pp. 21-28

3. Use of Sentinel - 2 images and aquatic vegetation relevee for classification of lakes' ecological state

HANGANU Jenică*, COVALIOV Silviu, DOROFTEI Mihai, MIERLĂ Marian

Danube Delta National Institute for Research and Development: Babadag Street No.165, Tulcea – 820112, e-mail: office@ddni.ro

**Address of author responsible for correspondence: HANGANU Jenica, Danube Delta National Institute for Research and Development: Babadag Street No. 165, 820112 Tulcea, Romania; e-mail: jenica.hanganu@ddni.ro*

ABSTRACT: At present, the characterization and monitoring of water bodies' ecological state is achieved with important financial resources supported by the EU member countries. Since human and financial resources are limited, the development of new mapping tools such as remote sensing ones may be a practical alternative for water bodies' assessment and monitoring, especially within Danube Delta, which has over 300 lakes, many of whom are difficult to access. The paper present the first results on developing a methodology to monitor Danube Delta lakes' trophic state by means of satellite image processing and field data on water depth, transparency and vegetation cover of floating and submerge aquatic vegetation (e. g. *Nymphaea sp., Nuphar luteum, Trapa natans, Stratiodes aloides, Ceratophyllum demersum, Potamogeton sp., Chara sp.*) It starts with the completion of the field database necessary to elaborate the methodology and then we have test a series of specific thematic algorithms for discrimination of aquatic vegetation types based on Sentinel 2 images. The next step will be integration of hydro morphological, chemical and biological data to run supervised classification of the satellite images in order to discriminate trophic status of different lakes.

Keywords: Remote sensing, aquatic vegetation relevee, lakes, ecological monitoring

INTRODUCTION

The Framework Directive with regard to water has stipulated a series of biological indices in order to characterize the water bodies' ecological state, including abundance and composition of aquatic macrophytes. The target objective of this work is to develop a remote sensing method for efficiently monitoring the water bodies' ecological state, complementary to the routine monitoring. As far as the use of remote sensing techniques for the description of The Danube Delta lakes' trophic status is concerned, we mention that a supervised classification for all the lakes has been carried out on the basis of Landsat TM images since 1998 (Ramsey, 1998) with good results for discriminating the transparency gradient, the types of both floating and submerse aquatic vegetation and the lakes Danube too, the information resulted from several temporal radar and optical images have been integrated during 2006 and 2010 and this produced satisfying results (Güttler *et al.*, 2013; Niculescu *et al.*, 2014) . The feasibility of characterizing the lakes' trophic state through remote sensing means has been recently assessed (Birk & Ecke, 2014). Remote sensing allows acquiring synoptic data which evenly covers large areas in time and space, repeatedly and non-intrusively, which makes its use in environment to be advantageous (Anker *et al.*, 2013). Nevertheless, the resolution of the generated images (in general of 0,5 m) allows identifying and mapping vegetation only at the growing shapes' level, such as emergent and floating ones. (Valta-Hulkkonen *et al.*, 2003; Bradley & Fleishman, 2008), except for the case where the water bodies are dominated by a single species (Gross *et al.*, 1987). Recently, Spanhove and colab. 2012 have concluded that 'it is less probable that individual plants should be recognized from space in the next future'. The evolution of aircrafts without pilots known as 'drones' generates images with a spatial resolution of about 5 cm and offers new opportunities to map and monitor macrophytes at the species level, namely the necessary scale to assess the ecological state (Husson *et al.*, 2013). It is possible that in the future, the spatial and spectral resolution of commercial remote sensing devices will allow species determination as well.

MATERIALS AND METHODS

Discrimination of aquatic vegetation types is based on Sentinel 2 images. Sentinel-2A is the second satellite of the European programme Copernicus, after the radar satellite Sentinel-1A launched in 2014. In partnership with The European Commission, within The Global monitoring of Environment and Security system (GMES), The European Spatial Agency (ESA) launches the mission Sentinel-2 which produces optical images dedicated to the territory and coastal areas' operational monitoring (Miettinen *et al.*, 2015).

The satellites will ensure a systematic coverage of the terrain with a 10-day repetition by a single satellite and a 5-day repetition by two satellites. The resulted images are high optical resolution, have 290 km visual bandwidth and a 10m, 20m or 60m resolution, depending on the spectral bands and ensure compatibility with the current missions SPOT and Landsat. Sentinel-2 is the first mission for the optical observation of the earth which includes four bands in 'red marginal vegetation', providing essential information with concern to the vegetation state. Sentinel-2 has 13 spectral bands out of which 3 are in close infra-red (SWIR).

