LAND COVER MONITORING AS PART OF A SURVEY ON WETLAND ECOSYSTEM CONSERVATION IN THE NEGOVAN VILLAGE AREA USING REMOTE SENSING TOOLS

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Abstract: The main purpose of the present survey is to apply remote sensing data to the investigation of different components of a wetland ecosystem, situated in the area of the village of Negovan (Sofia region), such as soil, vegetation and water, and their variation for certain temporal intervals including the vegetation period. This survey represents the process of interim ecological monitoring (IEM) implementation on the studied ecosystem. Data for the current condition of different ecosystem components - soil, vegetation and water components, and their variations within the selected time period of 5 years (2014-2018) have been obtained. Specific relations among wetland actual components conditions such as soil wetness and vegetation vs climate factors within the respective temporal intervals of wetland monitoring process have been established. Aerospace data with different temporal, space and spectral resolution, satellite data from Sentinel 2, MSI and aerophoto with a very high resolution have been used. The results for “Brightness”, “Greenness” and “Wetness” components obtained on the basis of orthogonalization of satellite data from Sentinel 2 have been introduced. The results reflect the value of Soil Adjusted Vegetation Index (SAVI), Modified Soil Adjusted Vegetation Index (MSAVI 2), Normalized Difference Greenness Index (NDGI) and Normalized Difference Water Index (NDWI), which are of great importance for the relationship between soil health indexes and ecosystem sustainability. Thematic maps are generated based on the results obtained by surveying land cover components. Data received for the current condition of Negovan wetland ecosystem and established variations of different parameters, including soil component could be used while assessing wetland ecosystem services.

Key words: wetland, interim ecological monitoring, remote sensing, land cover, SAVI, MSAVI, NDWI, NDGI

INTRODUCTION

The importance of wetlands can be defined as productive and valuable ecosystems with numerous functions that benefit society. Wetlands are transitional lands between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow wa-
ter. Although wetlands are singular elements in the landscape the required attention has not been given to them. In spite of that, the surface area covered by wetlands is relatively limited. They are locally important by hydrological, chemical, biological and ecological properties and their socio-economic value (Montes, Bifani, 1991). Wetlands are often characterized by high rates of primary production (Gross et al., 1990). They often act as a protective buffer against storms by water storage and flood abatement, and against erosion damage, by sediment stabilization. They contribute to water quality improvement by immobilizing various pollutants and nutrients and also play a role in geochemical cycling. On the other hand, there are some human activities and inappropriate land use, which provoke pressures on wetlands. As wetland areas often border with agricultural lands it is of importance to prevent them from chemical pollution or/and waste disposal. Their function as carbon sinks and recreational areas are also often under pressure. However, groundwater overexploitation and climate changes are also expected to provoke changes in abiotic and biotic components, depending on climatic drivers such as temperature, precipitation and water availability. It is of great importance to conduct monitoring to ascertain how past and actual conditions track with state of wetland ecosystem (Schaeffe, 1998). Changes in wetlands can occur very fast and information about their condition of wetlands in different time periods before, during and after changes appearance can be generated by applying interim ecological monitoring through remote sensing. Thus an overall approach must be developed in order to be able to manage wetlands in a long-term conservation way. Interim ecological monitoring based on remote sensing provides data about the degree to which the ecosystem has been improving or degrading over time. The interim ecological monitoring methodology (MIEM) includes remote sensing techniques that could enable the determination of the change in the surveyed area by analyzing different indicators of the ecosystem conditions and functional health its biomass production, water and land surface including soil state (Wray and Bayley, 2006).

