OBSERVATION OF SHKODRA LAKE WATER QUALITY USING SATELLITE IMAGERY

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ABSTRACT

Remote sensing imagery was applied to investigate the water quality of the Shkodra Lake. Distribution of phytoplankton, macrophytes, and sediments were calculated using Landsat and MODIS band combinations, and compared with data from *in situ*measurements. The impact of the wind and geomorphology of the area to the circulation of waters in the Lake was investigated as well.
***Keywords*:** Shkodra Lake, remote sensing, Landsat, MODIS, water quality

1. INTRODUCTION

Shkodra Lake is the largest lake in the Balkans with a surface area of 350-500 km^2 and a maximum depth of 8.3m. The main water supplier is Moraca River, with 63% of the total, and a large number of karstic springs (crypto-depressions), some of which are up to 60 m deep. Morača River also brings approximately 50,000 tons of suspended matter to the lake. The lake discharges through the Buna River to the Adriatic Sea with an average amount of 300 m^3/s.

Shkodra Lake is characterized by highly developed submerse and emergent vegetation and a rich flora and fauna with high endemism. As it is rich in biodiversity, the lake was proclaimed National Park (Montenegrin part), while the Albanian part was proclaimed a "Managed Natural Reserve" or IUCN Category IV (Dhora 2017).

Water quality is a continuous concern, as it is related to human's activities, like fishery, tourism, industry, etc.

The biodiversity and water quality of Skadar/Shkodra Lake are threatened by various forms of economic activities such as tourism and fishery in the lake as well as agriculture and industry in the lake water basin. Shkodra Lake is one of the hot-spots regarding the ecological status and biodiversity. Its aquatic ecosystem, water contamination have been continuously monitored and studied in addition of air pollution (Mezler, 1999; Hollert *et al*., 2004; GIZ, 2005; Rakaj *et al*., 2000; 2009; Rakaj, *et al*., 2006; Dhora and Rakaj, 2010; Frasheri *et al*., 2010; Mandija *et al*., 2010; Neziri *et al*., 2011; Malollari *et al*., 2012; Neziri, 2012; Rakaj, 2012; Rakocevic 2013; Alushi and Abdija, 2014; Bekteshi and Cupi, 2014; Frasheri *et al*., 2014; Mandija, 2013; 2015; Bushati and Neziri, 2016; Dhora *et al*., 2016; Dhora, 2017; Năpăruş-Aljančič *et al*., 2018).

During different seasonal periods, as a result of heavy rains and winds blowing from the north and south at speeds up to 6 m/s, lake waters are often disturbed by high concentrations of suspended matter, up to 50 g/m3 and chlorophyll a concentration (about 10 mg/m3) in the middle of the lake and more than 15 mg/m3 along the southeast coast. These recurring events occasionally form cyclonic circulation (counterclockwise) in the middle of the lake (Kostianoy *et al*., 2018).

During the last decade, direct/indirect remote sensing techniques have also been utilized in order to have a clear picture in a large scale of this basin and surrounding areas.

Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object, in contrast to in situ or on-site observation. Nowadays, it is used in numerous fields, including geography, land surveying and most Earth science disciplines (for example, hydrology, ecology, meteorology, oceanography, glaciology, geology); it also has military, intelligence, commercial, economic, planning, and humanitarian applications, among others. Remote sensing observations provide data and images at different spatial scales (Frasheri *et al*., 2010a.b; Frasheri *et al*., 2014; Kostianoy *et al*., 2018; Mandija *et al*., 2019). It is not time-consuming like *in-situ* measurements and it covers also the areas uncovered by field-based observations.

2. MATERIALS AND METHODS

Satellite imagery is used to evaluate the quality of ground water surfaces, including water turbidity, biomass (chlorophyll-a concentration), sediments, and lake surface roughness. Landsat 8 images was employed for the analysis of Shkodra Lake waters.

The water parameters such are phytoplankton, macrophytes, sediments, etc. are investigated using different satellite image band combinations; B4: B3: B2, B4: B3/B1, B2-B1 (enhanced), B2:B2, NDVI and NDWI (Mc Feeters, 2013; Gholizadeh 2016; Serrano *et al*., 2018; Avdan *et al*., 2019; Elhag *et al*., 2019); where bands used are: B1 – water aerosols, B2 – Blue, B3 – Green, B4 – Red, B5 – NIR, B6 – SW1, B7 - SW2.