The 13 bands cover a larger spectre from visible and close infra-red to short infra-red waves: classic blue (490nm), green (560nm), red (665nm) and close infra-red (842nm), bands dedicated to discriminating terrain coverage; 6 bands with 20m resolution: 4 narrow bands in the spectral domain of 'red marginal vegetation' (705nm, 740nm, 775nm and 865nm) and 2 SWIR wide bands (1610nm and 2190nm) dedicated to discriminating snow / ice / detection of clouds and vegetation affected by swamping; 3 bands with 60m resolution dedicated to atmospherically correction (443nm for aerosols and 940 for water vapours) and for detecting Cirrus clouds.

The Sentinel-2 Level-1C (L1C) MSI images have been downloaded from the platform "Sentinels Scientific Data Hub" (https://scihub.copernicus.eu/).
The satellite images processing has been done with the programme „Sentinel-2 Toolbox (S2TBX) version 2.0.4 on the platform SNAP (Sentinel Application Platform) version 2.0.2 on Windows 7 (64 bits). The programme "Sentinel-2 Toolbox" has been developed for ESA by CS (Communication & Systèmes), in partnership with Brockmann Consult, CS-România, Telespazio Vega Deutschland, INRA and UCL. The programme „Sentinel-2 Toolbox" consists of large set of visualisation models, analysis and processing of high-resolution optical images including the ones acquired by Sentinel-2 MSI sensors. Sentinel-2 images have already been ortho-rectified within the UTM 35N mapping system by ESA (level 1C).

The collection of vegetation samples - Ground Control Points (GCP) was carried out in June, July and September 2016. Each vegetation sample had a surface of approximately 25 m^2. The aquatic submerse plants were collected from the boat with a rake. The number of samples for each lake was established according to lake's size and the variation of aquatic vegetation coverage. The place for the samples was chosen as having been representative for the coverage and the type of the lake's aquatic vegetation. For example, if 6% of the lake is *Nitellopsis obtusa*, 30% *Ceratophyllum demersum* and 10% *Elodea canadensis*, then 6 vegetation samples are selected from the area with *Nitellopsis obtusa*, 3 from the area with *Ceratophyllum demersum* and 1 from the area with *Elodea canadensis*. For each sample, the geographic coordinates were recorded by means of a portable GPS, the water transparency and depth were set with the Secchi disk.

The abundance/dominance of each species was estimated visually by using the 7-level Kohler scale. The abundance/dominance is a mandatory characterization index for macrophyte communities, by being associated to each species identified within a vegetal association on the occasion of carrying out the macrophytes sample. It estimates the coverage ratio with aerial projections of the component species on the sample surface, considering them together (general coverage) and separately (specific coverage) as well.

For the ratio estimation of each species during the vegetation survey, it was firstly recorded the degree of macrophytes total coverage, then it was specified the percentage by which it participates to the making up of the vegetal group for each species in the floristic inventory. The percentage was rendered through abundance/dominance (AD), representing both the individuals number and the surface they cover.

In order to check the estimation precision, the abundance/dominance average values are added up for each species and it should correspond to the total coverage. In some cases, it may exceed the 100% value providing that the vertical projections of individuals intergrow.
In the same way, the degree of infestation with macrophytes was recorded - % PVI (percent of plant volume infested). This is a quality index related to the macrophytes presence within the water bodies. PVI is calculated as a multiplication between the value of the coverage surface and the value of the aquatic plant height out of the water mass, divided to the value of the water depth (Canfield et al., 1984). The additional physic and chemical data: pH, temperature, chlorophyll “a”, nutrients’ content etc., were measured in the same period of time, and all the available data were included in the analysis and calibration of the spatial data with the field ones.

RESULTS AND DISCUSSIONS

Distribution of vegetation samples - Ground Control Points (GCP) carried out in 2016 over the images (Fig. 1) was imported in ‘shape’ format. This allows spatial localisation of samples on the images and the identification of aquatic vegetation type present in that location from the database. By extrapolation, there can be determined the surfaces covered with various types of vegetation, estimated the water transparency classes, areas with active sedimentation etc.

