4. Results and primary interpretations

4.1 Color composites

As discussed in 3.6.1, color composites give the combination of three raster bands, each representing a different portion of the electromagnetic spectrum, in shades of red, green and blue (RGB images). For visual analysis, color composites give the maximum use, compared with human eye's capabilities.

Figure 15 gives the true color composite of our Sentinel-2A scene. We can see that the image offers a very close to natural color rendition. A larger scale view of the same color composite can be seen in Figure 16, where we can visualize better the large variation of captured details. The color of the lake, the constructed area around it, the vegetation area, even the atmospheric perturbation by clouding and aircraft trails are very well figured. The image reveals very well the area of the lake in deep blue color, an area of low less robust vegetation or constructed populated area, around the lake, in brighter bare soil colors and lighter green as seen in the large scale image. Outside this area there is an area of strong vegetation in deep green color. Clouding and plane trains are clearly visible in white color. In addition, in the large scale image (Figure 16), we can see that even in the low reflectance area of the water, details especially near the coast are visible.

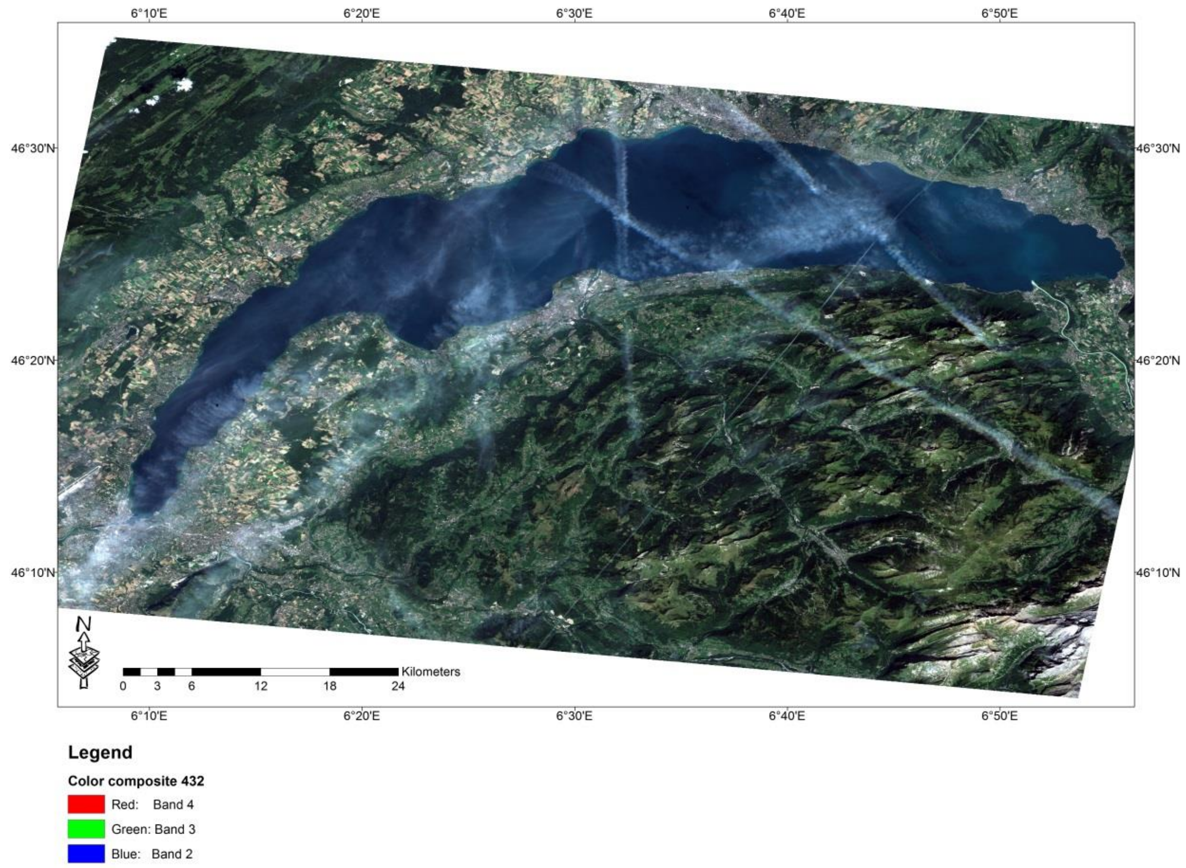


Figure 15: True color composite of the Sentinel-2A scene.

Figure 16: Large scale vision of the true color composite of the Sentinel-2A scene

Figure 17 presents the true color composite of the Landsat 7 ETM scene. The image contains unfortunately a lot of noise. There is intensive stripping covering the area of the lake. In Figure 18 we can observe a larger scale view of the image.

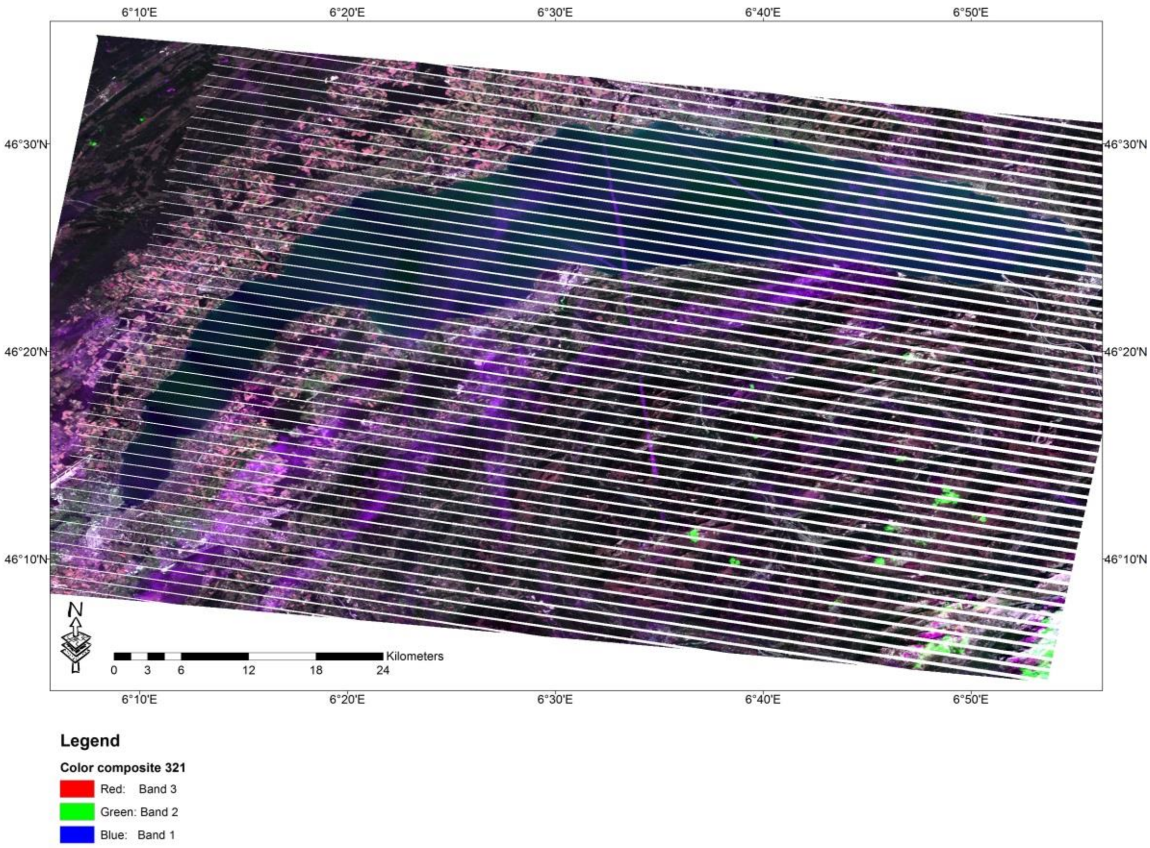


Figure 17: True color composite of Landsat 7 ETM scene.

