

APPLICATION OF SENTINEL-2 SATELLITE IMAGERY TO ASSESSMENT OF SPATIO-TEMPORAL CHANGES IN THE RESERVOIR OVERGROWTH PROCESS - A CASE STUDY: PRZEBĘDOWO, WEST POLAND

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Abstract: Water reservoirs in recent years have been subject to strong anthropogenic pressure leading to their eutrophication and overgrowing processes. The paper analyzes the temporal and spatial changes in overgrowing of the reservoir in order to identify the factors determining the dynamics of this process. The analysis was carried out on the example of Przebędowo reservoir of 12 ha, located in western Poland. 42 Sentinel-2 Level-1C satellite images from the period between the 4th July, 2015 and 6th April, 2018 were used in the study. The analysis of reservoir overgrowth process was based on the Water Adjusted Vegetation Index (WAVI). Overgrowth process was mapped by the simple segmentation algorithm using a threshold value. The analyzes were carried out using the SNAP and ArcGIS software. The results from 42 satellite images were grouped using cluster analysis (CA). Moreover, in order to indicate the factors determining the overgrowth process in terms of time and space, the main component analysis (PCA) was used. The obtained results show that the reservoir is subject to very intensive overgrowth over the entire surface. On the other hand, the dynamics of reservoir overgrowing in a year is related to thermal conditions and to a lower degree to the water level variability. Assessment of inter-annual changes in reservoir overgrowth was impossible because of the differences in temperature and temperature distribution over the analyzed years. The CA analysis allowed a division of the images into 4 groups, which present respectively the phase of plant growth, the phase of maximum coverage with plants, the phase of plants decline and the phase of minimal coverage with plants. The PCA analysis showed that the overgrowth process is initiated from the reservoir shore, the shallowest places are occupied first. Also, along the reservoir there is a gradient of overgrowth from the inlet to the outlet of the reservoir.

Keywords: dam reservoir, Sentinel-2, WAVI, overgrowth, spatio-temporal

1. INTRODUCTION

Lakes and reservoirs have important functions in the environment. However stressors such as anthropogenic activities or climate changes are threats to their ecological functions (Dörnhöfer & Oppelt, 2016). Increased input of nutrients and organic matter into the water bodies leads to eutrophication and overgrowth process (Alahuhta et al., 2016; Davis & Koop, 2006; Dąbrowska et al., 2016; Kowalik et al., 2014; Sojka, 2009,

Szczykowska & Siemieniuk, 2011; Zhang et al., 2016). Overgrowing process is one of the most import factor affecting the decrease in lake surface area (Choiński & Ptak, 2009; Ławniczak, 2010; Ławniczak & Kutyla, 2015; Skowron & Jaworski, 2017; Skowron & Piasecki, 2014). Lake overgrowth process is characterized by vast diversity (Skowron & Jaworski, 2017). Particularly strong changes have been observed in small and shallow lakes (Ławniczak et al., 2011). In Poland in small (with area below 80 ha) or medium (area from 80 to 200

ha) lakes, the extent of plant overgrowth was 14.3 and 9.6% respectively (Skowron & Jaworski, 2017). Skowron & Jaworski (2017) indicate that faster plant overgrowing rate is related to quantity and quality of biogenic substances inflowing to the lake and the share of the littoral zone in the lake's area.

Lakes and reservoirs play an important role in the environment. Therefore, in many countries monitoring programs have been introduced to protect their status. Aquatic vegetation monitoring often is conducted on the basis of data collected in situ and their laboratory analysis. The conventional monitoring is limited in terms of spatial coverage and temporal frequency. Lakes monitoring is mainly conducted at a single or at several measurement points which makes it impossible to analyze spatial variations. Conventional monitoring is time consuming and very expensive when dealing with large scales and frequent measurements (Silva et al., 2008).

An alternative might be the use of remote sensing to study surface water. Remote sensing data provide synoptic, spatiotemporal views and their integration with traditional monitoring data can lead to a better understanding of water bodies (Dörnhöfer & Oppelt, 2016). Remote sensing and GIS can be effective tools for eutrophication monitoring and assessment of temporal and spatial distribution of aquatic vegetation in lakes and dam reservoirs (Kanninen & Pellikka, 2004; Ma et al., 2008; Munyati, 2015; Nelson et al., 2006; Shekede et al., 2008; Zhang et al., 2016). Additionally, satellite data make it possible to compare the status of reservoirs in different regions in a country and in the world. The use of remote sensing may play a vital role in reducing the cost and time required for analysis (Chen et al., 2014; Nelson et al., 2006).

At first aerial photographs were most commonly used for remote sensing and water bodies monitoring. The advantages of aerial photographs are related to good spatial resolution, although its drawbacks are poor time and spectral resolution. Aerial photographs with visible and near infrared spectral band were used for mapping the dynamics of emergent plants (Brijs, 2011).

Observed in recent years rapid development of satellite sensors, remote methodologies and data availability have increased the use of remote sensing in the environment monitoring (Palmer et al., 2015; Wang et al., 2012). The medium resolution satellite images can successfully be used for monitoring (Liira et al., 2010; Ma et al., 2008). Multi temporal data provide the information allowing analyses of the spatial and temporal distribution of the aquatic vegetation and biomass assessment (Beck et al., 2006; Birk & Ecke, 2014; Bohn et al. 2017; Dogan

et al., 2009; Dörnhöfer & Oppelt, 2016; Luo et al., 2016; Maria et al., 2009; Zhang et al., 2018).

