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Katarzyna Dąbrowska-Zielińska, Wanda Kowalik,
Maria Gruszczyńska, Agata Hościło

SATELLITE-DERIVED VEGETATION INDICES FOR BIEBRZA WETLAND

WSKAŹNIKI ROŚLINNE DLA OBSZARU BAGIEN BIEBRZAŃSKICH WYPROWADZONE ZE ZDJĘĆ SATELITARNYCH

Instytut Geodezji I Kartografii, Warszawa
Institute of Geodesy and Cartography, Warsaw

ABSTRACT: The study has been carried out at the Biebrza Basin in Poland. The investigation aimed at finding the best vegetation index characterising different marshland habitats. The various indices were calculated on the basis of all considered spectral bands of low spatial resolution satellites as SPOT/VEGETATION, ERS-2/ATSR, and NOAA/AVHRR. The GEMI and EVI index calculated from SPOT/VEGETATION images was the best for distinguishing vegetation classes. The best correlation between LAI measured at the ground and the derived indices was with GEMI and EVI index. Soil moisture values calculated from ERS2/ SAR well characterised distinguished marshland humidity classes.

KEY WORDS: SPOT/VEGETATION, ERS-2/ATSR, NOAA/AVHRR, vegetation index, ERS2/SAR, soil moisture

1. INTRODUCTION

Montoring the biggest area of the marshes in Europe have been very important task for proper management in order to maintain this unique environment and to slow down worsening environmental conditions due to deterioration and degradation of the area. Nowadays, most of the area (about 77%) is strongly moisture deficient. Decreasing water table and changes in soil moisture were caused by drainage due to irrigation ditches starting from early 19th century when excessive rainfalls occurred that time flooded the area. However, interruption of the hydrographic network led to the draining of 50% of the wetland [6]. Precipitation deficit in recent years intensified lowering of the water table. These factors caused mineralisation and decomposition of peat soils into peat-moorsh and caused changes in vegetation. In this aspect there is a strong need to get information about changes in vegetation cover by examining the use of various vegetation indices calculated from spectral reflectance registered by radiometers situated on the following EO satellites: NOAA/AVHRR, SPOT VEGETATION, ERS-2.ATSR, ERS-2.SAR, and Landsat +ETM. The advantage of using these observations is the delivery of inexpensive repetitive information about seasonal and long-term changes of vegetation for proper protection and management of this unique, very often impenetrable area.

2. THE STUDY AREA

The investigation has been carried out in the area situated in northeast part of Poland in the Middle Basin of Biebrza Valley, which is considered as Ramsar Convention test site. Biebrza wetland is one of the biggest in Europe natural rich biotope, important zone for nesting and wintering for fauna. This area is protected due to the large amount of unique spices of flora and fauna. However, the Biebrza wetland is an object of versatile natural and ecological processes. The scrub encroachment, lowering of the water table, changes of the farming activity are the big problems noticed at this area. There is a great need for the monitoring such changes in this ecosystem.

3. DATA

Throughout each of the growing seasons and simultaneously to satellite overpasses the measurements of soil-vegetation parameters were carried out at plots chosen for different marshland habitats. For the study area it was possible to receive the following satellite data for the same or very close date: Landsat +ETM and SPOT/VEGETATION for the date 16.05.2000, ERS-2/ATSR for 17.05.2000, NOAA/AVHRR for 16.05.2000, ERS-2/ATSR for 02.05.2001, SPOT/VEGETATION for 03.05.2001, and NOAA/AVHRR for 04.05.2001. Different wave bands were applied to calculate vegetation indices and then it was examined which index gives the most differentiation in the particular area. The six ERS-2/SAR historical data from the years 1995 and 1997 were used for the derivation of algorithms for soil moisture estimation.