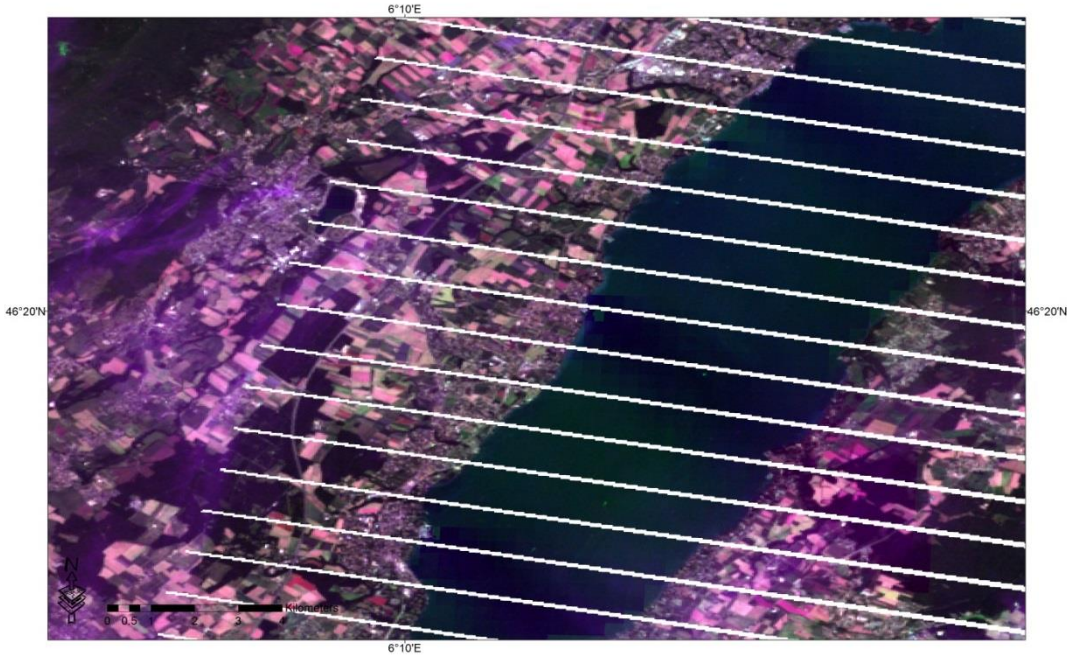


Figure 18: Large scale view of the true color composite band of Landsat 7 ETM scene.

We can see that the image appears in more intense red shades. Different features covering our area are visible, but in different colors than in the Sentinel-2A image before. The lake area appears in dark blue and green color and is difficult to discriminate any pattern details; the populated and less robust vegetation area around the lake is in pink color, resulting probably from a mix of red and blue band. The area of robust intense vegetation, further away from the lake outside the populated area, appears rather dark grey again with some pink nuances. There seems to be a perturbation of the reflectance captured by the satellite possibly due to atmospheric interference.

Figure 19 presents the false color NIR composite of Sentinel-2A scene. The only difference with the true color image is that the NIR band has been assigned to the blue shades.

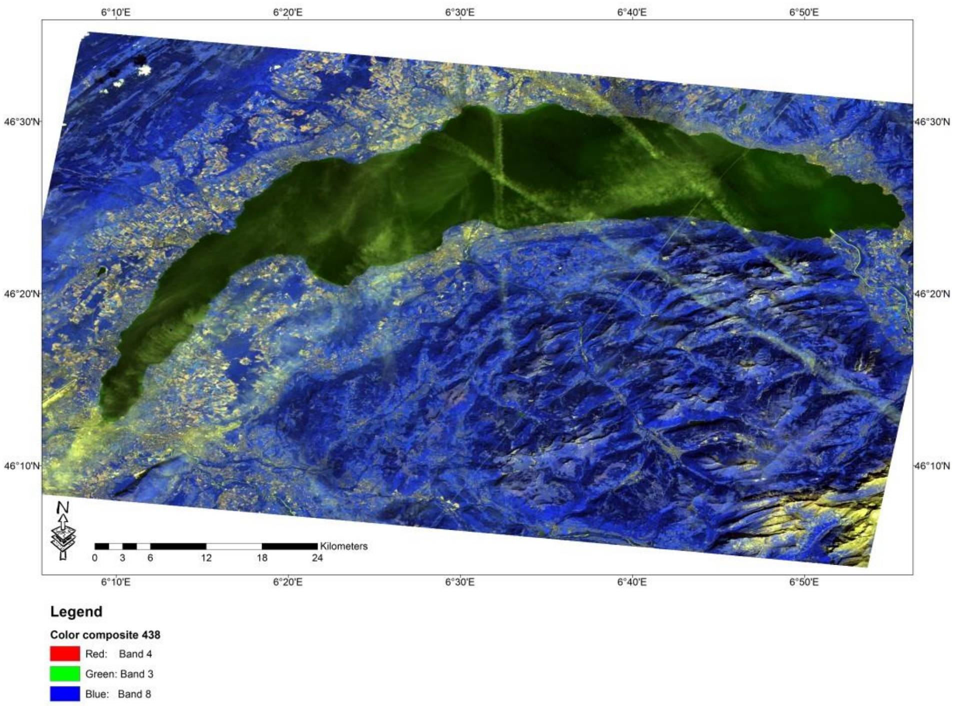


Figure 19: False color NIR composite band of the Sentinel-2A scene. The NIR, band 8 as shown in the legend, was attributed to the blue shades.

Robust green vegetation parts of the true color composite before, here appear as blue, as vegetation reflects infrared light. The parts of bare soil, construction, clouding or snow of high reflectance appear yellowish. Water appears dark as it absorbs NIR radiation.

Figure 20 presents the same false color composite for the Landsat 7 ETM image. Here we can see a visually better rendition than in the true color composite. Vegetation areas reflecting the NIR look bluish, while barren soils and clouding look brighter. The lake area looks dark as expected. Again we have the pinkish areas resulting from a misinterpretation in the blue and red region.

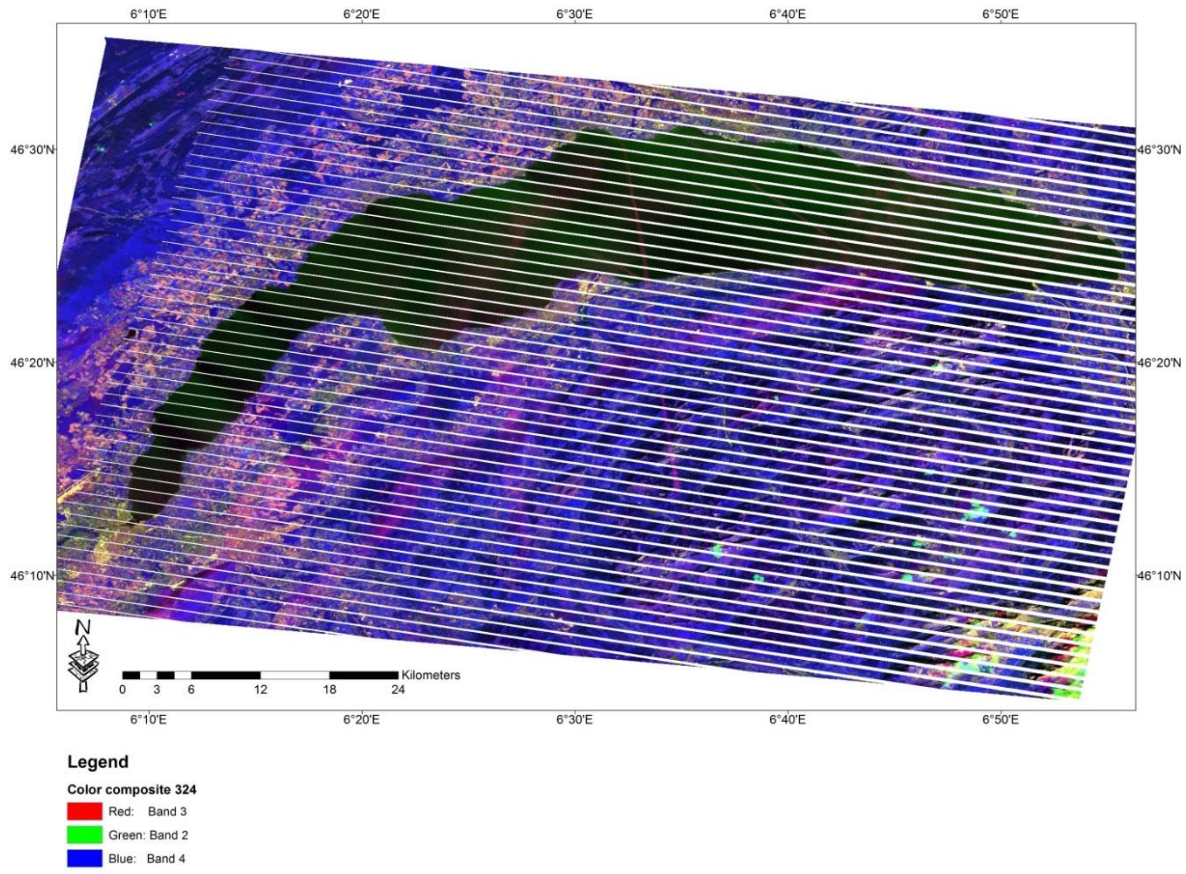


Figure 20: False NIR color composite of the Landsat 7 ETM scene. Band 4 representing the NIR was attributed to the blue shades.

4.2 Band ratioing and zonal statistics

As discussed in 3.6.2, the band ratioing transformations we conducted had as aim to reveal spectral reflectance of various features that we intended to observe. Figure 21 presents an overview of band ratios new rasters received for Sentinel-2A. In order to evaluate ratios outcomes, we implemented zonal statistics calculations around our two sampling points in the lake GE3 and SHL2 (Figure 12 in 3.3). Zonal statistics results were plotted in column charts for each band ratio and each of the two sampling sites. Figure 22 and 23 demonstrates the results for Sentinel-2A image, for the two different sampling sites. A full overview of the resulting tables from ArcGIS is given in Appendix A11. An evaluation of zonal statistics results is attempted using the in situ retrieved results, as discussed in 3.3. The in situ results can be seen in Table 5 and 6 hereafter. For the latter, we took into account average values for depths up to 10 m, which is presented in the tables in red.