Remote sensed data have good potential for detecting submersed, floating leaved and emergent aquatic vegetation (Birk & Ecke, 2014; Kanninen & Pellikka, 2004; Luo et al., 2017; Malthus & Georgeb, 1997; Zhao et al., 2012; Zhao et al., 2015). Remote sensing is best suited for identification of emergent and floating-leaf vegetation. It is possible to use remote sensing techniques for monitoring the distribution and dynamics of submerged aquatic vegetation (Zou et al., 2013). Mapping the distribution of submerged aquatic vegetation is very challenging and difficult (Luo et al., 2017) and the results may be of poor accuracy (Poikane et al., 2015). Satellite images additionally were used to detect weeds invasion, algae blooms, water compound concentrations, water transparency, water temperature and bathymetry (Frampton et al., 2013; Huang et al., 2014; Maria et al., 2009; Munyati, 2015; Shekede et al., 2008; Sun et al. 2014, Yang et al. 2017).

Poland has little water resources. Therefore, over the last few decades, construction of dam reservoirs has been undertaken at many sites. Water supplies in Poland strongly depend on the numerous dam reservoirs. Reservoirs provide drinking water and water for irrigation, energy production, fishery and recreational purposes. In Poland there are over 100 artificial dam reservoirs that cover the area of 350 km². About 70 have capacities higher than 5 million m³. However, the majority are small reservoirs with a capacity of less than 5 million m³. Small dam reservoirs are much more susceptible to degradation, which is related to their morphometric parameters e.g. small depth and volume (Bieroński, 2014; Pęczuła & Suchora, 2011). Additionally, dam reservoirs have larger basin areas which increases the inflow of nutrient and organic matter (Skoczko & Szatyłowicz, 2015). It is impossible to cover all reservoirs with traditional monitoring, although efficient monitoring of the overgrowth process is important for water bodies management (Zhao et al., 2012). Knowledge of the composition and distribution of aquatic vegetation, as well as their seasonal and interannual variations, is crucial for managing the water bodies ecosystems (Luo et al., 2016) and control of aquatic macrophytes dynamics (Zhang et al., 2016). However, there are a few studies devoted to monitoring of seasonal changes or phenology of aquatic vegetation types using moderate spatial resolution remote sensing data (Luo et al., 2016). Additionally (Thamaga & Dube, 2018) suggested that there is a need to develop new methodologies that can detect aquatic invasive plant species, especially in small water bodies. Lee et al.,

(2015) have suggested the use of a hyperspectral global mapping satellite mission which would provide the systematic data on aquatic ecosystems.

The aim of this study was to assess (1) seasonal and interannual variations in reservoir overgrowth process, (2) spatial changes in the overgrowth process, (3) and to link the overgrowth process with the morphometric parameters of the reservoir and hydrological conditions. The analysis of the reservoir overgrowth process was carried out on the basis of Sentinel-2 images from the period from July 2015 to April 2018. Data preprocessing, analysis and results presentation was carried out in the SNAP, ArcGIS and Statistica software.

2. MATERIALS AND METHODS

2.1. Study site

The Przebędowo reservoir is located in the Trojanka River catchment. Trojanka is a right tributary of the Warta river which is the third largest river in Poland. The reservoir was built in 2014. The surface area of the reservoir is 12.03 hectares and its total capacity is 0.162 million m³ (Korytowski & Waligórski, 2017). The reservoir has an elongated shape. Its length is 1450 m and its maximum width is 120 m (Fig. 1). According to the reservoir operating plan, the water levels should be kept within the range between 71.50 m a.s.l. and 72.50 m a.s.l. The mean

depth of the reservoir at the water level 72.50 m a.s.l. is 0.94 m. Since November 2015, measurements of water level in the reservoir have been carried out. The average monthly water level in the reservoir from November 2015 to February 2018 are shown in Figure 1b. During this period, the water level in the reservoir varied from 270 to about 330 cm.

Przebędowo reservoir is located in the central part of Poland, where the average annual temperature is about 9 °C and the precipitation is 530 mm. The growing season begins in April and ends in September. The average monthly temperatures in the period from January 2015 to April 2018 are shown in Figure 1c. Previous studies have shown that Przebędowo reservoir is highly vulnerable to degradation (Sojka et al., 2017). Overgrowth process depends on the morphometric parameters of the reservoir: shape, elongated coastline and low water depth. Moreover, a high share of arable land in the catchment area increases the potential inflow of nitrogen and phosphorus into the reservoir which promotes the overgrowing process. The reservoir has been subjected to a very intensive overgrowing process from the start of its operation. *Typha angustifolia*, *Glyceria maxima*, *Phragmites australis* and *Sparganium erectum* are the dominant plant communities observed in reservoir. The reservoir also contains small communities of *Typha latifolia*, *Ranunculus circinatus* and *Elodea canadensis*. *Lemna trisulca* and a small share of *Lemna minor*.