Image results were compared with data from field work done in 2014. Landsat images are obtained from USGS repository (https://earthexplorer.usgs.gov/) for dates 26-08-2013, 27-04-2014 and 28/08/2014.

Additional remote sensing data were collected using NASA's Earth Observing System Data and Information System EOSDIS. GIOVANNI portal provides data mad maps of the wind components (MERRA-2 Model M2T1NXFLX v5.12.4), absorption coefficient of non-algal material and phytoplankton (MODIS-Aqua_L3m_IOP_8d_4km v2018).

Field work was done for Chlorophyll a (Phytoplankton-Chl a) in 26/08/2013 and 27/04/2014 in depths of 3m-4m using a black glass bottles 1l (Rakocevic 2013); and for aquatic vegetation (Macrophytes) in 20/08/2014, by transect method in depths of 3m-4m using a bout and Double-sided Luther-rake with soft rope depth marked (Wetzel & Likens 2000) in the three following stations:

1. Sterbeq, 4.5 km from shore, depth 6.7m, coordinates N 42 11' 44" E 19 23' 03"
2. Zogaj, 2.3 km from shore, depth 5.5m, coordinates N 42, 04' 22.6" E 19 24' 13.9"
3. Shiroke, 2.2 km from shore, depth 4.6m, coordinates N 42 03' 41" E 19, 27' 13.9"

The temperature, depth and transparency of water were measured in advance by Disc Sechi.

All parameters were analyzed applying standard methods (Sartory and Grobbelaar 1984; Melzer, 1999), while the trophic state index (TSISD, TSI-CHLa) was calculated based on (Carlson 1977).

3. RESULTS AND DISCUSSIONS

3.1 Field-based observations

Table 1 reports about the transparency, chlorophyll *a* and macrophytes content for all the three stations.

Table 1: Analyzed data for three stations: Sterbeq, Zogaj and Shiroke

Nr	Stations	Transparency	Chlorophyll *a*	(TSI-SD)	(TSI-CHLa)	MI (macrophytes) 30/08/2014
		26/08/2013 and 27/04/2014				
1.	Sterbeq	2.8	3.17 2.70	42.51 36.31	41.64 37.53	3.66
2.	Zogaj	3.1	3.19 2.90	43.75 38.84	40.86 40.16	3.87
3.	Shiroke	2.6	2.97 2.60	41.67 36.87	42.61 38.63	3.84
RSD (%)		8.9	8.2	7.7	4.7	3.0

The results did not report any significant difference among the three stations. The relative standard deviation (RSD) was used for the dispersibility of values of water parameters.

$$\mathrm{RSD} = \frac{1}{\bar{x}}\sum\frac{1}{N-1}(x_i - \bar{x})^2 \qquad (1)$$

The result reported that RSD is lower than 10% for transparency, chlorophyll, TSI-SD, TSI-CHLa and MI, respectively, i.e. the stations do not differ from one another with regard to water properties.

Reflectance of turbid waters is higher in visible bands B1 – B5, compared with the reflectance of clear waters (Figure 1):

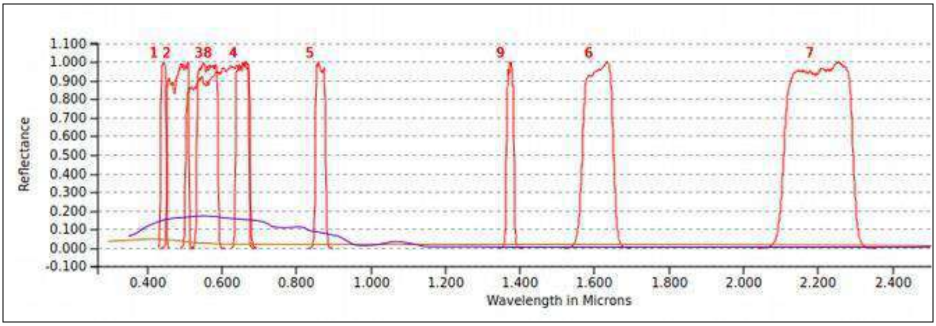


Fig.1: Reflectance of water: magenta ~ turbid, brown ~ clear waters (source USGS).