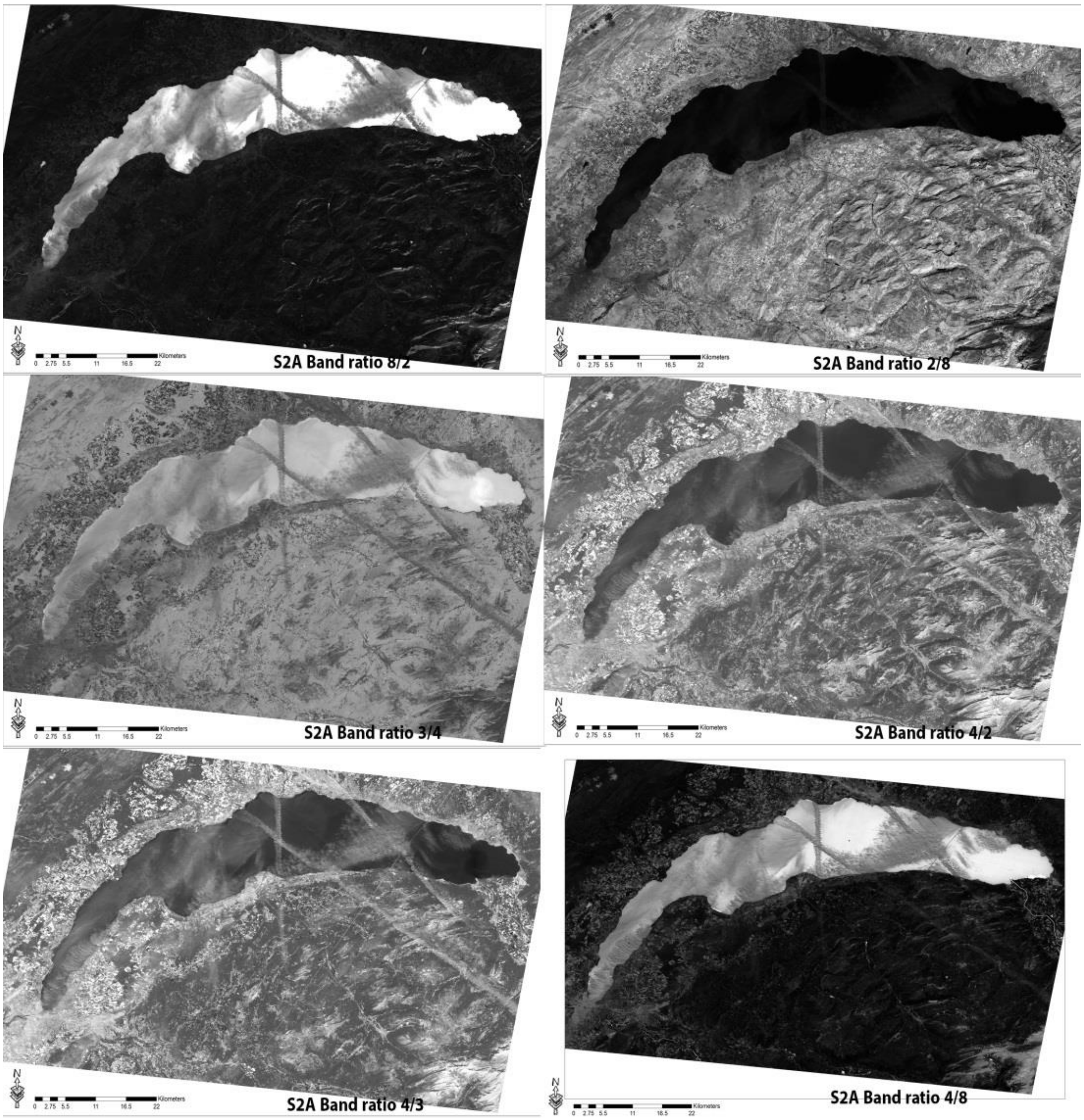


Figure 21: Overview of the resulting rasters from band ratioing of Sentinel-2A scene.

Table 5: In situ results of Chl-a, phosphates and nitrates in sampling site GE3. In red we can see the average value for measurements up to 10.

Date	Station	Coordinates	Depth	Chl.a	PO_4	NO_3
		(Swiss system)	(m)	(µg/L)	(mg/L)	(mg/L)
10.08.2015	GE3	506.100/128.040	0	4.34	0.011	0.296
10.08.2015	GE3	506.100/128.040	-10	21.29	0.009	0.327
				12.82	**0.01**	**0.31**

Table 6: In situ results of Chl-a, phosphates and nitrates in sampling site SHL2. In red we can see the average value for measurements up to 10.

Date	Station	Coordinates	Depth	Chl.a	PO_4	NO_3
		(Swiss system)	(m)	(μg/L)	(mg/L)	(mg/L)
03.08.2015	SHL2	534.700/144.950	0	1.90	0.011	0.336
03.08.2015	SHL2	534.700/144.950	-10	5.49	0.012	0.334
				3.69	**0.01**	**0.33**

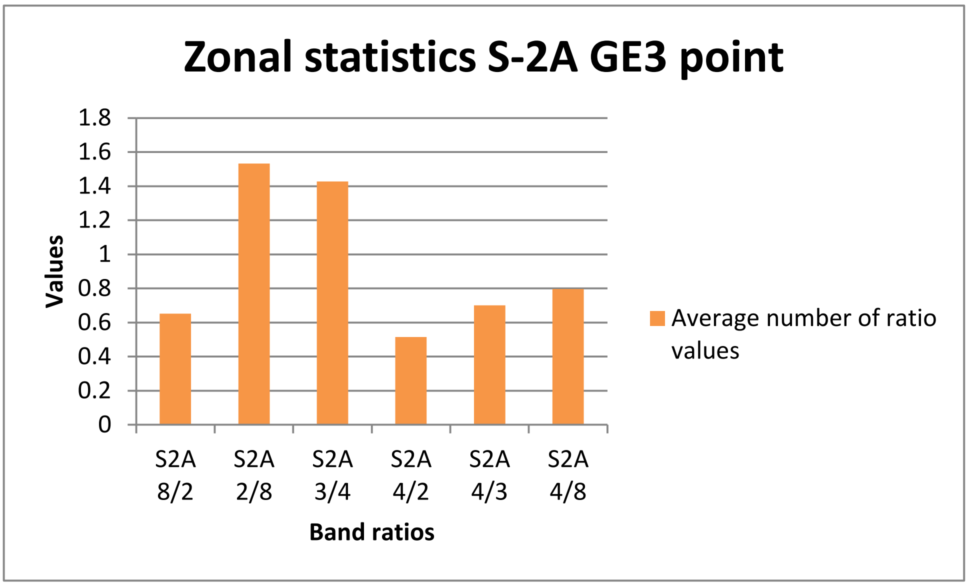


Figure 22: Column chart presenting zonal statistics outcomes of the Sentinel-2A scene, for GE3 sampling point.

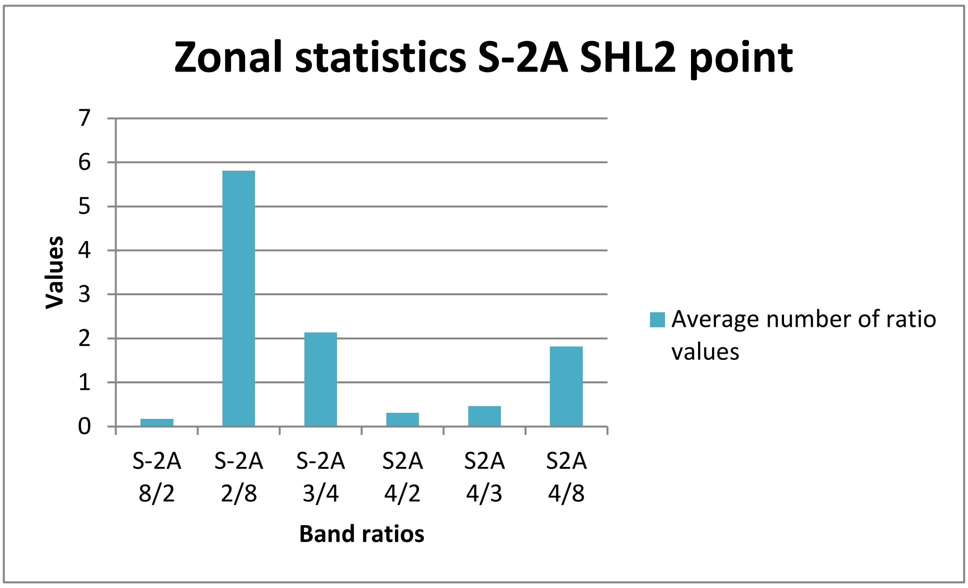


Figure 23: Column chart presenting zonal statistics outcomes of the Sentinel-2A scene, for SHL2 sampling point.