4. VEGETATION INDICES ESTIMATION USING REMOTELY SENSED DATA

The vegetation indices are calculated from remote sensing data taking into account jointly the features of vegetation responsible for reflection in various bands and combining this information from several spectral bands. They are usually easy to calculate without additional meteorological data. The aim of the study was to find the best vegetation index, which gives the largest number of classes to present variation of vegetation due to moisture conditions in the marshland area. The following indices, which included different bands, were calculated: ARVI, GEMI, EVI, MI, and NDVI. The Atmospherically Resistant Vegetation Index (ARVI, [4]), which is four times less sensitive to atmospheric effects than the NDVI, includes the spectral response of vegetation, which for our purpose was presented as follows:

$$ARVI = \frac{NIR - BLUE}{NIR + BLUE} \tag{1}$$

The Global Environment Monitoring Index (GEMI, [7]), which includes near infrared and red band and accounts for standard atmospheric effects and soil effects is calculated as follows:

$$GEMI = \frac{\eta(1 - 0.25\eta) - (RED - 0.125)}{1 - RED}, \eta = \frac{2(NIR^2 - RED^2) + 1.5NIR + 0.5RED}{NIR + RED + 0.5} \tag{2}$$

In order to reduce the effect of atmosphere and soil Liu and Huete [5] developed Enhanced Vegetation Index (EVI). This index presents the vegetation index product on MODIS [3] and is calculated as follows:

$$EVI = 2\frac{NIR - RED}{1 + NIR + 6RED - 7.5BLUE} \tag{3}$$

The Medium Infrared Index (MI, developed by authors) takes into account the reflection in medium infrared band. This index was considered to be sensitive to moisture of marshland vegetation and is calculated as follows:

$$MI = \frac{SWIR - RED}{SWIR + RED} \tag{4}$$

Normalized Difference Vegetation Index (NDVI) is well known and widely used for vegetation monitoring on a global and local scale. It is related to biomass by many authors. Also, it is known that is not corrected for the reflectance of soils what is important when vegetation is not dense. The weakness of NDVI is its sensitivity to atmospheric effect. NDVI index is calculated as follows:

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{5}$$

Calculated from various satellite data indices were compared and the best vegetation index, which gives the largest number of classes to present variation of vegetation due to moisture conditions in the marshland area was found.

5. RESULTS AND DISCUSSION

Results of the study are presented and discussed in the following section. Fig. 1 presents humidity of marshland habitats in the Middle Biebrza Basin created with phytoindication method [6]. This method uses plants species as habitat moisture indicators. There are seven distinguished humidity classes of habitats, which differ from permanently swamp areas to good moisture conditions. The class (1) of permanently swamp conditions (plant species with high demand of water) covers the smallest area and can be observed in northern part of the area. Good grassland moisture conditions (7) are noticed mostly in western part of Middle Biebrza Basin due to land reclamation (grasses and dicotyledons). Swampy occasionally drying marshland (3) exists in the middle part of the study area (reed, cattail, sedge, and moor-grass). Generally, south part of the study area is covered with very wet and locally paludified habitats (4) (canary, sedge) and east part is covered with moist and drying habitats (6) (grasses, herbs and weeds). The class (2) covers swampy habitat and class (5) represents wet and extremely moist conditions. The map of each index was overlaid on the map of humidity of marshland habitats in order to obtain the number of vegetation index classes in different areas.