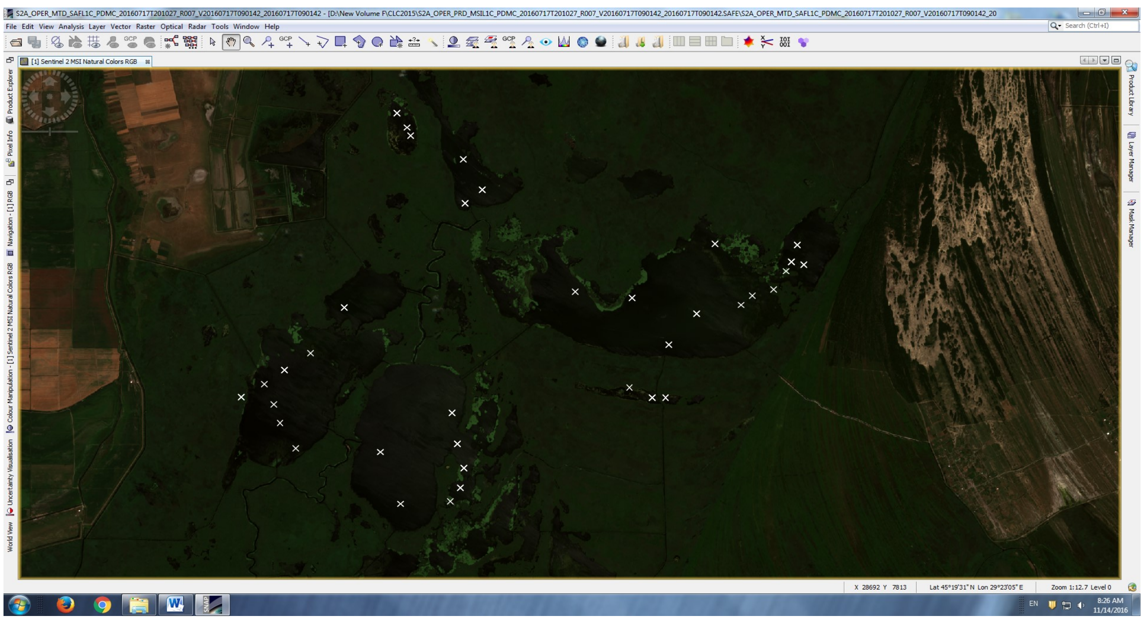

Figure 1 Distribution of vegetation samples (GCP) within the area of Matiţa – Merhei

For discrimination of the aquatic vegetation types, a series of specific thematic algorithms have been processed by means of Sentinel-2 Toolbox programme. The analyses results for each index considered useful for the discrimination of aquatic vegetation is rendered below.

a) The vegetation index

The algorithm ‘The Vegetation Index Ratio’ (RVI) indicates the vegetation quantity. It also reduces atmosphere and topography effects. The processing result is visualised in figure 2 where a good discrimination of both floating vegetation (*Nymphaea sp., Nuphar luteum, Trapa natans* and *Stratiodes aloides*) and areas with active sedimentation may be seen.