From the charts in Figures 22 and 23 we can see that the majority of band ratios give lower average values around the SHL2 sampling point, except for the S2A 2/8 and the S2A 3/4 ratio. The GE3 sampling point is in a less deep part of the lake, richer is dissolved substances and algae, which we would expect to increase total reflectance of the water and result to overall higher ratios. Nonetheless this depends on the ratio, the S2A 2/8 ratio is expected to have higher values in a part of clearer, deeper, open water area. Additionally, as mentioned before, the fact that we did not implement any atmospheric correction to our images probably results to misleading measured reflectance, especially in the band of red, for the S2A 3/4 ratio.

The band ratio S2A 2/8 (blue/NIR) gives, relatively to other bands, higher values for both sites, since water absorbs in the NIR and its reflectance is higher in the blue of the visible range. However, the ratio gives higher values in the SHL2 site which is a more open and clear water part of the lake, than in the GE3 less profound and close to the shore. The lower values of the same ratio in the GE3 site is expected, as it is richer in Chl-a (as presented in Tables 5 and 6) and part of the blue light is absorbed by algae.

The ratio S2A 4/8 (red/NIR) is expected to show a satisfying correlation with Chl-a content and we would expect to have lower values for the sampling point richer in Chl-a. Indeed, we see that the ratio showed a lower value at the GE3 sampling point, correlating with our in situ dataset.

From the rest of the bands, the ratio S2A 3/4 (green/red) would be expected to also correlate and reflect Chl-a content in the two sites , with higher values in parts of the lake with higher Chl-a content, as it absorbs in the red and has higher reflectance in the green. However, the ratio gives higher values in the SHL2 site (2.14), where we found lowest Chl-a content from the in situ measurements. In GE3 site the ratio shows lower average pixel values (1.42). We see then that due to the overlapping absorbance in the blue and green, this ratio does not conclude to a good Chl-a representative. Nonetheless, it is indispensable to apply atmospheric correction for retrieving accurate vegetation results. Additionally, it is important to notice that Sentinel-2A band configuration, offers 4 distinctive narrow bands for vegetation evaluation, which we did not use in this analysis. We only used the wider bands, closer to the Landsat band configuration.

Figure 24 presents band ratios' rasters, resulting from the Landsat 7 ETM scene. Here, we can see the lower level of visual quality results compared to Sentinel-2A band ratioing. There is always the stripping noise which is actually no data values and is important to be noticed at this point. Figures 25 and 26 hereafter, present the column charts of zonal statistics outcomes derived from the Landsat 7 ETM scene. Also here, the ratio ETM 1/4 (blue/NIR), shows higher values (1.69) in the SHL2 site (less turbid clearer water), and lower values (1.47), in the GE3 sampling point (more turbid higher Chl-a content), as expected. The ratio ETM3/4 (red/NIR) shows also correlation with the in situ data Chl-a content, giving a lower value in the GE3 sampling point. The ratio green/red ETM 2/3 is an interesting observation here, giving higher values for the GE3 point (4.04) and lower values at the SHL2 point (1.37), which is different to what we acquired in the Sentinel-2A scene. We see thus an inconsistency in the green, blue bands of the two satellites.

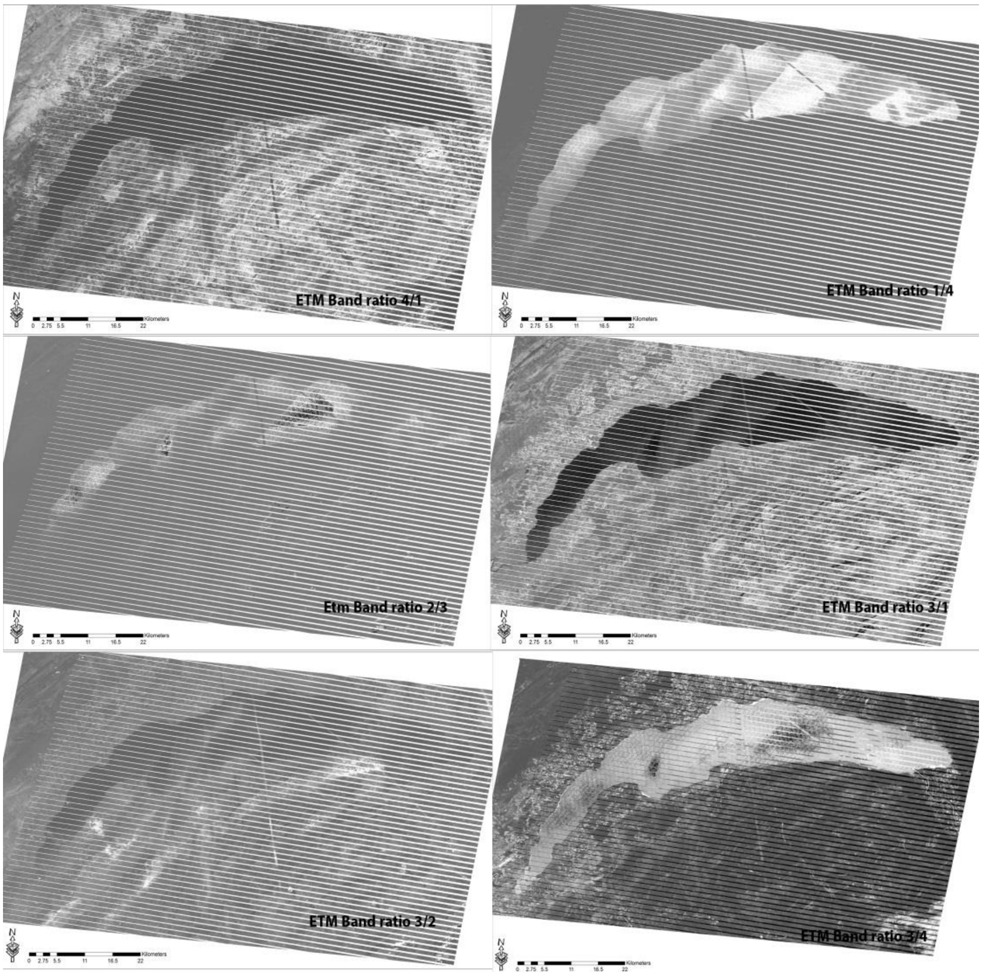


Figure 24: Overview of the resulting rasters from band ratioing of Landsat 7 ETM scene.

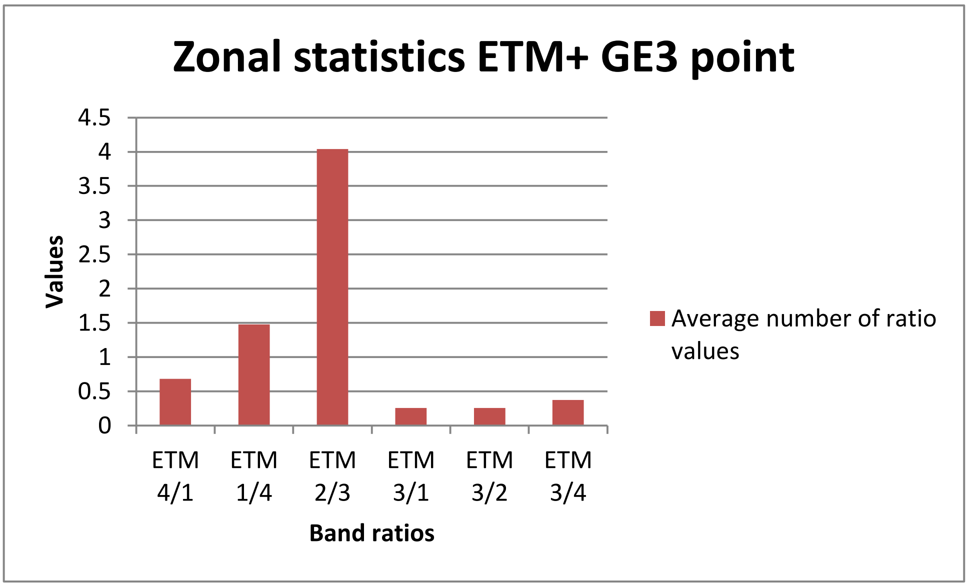


Figure 25: Column chart presenting zonal statistics outcomes of the Landsat 7 ETM scene, for the GE3 sampling point.