In Bulgaria, the National Action Plan for the Conservation of Wetlands of High Significance was prepared according to the terms of Reference approved with letter No 48-00-1503/26.11.2010 of the Minister of Environment and Water and in fulfilment of the national priorities in biodiversity protection. The plan includes 11 wetlands as priority territories that at present are part of the list of the Ramsar Convention. Additionally 25 wetlands that cover one or more of the Ramsar nomination criteria or have big potential for protection and restoration, but are not in the Ramsar Convention list have also been included. In the suggested horizontal measures for protection and wise use of wetlands, it was emphasized that monitoring is required for tracking any status changes and trends resulting from anthropogenic impacts and for the observation of background environmental changes. The main purpose of the current study is to present interim ecological monitoring (IEM) as an approach to assess wetland health, functions and values, using remote sensing techniques. For the observed area “Negovan wetland” we examined the vegetation indices (VIs) like NDGI, NDWI, and that accounting for soil - SAVI, MSAVI and establish their sensitivity to vegetation changes in spatio-temporal scale. Using remote sensing tools the early vegetative stress detection, habitat quality and hydrological regime and soil changes have been tracked.

MATERIAL AND METHODS

Study area

The study area is a wetland situated south of the village of Negovan, and near the southern dyke of the Lesnovska River named in the current study as “Negovan wetland”. The studied area is known as Western Lake (Small lake), which is part of the former Negovan marsh and is spread on 138 dka. The area has a high conservation value for nesting and wintering of birds and especially waterfowl, which follow the migration road Via Aristotelis (Figure 1).

In the period 2013-2015, restoration measures were performed including rehabilitation of riparian wetlands with priority habitats and bird species in former and active quarry ponds along the Les-
novska River, restoration of priority habitat 91E0 - Alluvial forests with Alnus glutinosa and Fraxinus excelsior (Alno-Pandion, Alnion incanae, Salicion albae) and habitat 92A0 - River galleries of Salix alba and Populus alba. Improvement of breeding and migration conditions for priority and other bird species related to riparian wetlands and included in the new Birds Directive 2009/147/EC, re-introduction of conservatively significant aquatic species of animals and rare plants. The restoration activities were funded by the Operational Environment program 2007-2013 under the project “Restoration of priority “wetlands” habitats and species of European importance along the Lesnovska River (in the region of Negovan village)” with Sofia municipality as the beneficiary.

As a result, islands with natural landscapes form close to the natural relief and the existing island outline in the wetland was created. The newly-formed islands have been afforested only with Salix alba type. Micro-lakes between the islands have an area of at least 500 m². The lakes have a maximum depth of 90-130 cm with a relatively flat bottom and slope to the shore from 1:20 to 1:4. The channels connecting the individual micro lakes have a width of at least 8 m. The maximum depth of the canals is 80-90 cm with a relatively flat bottom and slope to the shores 1:4, except for the bypass where the slope to the shores is 1:3. The bypass channel has a linear shape along the western and southwest boundaries of the wetland site with separate widenings (Radeva, 2015).

The soil of the studied wetland area is formed on the alluvial deposits by the water flow of the Lesnovska River. They are formed mainly by gravel, sand and to a lower degree clay. The existing clay layer, covered alluvial materials is defragmented. Because of the physical characteristics of the alluvial depositions, the formed soil has good filtration properties. Soil morphological features described were colour, texture, structure, included materials and horizon boundary.

Two sampling sites (SS) were established. The first one – designed by SS1 was positioned on the edge of the Small lake (naturally formed). The depths of each soil profile were limited by the presence of water table and reached up to 90 cm. The soil is sandy loam to loamy sand in texture for surface and subsurface soil horizon with weak, medium crumb structure. Many fine and medium roots were observed (Figure 10). The fluvic material within soil volume at the mentioned depth is higher than 25%. The surface horizon is blackish-grey coloured and without obvious changes along soil depth. No horizon differentiation. As the soil is well drained, and with a low clay content, the seasonal saturation with water has not provoked the processes of oxidation/reduction of the Fe and Mn ions. The sandy structure of these soils could be attributed to the fluvial characteristics of parent materials. The sediments are represented mainly by the irregular alternation of gravels, sands, clays, loamy sands, rare cobbles, and boulders (Yaneva & Donkova, 2017). The predominant size of the gravels is from fine - to medium with a diverse petrographic composition (granite, pegmatite, sandstone, quartzite, quartzitized sandstone, trachiandezite, rhyolite). The age of sediments is Holocene.

