Detection of the effect of the current water crisis on the reduction of the water surface of the Po River, Italy

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SUMMARY

Italy has been dealing with a major environmental problem in recent times – the water crisis. It is known that this environmental problem can be caused by droughts, lack of rain, and pollution. In July 2022, the Italian government declared a state of emergency in five regions due to the intense water crisis, which coincided with one of the most severe droughts experienced in the last 70 years by the Italian territory. The 652 km-long Po River is the main and longest Italian river and has suffered greatly from the lack of water in its surroundings. This study aims to detect the changes that occurred in the Po River watershed by means of multispectral images (pre- and post-water crisis) obtained by the Sentinel-2 satellite. A methodology different from conventional ones is implemented, which highlights changes by the analysis of images acquired before and after the water crisis. The method is compared to conventional techniques that use subtraction of indexes for the detection of changes. The results obtained here are promising, as the proposed method is a fast and effective approach to mapping the effects of water crisis, besides potentiating the application of the methodology in other areas.

KEYWORDS: Water crisis. Remote Sensing. Change detection.

1 INTRODUCTION

On 4th of July 2022 the Italian government declared a state of emergency in five regions of northern Italy, as a response to the severe water crisis. These regions – Emilia Romagna, Friuli Venezia Giulia, Lombardia, Piemonte, and Veneto – have been heavily hit by drought, as well as the Po River, whose level has been the lowest in 70 years. The Po is the longest and the main Italian river, stretching out for *circa* 650 km along the Val Padana (Po Valley), the richest area in Italy.

The lack of rain is one of the factors that contributes to this environmental problem, causing the reduction of water volumes in lakes and rivers. This crisis has affected 30% of the Italian agriculture production and, according to the Italian Union of Agricultural and Food Workers, it has already reached the pig farms of the Po Valley, where the internationally well-known Parma ham is produced.

The drought that has affected the Po River watershed is the apex of a variety of meteorological changes in Italy, which resulted from the climatic crisis that has impacted the planet as a whole. In 2022, Italy recorded 70% less snow on its mountains, when compared to expected mean snow volumes. A drop of 50% in mean rainfall in the last three decades was also observed.

The detection of environmental changes has improved with the use of multitemporal data, which allows the quantitative analysis of the effects of the phenomenon in question. The present study aims to aid the detection of changes, on the water surface in a section of the Po River strongly impacted by drought using images obtained by remote sensors. Sentinel-2 multispectral images were used to generate products from spectral indices and operations between bands, with the objective of detecting changes represented on a map of changes. The images used in this study were acquired in two dates – before (pre-) and after (post-) water crisis.

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2 OBJECTIVE

The objective of this study is to propose a fast and effective method to detect changes on the water surface of the Po River by treating Sentinel-2 images using the QuantumGIS (QGIS) software.

3 METHODOLOGY

Two multispectral images were selected for this study, one representing the pre-water crisis, dated 13^{th} October 2021, and the other the post-water crisis, dated 30^{th} June 2022. Both were acquired by Sentinel-2 satellite at level 2A, which are surface-reflectance orthorectified products with basic pixel classification (including classes for different types of clouds). The download of the images is free and available on: https://scihub.copernicus.eu

After the choice of the study area, Sentinel-2 multispectral images, already corrected for atmospheric effects, were selected in order to represent pre-water crisis and post-water crisis events occurring between 2021 and 2022 in the Po River watershed in northern Italy.

The raw data were then pre-processed using the SNAP software. The images were re-sampled so as to make them equivalent in relation to pixel size, thus enabling the application of indices and operation between bands.

After pre-processing, spectral indices are generated. The main characteristic of these indices is the enhancement of specific features and targets that are not discernible on the original images. Taking into account the variety of targets present on the Earth’s surface and their specific physical, chemical, and biological compositions, several spectral indices have been developed and that aid to distinguish targets on the spectral images and to extract relevant information (SILVA et al., 2019). Among these indices, the NDWI (Normalized Difference Water Index) proposed by Gao (1996) and the NDWI proposed by McFeeters (1996) are adopted in this study.