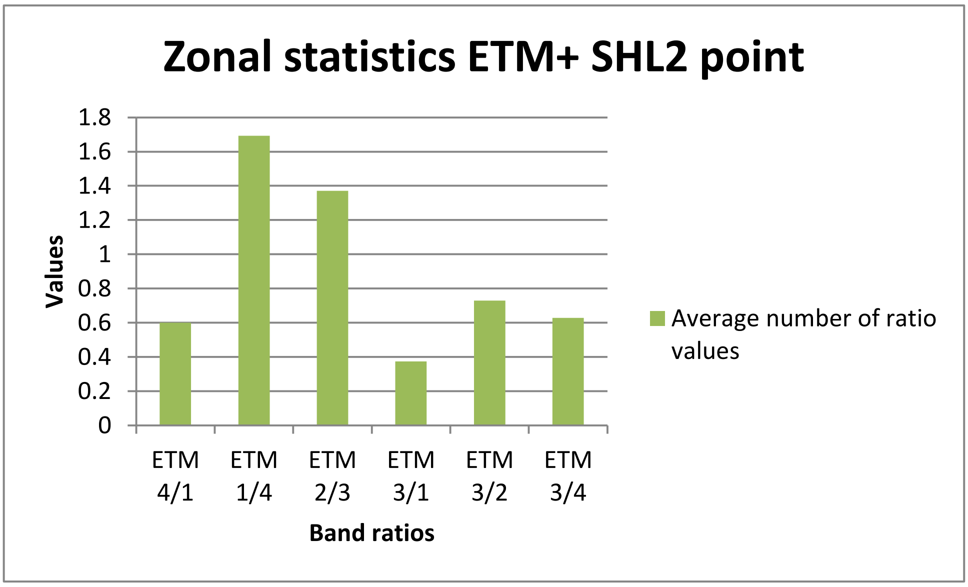
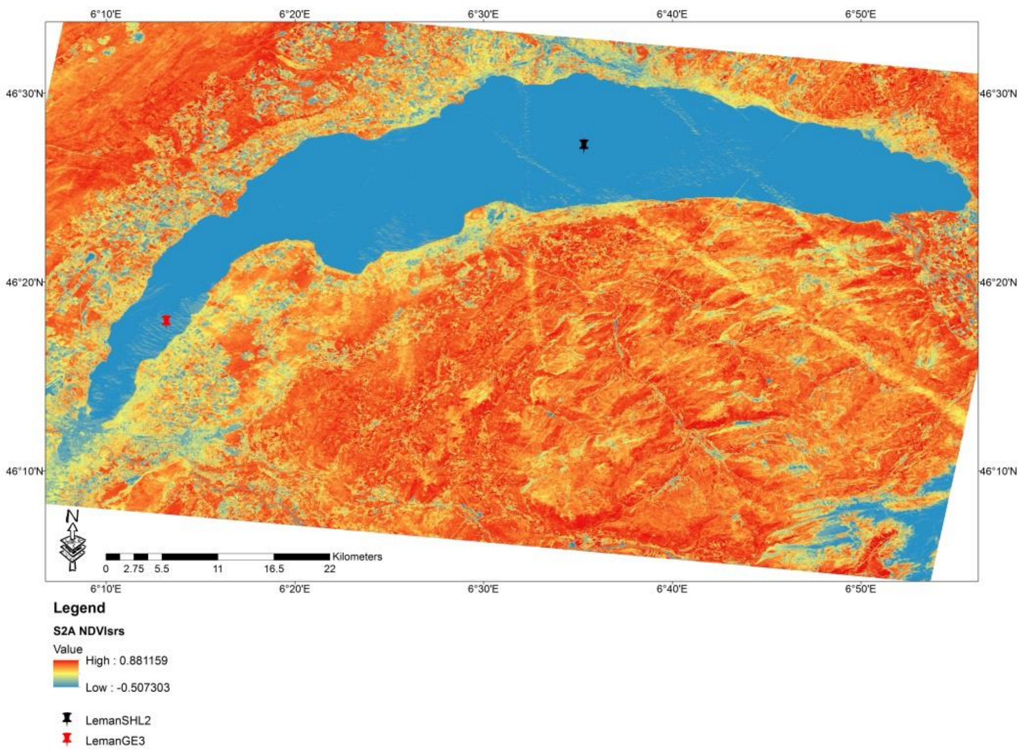


Figure 26: Column chart presenting zonal statistics outcomes of the Landsat 7 ETM scene, for the SHL2 sampling point.

4.3 Indexes

Indexes are very useful tools in remote sensing for retrieving optical active components concentrations in water bodies. The indexes presented in 3.6.3, were applied separately in our Sentinel-2A and Landsat 7 scenes.

With respects to Sentinel-2A image, Figure 27 shows the result of classic satellite remote sensing $NDVI_{SRS}$ index.



The index gave values from -0.50 to +0.88. Lower values are presented in blue, close to zero values in yellow and higher positive values in red. This index, as discussed, incorporates bands 4 (red) and 8 (NIR) and is mostly used in retrieving soil vegetation. Strong vegetation absorbs most of visible wavelengths and reflects most of the NIR. Positive values close to 1 are considered as vegetated areas, values close to -1 represent water or humid areas and values close to 0 are generated from features of high brightness, bare soil or clouds.

We can see that the ratio shows indeed higher values in the parts of intensive vegetation. For the areas around the lake where vegetation type changed, with less robust vegetation, crops and constructed areas the index is close to 0 painting these areas yellow. The areas of strong vegetation the NDVI takes high positive values painting them red in the figure. With respects to the water body area, which is our main interest, we wouldn't expect any color variations from this index. The lake appears blue, with index values very close to -1 as water absorbs most of the NIR radiation and has low reflectance in the red overall.

Figure 28 presents the outcome of $NDWI_{SRS}$ index in the Sentinel-2A scene. The index incorporated the bands 3 (green) and 8 (NIR). Then index is important for estimating water contents and soil moisture. Lower values are typically non water features, terrestrial

Figure 27: The $NDVI_{SRS}$ index of the Sentinel-2A scene.

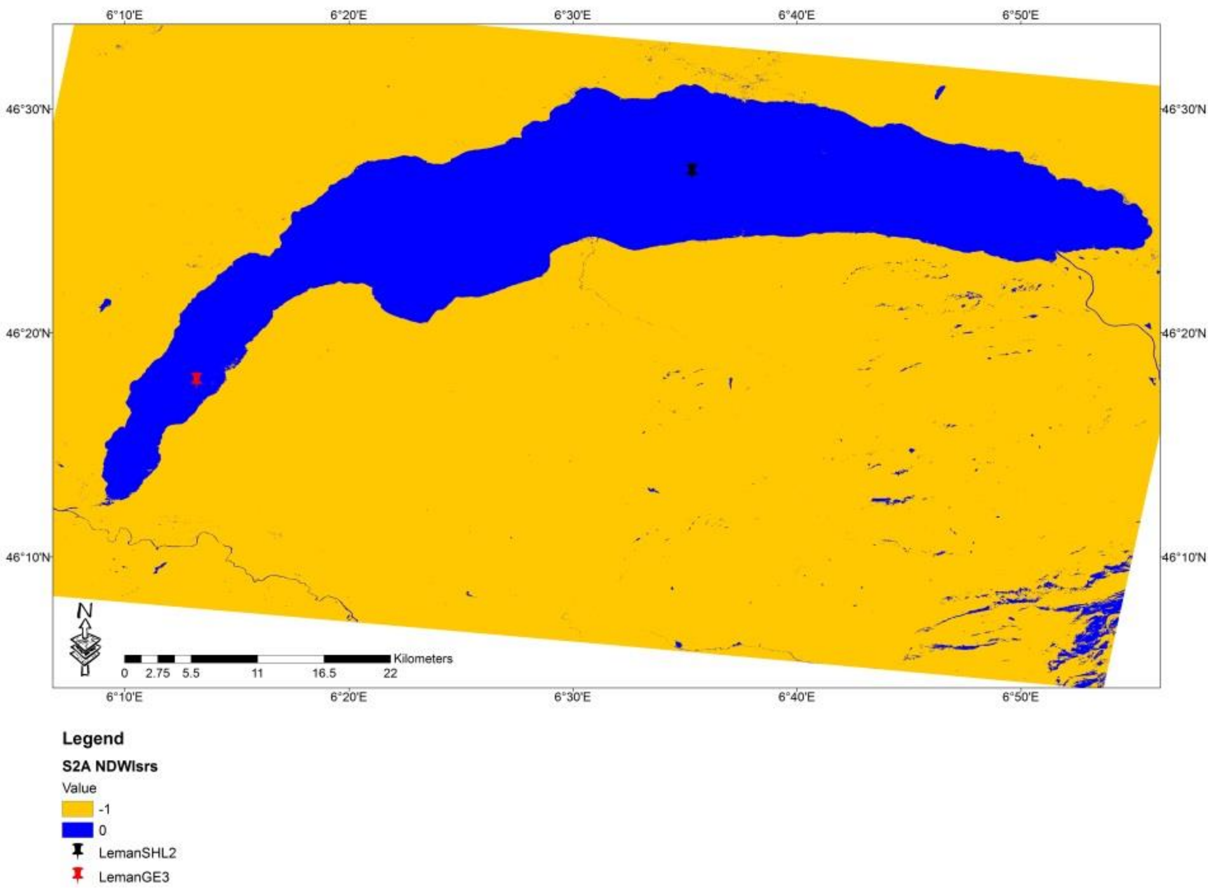


Figure 28: $NDWI_{SRS}$ results distribution in the Sentinel-2A image.

The index ranged from -1 to 0, with negative values representing non water areas and 0 water and more humid areas. The ratio, as we can see, delineates perfectly the lake, revealing also some other humid areas and watercourses in the region around the lake.