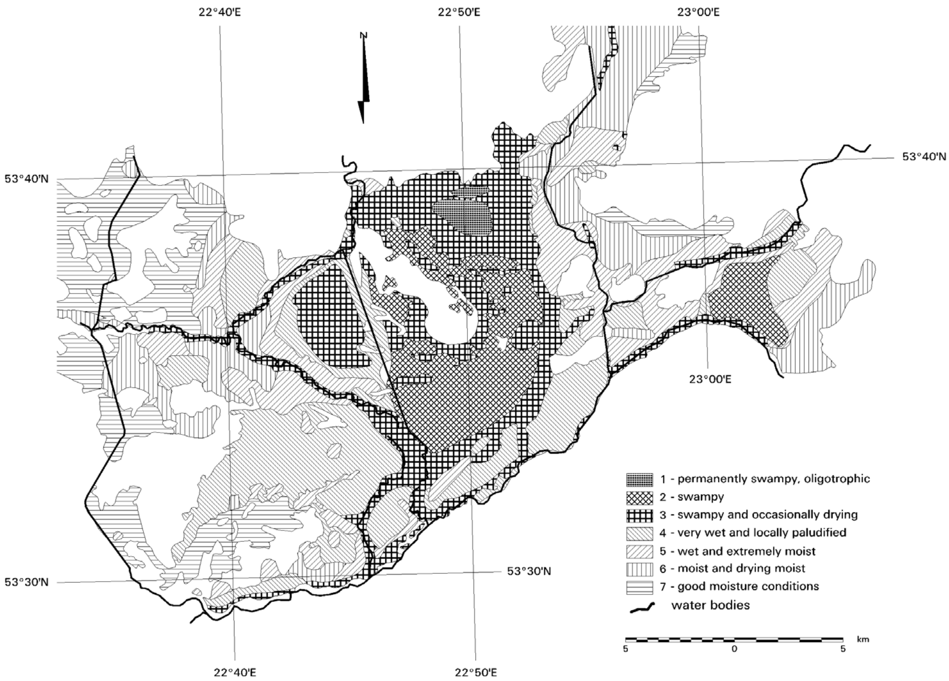

Fig. 1. Humidity of marshland habitats in the Middle Biebrza Basin created with phytoindication method (Okruszko, [6])

Fig. 2 a–c presents the number of values of vegetation index classes in each area of the marshland humidity class. The number of calculated EVI and GEMI classes is high. There are more than 150 different classes of EVI and GEMI calculated from SPOT/VEGETATION (03.05.2001) in the habitat class 3, 4 and 5. The number of calculated NDVI classes from the same sensors and for the same marshland humidity represent different group of vegetation, which occurs in these classes due to severe changes in moisture conditions. It can be concluded that EVI and GEMI much better represent the variety of vegetation and its changes. In each of the habitats' humidity classes GEMI index calculated from VEGETATION gives more information about vegetation changes than GEMI calculated from ATSR. There is no big difference in the NDVI calculated from different sensors in the number of classes. However, the index calculated from VEGETATION and ATSR gives the biggest number of variety while index from NOAA/AVHRR gives less number of NDVI classes within most of habitat humidity.

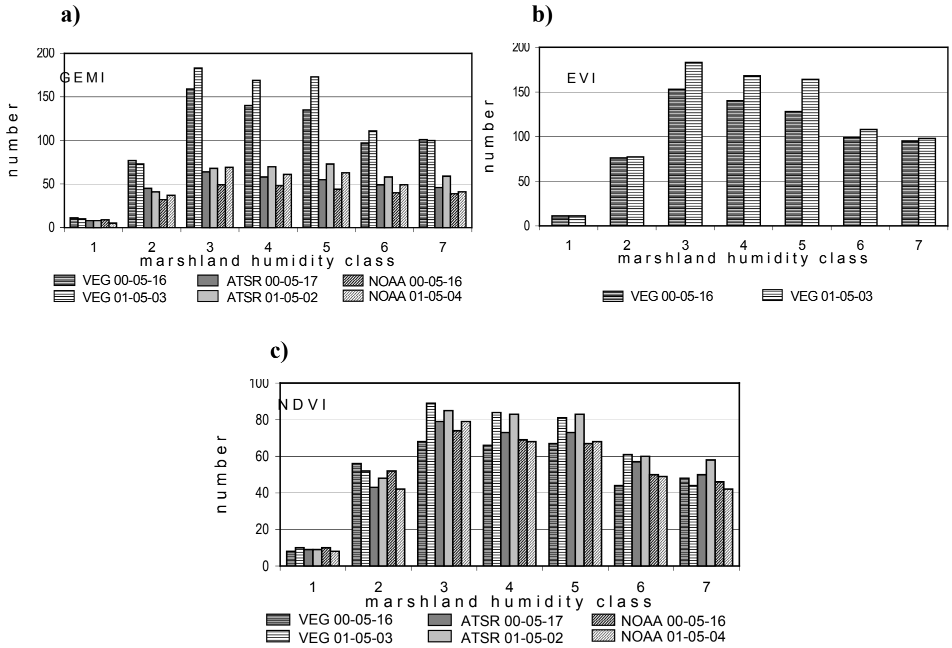

Fig. 2. a) Number of values of GEMI classes in each area of the marshland humidity class; b) Number of values of EVI classes in each area of the marshland humidity class; c) Number of values of NDVI classes in each area of the marshland humidity class