The NDWI proposed by Gao (1996) enhances features related to water in detriment to other targets. The SWIR spectral band is used to calculate this index, as it is able to quantify the moisture present in the vegetation (Pereira et al., 2018; Marra, 2020).

$$NDWI = \frac{\rho NIR - \rho SWIR1}{\rho NIR + \rho SWIR1}$$

The calculation of the NDWI proposed by McFeeters (1996) includes a band of the green spectral region (490nm – 580 nm) and another of the near infrared (760 nm-1000 nm).

$$NDWI = \frac{\rho Green - \rho NIR}{\rho Green + \rho NIR}$$

Additionally, the Normalized Difference Build-Up Index (NDBI) proposed by Zha et al. (2003) enhances impervious surfaces, such as roofs, paved and cemented areas, paved roads and more impervious bare soil, according to the following equation:

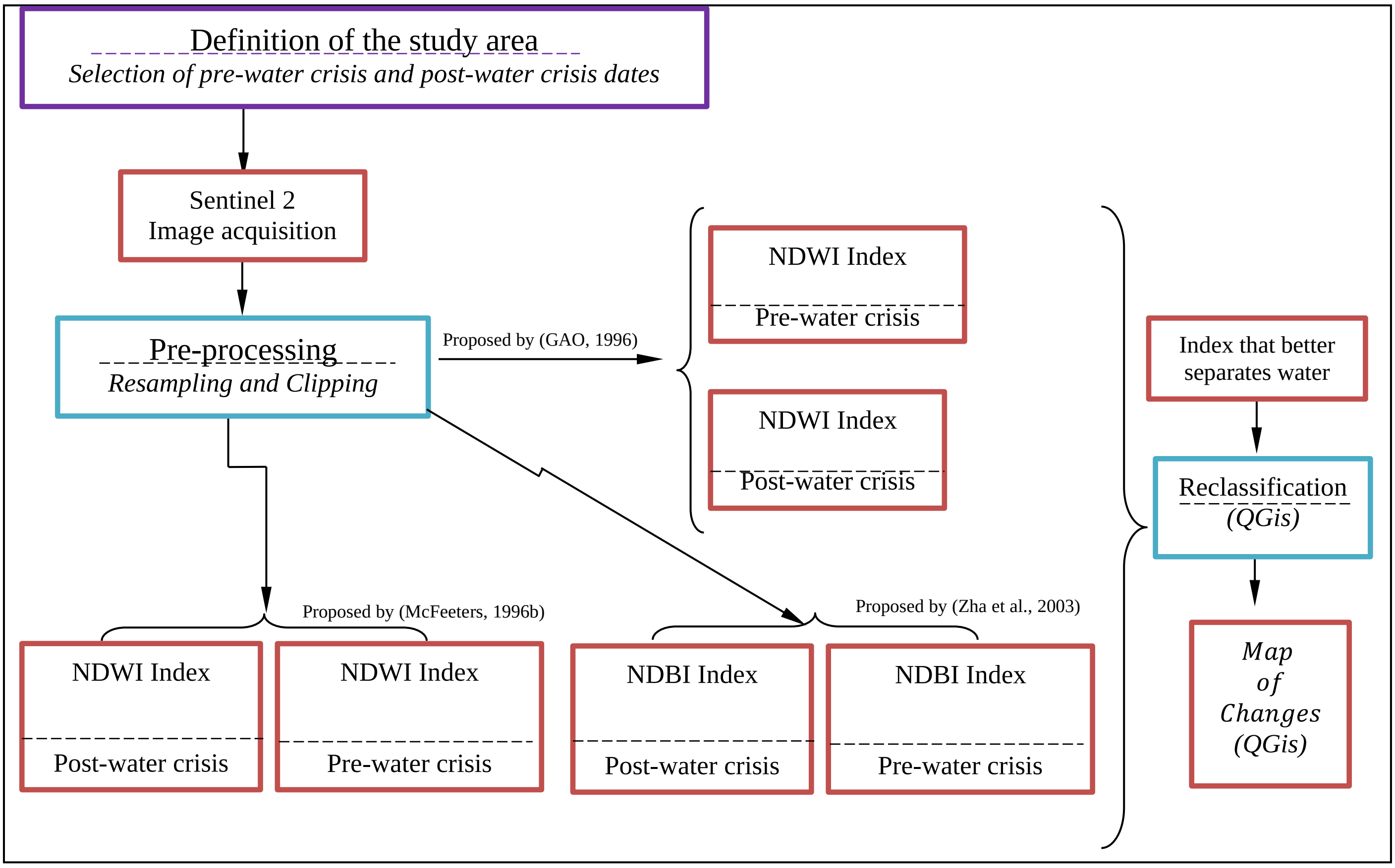
$$NDBI = \frac{\rho SWIR1 - \rho NIR}{\rho SWIR1 + \rho NIR}$$