3.2 Satellite-based observations

3.2.1 Landsat products

Histograms of gray scale images are two and three-modal, which separates land pixels from water pixels, in part of cases even sea pixels from lake pixels. Enhancing of false color images for separation of water proprieties are based in modes of histograms as in Figure 2:

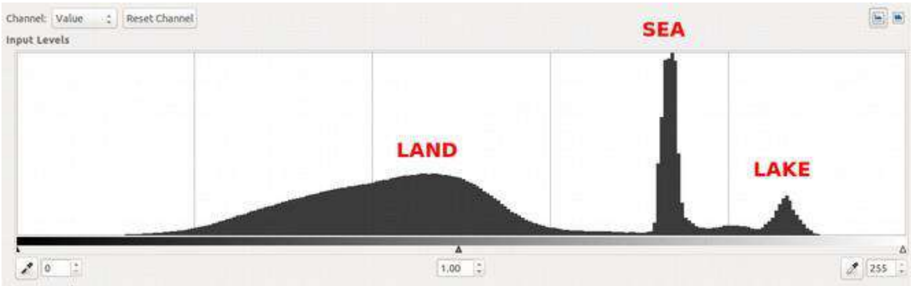


Fig.2: Separation land pixels from water ones based on typical histograms

Color coding for gray scale images is made using the palette in the Figure 3:

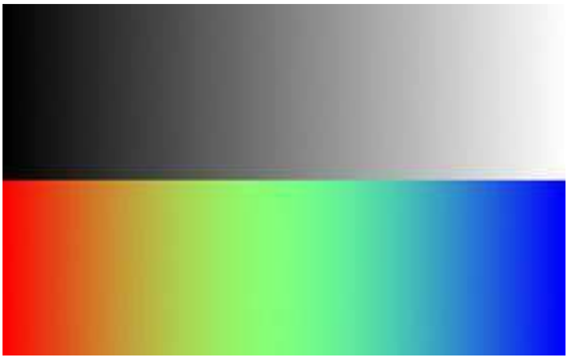
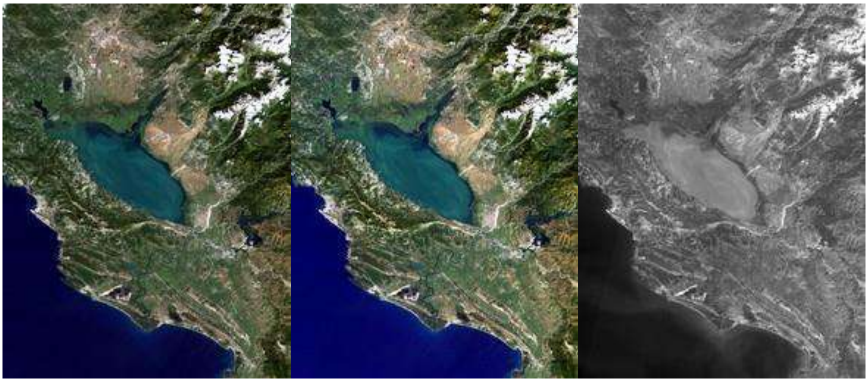


Fig.3: False color palette compared with the grayscale.

Satellite images of 28/08/2014 were the best from the cloud coverage point of view, relative to measures of Macrophytes in 30/08/2014. The view of Lake in natural colors with band combination B4: B3: B2, false color combination B4: B3: B1 as RGB, and enhanced difference B2–B1 are given in Fig. 4:

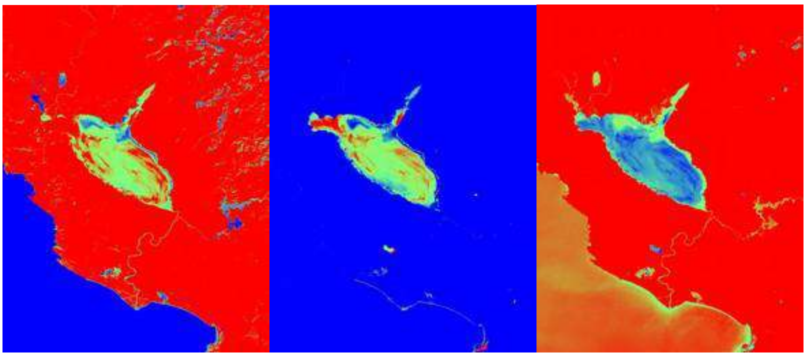


a) B4: B3: B2 b) B4: B3: B1 c) B2 – B1 (enhanced)

Fig.4: natural colors and impact of band B1.