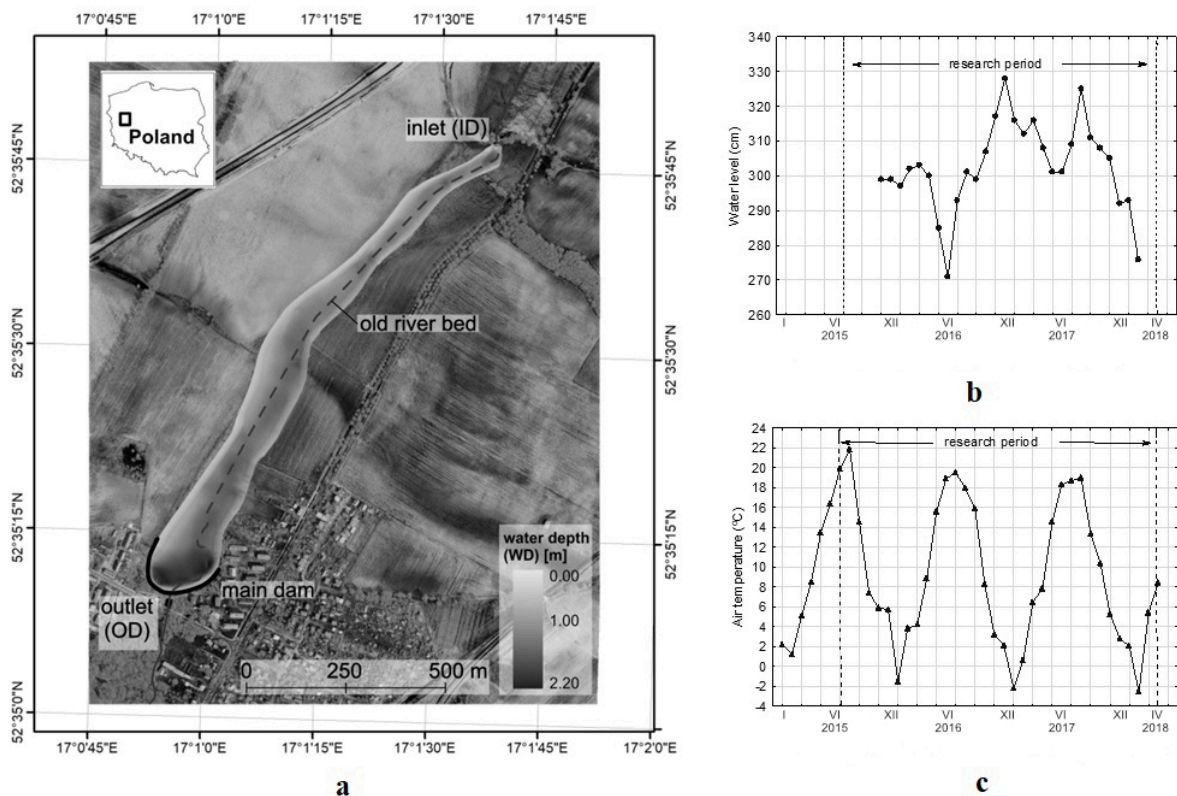


Figure 1. Study site location (A), water levels in the reservoir (B) and air temperature (C) in the period 2015-2018.

2.2. Data collection and preprocessing

Sentinel-2 Level-1C data were acquired from the Copernicus Open Access Hub European Space Agencies (<https://scihub.copernicus.eu/>). The images with cloud cover less than 5% from the period of 4rd July, 2015 and 6th April, 2018 were collected.

SENTINEL-2 carries the Multi-Spectral Instrument (MSI) that provides data in 13 spectral bands – from visible (V), near infrared (NIR) to short wave infrared range (SWIR) with a swath width of 290 km. The spatial resolution of the data varies from 10, through 20 to 60 meters (Table 1). During the period from 23rd June to 7th March 2017, only the Sentinel-2A satellite was operating, which provided data with a time resolution of every 10 days. From 7th March 2017 when the Sentinel-2B was launched, the time resolution is 5 days in cloud-free conditions. The Sentinel-2 Level-1C product is provided in Top of Atmosphere (TOA) reflectance in 100 km by 100 km tiles. The radiometric resolution of the data is 12-bit. The Sentinel-2 Level-1C products are in UTM/WGS84 projection and horizontal datum. The Level-1C product processing includes geometric corrections (sub-pixel registration and resampling) using a 90 m Digital Elevation Model (DEM).

Table 1. Characteristics of Sentinel-2 products

Band number	Central wavelength [nm]	Width [nm]	Spatial resolution [m]
1 – Coastal aerosol	443	20	60
2 - Blue	490	65	10
3 - Green	560	35	10
4 - Red	665	30	10
5 – Vegetation Red Edge	705	15	20
6 - Vegetation Red Edge	740	15	20
7 - Vegetation Red Edge	783	20	20
8 – NIR	842	115	10
8a - Vegetation Red Edge	865	20	20
9 – Water vapor	945	20	60
10 – SWIR - Cirrus	1380	30	60
11 – SWIR	1610	90	20
12- SWIR	2190	180	20

A total of 42 Sentinel-2 multispectral images from the period of July 2015 to April 2018, were selected for further analysis (granule: 33UXU). In the first year of the Sentinel-2 operation 7 images were acquired (Table 2). In the subsequent years 2016 and 2017, 18 and 14 images were acquired respectively.