We will now present the three chlorophyll index, which as discussed in 3.6.3 are based on situ reflectance measurements, with application on satellite remote sensing scenes. These indexes used the narrow vegetation bands of Sentinel-2A band configuration. Figure 29 shows the $NDCI_{RIS}$ index in Sentinel-2A image.

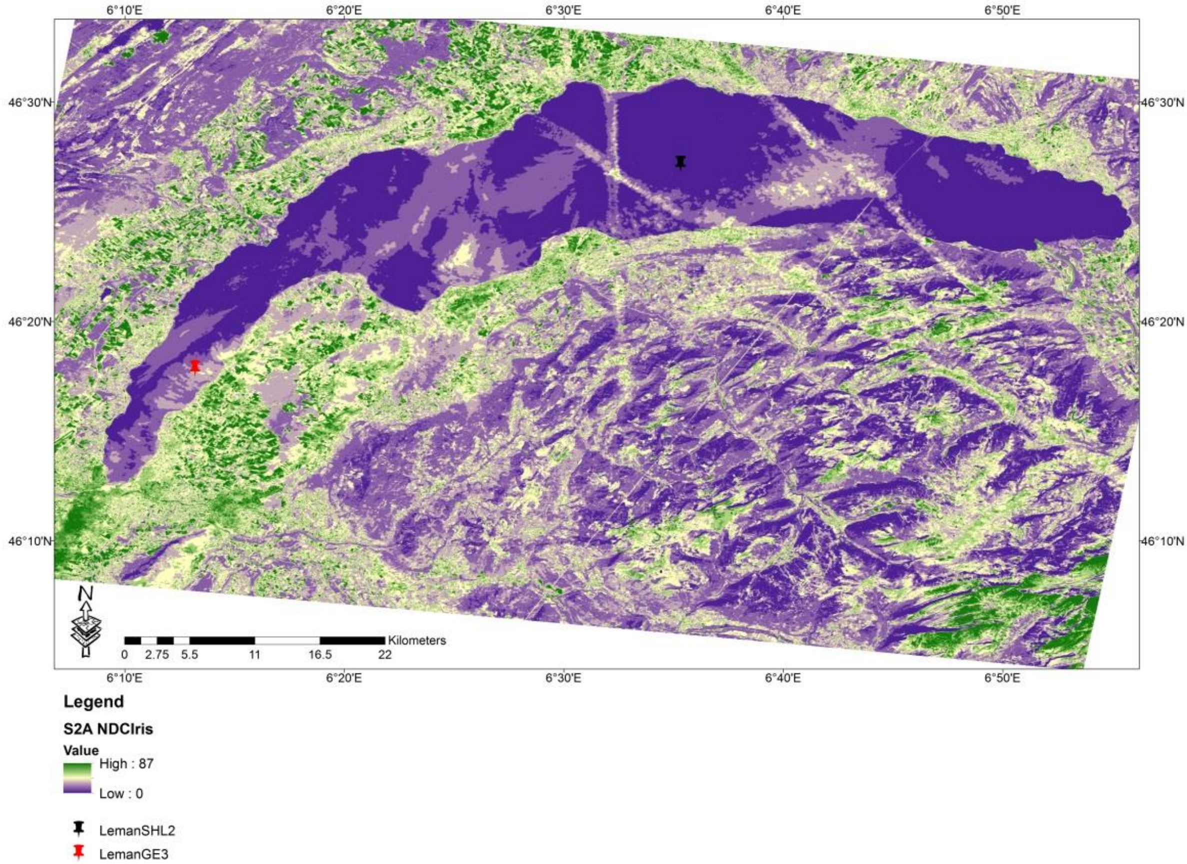


Figure 29: $NDCI_{RIS}$ index in Sentinel-2A image.

The index took values from 0 to 87, with higher values representing higher content of chlorophyll. The ratio was built to predict chl-a content in waters, using corresponding bands in order to eliminate other constituents such as colored dissolved organic matter or other detritus that affect spectral channels in the blue and green part. This ratio used mostly red bands for eliminating interference derived from increased turbidity. We used band 5, which is included in the four red edge vegetation bands of Sentinel-2A and band 4. As we can see in Figure 29 and with respects to the water body area, we can distinguish some color variations. Better visible in the large scale Figure 30. However, since we haven't implemented any atmospheric correction calculation on the image is hard and very unsafe to draw any conclusions.

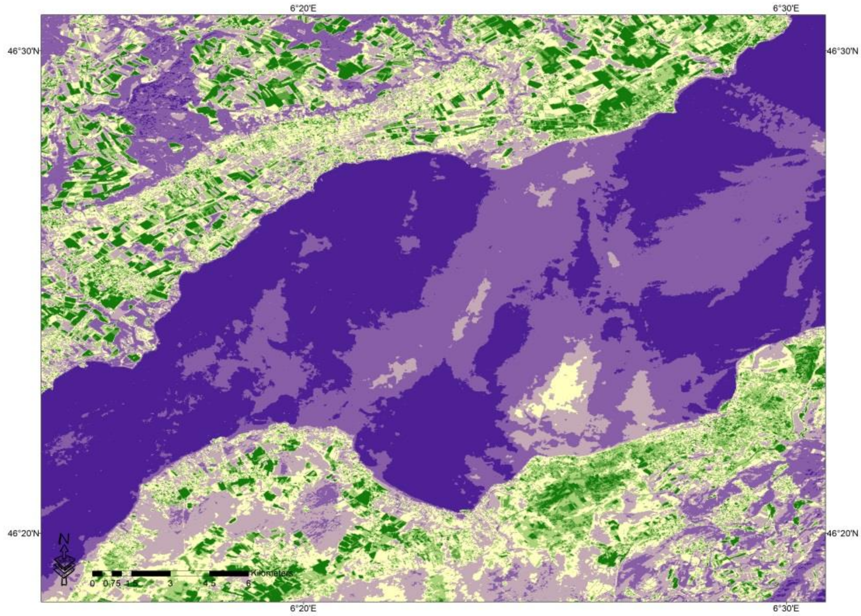


Figure 30: Large scale view of the $NDCI_{RIS}$ in Sentinel-2A image.

The same is also for the indexes $NDVI_{RIS,}$ which used the red-edge vegetation band 6 and band 4, and the $NDBI_{RIS}$ that used bands 3 and 4, presented in Figures 31 and 32.

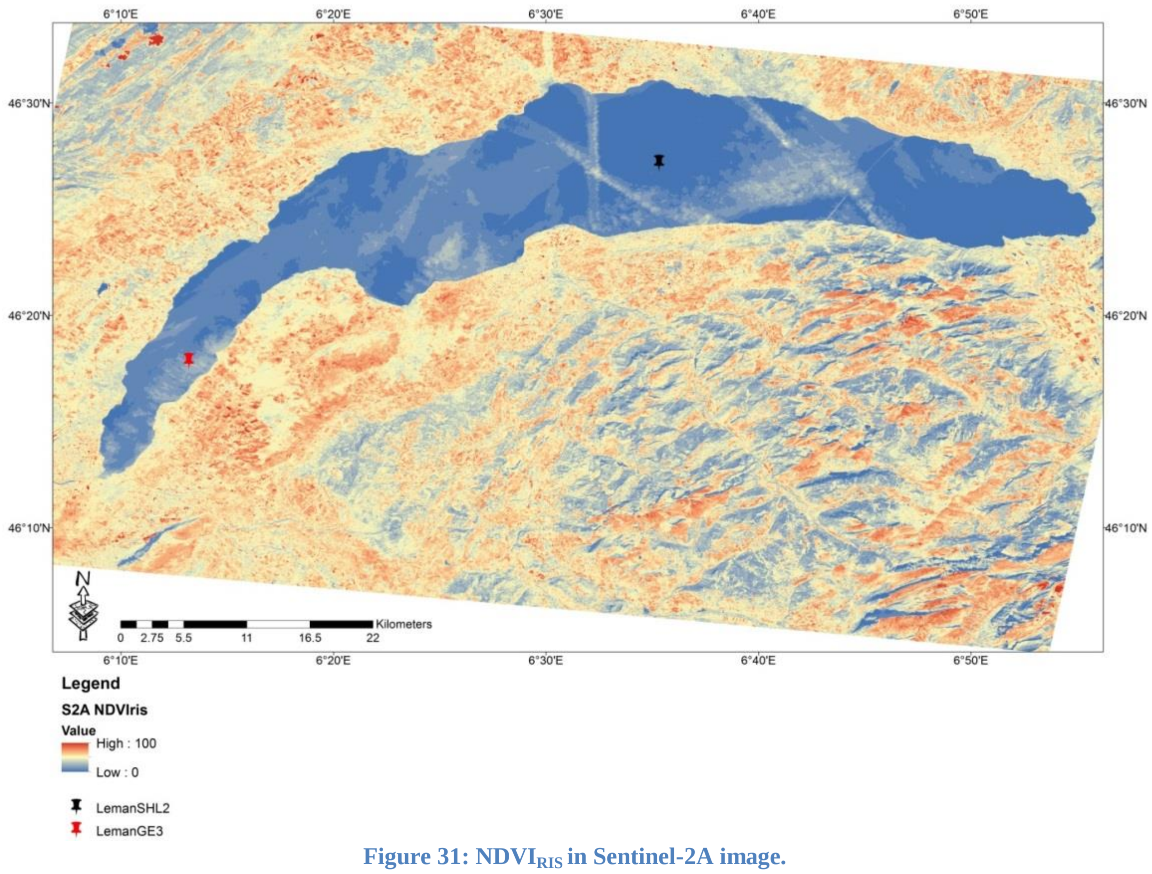


Figure 31: $NDVI_{RIS}$ in Sentinel-2A image.