METHODS

For the purpose of the present study methods of satellite data processing that include orthogonalization of satellite images, correlation analysis and multicomponent analysis were used (Nedkov, 2017b). Methods for image orthogonalization are used for calculating different characteristics of soil and vegetation, which eases the analysis of Earth surface changes. Quantitative methods are
required to compare different landscapes, identify significant changes through time, and relate landscape patterns to ecological function. Composite images from Sentinel 2 (MultiSpectral Instrument – MSI L1C) are designed. Composite images for the dates presented in Table 1 are generated. Afterwards, a test area comprising the territory of the surveyed wetland was subset. The composite images are georeferenced in UTM WGS 84 – 35N and orthogonalization is performed (Tasseled Cap Transformation-TCT). Tasseled Cap Transformations (Brightness/ Greenness/ Wetness) performed significantly better than the original Sentinel 2 data. This suggests that the Tasseled Cap Transformations successfully preserve and highlight information relevant to vegetation, water surface, soil while simultaneously reducing the “noise” information that reduce the object recognition degree. The Wetness component was applied and the change dynamics of water surface wetland was tracked. Greenness component of TCT has been applied for tracking the vegetation changes related to vegetation overgrowing and decrease in water surface of the Negovan wetland. Brightness component reflects the condition of soil surface (without vegetation), wet/ dry soil (Nedkov, 2017a) or bare areas in different temporal intervals. TCT images are decomposed in separate layers Brightness, Greenness and Wetness for each date from the temporal interval of IEM. After obtaining the components in the GIS environment, a classification of Wetness, Greenness and Brightness layers has been performed. The result from the classification for Wetness component is defining the area of the water surface of the wetland for each temporal interval of IEM. Similarly, the result from the Greenness component classification is defining the spatial distribution of vegetation for each temporal interval of IEM. The classified Wetness layers for different dates are overlapped in GIS on the aerophoto image with a very high spatial resolution (0.05m). The latter image is provided immediately after restoration activities that have been completed in 2015. The same procedure was applied for the classified Greenness layers for the same temporal intervals of IEM as for the Wetness layers. The degree of water surfaces variations of the wetland during different temporal intervals was quantitatively assessed while the tendency for its variations was determined. The quantitative assessment was completed based on the values of the classified Wetness component for the respective temporal intervals of the IEM. The function of quantitative assessment refers to all Wetness positive values that exceed a certain threshold. The variation degree of vegetation distribution on the wetland was quantitatively assessed for different temporal intervals, as the variation tendency was determined. The function of quantitative assessment refers to all Greenness positive values that exceed a certain threshold (Radeva et al, 2018b). The Brightness component associates with the soil reflectance and is related to the Greenness component (vegetation presence or absence) (Wang et al., 2004; Patel et al., 2008) and the Wetness component (defining the soil moisture) (Mallick et al., 2009).

For the present study, very high resolution data (aerophoto images) and multispectral satellite data from sensor Sentinel 2 before and after the application of restoration activities on Negovan wetland territory were used. Terrestrial data from precedent temporal intervals were used for the verification of the obtained results from IEM application. Cloud free and high quality imagery was acquired mainly from August to September for the 5-year period when vegetation was at its most flourishing period. The study territory was filming with an unmanned aircraft, using a 4-channel RGB + NIR camera in autumn period 2018. The spatial resolution of the resulting image is 0.05 m. A high accuracy of the scale with a pitch of 0.05 m was generated using cloud technology and a file in format 20180921_densified_point_cloud.las was obtained. A model of elevation / relief, i.e. the water level where in the newly formed part of the wetland is determined from the cloud.