However, obtaining the set of images for each of the month was not possible. In the last year from January to April only 3 images were acquired. Generally the images were not obtained for January. For the remaining months the number of acquired images ranged from 2 to 6. During the preprocessing stage the images with clouds within the range of the analyzed reservoir were removed. Then a Sen2Cor plugin, working in SNAP environment, was used to develop Bottom of Atmosphere (BOA) reflectance images

2.3. Data processing

The analysis of reservoirs overgrowth process was based on Water Adjusted Vegetation Index (WAVI). Previous research has shown that the WAVI Index is the most appropriate for detection of the overgrowth process in the reservoirs (Hestir et al., 2015). The WAVI index was originally introduced by Villa et al., (2014) for detection of the main types of aquatic vegetation in lakes.

WAVI is combination of NIR (ρ_{NIR}) and blue (ρ_B) bands. In equation, L is a background signal correction factor which allows adjustment of the influence of vegetation background. The value of signal correction factor for the calculations was set at 0.5 according to Villa et al., (2014). The WAVI index calculation was performed in the SNAP software using the Band Maths tool. The calculations were performed assuming a WAVI raster resolution of 10x10 m. In the next stage, rasters with WAVI index values were clipped by a vector mask (Area Of Interest - AOI) which represents the spatial extent of the reservoir. For further analysis 1002 pixels were chosen. Analysis was carried out for pixels which comprised more than 50% of the area of the reservoir.

The WAVI raster data were converted into vector data, using Raster to polygon tool in ArcGIS 10.5 software. Then the attribute tables of each of the vector files were merged. In this way, a single vector file was created in which the row number is a pixel number from 1 to 1002, while columns 1 to 42 show WAVI values for each of the analyzed images.

$$WAVI = (1 + L) \frac{\rho_{NIR} - \rho_B}{\rho_{NIR} + \rho_B + L} \quad (1)$$

The overgrowth process was mapped by the simple segmentation algorithm using a threshold value set to 0.2. It means that when WAVI takes a value below 0.2, then there is still water surface or floating plants and when it is higher than 0.2, the reservoir surface is overgrown with emergent plants (Villa et al., 2015). Finally, overgrown areas for each image were calculated in ArcGIS software using Reclassify function.

Table 2. List of images obtained for analysis

Years	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
2015							2	4	1				7
2016		1	2		2	4	1	2	3		2	1	18
2017			1	2	1	2	1		2	3	1	1	14
2018		1	1	1									3
Total	0	2	4	3	3	6	4	6	6	3	3	2	42

Percentage of the overgrowth is defined as proportion of the aquatic plant cover, where 100% is the total surface of the reservoir. It was calculated in ArcGIS software using Raster Calculator function. In order to determine potential factors affecting the process of reservoir overgrowth, variables describing the water depth (WD), distance from reservoirs bank (BD), distance from old riverbed (RD) and distance from reservoirs inlet (ID) and outlet (OD) were assigned to each pixel. To determine the depth at any location of the reservoir, depending on the current water level, the reservoir digital elevation model (DEM) was used. The DEM was developed in the ArcGIS environment on the basis on the data obtained from geodetic measurements from the reservoir technical design project.

2.4. Statistical data analysis

In order to analyze seasonal changes in the overgrowth process, cluster analysis (CA) was performed. The Ward method was used to assess the similarities and differences between rasters showing the values of the WAVI index. In the Ward method, analysis of variance is used to estimate the distance between clusters. As a measure of similarity, the square of the Euclidean distance was used. To establish groups in the CA method, the cut-off criterion of 66% was used. In addition, subgroups were separated within the groups. As a cut-off threshold, the value of 25% was assumed. Accepting the threshold value at the proposed level allowed separation of relatively homogeneous subgroups without creating a large number of small subgroups (Ptak et al., 2018). On the basis of the images within each subgroup, the mean WAVI index values were determined. In this way, rasters (representatives of subgroups) were created illustrating the seasonal dynamics of the reservoir overgrowth process. The analysis of the significance of differences between images representing groups defined by the CA method was carried out by the non-parametric Wilcoxon signed-rank sum test. The Wilcoxon test was used to verify the null hypothesis that the median of a distribution is equal to a certain value.

In order to determine the inter-annual changes in the overgrowth process in the reservoir, the values of

the WAVI index for July and September in the years 2015-2017 were compared. In the other months of the growing season, such analysis was impossible because of the lack of data. The aim of this analysis was to present the inter-annual dynamics of the reservoir overgrowth process. The analysis of the monthly changes in the reservoir overgrowth process was carried out in relation to average air temperatures and water levels. Thermal conditions (air temperature) data was obtained from the Institute of Meteorology and Water Management – National Research Institute (IMGW-PIB). Monthly WAVI values were calculated as an average of images for specific dates.

The effects of morphometric and hydrological conditions on overgrowing process were evaluated on the basis of the PCA analysis performed for the images representing representatives of individual groups the morphometric and hydrological variables analyzed were WD, BD, RD, ID and OD. The PCA analysis permits simplification of the structure of the data set and presentation in new orthogonal spaces defined by the principal components (PC). The Kaiser criterion was used to distinguish significant principal components (PC). To assess the correlation between principal components and analyzed data the method proposed by Liu et al. [40] has been used. The values of this method equal to >0.75, 0.75–0.50, and 0.50–0.30 indicate strong, moderate and weak relationship, respectively. In the final stage of the overgrowth process, the relationship between median WAVI index and air temperature was analyzed.