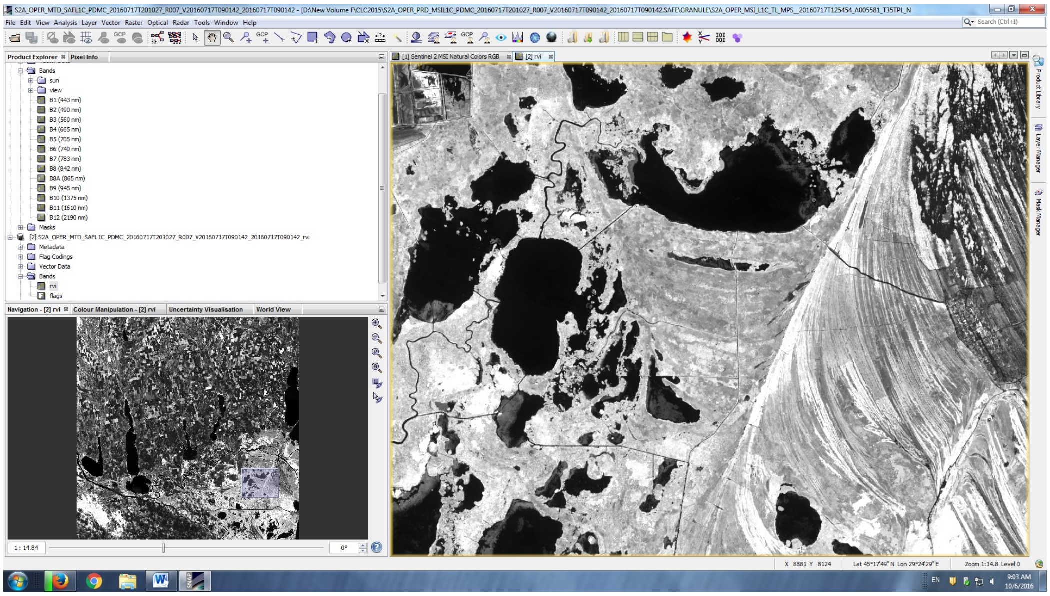

Figure 2 Results of image processing for The Vegetation Index

b) The algorithm 'Pigment Specific Simple Ratio' or the chlorophyll index was developed by Blackburn (1998). The algorithm PSSR has the strongest and most linear correlation among chlorophyll 'a', 'b', carotenoid pigments and plant concentration on the surface unit (Fig. 3). For Sentinel-2, the formula is:
B7 / B4: B7 = 783 nm (15 nm) and B4 = 665 nm (30 nm)

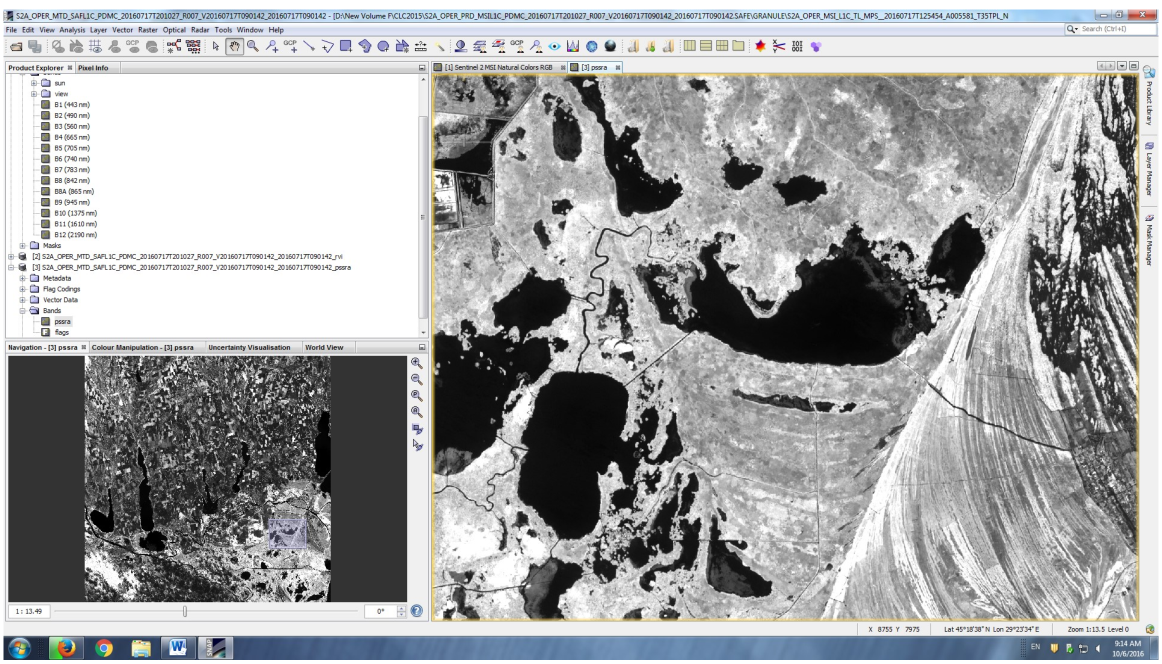

Figure 3 Results of image processing for The Chlorophyll Index

c) The Water Index and the normalized vegetation differentiation index (NDVI)
The algorithm Normalized Difference Water Index' (NDWI) was developed by Gao (1964) and determines the molecules of liquid water in vegetation which interacted with the received solar radiation. NDWI is sensitive to the changes of water content in vegetation. It is less sensitive to the atmospheric effects than NDVI (The Normalized Differentiation Vegetation Index). NDWI does not completely eliminates the reflectivity effects of the ground soil, therefore it should be considered an independent vegetation index. It is complementary and not a substitute for NDVI. The result of processing these algorithms (NDWI, NDVI) is rendered in figure 4, respectively 5 on the processed images, there can be seen the areas with a larger aquatic vegetation coverage.

d) The second algorithm 'Normalized Difference Water Index '(NDWI2) was developed by McFeeters (1996) with the purpose to detect surface waters within wet environments and to allow measuring the width of the water surfaces (Fig. 6).