The data used for IEM on the studied ecosystem are presented in Table 1. Aerophoto images obtained in June 2015 and September 2018 are with a very high resolution (0.05 m) and serve as a measure of biophysical properties of surface environments (e.g., vegetation, water and soil) of relevance to conservation, changes in the state of land cover or habitat quantity/quality and generate categorical products (2D/3D thematic maps and spatial distributions).
Table 1. Satellite and air photo data for interim ecological monitoring

| №  | Sensor   | Temporal interval                                      |
|----|----------|--------------------------------------------------------|
| 1  | Sentinel 2 | 29/09/2014, 18/10/2014, 06/11/2014, 17/04/2015, 23/09/2016, 09/04/2017, 09/04/2017, 06/11/2017, 10/06/2017, 11/08/2017, 24/04/2018, 09/05/2018, 08/06/2018 |
| 2  | Aerophoto | June 2015, September 2018                               |

For the purpose of land cover monitoring on the Negovan wetland, two approaches were applied: interim ecological monitoring methodology (MIEM) and the field survey approach, that includes soil sampling and soil morphological description. The second approach serves as a verification of indicators used in MIEM to assess the condition of the wetland.

**Interim ecological monitoring methodology (MIEM)**

MIEM includes an investigation of a full set of monitored “response”, exposure, habitat and stressor indicators. A healthy ecosystem may be defined only by reference to a few parameters, and the absence of disease is based on a comparison with one or more poorly quantified “ideal” ecosystems. In the process of ecosystem monitoring three groups of parameters were surveyed. The first group of parameters refers to productivity and includes floral and faunal components, designated with 1. The second one refers to biodiversity (floral and faunal species existing in a certain type of the ecosystem, in terms of community composition and structure, as well as the functional niches that are represented – group 2); and the third one refers to sustainability, defined as the robustness of the wetland (group 3), i.e., its resistance to changes in structure and function and persistence over long periods of time, as measured by both wetland’s size and water balance. The suggested methodology can be expressed with the following equations (Radeva, 2018):

\[
\Delta A_{t,j,t_m}^i = A_{t,j}^i (p_1^1, p_2^1, ..., p_k^1) - A_{t,m}^i (p_1^1, p_2^1, ..., p_k^1)
\]

where:

- \( \Delta A_{t,j,t_m}^i \) – Assessment for temporal intervals before and after the application of interim ecological monitoring for a certain ecosystem type (i)
- \( A_{t,j}^i \) – Assessment for temporal interval before the application of interim ecological monitoring for a certain ecosystem type (i)
- \( A_{t,m}^i \) – Assessment for temporal interval at the time of interim ecological monitoring application for a certain ecosystem type (i)

\[
P_i^1, P_i^2, ..., P_i^k \quad (\text{indices group parameters 1), 2), 3})
\]

The methodology provides information on physical alterations to the wetlands (flooding, human activities, etc.), soil moisture, and the wetland hydrological regime. In this study, we analyze vegetation indices for quantifying biomass or vegetative vigor derived from spectral bands, like NDGI; soil-line related indices, which include soil-line parameters, such as the soil-adjusted vegetation index or SAVI (Hu et al., 1989) and the modified MSAVI (Qi et al., 1994) and NDWI (Gao, 1996).

The normalized difference vegetation index (NDVI) is the most commonly used vegetation index. It is a measure of the slopes of the vegetated isolines. NDVI is based on the concept that all isolines converge at the origin. To minimize the discrepancies that come from the fact that the isolines are neither converging at the origin nor parallel to the soil line (Hu et al., 1989) modified NDVI by shifting the converging origin along the soil line and obtained a soil adjusted vegetation index (SAVI)

\[
\text{SAVI} = \left( \frac{\rho_{\text{NIR}} - \rho_{\text{RED}}}{\rho_{\text{NIR}} + \rho_{\text{RED}} + L} \right) (1 + L)
\]

where L was fixed at 0.5 as an optimal value.