3. RESULTS

The analysis of the Przebędowo reservoir overgrowth process was based on the WAVI index results from July 2015 to April 2018. The values of the WAVI index were characterized by seasonal variability. The lowest values were observed in the period from January to April, while the highest values in August and September (Fig. 2). The highest variation in WAVI values was observed in August, while the lowest in February. The reservoir overgrowing process was determined by thermal conditions (air temperature). Inter-annual variability of WAVI values in individual months are primarily the result of thermal conditions that stimulate the process

of plant development. The reservoir overgrowing process is also affected by water level variability.

Assuming the threshold WAVI value to separate the overgrowth zone in the reservoir at 0.2 level, it should be noted that in the period from February to April values higher than 0.2 were from 7% to 18%. Figures 3a and 3b show the relationship between the average values of WAVI index and percentage of overgrowth and average values of air temperature. The process of overgrowth in the reservoir begins in April, with a delay of about 1 month in relation to the growth of terrestrial plants. An increase in WAVI index and an increase in the number of pixels with WAVI value higher than 0.2 occurs from May to August. The most dynamic changes are noted in May and June. In subsequent years, the increase in overgrown area in these two months ranged from about 20% to 50%. In the period from August to September there is usually a slight increase in pixels with WAVI values higher than 0.2, despite the fact that a decline in air temperature is already observed. This is probably due to the fact that the water temperature declines slower than the air temperature.

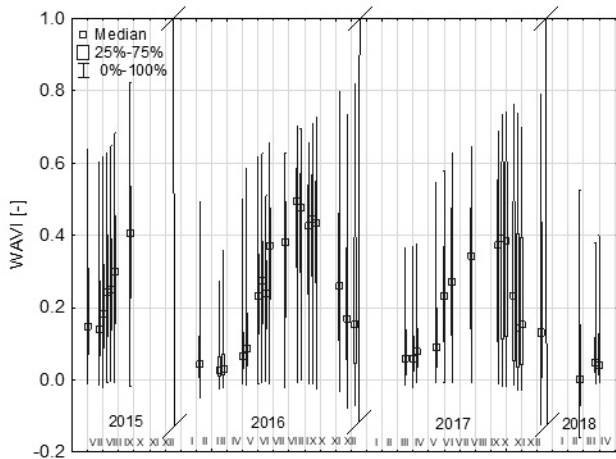
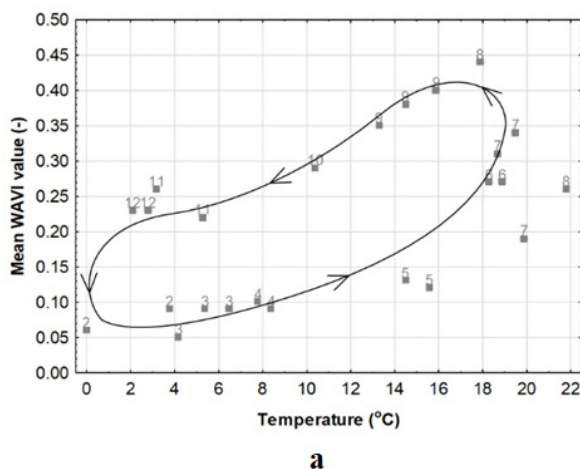
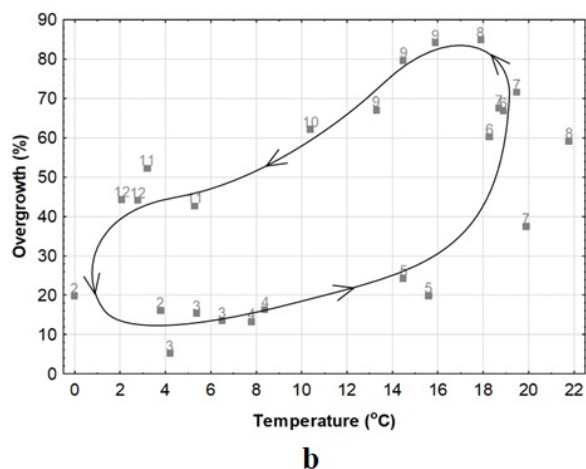


Figure 2. Variability of WAVI index during the analyzed period.



a



b

Figure 3. Relationships between the mean value of the WAVI index (a) and the percentage of the overgrowth (b) and average monthly air temperatures.

From September to December, the plants gradually disappear from the reservoir by an average of about 15% per month. In order to assess the inter-annual changes in the reservoir overgrowth process, the values of the WAVI index were compared in July and September. The lowest values of WAVI index were recorded in July 2015, on average 0.18, in subsequent years the values were at a similar level and amounted to 0.32. In July 2015, the WAVI index values higher than 0.2 were around 35%, while more than twice as high values were recorded in July 2016 and 2017. The main factor responsible for such differences in WAVI values were the thermal conditions, in May and June 2015 the temperatures were from 1°C to even 2°C lower than in 2016 and 2017. In July and August 2015, the highest temperatures were recorded, which contributed to the intensification of the overgrowth process. The average WAVI values in September 2015-2017 were at a similar level. In contrast, the area of the reservoir in which WAVI values exceeded 0.2 in 2015 and 2016 was around 80% and in 2017 around 65%. These differences can be explained by thermal conditions in the period from July to September; the temperature in 2017 was from 0.7°C to 1.7°C lower than in 2015 and 2016. Also, in 2017 in the period from July to September, in the reservoir the water level was higher by about 10 to 20 cm. Analysis of the WAVI index values in subsequent years makes it impossible to assess the direction of the overgrowth process. In such a short period, the overgrowing process is related to the thermal conditions in the previous period, additionally it can be modified by changes in water level.