These indices have been widely studied and assessed, conferring them credibility and reliability. Therefore, they can be used as tools to quantify and monitor natural and anthropic phenomena and events. It is stressing out that, despite a large number of useful indices are available in the literature, NDWI and NDBI are highlighted here because they were chosen for this study.

Both NDWI proposed by Gao (1996) and by McFeeters (1996) were calculated for the pre- and post-water crisis images. NDBI was also calculated, because it cannot only separate soil from water, but water from bare soil as well. The index that best detects targets subjected to changes was selected to elaborate a map of changes using QGIS. This map of changes was generated using only the index that best identified the Po River course, after a reclassification performed by QGIS.

The final product is a map of changes obtained from the indices that best defines the target in question and that best detects the changes that occurred between the selected dates. Figure 1 is a flow chart of the proposed methodology.

Figure 1: Flow Chart representing the proposed methodology

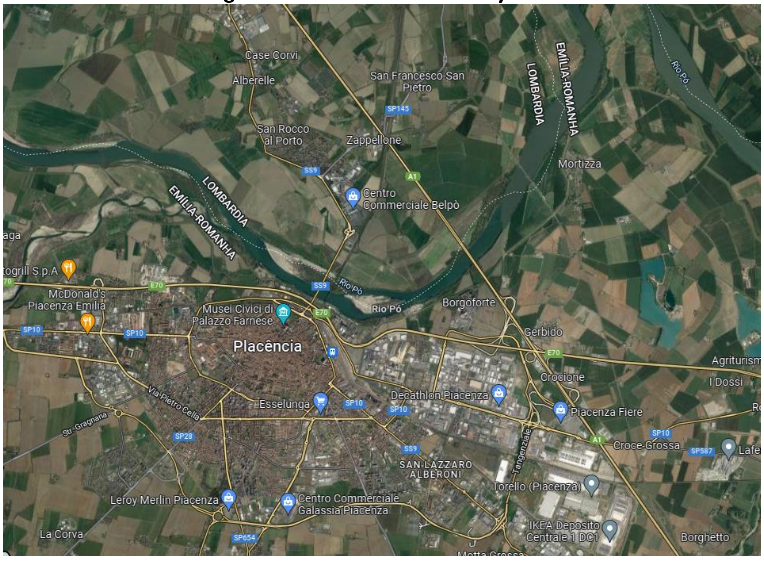


Source: The author

4 RESULTS

Firstly, it is worth mentioning again that the Po River runs for 652 km, and that only a section of it was selected for this study, being the city of Piacenza the closest to such section.