The natural color reflectance of the Lake is dominated by green nuances indicating also the presence of circular flow of waters. Differences between images B4: B3: B2 and B4: B3: B1 are almost invisible except clearer blue color in the Adriatic Sea waters (Fig.4a and b), indicating its clearness compared to Lake waters. Enhanced difference between B2 and B1 in Fig.4c indicates high values for the Lake surface, corresponding with the turbidity of waters; sediments are also visible in the Adriatic Sea around Buna River delta, Great Beach (Ulcinj, Montenegro) and Velipoja.

Combination of Blue/Green bands, difference vegetation index NDVI = (NIR-Red)/(NIR+Red), and difference water index NDWI=(green-SW2)/(green+SW2) are presented in FIG.5:

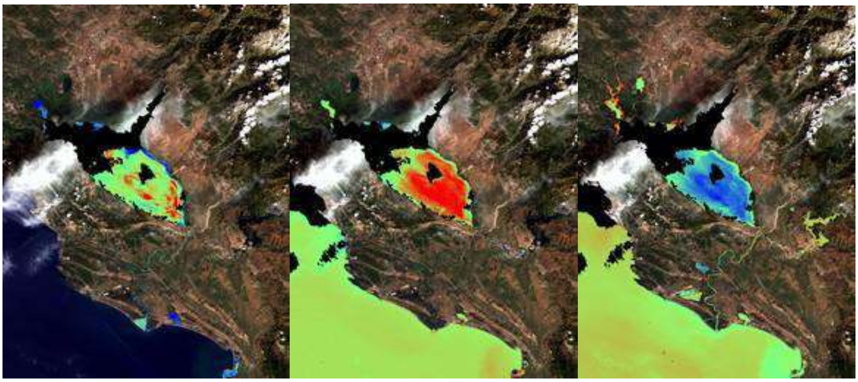


a) B2/B3 b) NDVI c) NDWI

Fig. 5: false color band combinations for water quality and chlorophyll.

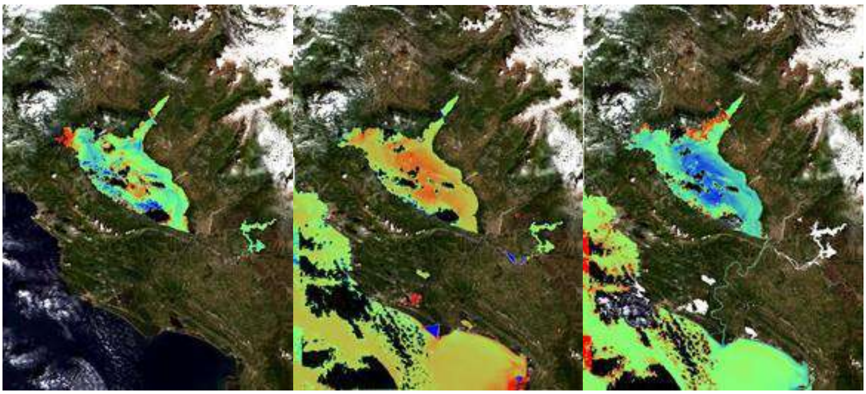
Comparing different reflectance in Green and Blue, the dominance of Green band indicates turbid waters. The status of colors in Fig.5a indicates high values of the ratio Blue/Green only in northeastern shores of the Lake. The same happens for the normalized difference vegetation index NDVI in Fig.5b. While normalized difference water index NDWI reflects the difference between Green and InfraRed bands, with high values for turbid waters, which is visible in Fig.5c where high values of this index cover most of the Lake surface. Both these figures suggest that the major part of the lake is characterized by high turbid waters. Only the Albanian bridges and Montenegro western littoral reflects a different picture, characterized by clearer waters.