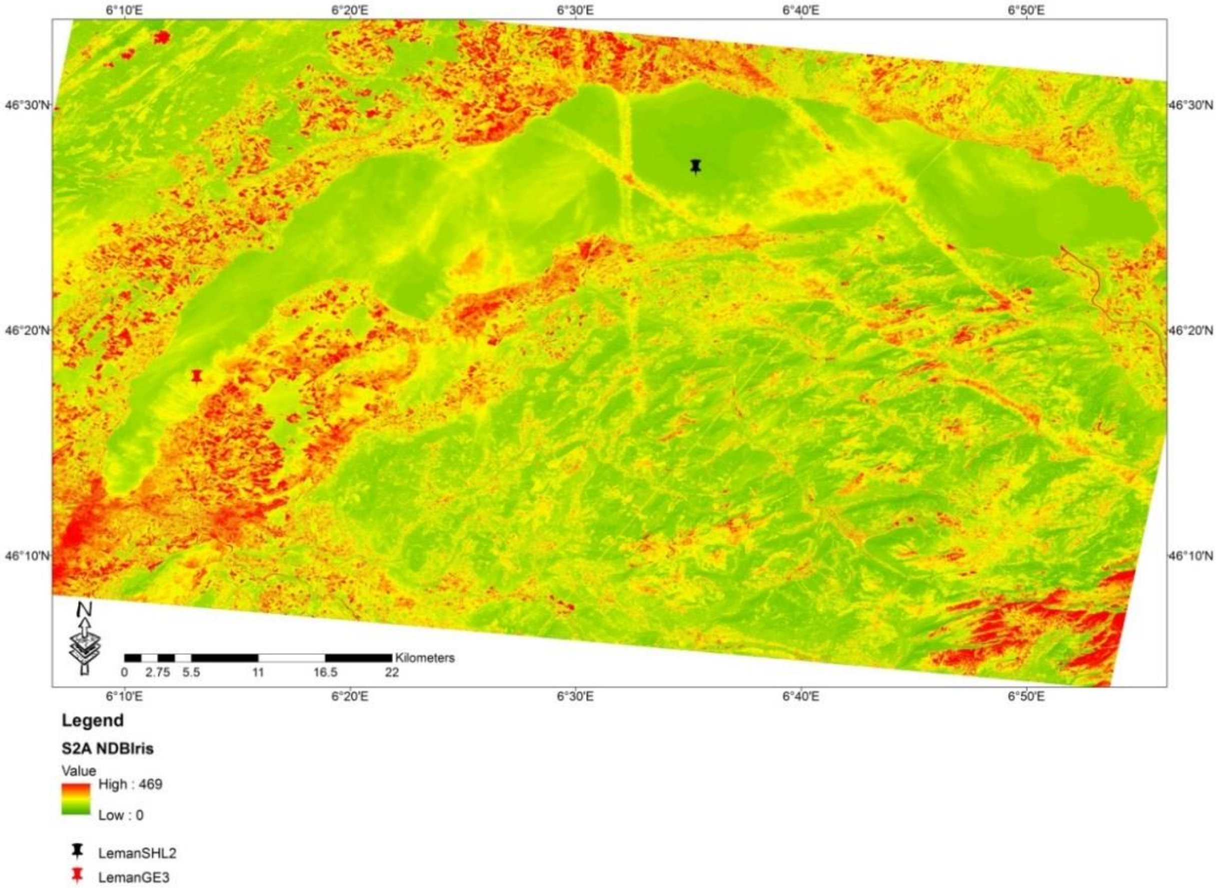


Figure 32: $NDBI_{RIS}$ in Sentinel-2A image.

The indexes $NDVI_{SRS}$, $NDWI_{SRS}$ and $NDBI_{RIS}$ were also calculated for the Landsat 7 ETM scene. The indexes $NDCI_{RIS}$ and $NDVI_{RIS,}$ in the case of Landsat 7 band configuration coincided with the normal $NDVI_{SRS}$ bands.

Figure 33 show the outcome of normal $NDVI_{SRS}$ in the Landsat 7 scene. The index took values from -1 to 1. The overall quality result of the index is very low. Compared with the $NDVI_{SRS}$ of Sentinel-2A image in Figure 27, we can see that even high vegetation delimitation shows differences.

Figure 34 present $NDWI_{SRS}$ result on Landsat 7 ETM scene. Again as we can see that the index fails to represent accurately the limits of water content in the area.

Finally, in Figure 35 we can see the $NDBI_{RIS}$ result on Landsat 7 ETM scene. This index seems to have a better visual result, in defining some type of soil vegetation.

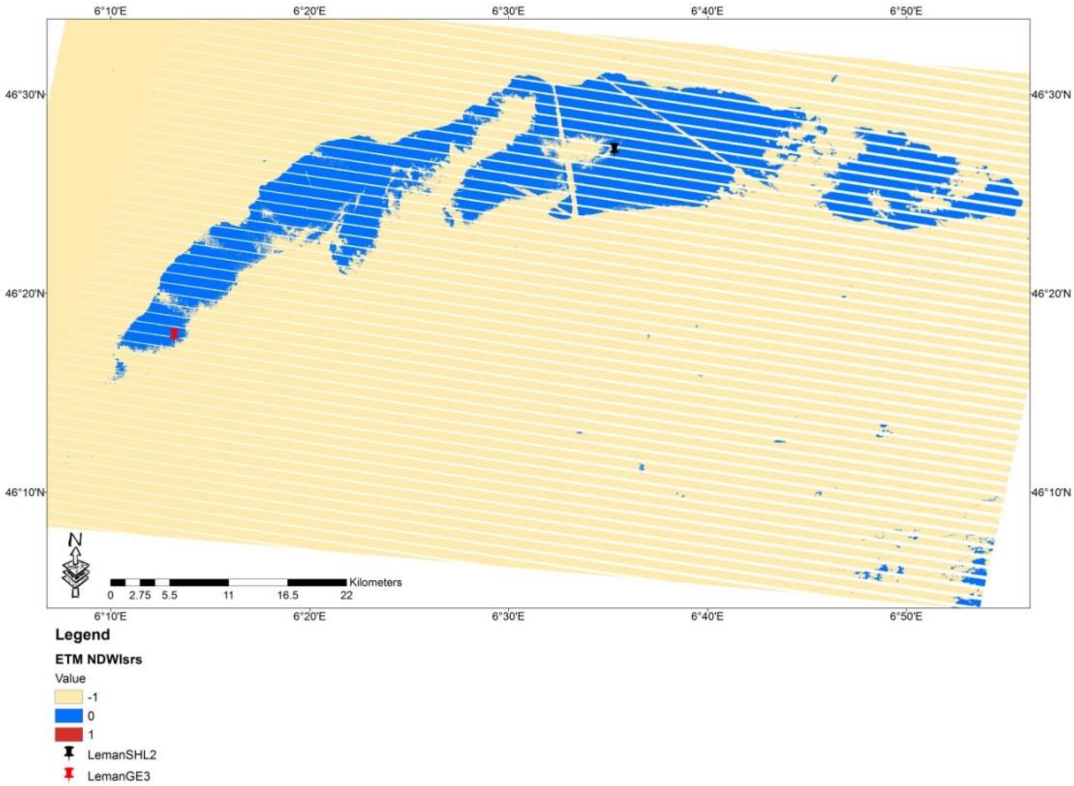


Figure 33: NDVI$_{SRS}$ result on Landsat 7 ETM scene.

