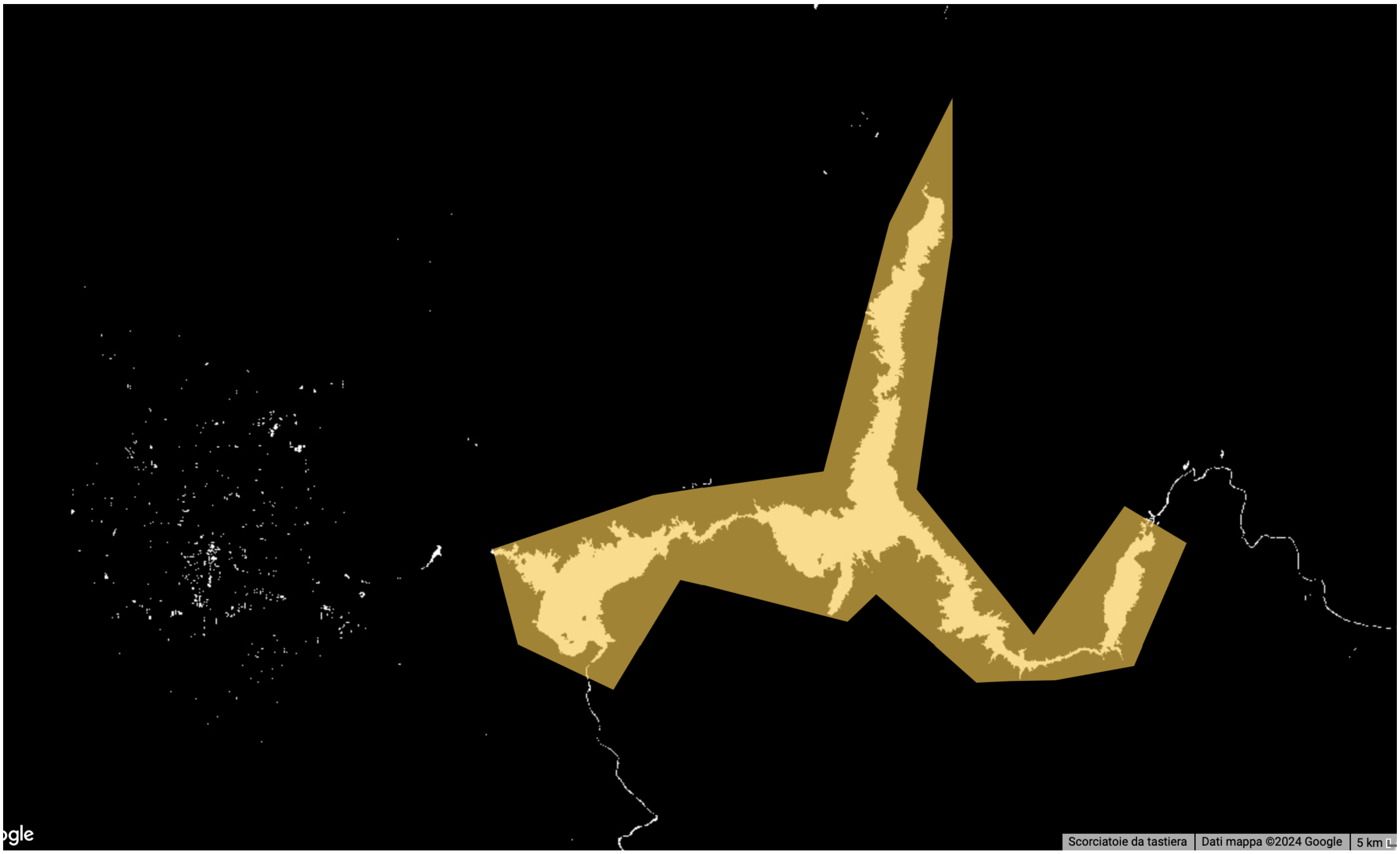


Figure 7: Region of interest (MNDWI)

2.4.2 Filter the collection

The Landsat 8 Collection used is the *USGS Landsat 8 Collection 2 Tier 1 TOA Reflectance*, this collection is made up of images of all the world, in a time span that goes from **2013-03-18** to **2024-05-24**, dates are in yyyy/mm/dd format.

As **time interval** was chosen a two month time span for each year: May and June, using the same months for each year provides consistency to the analysis.
Of course as **region of interest** the entire area described in 2.4.1 has been selected.

2.5 Results

Looking at the time series achieved it is clear that the water basin is shrinking during the years. To be more specific in the last ten years it has shrunk by 80.78 km^2, going from 370.3 km^2 in 2013 to the 289.5 km^2 in 2023, for a total reduction of the 21.8% in ten years.