Field values from 30/08/2014 for macrophytes (MI) are lower for Sterbeq (northeast shore of the Lake) compared to the values found in Zogaj and Shiroke (south-east past of the lake). Turbidity of waters with low levels of NDVI indicate presence of sediments and other polluters not related with chlorophyll.



B2:B3 NDVI NDWI

Fig.6: The status of Lake in end of 25 August 2013.



B2:B3 NDVI NDWI

Fig.7: The status of Lake in 8 May 2014.

There are some differences between the satellite observations during 25/08/2013 and 08/05/2014 (Fig. 6-7). The ratio bands B2:B3 indicates a more turbid state of the lake during the second date, due to the presence of chlorophyll among others. In addition, NDVI maps indicate more vegetation during 08/05/2014 compared to 25/08/2013.

The images of Figure 6 and 7 show: i) circulation of Lake waters in anti-clock sense, ii) increase of turbidity in central regions of lake, caused water circulation, and iii) low values of NDVI in central areas of the lake.

3.2.2 MODIS products

The MODIS-Aqua products given by GIOVANNI platform were used for a detailed information about spatial distribution of the phytoplankton and non-algal materials (due to gelbstoff, detrital material, and CDOM), as well as the chlorophyll concentrations.

Figure 8 depicts the spatial distribution of the averaged phytoplankton, non-algal materials and chlorophyll, as well as the chlorophyll concentrations over the Shkodra Lake during the periods from 25-May to 8-Oct for the two consecutive years, 2013-2014.

Spatial distribution of the absorption coefficients over Shkodra Lake, suggest that phytoplankton has been non-uniformly distributed during these two consecutive years. Meanwhile, during 2013 the maxima was reached over the Sterbeq shore and the central part of the lake, in 2014 even higher values are obtained especially in Sterbeq shore and a fraction of the norther part of the lake.

On the other hand, in 2013, the non-algal material appeared to be more concentrated in the northern part of the lake and in Sterbeq shore, while in 2014 lower concentrations were observed with higher values in separated parts of the lake. Chlorophyll concentrations in these two periods were higher over the northern part of the lake.