The index MI gives smaller amount of classes than NDVI. In the first class of habitat humidity the variation of all indices calculated from the sensors give the smaller amount of classes, as there is no variety of vegetation in this class. The index GEMI characterises very well marshland habitat. The correlation between the indices calculated from the data from all sensors and averaged in each habitat humidity class give very good results in the correlation between the index values and humidity classes (fig. 3 a–d). The correlation is linear; the highest GEMI index represents the class of good moisture conditions. Accumulation of green biomass is the highest in this class as moisture conditions are the best.

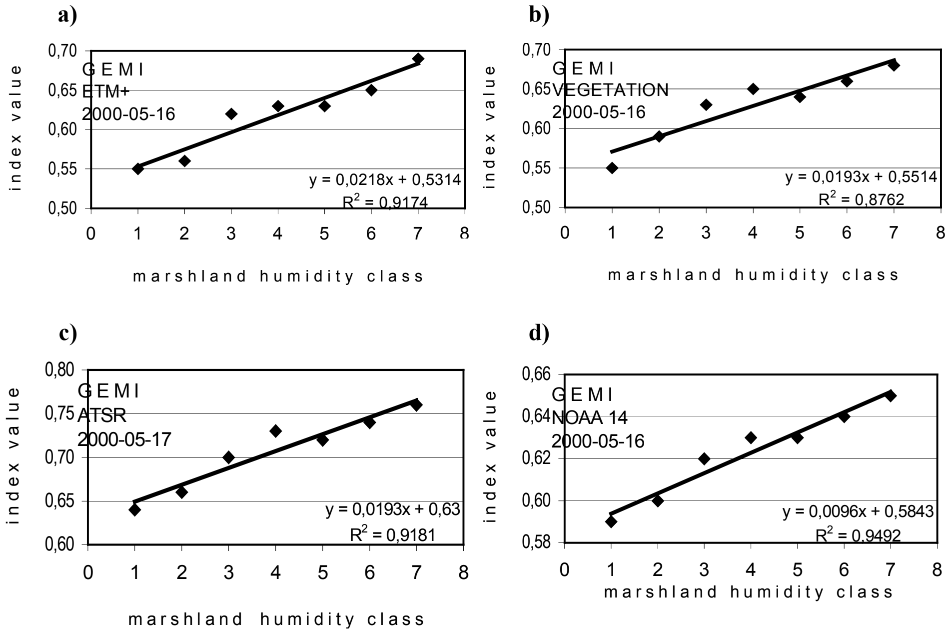

Fig. 3. a) Relationship between the GEMI index from +ETM and marshland humidity class; b) Relationship between the GEMI index from VEGETATION and marshland humidity class; c) Relationship between the GEMI index from ATSR and marshland humidity class; d) Relationship between the GEMI index from NOAA and marshland humidity class

The relationship between EVI and marshland humidity classes is also high, but lower than taking into account GEMI index (fig. 4 a–b). Relationship between NDVI, MI and ARVI and marshland humidity classes is not so significant.

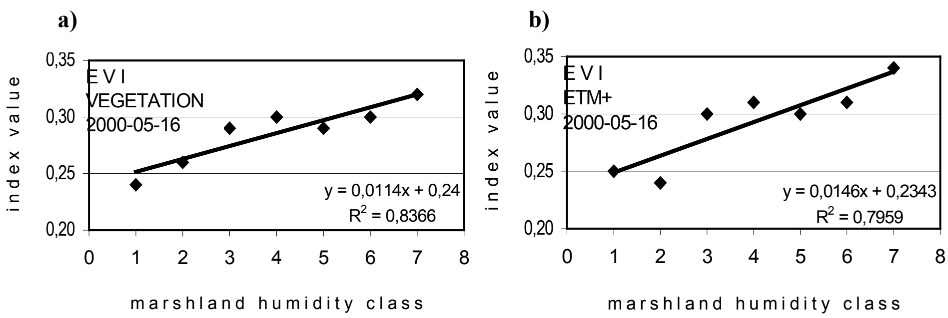

Fig. 4. a) Relationship between EVI index from +ETM and marshland humidity class; b) Relationship between EVI from VEGETATION and marshland humidity class