CA analysis allowed grouping the images according to WAVI index values. The views were divided into two main groups Group 1 and Group 2 (Fig. 4a). Three subgroups were separated within Group 1.

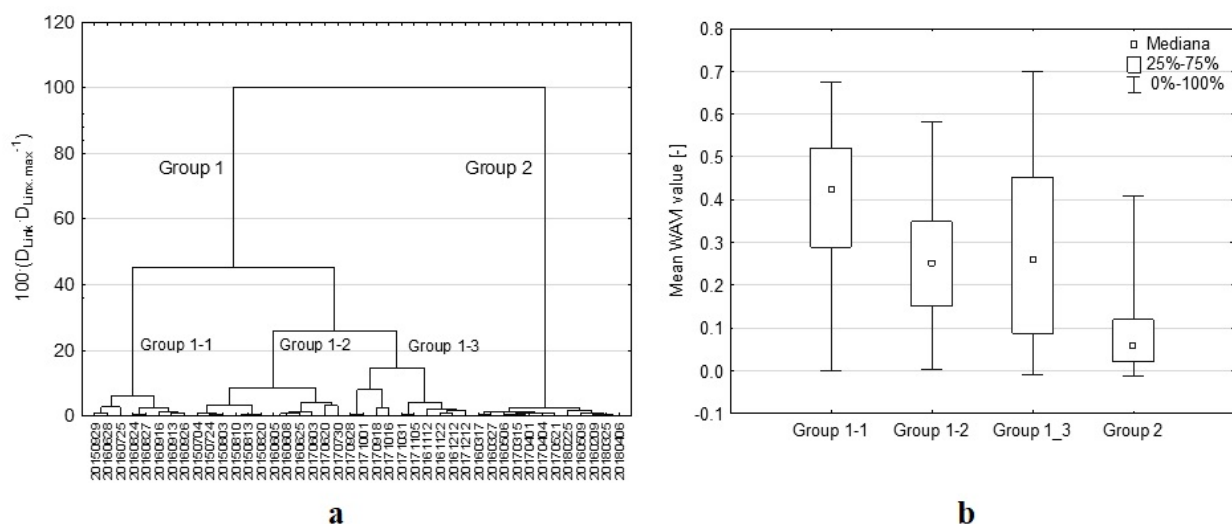


Figure 4. Results of CA analysis (a) with their characteristic (b).

Subgroup 1-1 (maximum reservoir overgrowth level) includes images in which the WAVI index values were at the highest level (Fig. 4b). Within this group there were mainly images from July to September 2016 and September 2015. The average value of WAVI index within this group is 0.40. The number of pixels assigned to WAVI index higher than 0.2 within this group was over 83%. At the turn of May and July 2016, the lowest water level was observed in the reservoir, about 20 cm lower in relation to the average level. Such conditions favored intensive development of plants within the reservoir from July to September 2016.

Within subgroups 1-2 and 1-3, slightly lower WAVI values were observed, on average 0.25. The percent of pixels with WAVI value above 0.2 in the sub-group 1-2 was about 60%, while in the sub-group 1-3 - about 50%. The images recorded from June to August were classified to subgroup 1-2 (phase of overgrowing of the reservoir). During this period there is an increase in the area occupied by plants. However, subgroup 1-3 (the phase of plants declining) included the images taken from October to December, which described the period of disappearance of plants in the reservoir. WAVI values in subgroup 1-3 were characterized by higher variability than subgroup 1-2. The lowest WAVI values occurred within Group 2 (minimum plant cover phase) on average 0.01, in which only 14% of the pixels had WAVI values above 0.2. WAVI values in group 2 were characterized by the lowest spatial variability within the reservoir. The analysis performed using the non-parametric Wilcoxon signed-rank sum test revealed statistically significant differences between the groups, at the $\alpha=0.05$ level.

Spatial analysis showed that during the phase of minimum reservoir coverage with plants (Group 2) there is vegetation mainly along the north-eastern shore