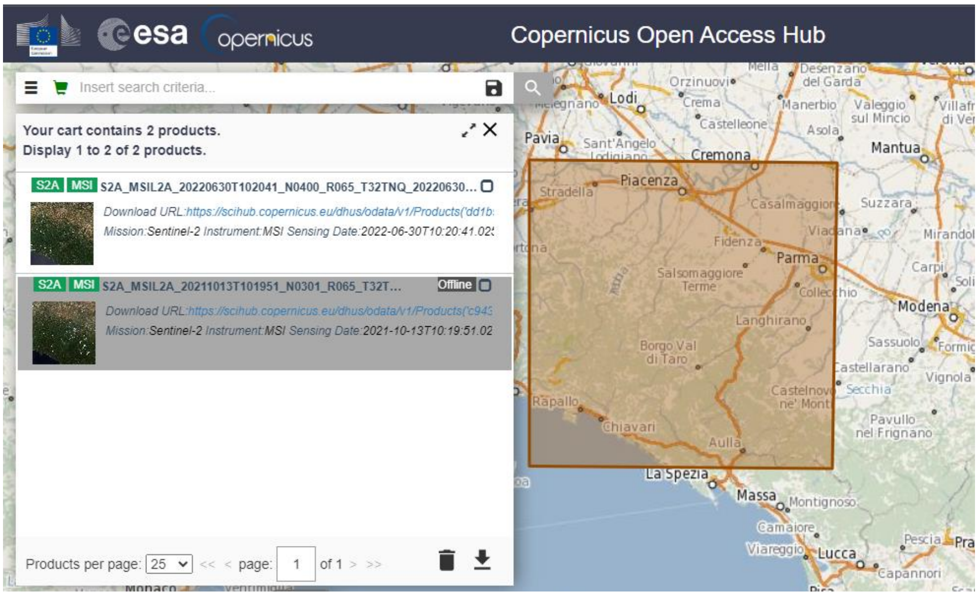
Figure 2: Location of the study area



Source: Google Earth

After selecting the study area, two images were downloaded from the Copernicus platform: one representing the pre-water crisis (dated 13^{th} October 2021) and the other the post-water crisis (dated 30^{th} June 2022).

Figure 3: Downloading the images using the Copernicus plataform



Source: The author, 2022

As mentioned before, the downloaded images were surface-reflectance orthorectified. Thus, it was not necessary to perform any other correction, either geometric, orthometric and/or atmospheric.

SNAP was used to resample the pixel size to 20 meters in order to match pixel dimensions of the visible and near-infrared bands with those of the mid-infrared bands. After resampling, the images were reduced to the scene of interest, that is, a section of the Po River close to the city of Piacenza. Figures 4 and 5 present the print screen of the resampled pre- and post-water crisis images.

Figure 4: Sentinel-2 pre-water crisis image (13^{th} October 2021)

Source: The author, 2022

Figure 5: Sentinel-2 post-water crisis image (30^{th} June 2022)