Fig. 5 shows distribution of GEMI index for the area of Middle Basin. Also, GEMI index was calculated from +ETM data in its resolution. The areas with low values of indices on +ETM image are distinguished by low values of indices calculated from the data provided by low spatial resolution satellites. The index GEMI calculated from ATSR had the highest values, but the distribution of values from VEGETATION and NOAA follow better the values from +ETM. The ground measurements of LAI represented 43 of 1 km^2 pixels. Fig. 6 a–f presents the best correlations between LAI values and each of the indices calculated from the sensors. It is shown that the highest precision to obtain Leaf Area Index is to apply GEMI or EVI index from VEGETATION. The less precise in obtaining LAI was applying GEMI calculated from NOAA satellite (Fig. 6b).

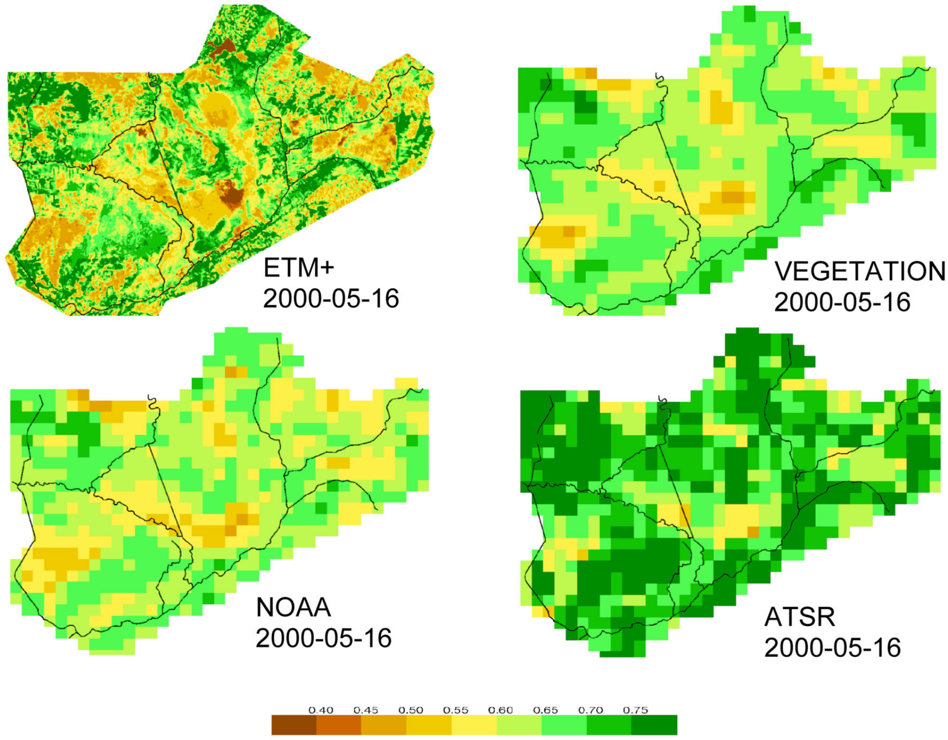

Fig. 5. Distribution of GEMI from different satellites in the Middle Biebrza Basin