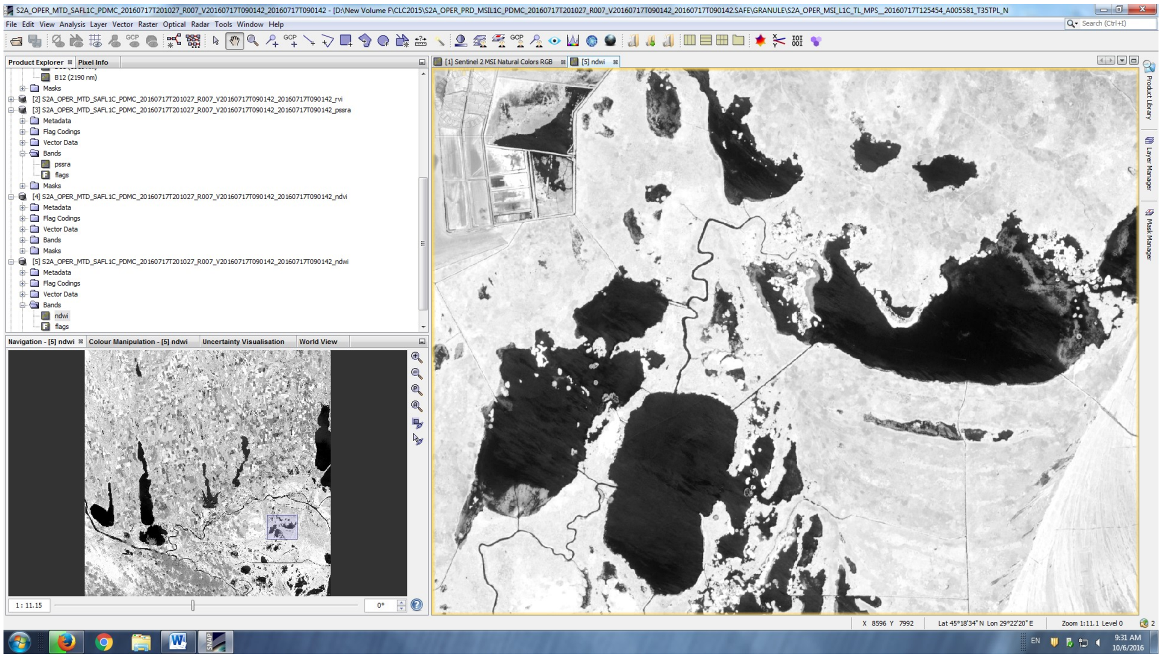

Figure 4 Results of image processing for The Normalized Difference Vegetation Index (NDVI)