Qi et al (1994) modified the SAVI by modelling the soil adjustment factor L for each isoline as a
function of reflectance in red and NIR regions and obtained a modified SAVI (MSAVI)

\[
MSAVI = \{(2\rho_{\text{NIR}} + 1)^2 - \sqrt{(2\rho_{\text{NIR}} + 1)^2 - 8 (2\rho_{\text{NIR}} - \rho_{\text{Red}})}\}/2
\]

The spectral reflectance of a plant canopy is a combination of the reflectance spectra of plant and soil components. A linear relationship between the red and near infrared reflectance on bare soil (the soil line) can be developed from base soil areas at a site and incorporated into vegetation indices to reduce the influence of the soil on the vegetation response (Rondeaux et al., 1996). Although, soil type is the main factor of variation of the soil line, in the study area, the dominated Soil Group, according to the World Reference Base for Soil Resources (IUSS Working Group WRB, 2015) is Fluvisols and hence – no different soil lines could be defined.

NDGI has a high sensitivity for both abrupt and minimal changes to the vegetation status, regardless of the sensor used to obtain the source satellite images. Thus, NDGI reflects the vegetation’s dynamics of change depending on temporal periods. NDGI can have values ranging from +1 to −1. Using NDGI, an appraisal can be made of the negative and positive changes of the vegetation. The following equation is applied

\[
\text{NDGI} = \frac{\text{GR}_n(t_2) - \text{GR}_n(t_1)}{|\text{GR}_n(t_2)|} + |\text{GR}_n(t_1)|
\]

where GRn(t1) and GRn(t2) represent the normalized values of the Greenness components at time points t1 and t2, respectively, and |GRn(t2)| and |GRn(t1)| represent the absolute values of the same components.

The values of GRn(t1) and GRn(t2) are obtained based on the following equation:

\[
\text{GR}_n(t) = \text{GR}(t) - \text{E} \{\text{GR}(t)\}/\text{SD}[\text{GR}(t)]
\]

where \(\text{E}[\text{GR}(t)]\) is the mean of \(\text{GR}(t)\). In this case, for the normalized values one can obtain \(\text{E}[\text{GR}(t)] = 0\) and \(\text{SD}[\text{GR}(t)] = 1\), which means that the values of GRn(t) are absolutely comparable (standardized), regardless of the sensor and time of satellite image capturing (Nedkov, 2017a).

The Normalized Difference Water Index (NDWI) was first proposed by McFeeters in 1996 to detect surface waters in wetland environments and to allow for the measurement of surface water extent and it produces a single grayscale image, where water is bright. Although the index was created for use with different images data, it has been successfully used with other sensor systems in applications where the measurement of the extent of open water is needed (Radeva et al., 2018a, Radeva 2018, Turner, 1989, Schaeffe et al., 1988).

The NDWI is calculated using the following equation:

\[
\text{NDWI} = \frac{(\text{Band}_2 - \text{Band}_4)}{(\text{Band}_2 + \text{Band}_4 )}
\]

where, Band 2 is the TOA green light reflectance and Band 4 is the TOA near-infrared (NIR) reflectance.

Based on the data acquired and processed by means of remote sensing and for the purpose of the present study equitation (1) and (2) can be applied for wetland investigated in this paper as follows:

\[
\Delta A_{2015,2018}^{NW} = A_{2015}^{NW}, SAVI_{2015}^{NW}, MSAVI_{2015}^{NW},
\]

\[
\Delta D_{2015,2018}^{NW}, NDG_{2015}^{NW}, NDWI_{2018}^{NW} - A_{2018}^{NW}, SAVI_{2018}^{NW},
\]

\[
\text{MSAVI}_{2018}^{NW}, \text{NDG}_{2018}^{NW}, \text{NDWI}_{2018}^{NW}
\]

\[
\Delta A_{2015,2018}^{NW} = \begin{cases} < 0, \text{ where } j \in 1, n; m \in j, 1 \leq m \leq n \\ > 0 \end{cases}
\]

where,

\(\Delta A_{2015,2018}^{NW}\) – Assessment for temporal intervals before(2015) and after(2018) the application of interim ecological monitoring for wetland ecosystem in Negovan (NW)

\(\Delta A_{2015}^{NW}\) – Assessment for temporal interval before (2015) the application of interim ecological monitoring for a wetland ecosystem in Negovan (NW)

\(\Delta A_{2018}^{NW}\) – Assessment for temporal interval at the time of interim ecological monitoring application for a certain ecosystem type (i)

SAVI - Soil Adjusted Vegetation Index (index group parameters)

MSAVI - Modified Soil Adjusted Vegetation Index (index group parameters)

NDGI - Normalized Difference Greenness Index (index group parameters)

NDWI - Normalized Difference Water Index group parameters
Using quotation (3) the results on the sensitivity of the index parameters used in quotation (1) are presented in the “Results and discussions” section.