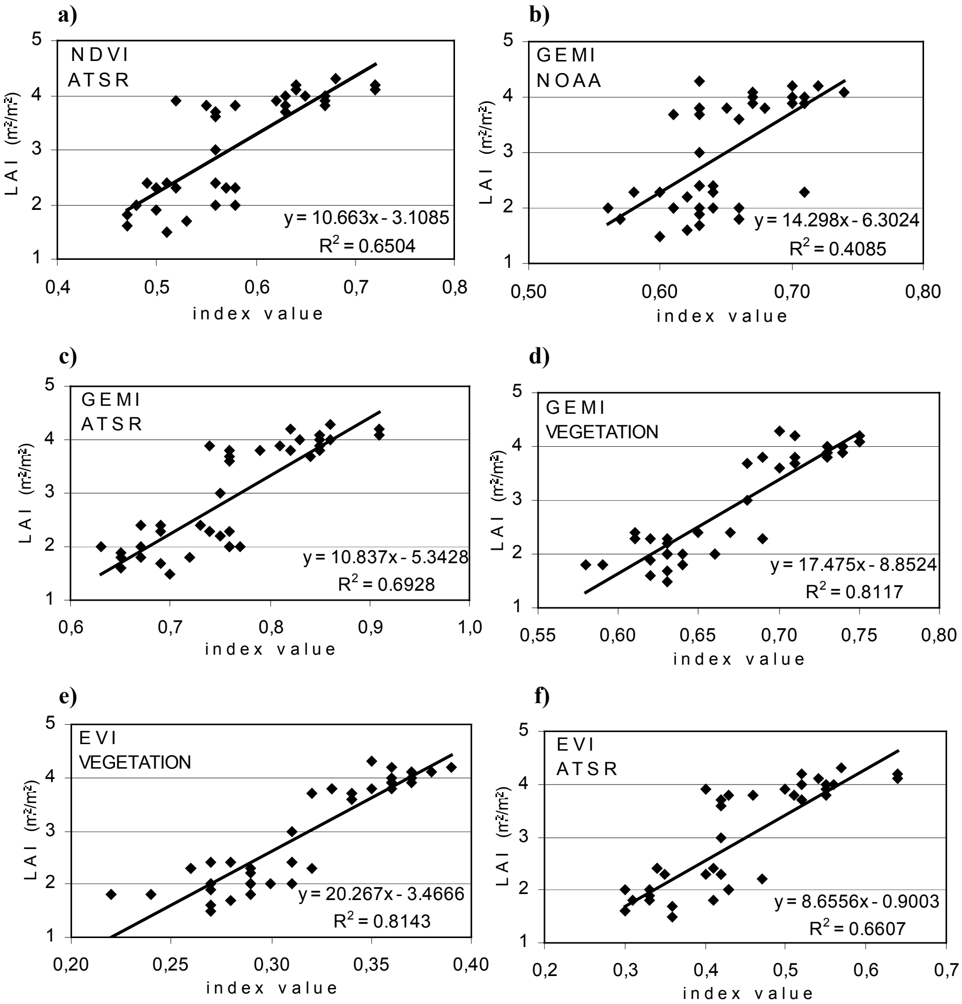

Fig. 6. a) Relationship between LAI and NDVI from ATSR; b) Relationship between LAI and GEMI from NOAA; c) Relationship between LAI and GEMI from ATSR; d) Relationship between LAI and GEMI from VEGETATION; e) Relationship between LAI and EVI from VEGETATION; f) Relationship between LAI and EVI from ATSR

It was possible to integrate the microwave data from ERS-2/SAR to obtain soil moisture and to relate soil moisture to habitat humidity classes. The backscattering coefficient calculated from SAR data values represents in active microwave the integrated respond of several soil–vegetation parameters as soil moisture, surface roughness and vegetation cover. One of the approaches that have been considered in this research was to match LAI to surface roughness [1], [2]. LAI values were calculated for each of the marshland humidity habitat classes from the equation derived from the relationship between LAI and GEMI (fig. 6d). Then, surface roughness has been classified into three classes using the following LAI values: <2; 2–3; >3. From historical ERS-2/SAR images the backscattering coefficient was calculated and related to soil moisture within each of the LAI classes. For each of the LAI classes the obtained correlations were high [2]. Derived algorithms were used to calculate soil moisture from SAR data. LAI classes were calculated in the function of GEMI index. Calculated soil moisture values were compared to marshland humidity classes.

Fig. 7 shows the correlation between soil moisture derived from SAR data and habitat humidity classes. The lowest moisture is considered in the class 7 (close to 30%), where the grassland moisture conditions are good.