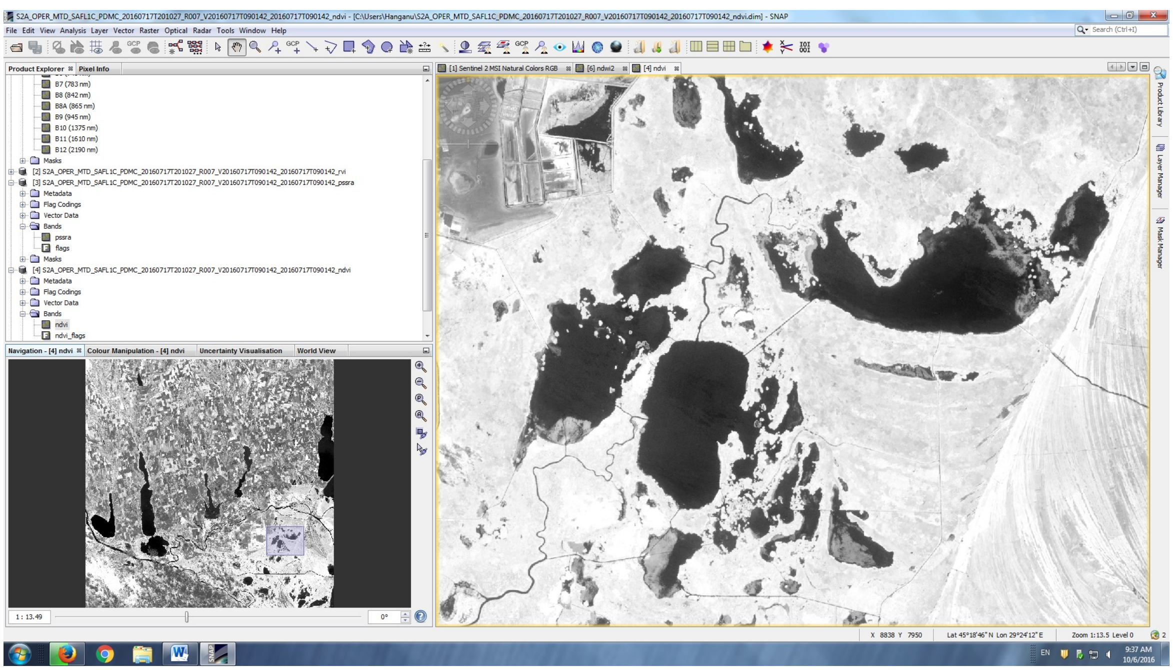

Figure 5 Results of image processing for The Water Index (NDWI)

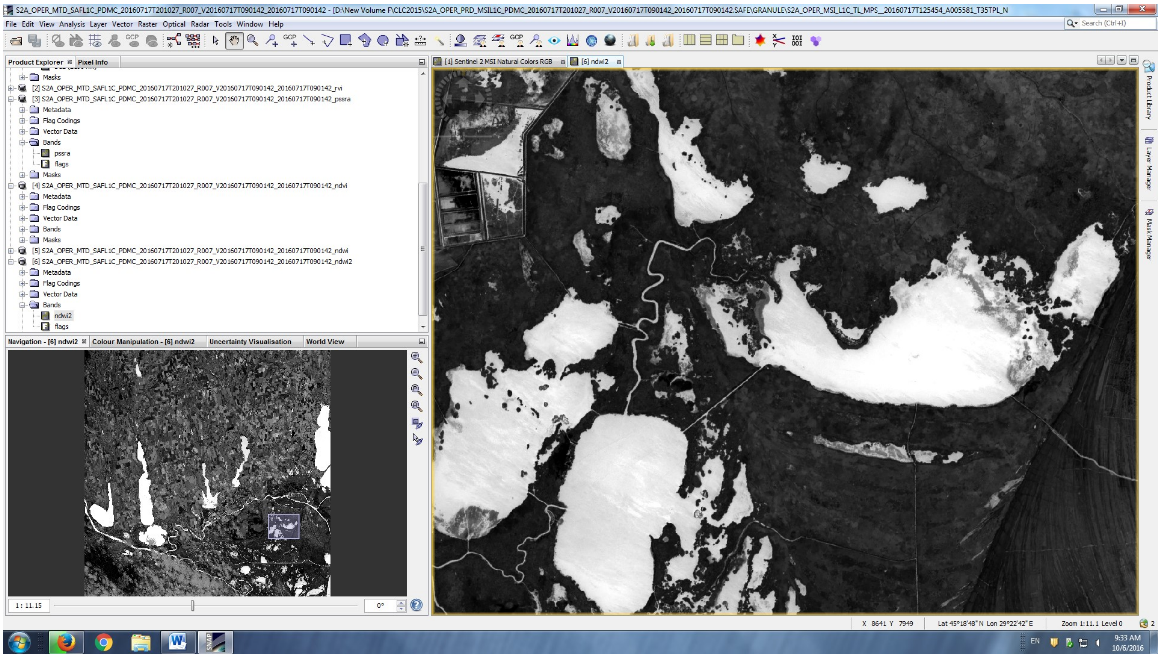

Figure 6 Results of image processing for the second algorithm ‘Normalized Difference Water Index’ (NDWI)