2.5.1 State of health for Lake Mead National Recreation Area during the years

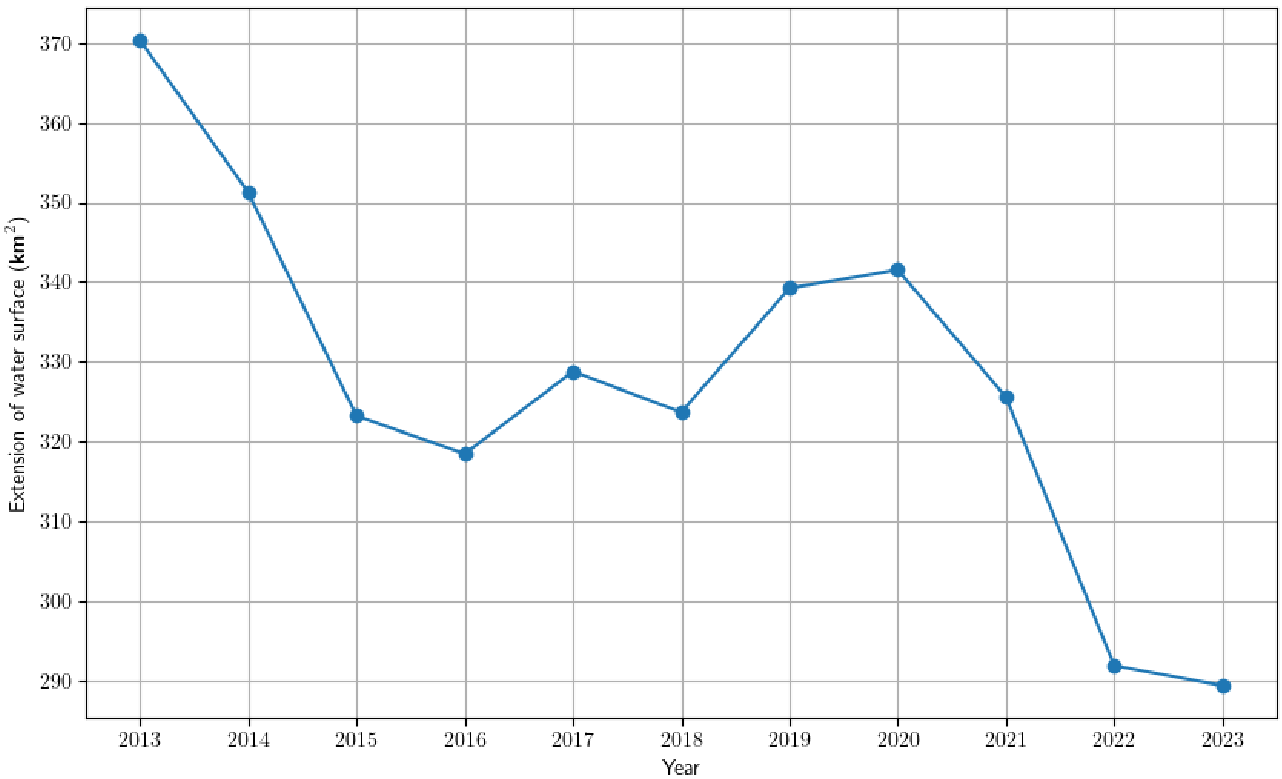


Figure 8: State of health for Lake Mead National Recreation Area

References

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[2] " "Compton J. Tucker. “"Red and photographic infrared linear combinations for monitoring vegetation"”. In: *Compton* (1979). URL: https://core.ac.uk/download/pdf/42872724.pdf.

[3] "Google". “"Timelapse from 1984 to 2022 of the urban growth of Las Vegas, Nevada, USA"”. In: *Google Earth Engine* (). URL: https://earthengine.google.com/timelapse/.

[4] "GeoPard Agricolture". “"Normalized Difference Vegetation Index (NDVI) Make Farmer Life Easier"”. In: *GeoPard Agricolture* (). URL: https://geopard.tech/blog/what-is-ndvi-normalized-difference-vegetation-index/.

[5] "Provincia autonoma di Bolzano - Alto Adige". “"Tempesta Vaia un anno dopo, sgomberati i due terzi degli alberi"”. In: *News ufficio stampa* (Oct. 2019). URL: https://news.provincia.bz.it/it/news-archive/631895.

[6] "Riccardo De Marco". “"La tempesta Vaia del 2018 e i danni devastanti dell'evento meteorologico sulle foreste alpine"”. In: *Geopop* (Oct. 2023). URL: https://www.geopop.it/la-devastante-tempesta-vaia-del-2018-i-danni-dellestremo-evento-meteorologico/.

[7] "Earth Resources Observation and Science (EROS) Center". “"Urban Growth in Las Vegas, Nevada, USA"”. In: *Earth Resources Observation and Science (EROS) Center* (). URL: https://eros.usgs.gov/media-gallery/image-of-the-week/urban-growth-las-vegas-nevada-usa#:~:text=For%20example%2C%20Las%20Vegas%2C%20Nevada,of%20the%20first%20Landsat%20satellite..

[8] "Roberta Ravanelli". “"Lectures of the Remote Sensing and Geo Big Data class"”. In: *Sapienza University of Rome Geodesy and Geomatics Division (DICEA)* (2023).

[9] "United States Geological Survey". “"What is remote sensing and what is it used for?"” In: *United States Geological Survey* (). URL: https://www.usgs.gov/faqs/what-remote-sensing-and-what-it-used#:~:text=Remote%20sensing%20is%20the%20process,typically%20from%20satellite%20or%20aircraft)..