Field survey approach

The field approach includes determination of plots’ sizes, i.e. the identification of: the landscape and environmental variables, natural and human induced disturbances, changes in hydrological integrity, dominant plants, physico-chemical parameters of the territory. The assessment of the vegetation state and variability and soil sampling was performed. Field observation was done according to the Handbook for monitoring of the wetland condition (Clarkson et al., 2004). Sampling and description of soil followed the Soil survey manual (1993). Soil morphological features described were color, texture, structure, included materials and horizon boundary according to Soil Survey Staff (2014).

RESULTS AND DISCUSSION

In Figure 2 images from Google Earth with different dates and for a four-year period, as well as composite satellite images for 2014, 2015, 2016, 2017, 2018 (Ch 432, 482, 1384) from Multispectral

**Figure 2.** The Negovan wetland (Sofia region, Bulgaria) from Google Earth for different temporal dates and Sentinel 2 (a, b, c, d, e, f)

**Figure 3.** The Negovan wetland (Sofia region, Bulgaria), a. Aerophoto image after restoration activities in 2015, b. Aerophoto image from September 2018
Instrument (MSI) from Sentinel 2 for the Wetland in the area of quarry lakes in the village of Negovan were presented.

For the estimation of the vegetation changes, soil background variations and atmospheric conditions, the Vegetation Indices (VIs) were considered. Quantitative assessment is made with the help of NDWI, NDGI, Soil Adjusted Vegetation Index (SAVI), Modified Soil Adjusted Vegetation Index (MSAVI 2), which are part of VIs index family.

**NDWI assessment**

The introduction of Normalized Difference Water Index (NDWI) is of importance for our study as it estimates the extent of open water territory (EEA, 2005). NDWI values above zero are assumed to represent water surfaces, while values lower than or equal to zero are assumed to be non-water surfaces. The NDWI was calculated for two points in time – 09.04.2017 and for 23.07.2017. The established values show a lower variation of the index around zero for the first data – earlier spring (09.04.2017) and higher variation at the second time point - 23.07.2017. The main reason for the observed changes is the vegetation appearance in the summer period, represented by the greenness component of the TCT (Figure 5). The 3D- distribution of Wetness/Greenness shows a considerable increase in the Greenness component.

**NDGI assessment**

The results of the analysis show that the use of NDGI enables a more precise appraisal of momentary vegetation state changes, which is also standardized and much more sensitive both towards maximal and minimal deviations. In case NDGI is < 0 a negative process of vegetation change occurs, and in the opposite case – if NDGI is > 0, a positive change is registered. The degrees of changes are shown by a particular index value. The total degradation of vegetation is registered when NDGI = −1, it reflects, whereas NDGI = +1 indicates the appearance of vegetation (Nedkov, 2017a). The analysis of the NDGI is represented in Figure 4 a. and b. shows that the red colour in the water polygons represents a lack of water in the territory of wetlands.

**SAVI assessment**

The results show that SAVI values seem to be less affected by soil brightness variations, and thus VIs values obtained for a given canopy cover are similar, regardless of the soil background.

**MSAVI assessment**

The difference in the results obtained for SAVI and MSAVI is insignificant. As for the calculation of the MSVI the constant soil adjustment factor L was replaced with a self-adjusting L. It is more sensitive than SAVI to the degree of impact of the soil moisture reduction process in the wetland ecosystem. MSAVI quantifies a significant decrease in humidity, which is related to water level reduction within the wetland territory. This process is mainly due to the uptake of water by vegetation.