CONCLUSIONS

Within this study we have test a series of specific thematic algorithms for discrimination of aquatic vegetation types based on Sentinel 2 images. During this stage, the database has been completed with vegetation samples covering 44 lakes of the Danube delta and transformed in shape format to be imported for further supervised classification of satellite images. For the discrimination of aquatic vegetation types, a series of specific thematic algorithms were processed by means of Sentinel-2 Toolbox programme. The Vegetation Index carried out a good discrimination of both floating vegetation (*Trapa natans*) and areas with active sedimentation. By processing the algorithm ‘Pigment Specific Simple Ratio’ or The Chlorophyll Index, information regarding plant concentration on the surface unit has been gathered. The algorithm ‘Normalized Difference Water Index’ (NDWI) has proved to be very useful in getting a gradient of coverage with aquatic vegetation on each lake. In a next stage of the work we will run supervised classification of the satellite images aiming to contribute to the optimization of a lake quality’s monitoring.

ACKNOWLEDGMENTS

This work was written with support of the Nucleus Programme PN 47N/2016 funded under the Ministry of Education was made during research project PN 16 28 01 02 „Support studies for methodology assessment of lakes ecological features by macrophyte species”

Această lucrare a fost elaborată în cadrul temei de cercetare: “Studii suport pentru elaborarea metodologiei de caracterizare a stării ecologice a lacurilor pe baza speciilor de macrofite acvatice”, finanțate de Ministerul Educației prin Programul Nucleu. Contract nr. 47N/ANCS/2016.

REFERENCES

Anker Y., Hershkovitz Y., Ben Dor E., & Gasith A., 2013. Application of aerial digital photography for macrophyte cover and composition survey in small rural streams. River Res. Appl. pp. 925-937.

Birk S., & Ecke F., 2014. The potential of remote sensing in ecological status assessment of coloured lakes using aquatic plants. Ecological Indicators 46, pp. 398-406.

Bradley B. A., & Fleishman E., 2008. Can remote sensing of land cover improve species distribution modelling? Journal of Biogeography, 35: pp. 1158–1159.

Canfield D.E., Shireman J.V., Haller W.T., Watkins G.E. & Maceina M.J., 1984. Prediction of chlorophyll a concentration in Florida lakes: importance of aquatic macrophytes. Can. J. Fish. AquaL ScL, 41, pp.497-501.

Gross M.F., Hardisky M.A., Klemas V., & Wolf P.L., 1987. Quantification of biomass of the marsh grass *Spartina alterniflora* Loisel using land-sat thematic mapper imagery. Photogramm. Eng. Rem. S. 53, pp. 1577–1583.

Güttler F., Niculescu S., & Gohin F., 2013. Turbidity retrieval and monitoring of Danube Delta waters using multi-sensor optical remote sensing data: An integrated view from the delta plain lakes to the western–northwestern Black Sea coastal zone, Remote Sensing of Environment, 132, pp. 86–101.

Miettinen J., Stibig H.-J., Achard F., Hagolle O. & Huc M., 2015. First Assessment on the Potential of Sentinel-2 Data for Land Area Monitoring in Southeast Asian Conditions, Asian Journal of Geoinformatics, Vol.15, No.1, pp. 23-30.

Husson E., Hagner O., & Ecke F., 2013. Unmanned aircraft systems help to map aquatic vegetation. Appl. Veg. Sci. pp. 567–577.

Niculescu S., Lardeux C., Grigoras I., Hanganu J., & David L., 2014. Synergy between LIDAR and RADARSAT-2 images for the recognition of vegetation structures in the coastal wetlands of the Danube Delta. Geophysical Research Abstracts Vol. 16, EGU2014-5160-1, 2014 EGU General Assembly.

Ramsey E., 1998. Radar remote sensing of wetlands. Remote Sensing Change Detection: Environmental Monitoring Methods and Applications, R. Lunetta, and C. Elvidge (Eds). Chapter 13, pp. 211–243.

Spanhove T., Vanden Borre J., Delalieux S., Haest B., & Paelinckx D., 2012. Can remote sensing estimate fine-scale quality indicators of natural habitats? Ecol. Indic. 18, 403–412.

Valta-Hulkkonen K., Partanen S., & Kanninen A., 2003. Remote sensing as a tool in aquatic macrophyte mapping of a eutrophic lake: a comparison between visual and digital classification. Proceedings of the 9th Scandinavian Research Conference on Geographical Information Science, 4, Espoo, Finland, pp. 79–90.

Received 7 March 2017
Revised 11 April 2017