of the reservoir. However, in the phase of plant growth (Group 1-2), the plants in the reservoir do not occur only on a small part in the center of reservoir, the old Trojanka riverbed and near the main dam. In the stage of maximum coverage of the reservoir with plants (Group 1-1) only in the vicinity of the main dam and in the place of the old Trojanka riverbed in the central and lower part of the reservoir there was a surface not covered with plants (Fig. 5). In the phase of plants decline (Group 1-3), the central part of the reservoir was first exposed. The PCA analysis was conducted to show morphometric and hydrological factors that influence the process of overgrowth in the phases highlighted in CA analysis. The analysis allowed separation of two main components PC1 and PC2, whose eigenvalues were higher than 1. The distinguished main components explain, respectively, 78.29 and 16.02 internal data structure. WAVI values were strongly correlated with PC1 for all groups distinguished by the CA method. In addition, the values of depth (WD) and distance from the edge (BD) were correlated positively to PC1 (Fig. 6). The second component of PC2 was positively correlated with WAVI values for Group 1-1 and the distance from the inlet to the reservoir (ID) and negatively – with the distance from the outlet from the reservoir (OD). The values of WD and BD determine the strongest overgrowth process in the plant growth phase (Group 1-2) and in the decline phase (Group 1-3). The growth of plants takes place first from the shore, the shallowest places are first occupied, while in the phase of decline of plants (group 1-3), the plants survive the longest in these places. In the phase of maximum reservoir overgrowth (Group 1-1) the depth (WD) and the distance from the shore (BD) are less important; the occurrence of plants is related to the distance from the inlet to the reservoir (ID) and the distance from the reservoir outlet (OD).

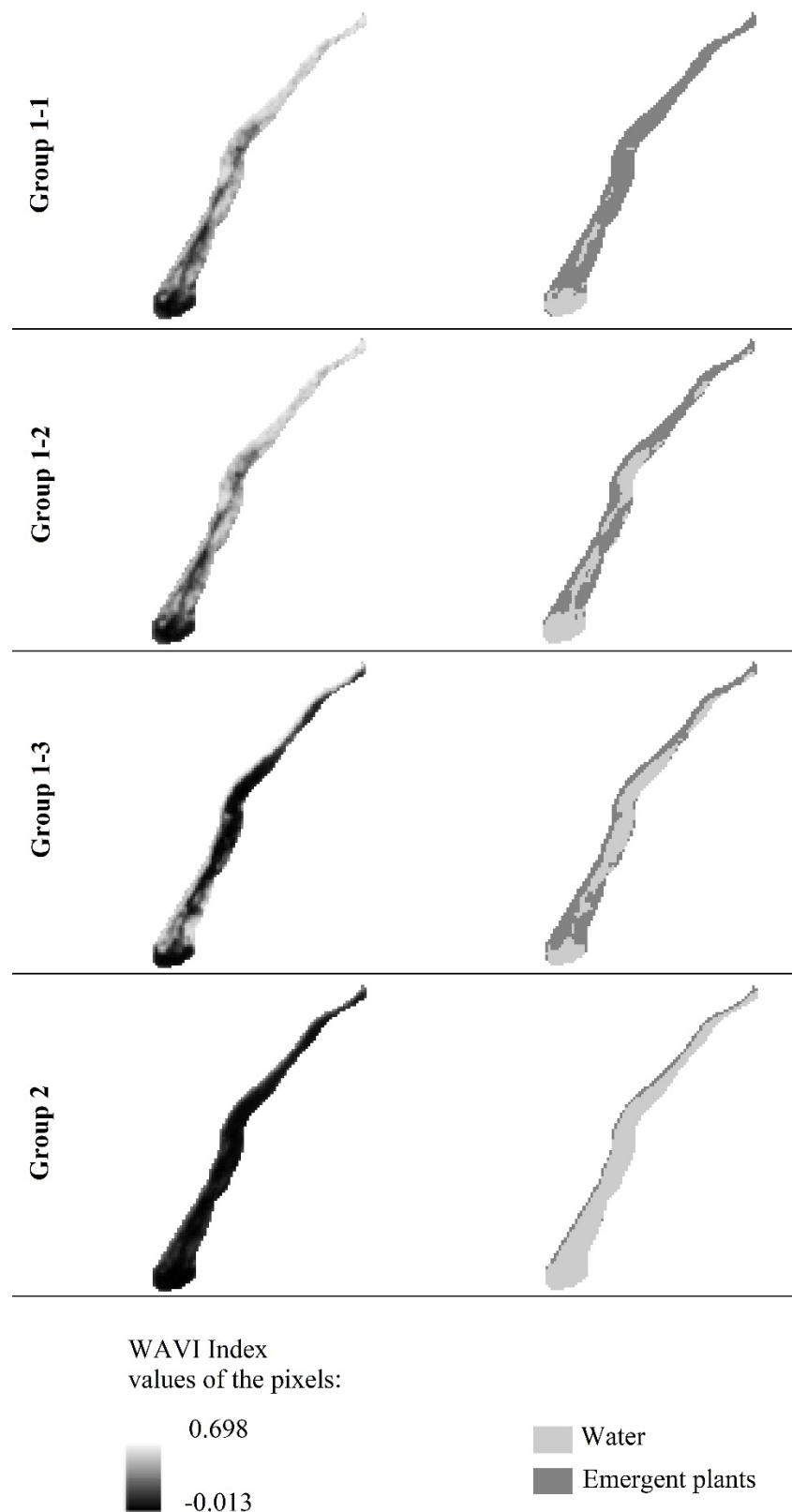


Figure 5. Spatial changes in the overgrowth process in groups distinguished by CA method.