Source: The author, 2022

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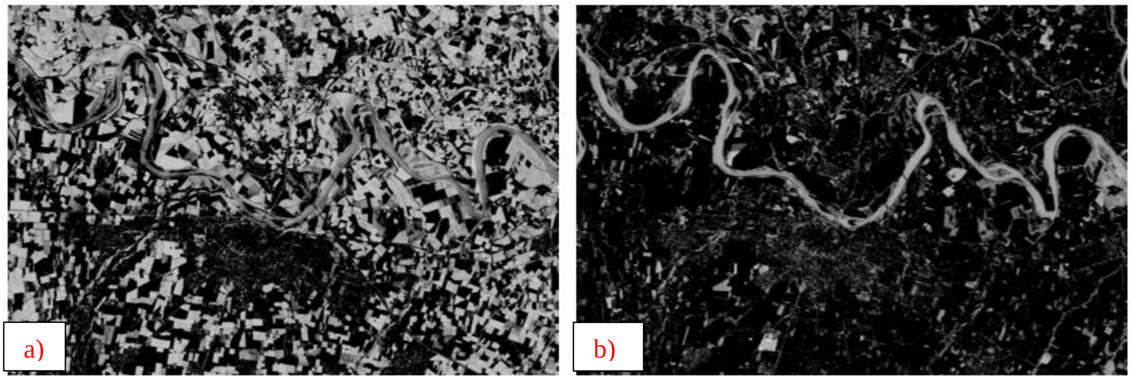
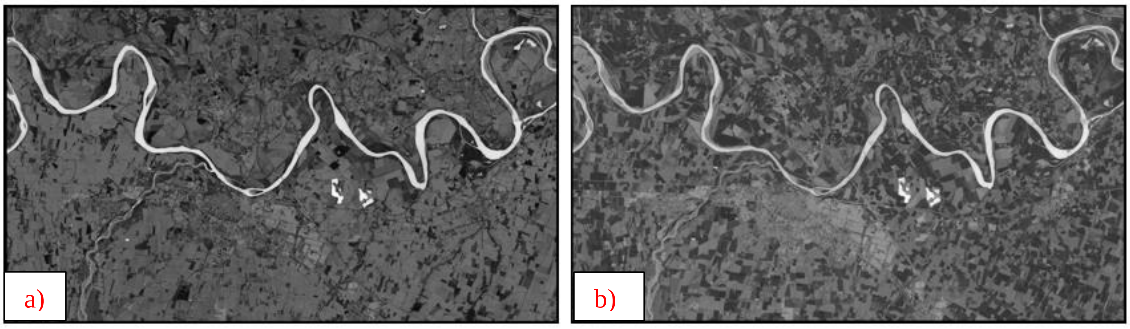
These images are from near infrared band 8. Using SNAP, the indices NDWI (Gao, 1996), NDWI (MCFEETERS, 1996), and NDBI (ZHA et al., 2003) were calculated, as shown in Figures 6 to 8.

Figure 6: NDWI (GAO, 1996). a) Pre-water crisis (13^{th} October 2021). b) Post-water crisis (30^{th} June 2022).



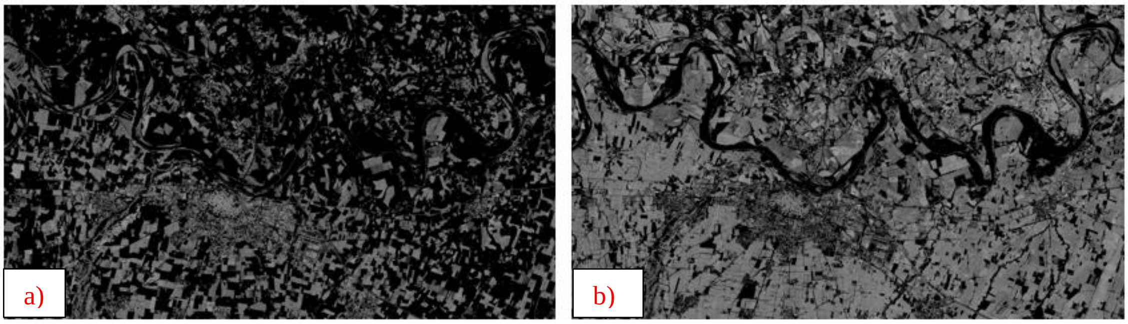
Source: The author, 2022

Figure 7: NDWI (MCFEETERS, 1996). a) Pre-water crisis (13^{th} October 2021).
b) Post-water crisis (30^{th} June 2022).



Source: The author, 2022

Figure 8: NDBI (ZHA et al., 2003). a) Pre-water crisis (13^{th} October 2021). b) Post-water crisis (30^{th} June 2022).