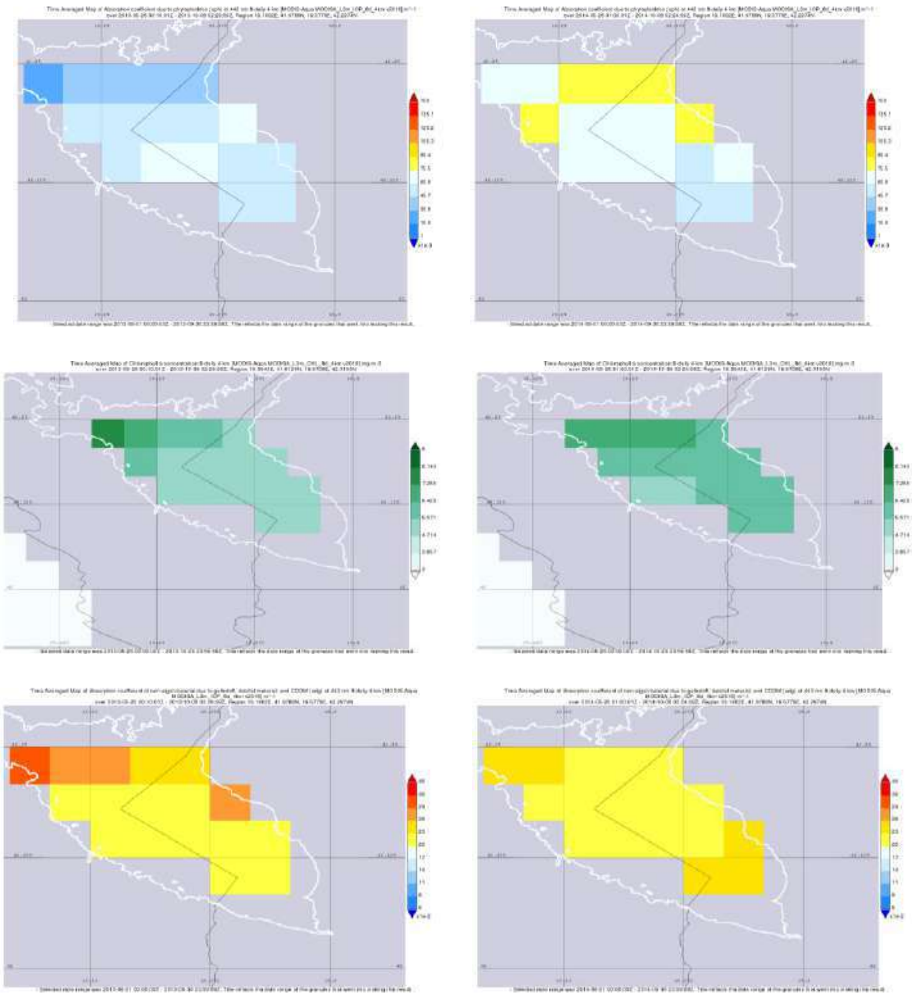
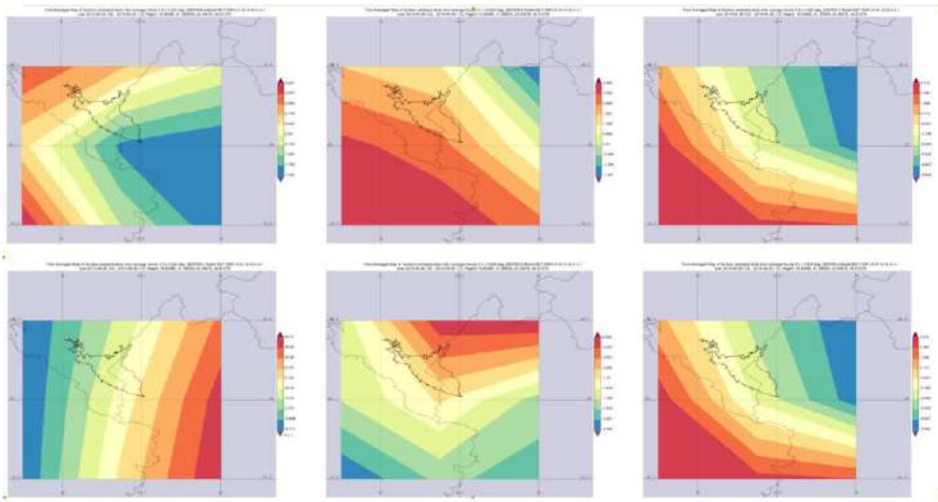


Fig.8: GIOVANNI-Time Averaged Map of Absorption coefficient due to phytoplankton (upper panel) and non-algal material due to gelbstoff, detrital material, and CDOM (middle panel) as well as chlorophyll concentrations (lower panel), at 443 nm 8-daily 4 km [MODIS-Aqua MODISA_L3m_IOP_8d_4km v2018]. 25/05 - 0808, 2013-2014.

3.3 Wind speed analyses

Little is known about currents in Skadar/Shkodra Lake, but due to its shallowness (mean depth 5 m), the wind direction should play a key role in the formation of the circulation patterns in the lake (Kostianoy et al. 2018). We analyzed the surface wind speed to determine which factor contributes in the water circulation in the lake the most. Consequently, the u and v wind components during the satellite observations were averaged. Figure 9 depicts the maps of northward and eastward winds during 25/08/2013, 08/05/2014 and 28/08/2014.



25/08/2013 08/05/2014 28/08/2014

Fig.9: GIOVANNI-Time Averaged Map of Surface northward and eastward wind components. Wind maps over the Shkodra Lake during three days 25/08/2013, 08/05/2014 and 28/08/2014. The upper and lower panels represent northward and eastward winds, respectively, (source NASA's Earth Observing System Data and Information System EOSDIS).