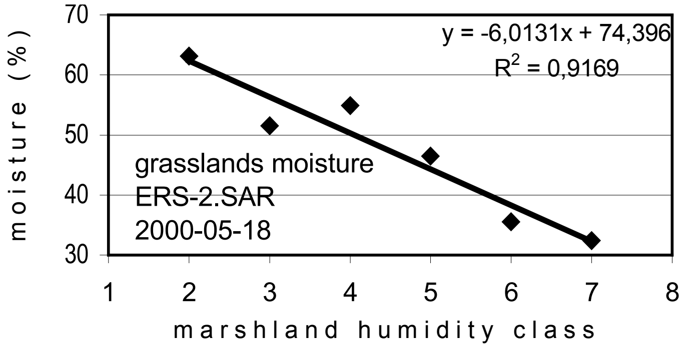

Fig. 7. Relationship between soil moisture calculated from ERS-2.SAR and marshland humidity

6. CONCLUSIONS

GEMI and EVI indices calculated from VEGETATION give the highest number of classes, which characterise marshland habitat. The various soil-vegetation indices have been calculated using different spectral bands for obtaining LAI values. For this purpose, the best indices were GEMI and EVI from VEGETATION. Calculated LAI was used for surface roughness classification needed for soil moisture estimation from ERS-2/SAR data. The possibility to use indices from low spatial resolution satellites is very beneficial for monitoring changes in marshland vegetation due to changes in soil moisture and habitat humidity.

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WSKAŹNIKI ROŚLINNE DLA OBSZARU BAGIEN BIEBRZAŃSKICH WYPROWADZONE ZE ZDJĘĆ SATELITARNYCH

Streszczenie

Biebrzański Park Narodowy został założony w 1993 roku w celu ochrony unikalnych walorów przyrodniczych bagiennej doliny rzeki Biebrzy. W wyniku panujących warunków wodnych oraz morfologii terenu na obszarze tym wykształcił się największy w Polsce ekosystem torfowisk niskich i wysokich. Na skutek zmian w użytkowaniu rolniczym oraz z powodu budowy kanałów odwadniających, ten unikalny naturalny ekosystem bagienny został zachwiany. Zmienione warunki wilgotnościowe doprowadziły do degradacji gleb torfowych i w konsekwencji do zmiany szaty roślinnej. Obecnie istnieje potrzeba monitorowania niekorzystnego dla środowiska procesu osuszania bagien, a jedynie możliwą do zastosowania na tak dużą skalę metodą, jest metoda teledetekcji. Badania skoncentrowano na obszarze zlokalizowanym w Basenie Środkowym Biebrzy, na którym do tej pory przeprowadzono wiele eksperymentów naukowych, i dla którego zgromadzono wiele informacji niezbędnych do realizacji niniejszego przedsięwzięcia.

W opracowaniu uwzględnione zostały dane satelitarne i naziemne archiwalne pochodzące z lat 1995 i 1997 oraz dane otrzymane w trakcie trwania badań lat 2000–2002. Wykorzystno dane satelitarne otrzymywane w optycznym i mikrofalowym zakresie widma elektromagnetycznego. Z zakresu optycznego (Landsat ETM, ERS-2.ATSR, SPOT VEGETATION, NOAA/AVHRR) zostały wyznaczone wskaźniki roślinne charakteryzujące powierzchnię ze względu na stopień uwilgotnienia i fazę rozwoju roślin. Poprzez klasyfikację obszaru wyróżniono łąki na różnych rodzajach siedlisk. Klasyfikowane były zdjęcia wykonane przy użyciu skanerów Thematic Mapper (TM) i Enhanced Thematic Mapper (ETM+) pracujących na satelitach z serii Landsat oraz zdjęcia mikrofalowe wykonane przy użyciu urządzenia SAR umieszczonego na satelicie ERS-2. Przy klasyfikacji wykorzystano wyniki badań terenowych.