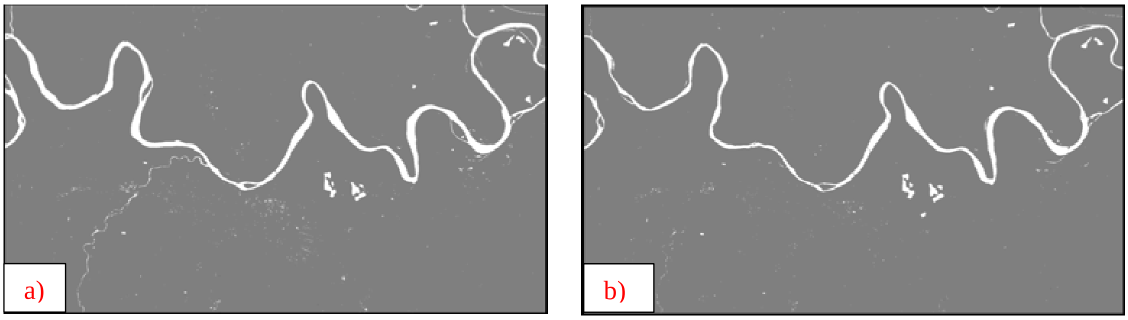
Source: The author, 2022

It is possible with a simple visual analysis to infer that Figure 7 best highlighted the Po River course, separating it from what is ‘not water’. This result shows that the NDWI proposed by McFeeters (1996) was the best in separating targets and therefore the map of changes was generated from it. It is worth mentioning that the indices NDBI (ZHA et al., 2003) and NDWI (Gao, 1996) led to better results regarding the post-water crisis event, highlighting changes in targets around the Po River, as during the drought, the responses tend to be enhanced, as seen in Figure 6b and 8b. Besides, the images were acquired during different seasons (fall 2021 and spring/summer 2022), which justifies changes in lighting and in natural target conditions.

As cited before, the NDWI proposed by McFeeters (1996) is more sensitive when compared to the other indices, enhancing the target 'water' from both scenes, even in different lighting conditions and seasons, among other parameters.

Using QGIS, the two NDWI images were reclassified with the Semi-Automatic Classification Plugin, thus defining two classes: 'water' and 'not water' (Figure 9).

Figure 9: Reclassification using NDWI proposed by McFeeters (1996). a) Pre-water crisis (13^{th} October 2021). b) Post-water crisis (30^{th} June 2022).



Source: The author, 2022

The reclassification was a success, highlighting in white all the water bodies and ignoring the other objects that are not the feature of interest. These results made possible the elaboration of the map of changes using the QGIS raster calculator. From differences between the reclassified images, it enhances the changes between the two images, resulting in a raster image with the changes that occurred during the time interval between the two images. This tool acts as a pixel-to-pixel algorithm, identifying the intersections of common points on the image, highlighting the changes that occurred between different events on the basis of raster pixel values obtained from the binary image.