4. DISCUSSION

The obtained results show that the process of overgrowth of a shallow dam reservoir can be very

dynamic in time and space. The analyzed reservoir is very shallow (mean depth 0.94 m), therefore it is fully exposed to intensive plant development. The main factor determining the dynamics of the reservoir

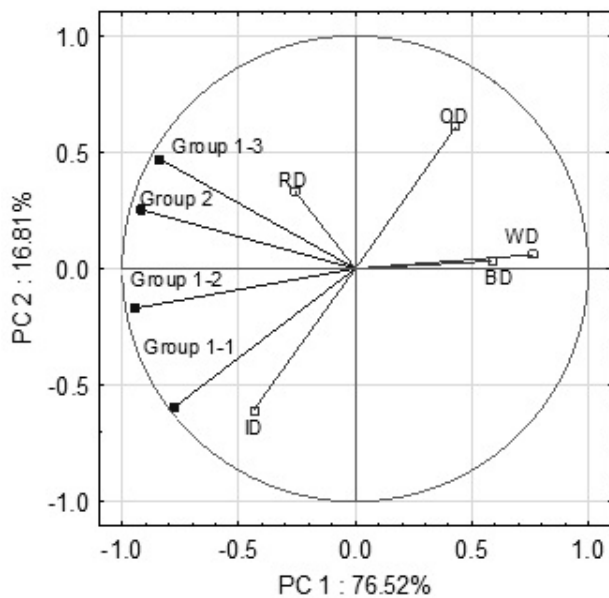


Figure 6. The results of the PCA analysis.

overgrowth process in a year are the changes in of air temperature. Luo et al., (2016) indicate that air temperature has a direct effect on the growth of emergent, floating-leaved and floating vegetation and a significant, but delayed effect on the growth of submerged vegetation. Our studies show that the annual changes in the reservoir overgrowth process were less dependent on changes in water levels. Slightly different results have been obtained by Zhang et al., (2016), who showed that the distribution of vegetation was more and negatively correlated with mean water levels.

In lakes, the overgrowth process is associated with the morphometry of lake basins, mainly in the littoral zone (Skowron & Jaworski, 2017). It has been indicated (Havens et al., 2004; Van Geest et al., 2005) that beneficial for aquatic vegetation are shallow and stable water levels reservoirs. The depth of water bodies plays a significant role in the process of overgrowth (Skowron & Jaworski, 2017). In the analyzed reservoir, the overgrowth process begins from the shore in the shallowest places. Skowron & Piasecki (2014) have shown that the lakes overgrowth process decreases with the distance from the shore. The process of reservoir overgrowth is characterized by spatial variability and progresses from the reservoir inlet to the outlet (main dam). Similar results have been obtained by (Liira et al., 2010) who revealed that the vicinity of large inflows had the strongest positive effect on the expansion of macrophytes.

Previous studies have shown that the satellite data collected in the period of study can be useful for monitoring the spatio-temporal dynamics of aquatic vegetation (Zhao et al., 2012). However, it should be

taken into account that the aquatic vegetation is uncertain in space and dynamic in time (Zhao et al., 2011). For the reservoir studied is difficult to assess inter-annual changes in the overgrowth process. They are associated with the changes in meteorological and hydrological conditions and the regulation of water levels. The errors generated at the stage of image analysis from year to year may lead to overinterpretation. The approach to image classification allowed distinction of two classes of objects within the vegetation and open water reservoir. Zhao et al., (2012) have indicated that using classification trees models (with one threshold value developed for certain image dates to other time periods within the same year or among different years) can reduce the classification accuracy. It has been shown that in the case of analysis of emergent vegetation, floating-leaf vegetation, submerged vegetation and open water dynamics it is necessary to modify the thresholds value using extreme spectral indices to improve the stability of the models (Zhao et al., 2012).

Considering the number of reservoirs, there is a need to develop monitoring of reservoir overgrowth on the basis of satellite images. It is particularly important to cover more reservoirs with the tests, which will allow assessment of the state of degradation and to compare the natural conditions. Understanding the spatio-temporal dynamics of overgrowth process would allow effective management of reservoirs. For example, Zhang et al. 2016 have shown that regulation of water level also may be used for the restoration of aquatic vegetation.

5. CONCLUSION

The analyzes presented in the study allowed the evaluation of seasonal and inter-annual variations in reservoir overgrowth process, spatial changes of the overgrowth process and permitted correlation of the overgrowth process with the morphometric parameters of the reservoir and hydrological conditions. Analysis of the WAVI index values calculated from the Sentinels-2 satellite imagery permitted drawing the following conclusions.

- The dynamics of the reservoir overgrowth process depends on the thermal conditions that are modified by changes in water level in the basin.
- In the phase of plant growth in the reservoir, the highest dynamics of changes was observed at the turn of May and June,
- In the phase of plants decline in the reservoir, the

highest dynamics of changes was observed at the turn of October and November,

- The thermal conditions of the water show strong relationship with the aquatic vegetation cover,
- CA analysis allowed a division of the images into four groups, which describe the phase of plants growth in the reservoir, the phase of maximum coverage of the reservoir with plants, the phase of plants decline from the reservoir and the phase of minimal coverage of the reservoir with plants,
 - In the phase of plant growth in the reservoir and their decline, the main impact on its distribution has depth and distance from the shore,
 - In the phase of maximum coverage, the presence of plants is related to the distance from the inlet and outlet.

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Received at: 29. 06. 2018

Revised at: 24. 08. 2018

Accepted for publication at: 31. 08. 2018

Published online at: 05. 09. 2018