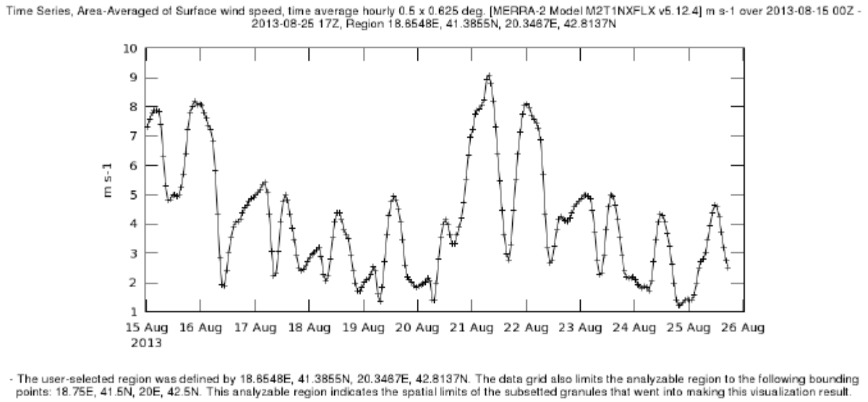
Despite the low wind speed values, the maps in the Fig. 9 suggest an important feature of the wind directions over the lake during this period. The wind directions are inconsistently distributed over the entire lake area. Northward and eastward components are variable over the area, changing even their signs. This fact gives some insights over the water circulation over the lake, observable in the satellite images.

Average values of the wind speed components results are presented in Table 2.

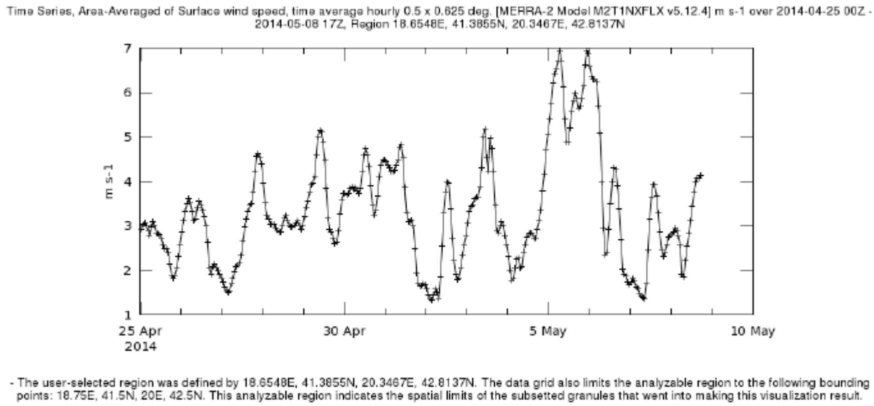
Table 2. Wind speed north and east components as well as the total vector over Shkodra Lake for three days; 25/08/2013, 08/05/2014 and 28/08/2014.

Date	Component N	Component E	Total speed	Direction
25/08/2013	2.15	1.60	2.68	NNE
08/05/2014	1.30	-0.80	1.53	NNW
28/08/2014	2.00	-1.15	2.31	NNW

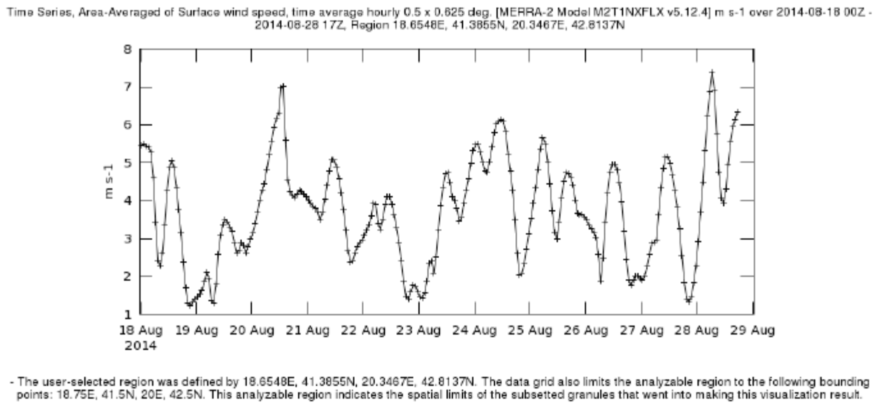
However, daily wind values may not present the whole wind effect on turbidity. Sediments lifted by the wind activity, can remain suspended up to several days. Consequently, time series of the area-averaged of surface wind sped are analyzed. For each of the three days, we have chosen an interval of 10 days prior the satellite imagery was taken. Figure 10 shows the time-series of the total surface wind speed for 10-days period ending at the three satellite-observation dates.