Z danych mikrofalowych zarejestrowanych przez satelitę ERS-2 obliczono współczynnik wstecznego rozpraszania i wyprowadzono algorytmy wyznaczania wilgotności gleby. Wyznaczono również związek pomiędzy poszczególnymi klasami wilgotności gleby a wskaźnikami roślinnymi uzyskanymi z różnych satelitów oraz wyznaczono obszary, na których zaszły największe zmiany wilgotności.

W wyniku przeprowadzonych analiz wybrano następujące wskaźniki roślinne: ARVI, EVI, GEMI, MI, NDVI, których wzory podane są poniżej:

$$ARVI = \frac{NIR - BLUE}{NIR + BLUE}$$

$$\mathrm{EVI} = 2.0 \cdot \frac{NIR - RED}{1 + NIR + 6 \cdot RED - 7.5 \cdot BLUE}$$

$$\mathrm{GEMI} = \frac{\eta(1 - 0.25\eta) - (RED - 0.125)}{1 - RED}, \eta = \frac{2(NIR^2 - RED^2) + 1.5NIR + 0.5RED}{NIR + RED + 0.5}$$

$$\mathrm{NDVI} = \frac{NIR - RED}{NIR + RED}$$

$$\mathrm{MI} = \frac{SWIR - RED}{SWIR + RED}$$

gdzie:
ARVI – Atmospherically Resistant Vegetation Index, Kaufman i Tanre, 1992;
EVI – Enhanced Vegetation Index, Liu i Huete, 1995;
GEMI – Global Environment Monitoring Index, Pinty i Verstraete, 1992;
MI –Medium Infrared Index, wyprowadzony przez autorów, 2002;
NDVI – Normalized Difference Vegetation Index, powszechnie używany od dawna.

Wskaźniki roślinne łączą dane teledetekcyjne z biofizycznymi charakterystykami powierzchni czynnej, a w szczególności z powierzchnią projekcyjną liści, akumulowaną radiacją w procesie fotosyntezy, biomasą, i gęstością pokrycia roślinnością. Istnieje duże zainteresowanie rozwijaniem i wprowadzaniem wciąż nowych indeksów ze względu na ich związek z wieloma cechami roślinnymi, a równocześnie nie czułych na osłabiający wpływ gleby i atmosfery. Pozostaje jednak nadal aktualne, jakie cechy roślin wpływają na wartość wskaźnika, dla jakich warunków dany indeks może być zastosowany, jak również z jaką dokładnością mogą być poszczególne parametry roślinne obliczane. Wskaźniki roślinne, ze względu na łatwość ich obliczania bez konieczności stosowania dodatkowych danych, znalazły zastosowanie w rolnictwie do prognozowania plonów, ustalania terminów nawodnień.

Istotnym elementem pracy było znalezienie takich wskaźników roślinnych obliczanych ze zdjęć satelitarnych wykonanych w optycznym zakresie widma, które pozwoliłyby na dokładne szacowanie wskaźnika powierzchni projekcyjnej liści tzw. LAI. Wskaźnik ten jest niezbędny do szacowania wilgotności gleby ze zdjęć mikrofalowych, gdyż odzwierciedla szorstkość badanej powierzchni roślinnej. Analiza zmian wilgotności gleby umożliwiła wyznaczenie obszarów o zróżnicowanym uwilgotnieniu i opracowanie metody jej monitorowania na obszarach bagiennych.

Najsilniejszą zależność otrzymano dla wskaźników EVI i GEMI obliczonych z danych satelitarnych SPOT VEGETATION ($R^2 = 0.81$), najsłabszą dla wskaźnika GEMI obliczonego z danych NOAA/AVHRR ($R^2 = 0.41$). Wyprowadzone na podstawie analizy statystycznej algorytmy o najwyższych korelacjach mogą być zastosowane do szacowania wskaźnika LAI dla roślinności bagiennej.

SŁOWA KLUCZOWE: SPOT/VEGETATION, ERS-2/ATSR, wskaźnik zieleni, ERS-2/SAR, wilgotność gleby

Recenzent: prof. dr hab. Andrzej Ciołkosz, Instytut Geodezji i Kartografii, Warszawa