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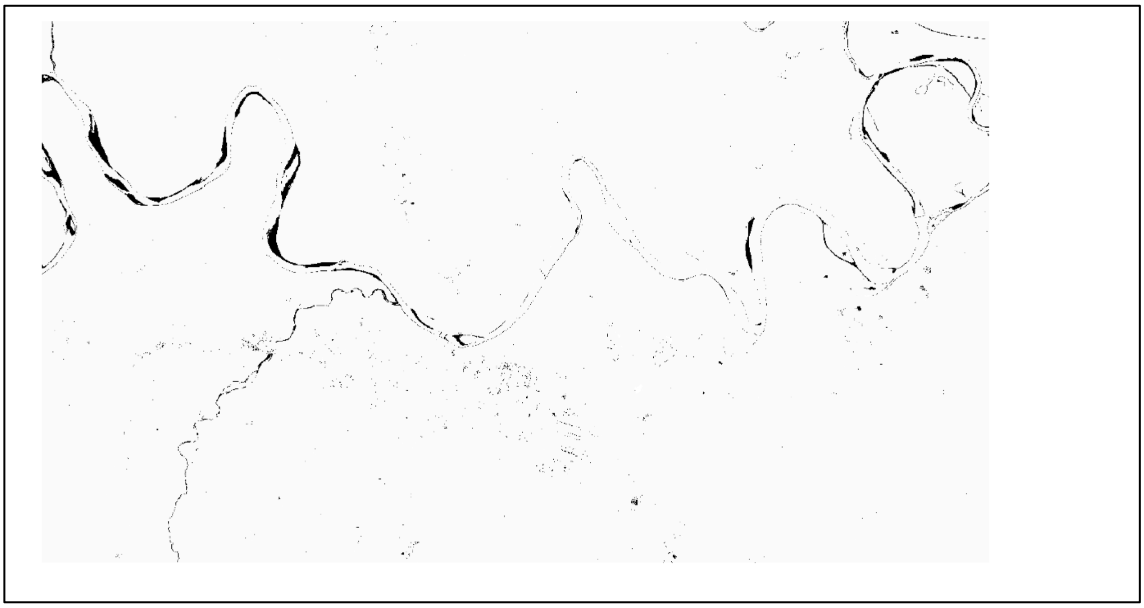
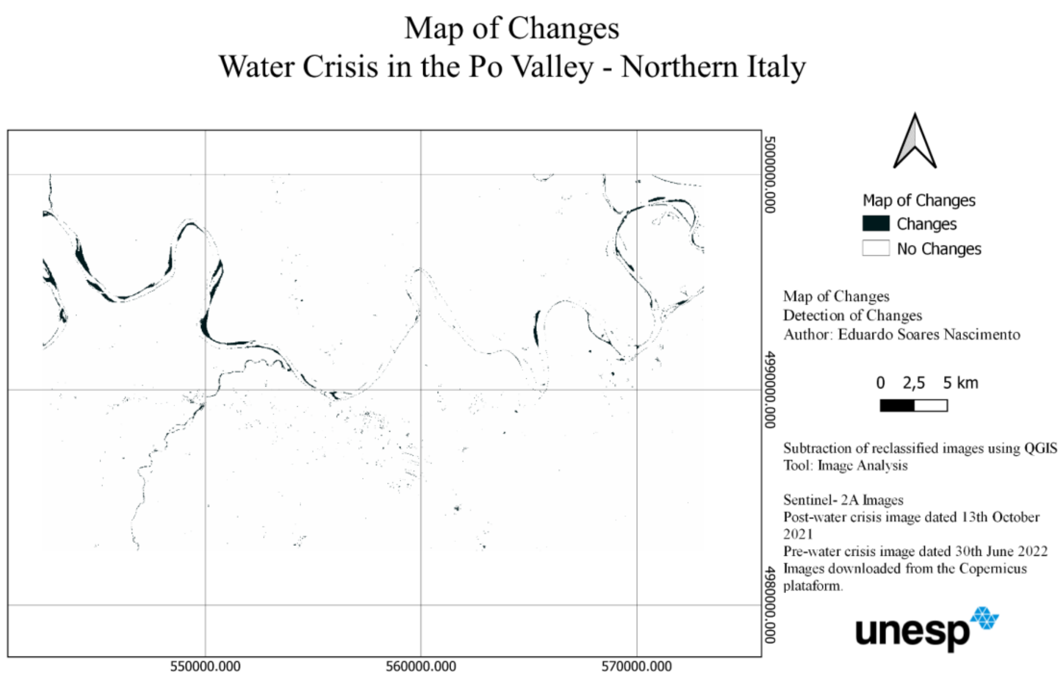
Figure 10: Changes in the reclassified images



Source: The author, 2022

The map of changes was created from Figure 10, as shown in Figure 11.