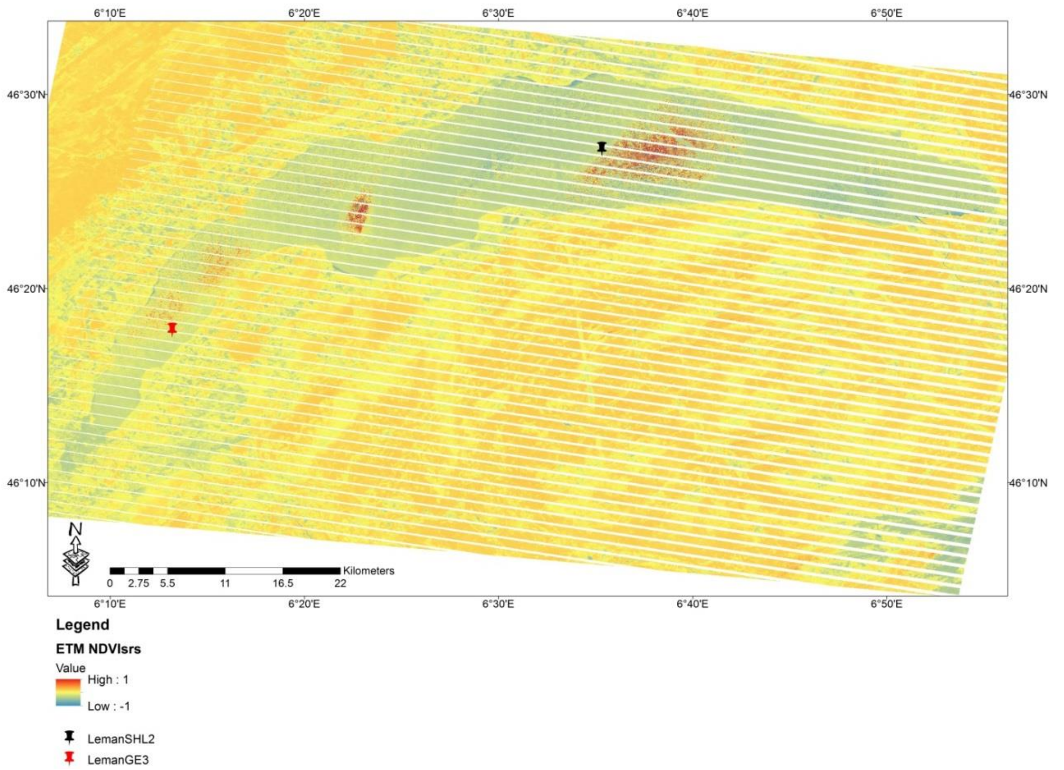


Figure 34: NDWI$_{SRS}$ result on Landsat 7 ETM scene.

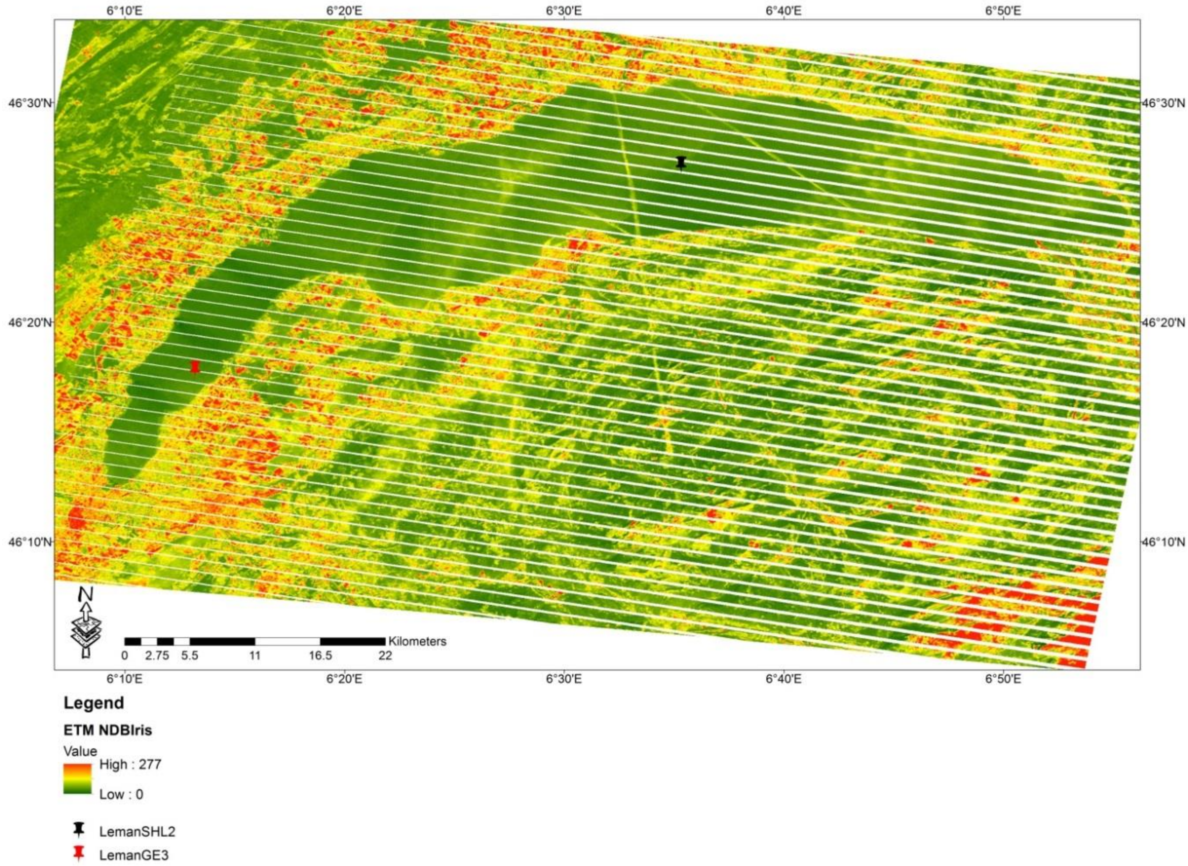


Figure 35: $NDBI_{RIS}$ result on Landsat 7 ETM scene.

5. Discussion

As seen in the results, we can estimate that overall Sentinel-2A scene gave better quality results and revealed high potential for retrieving more adequately optical active components from water bodies, with its low reflectance whatsoever.

To be more precise and if we take a closer look to our results this consideration has a base. True color composite of Sentinel-2A scene attributed almost completely natural colors. The image was of great quality overall, at 10 m pixel size, offering really impressive views and remarkable detail even in the low reflectance water area. In the large scale figure of the same composite we were able to visualize the captured detail. This fact verified the high spectral sensitivity of the Sentinel-2A MSI sensor and its very realistic band placement. The false color NIR composite also verified the accurate placement of this band.

Band ratioing results were again satisfying with very good quality resulting rasters for the Sentinel-2A scene. We concluded good response of ratios of certain bands, the blue and the NIR, however less effective red band response. High radiometric resolution of this sensor coupled with the fact that we did not applicate any atmospheric correction before image treatments is probably the answer to this drawback. In fact, many studies have shown the importance of atmospheric correction before interpretation of satellite images and their large source of noise for accurate surface reflectance measurements (Bagheri, 2011; Honkavaara, et al., 2009). Such errors can increase uncertainty depending on the spectral channel. In particular, with respects to vegetation ratios and indexes, influences can be significant and deviations from being able to draw real reflectance of the constituent feature, large (Hadjimitsis, et al., 2010).

Indexes implementation revealed the added value and high potential of the narrow red-edge bands of Sentinel-2A. Again the need for efficient atmospheric correction was obvious, nonetheless there is an unquestionable advantage drawn from the narrower bandwidth, more careful band placement and pixel size over the heritage satellites. All characteristics were reflected in the transformed rasters of our study.

It is possibly unfair to make any direct comparisons with Landsat 7 ETM scene, as there is also Landsat 8 in orbit, a more updated and improved version of it, which unfortunately did not have any available scenes for the aimed period. However, since both are considered as heritage of the newcomer Sentinel-2 missions, differences must be considered. The true color composite of the Landsat 7 scene was overall of inferior precision and quality. There seemed to be a failure in visible color accounting from the reflectance received. There was a perturbation of the reflectance captured by the satellite possibly due to atmospheric interference. Other than that, color differences to natural nuances could be due to bad spectral resolution. The problem seemed to be mostly in the differentiation of different types of vegetation, in the red region. The sensor gets real reflectance for the parts where the absorption-reflectance is more intense i.e. in the forest parts beyond the crop and populated area around the lake. The difference came out as pink, a mixture of blue and red. The implementation of different indexes, made obvious the great disadvantage by the non-appropriate band placement and large bandwidth. There was problems differentiating reflectance, mainly in the visible part of the spectrum where reflectance is basically low with respects to water bodies.

It is important though to notice that this study was based on a qualitative evaluation of the analyzed scenes, without any further atmospheric correction calculation before, which made difficult to detect in precision new advances in water optical constituent capturing. However, overall evaluation of Sentinel-2A scenes made obvious its high potential, as it gave overall better reflectance values, better color intensities, higher resolution by revealing more detail. All these characteristics coupled with its higher temporal resolution, make a cogent new sensor package. However, added value of these characteristics always depends on observed features. In any case, for inland waters Sentinel-2 seems to present significant better characteristics than its heritage.

6. Conclusion

Increasing stresses on lakes all over the world have generated the need for cost effective and quick water monitoring techniques. Satellite remote sensing has proven to give better results in both temporal and spatial scale. However, the extent and complex interactions of light, which constitutes the base for remote sensing on one hand and the large variability of lake constituents on the other hand, makes indispensable the use of accurate sensors, of high sensitivity, with the best possible band location and bandwidth. These are the variables that mostly create noise to signals received from satellites.

In this study, we made obvious that improvements of these variables has a high added value and give a high potential to reach very low levels of received noise for the signals received from satellites. Sentinel-2A, with its improved characteristics enlightened this way and the great potential it carries.