The high reflectance associates with a brightness component of the TCT, observed in the current study, for September 20018 (5 years after...
Figure 5. Thematic maps for a. MSAVI, b. SAVI and values of the Negovan wetland territory.

Figure 6. a. Aerophoto Image in 2014 year merged with TCT from Sentinel 2 image for 09/04/2018, b. 3D-distribution of W/Gr 09/04/2017, c. Aerophoto Image in 2014 year merged with TCT 24/04/2018, d. 3D-distribution of W/Gr 24/04/2018, e. Aerophoto Image in 2014 year merged with TCT 09/05/2018, f. 3D-distribution of W/Gr 09/05/2018, g. Aerophoto image in 2014 year merged with TCT 08/06/2018, h. 3D-distribution of W/Gr 08/06/2018.
restoration activities), indicates a dry soil surface (Figure 5 and 8). Additionally, data in Figure 5 show the prevailing part of the area with vegetation (Greenness component) over the wetness component (water). These results clearly indicate a considerable decrease of the water surface area of the wetland territory. The values, obtained for soil adjusted vegetation index (SAVI) and modified soil adjusted vegetation index (MSAVI) are both high and confirmed the deterioration of the hydrological state of the studied wetland. The considerable decrease of the water territory for last five years will provoke future ecosystem changes of the wetland territory.

Vegetation sensitivity proves that VIs can enhance the vegetation signals not found in individual spectral bands. The results show that the quantified indices are sensitive to water surface and vegetation distribution change. It is important to notice that the NDGI index is sensitive to the change from vegetation to soil and vice versa (Table 2).

In Figures 5, 7, 8 and 9 the results show the relations between water surface, vegetation dynamics and soil by temporal - spatial distribution of Brightness, Greenness and Wetness components for the studied area.

On TCT images shown in Figure 6, the Brightness, Greenness and Wetness components are shown in red, green, and blue, respectively. The different pseudocolours reflect the current condition of the vegetation and soil. Transitioning from yellow to green indicates a differing density and degree of plant vegetation state. Transitioning from yellow to blue-green indicates different density, stage of development, and moisture content in the vegetation Red and Dark Red correspond to dry soils and very dry soils, respectively. A transition from red to blue and from red to dark purple indicates wet soil and hence related to the soil moisture content.

In case of favorable environmental conditions for the studied wetland, the ratio between the Brightness / Greenness / Wetness components is as follows: The Brightness component values are negative and graphically located under the Wetness component. The values of the Greenness component and Wetness component are clearly distinguishable.

Rivers and water bodies are shown in blue. Analysis of the presented scatterplot diagrams shows a high degree of differentiation, of Brightness, Greenness, Wetness components in the space of object identifiers. This ensures precise and reliable recognition and separation of different components of the land cover. The analysis of the obtained results indicates that applying TCT for Sentinel-2 images allows for a more precise classification and tracking of changes of the current condition of the soil and vegetation components of the land cover. On the one hand, this is ensured by the better spatial resolution, and on the other - by the better spectral resolution in the near infrared part of electromagnetic spectra (band 5, band 6, band 7, band 8, band 8a, band 9) on the sensor MSI of satellite Sentinel-2. (Nedkov, 2017b).

In case of favorable environmental conditions for the studied wetland, the ratio between the Brightness / Greenness / Wetness components is as follows: The Brightness component values are negative and graphically located under the Wetness component. The values of Greenness component and the Wetness component are clearly distinguishable.

The results of the study show high Brightness values due to the prevalence of dry soil and the reduction of the surface water area. The values of

| Index  | Sensitivity degree | Index sensitivity to Wetland function | Index application for wetland health assessment |
|--------|--------------------|--------------------------------------|-----------------------------------------------|
| NDWI   | Water surface      | Medium                               | applicable                                    |
| NDGI   | Vegetation & Soil  | High                                 | applicable                                    |
| SAVI   | Soil               | Medium                               | applicable                                    |
| MSAVI  | Soil               | High                                 | applicable                                    |
the Wetness and Greenness components are similar, which is an indicator of the overgrowth within the wetland territory. The values of the Greenness component are also below “0” which is a clear indicator of ecosystem disturbances and only on the very small areas, the values vary around and above zero (Figure 9).