Figure 11: Map of changes



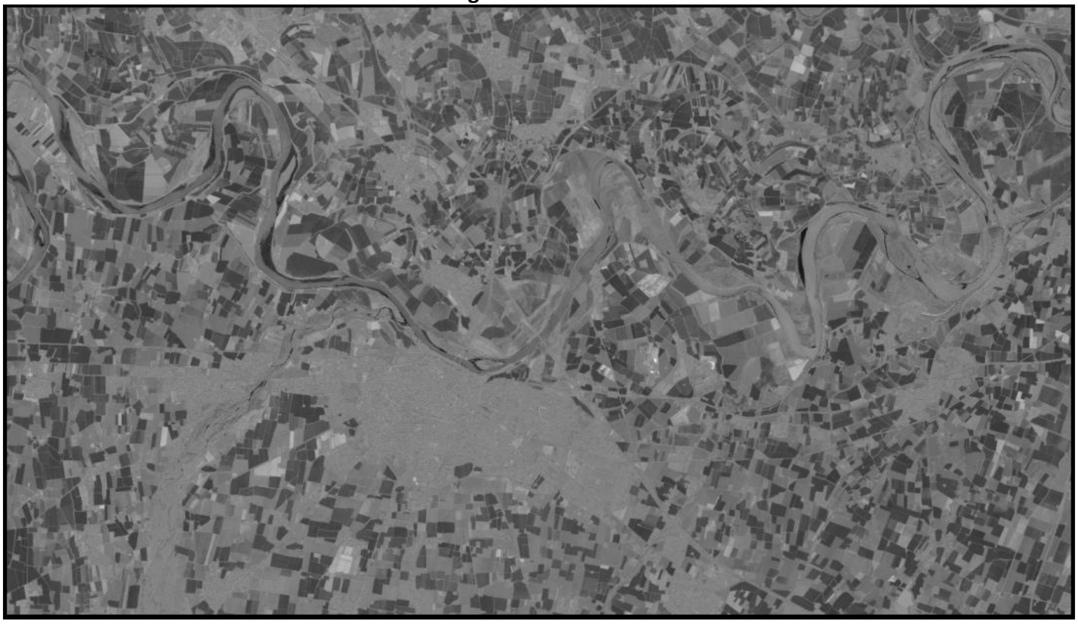
Source: The author, 2022

In Figure 11, the changes that occurred between the events are represented in black. The change in the Po River water level is conspicuous, as well as in its tributaries. The river has funneled and lost water volume mainly in the curves. By considerably losing its water volume, the river lost power in the curves, causing the funneling of its tributaries.

For comparison and using QGIS, differences in NDWI were calculated according to the following equation:

$$\Delta NDWI = NDWI_{pre-water\ crisis} - NDWI_{post-water\ crisis}$$

Figure 12: ΔNDWI



Source: The author, 2022

Many features represented in Figure 12 in medium gray are very similar to the color attributed to the water course. Whereas ΔNDWI emphasizes the differences obtained by a simple subtraction of indices, the proposed method is visually more adequate for the analysis and detection of changes in the water surface of the Po River and its tributaries.

5 CONCLUSION

The method presented and implemented in this study produces very satisfactory results regarding the detection of changes. This method is based on the application of the index that best enhances the object of study, which in our study case is a section of the Po River (northern Italy). A reclassification of the pre- and post-water crisis images was performed using QGIS, in order to obtain a class with the feature of interest (‘water’) and another with all other features (which are not of interest – ‘not water’). Finally, the reclassified images were submitted to the QGIS raster calculator, by means of which the subtraction of images consists of the intersection of common points on the images on the basis of raster pixel values, showing only the changes that occurred between the pre- and post-water crisis events.

It is worth mentioning that this methodology differs from that of subtraction of indices, which subtracts all features. This was not necessary in the present study, thanks to our alternative approach. Our result is more filtered in relation to the objects present in the images, being recommended to objects properly separated from others. Further reclassification is possible using QGIS.

The images used in this study were not acquired under the same conditions and seasons (October 2021 and June 2022). The change in natural cover is noteworthy, and consequently the indices selected for this study ‘contain’ different results regarding the separation of the target ‘water’ (pre- and post-water crisis). Lighting changes also occurred, causing differences in the result after the application of the index. Even in these conditions, NDWI (as proposed by McFEETERS, 1996) proved to be more sensitive than the other indices, thanks to the fact that even under different conditions, results derived from its application were better (that is, the separation of the target ‘water’), attesting its efficiency in relation to the other indeces.

The objective of this study was successfully reached, and it is suggested for future methodologies aiming at the detection and analysis of changes. The application of other spectral indices, or a combination of indices, is also suggested to refine the method proposed here.

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