15/08/2013 - 25/08/2013



25/4/2014 - 08/05/2014



18/08/2014 - 28/08/2014

Fig.10: Time Series, Area-Averaged of Surface wind speed, time average hourly 0.5 x 0.625 deg. [MERRA-2 Model M2T1NXFLX v5.12.4] m s^{-1}, Region 18.6548E, 41.3855N, 20.3467E, 42.8137N (source NASA's Earth Observing System Data and Information System EOSDIS).

Time series in the Figure 9 suggest that wind speed did not exceed the value of 9 m/s, during the entire 10-days period prior the satellite images were taken. During the first period, the wind speed reached up to 8-9 m/s during 3-4 days before the satellite image was taken. After that, its values were lower than 5 m/s. Similar situation is observed also during the second period, where wind speed reached the peak on 7 m/s 2-3 days before the satellite image and then decreased lower than 5 m/s. Even lower wind speed was observed during the third period. Maximal values reached up to 5-6 m/s during this period.

Shkodra Lake has northwest-to-southeast extension, and is bordered by mountains in southwest shores. This terrain configuration favors winds from north and east with greater speed during southwestern shores, contributing to water circular observed in satellite images (Fig. 11).

Fig.11: SRTM digital terrain model of Shkodra Lake area (source USGS).

All these wind speed values may be considered low to be the principal factor water circulation and suspended matter in the lake during the investigation periods (Anthony and Downing, 2003; Cho, 2007; So *et al.*, 2013). Thus, wind activity together with Buna and Moraca (even Drini in special cases) rivers streams contribute in this circulation patterns of the lake's waters.

About the role of Drini River, we have compared Landsat images in Near Infra-Red band for years 1975 – 2009, combined in a false color image (Red indicates areas of lost land surfaces covered with water, cyan-blue areas of lost free water surfaces due to sediments and vegetation (reeds). Northern shores of the lake are clearly characterized by development of vegetation areas covering free water surface, and sedimentation is visible in southeastern corner of the lake where the Buna River source is situated (Fig. 12). At the same time abrasion of sandy shores at Buna River delta are visible, and deposition of sands at Velipoja beach (Frasheri *et al.*, 2010a, Frasheri *et al.*, 2014).

Fig.12. Shoreline changes during 1975-2009, aerial view of Buna source and Buna delta.

4. CONCLUSIONS

Remote sensing based on satellite imagery offers a clear view of the status of Lake waters, including distribution of suspended mater of different kind and phytoplankton, chlorophyll distribution and concentration, water circulation patterns, wind activity, etc.

Comparing spectral particularities from Landast images with few field data, the conclusion is that Shkodra Lake waters have high content of different pollution mass, mostly sediments and vegetation residuals, and less algae and other living vegetation mass, which is indicated by low levels of infrared radiation. Less polluted result Adriatic seashore, except the Buna delta, where polluted mass was observed too.

An interesting feature of the water's dynamics in Shkodra Lake is their rotational circulation, which might be due to wind activity, rivers flow, karst springs and additional minor environmental factors.

Comparison of infrared images for a long time period of 30 years indicates changes in shoreline of Shkodra Lake and Buna River delta. In the northern shores of the Lake there is a continuous development of emergent vegetation (reeds, bulrushes, cattails etc.) and reduced free water surface due to sediments from rivers and erosion of agriculture lands and shores around it. At the same time development of sediments and loss of free water surface is observed at beginning of Buna River, near Shkodra City, which shows temporary water leakage with sediments (flows), at the time of floods, from Drini River to the lake (i.e. inversion of water flow).

MODIS-Aqua data also suggest higher non-algal material as well as chlorophyll concentrations over the north shore of the lake. Meanwhile, MODIS data show more distributed the phytoplankton data, with lower values over the north of the lake. Their correlations range from low positive in the inner part of the lake to negative around most of its shores.

Although some interesting results have been obtained from this work, it is imperative that more detailed field observations data are needed in the future to identify all water quality components/ingredients. In-situ measurements must be carried out in more sites distributed over the lake shore but also inside the area of the lake. These data combined by the remote sensing observations give the possibility to extrapolated results with minor error over the entire area.

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