Figure 8 presents the images with a very high resolution of 0.05m made in September 2018. They show the current state of the Negovan wetland area and confirm a prolonged overgrowth process. Possible causes are the deterioration of the hydrological status of the wetland as a result of the deposition of organic matter from the existing vegetation, anthropogenic activity (unregulated landfills, breaching of the food chains developed in 2014, when the restoration activities were carried out.

Since the connections/ channels with a water source (inflows) and water discharges (outflows) are disturbed, the deterioration of the ecosystem sustainability will continue. Such changes in the wetland hydrology and nutrient/pollutant inputs are reliable indicators of certain types of stress for vegetation community composition and abundance (Novitzki, 1989). Physiological stress can be detected by remote sensing techniques, even before visible symptoms appear in the field. The depth of water in various portions of a wetland during long-term fluctuations in precipitation and flood is critical to many wetland characteristics and functions, including species abundance and variability. This statement is well demonstrated through the results shown in Figure 7, where clear negative correlation exists between wetness and greenness vectors for all studied time intervals.
Results from the MIEM application were verified with the results from the field survey approach. Field observation shows that the soil profiles, established in the territory of the naturally formed wetland, are under periodical flooding conditions and have a clear evidence of stratification. Soil horizons are weakly developed, although a distinct topsoil Ah-horizon is formed. The soil profile is A-C. Prolonged saturation in the lower (C-horizon) creates anaerobic conditions that greatly reduce oxidation of organic matter. Redoximorphic features, which are common for Fluvisol, are more pronounced in the lower part of the profile.

The soil organic carbon content (SOC) is an important factor in modifying soil physical properties and serving as potential nutrient reserves. The organic matter tends to accumulate in the surface horizon of soils that is saturated in the growing season. Its content in the studied soil ranges from 72.23 g.kg⁻¹ in the upper 21 cm to 16.67 g.kg⁻¹ in the lower soil horizon respectively up to the 60 cm depth. The total nitrogen content varies from 5.15 mg.g⁻¹ to 1.02 mg/g⁻¹. The results obtained for total organic carbon and nitrogen show high organic material in the surface soil layer due to the accumulation of the organic materials at a different degree of decomposition. The texture varies from coarse sand to fine sand, which provides good permeability. The soil is very dark grey coloured in the upper horizon to dark greyish along the soil profile. Within the field observation, the newly formed islands through shaping dykes and recovering techniques of the naturally existing ones were found to be impacted by some soil-forming factors and processes, which lead to substrate change. The area is prevailing covered with grass and shrub vegetation, and as a result of that very fine decomposed dead organic material was found.

Figure 8. Negovan wetland (Sofia region, Bulgaria) Aerophoto VHR 0.05m September 2018 (a, b, c)

Figure 9. 3D diagramme of the distribution of Brightness, Greenness and Wetness component for September 2018 for Negovan wetland.
The particular approach of Interim ecological monitoring Methodology (MIEM) to complete land cover observation as part of a survey on the wetland ecosystem condition based on aerospace data for a 5-year period after restoration activities was planned and implemented. Preprocessing of the TCT for Sentinel-2 images gives more precise and reliable results compared to other sensors and methods of monitoring of the vegetation, soil and water territory. A quantitative comparison of the efficiency of indices such as NDWI, NDGI, SAVI and MSAVI was found to be an effective tool for a simultaneous assessment of the vegetation, soil and water components condition in certain temporal intervals during the Negovan wetland monitoring. Based on the obtained results for indices values the degree of their sensitivity for the purposes of changes identification in the wetland environment was established. The critical threshold of indices values gives opportunities to identify measures for minimizing future negative consequences on the ecosystem health in the Negovan village wetland.

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