Using of Sentinel-2 images for automation of the forest succession detection

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ABSTRACT
The study was performed for the part of the administrative district Milicz. The authors analysed the parcels where the changes in land use, compared to the cadastral data, were found. The areas of interest were the parcels, where agricultural use was abandoned and the forest succession progressed. This paper investigates the possibility of applying satellite images Sentinel-2A for the automation of land use/land cover change detection, mainly in the aspect of monitoring uncontrolled forest succession. The results of the supervised classification of images Sentinel-2A were referred to the results of the traditionally applied manual vectorization of aerial orthophotomap. The difference for area covered by trees or shrub was 3.85% of the analysed parcels area. Analysing the results for each parcel in which the process of succession occurred, the mean difference is on average 2.25% for one parcel. The mean difference in the absolute value of the total area of participation in individual land use plots was about 1.54% of the analysed area.

Introduction

Monitoring of land use/land cover (LULC) changes is essential in the aspect of the programmes of the European Union, including the subject of proper land management and granting direct subsidies to agriculture. Farmers are obliged to maintain their farmland in so-called “good agriculture”, i.e. they have to prevent soil erosion and succession of vegetation not being useful for agricultural production. Monitoring the areas of vegetation left to natural forestation is also important in the context of people safety and environmental protection. It is important in monitoring fire hazard in terms of protect civilians and any kind of properties or land regardless of the ownership. This issue is also vital for the assessment of biomass, renewable energy and problems of carbon sequestration (Susyan, Wirth, Ananyeva, & Stolnikova, 2011).

The objective of this work was to define the possibilities of automation in the LULC monitoring, regarding the identification of the areas of forest succession. The land abandonment, forest succession and discrepancy between the cadastral data and situation on the ground are well-known problems over Poland. The need for the assessment and monitoring of forest extent and discrepancy between the official forest evidence and situation on the ground in Poland was already reported by various authors (Hościlo, Miroszczyk, & Lewandowska, 2016; Jabłoński, 2015; Kolecka et al., 2017; Kozak, Estreguil, & Troll, 2007; Wężyk, Szostak, & Tompalski, 2009). The problems concerning the LULC changes and forest succession are similar to those of the other countries or regions (Bergen & Dronova, 2007; Bowen, Mcalpine, House, & Smith, 2007; Lasanta et al., 2017; Linder, Lash, & Cramer, 1996; Navarro & Pereira, 2012; Okonomakis & Ganatsas, 2012; Pelorosso, Della Chiesa, Tappeiner, Leone, & Rocchini, 2011; Prévosto et al., 2011; Ruskule, Nikodemus, Kasparinska, Kasparinskis, & Brūmelis, 2012; Stellmes, Röder, Udelhoven, & Hill, 2013). This situation calls for an effort to monitoring land cover dynamics using high-resolution satellite images (Alcantara, Kuenmerle, Prischhepow, & Volker, 2012; Dvavanche, Poulun, & Lefebvre, 2009; Kozak, Estreguil, & Ostapowicz, 2008; Pazár, Lieskovský, Feranec, & Ofahe, 2014; Peterson & Aunap, 1998; Vega-Garcia & Chuvieco, 2006) or airborne laser scanning (ALS) data (Bork & Su, 2007; Falkowski et al., 2009; Kolecka et al., 2015; Singh, Vogler, Shoemaker, & Meentemeyer, 2012; Szostak, Wężyk, & Tompalski, 2014).

The general aim of this paper was to indicate the possibilities of using geoinformation methods in the process of monitoring LULC changes, based on the newest geodata – satellite images Sentinel-2, in reference to traditionally applied manual vectorization methods of the aerial orthophotomaps or Landsat images. Sentinel-2A images were selected to the analyses, as the newest, generally available geodata, made available by the European Space Agency (ESA).
Mission Sentinel-2 consists of two satellites: Sentinel-2A (lunched in 2015) and Sentinel-2B (lunched in 2017), which will operate at altitude of 705 km in the same orbit, phased at 180° to each other and the orbit inclination 98.5°. The satellites are equipped with modern multi-spectral high-resolution scanners, 13 spectral channels, resolution: 10, 20 and 60 m and swath width of 290 km. The revisit time is 10 days for one satellite and 5 days for two satellites.

**Study area**

The study area (Figure 1) is situated in the locality called Pracze (51°28’30″ N, 17°12’30″ E) – the administrative district and commune of Milicz, the Lower Silesia Province, in the south-east part of Poland. The analysed parcels are marked in the ground cadastre as arable lands, meadows or pastures. They were selected due to the direct neighbourhood (a buffer zone of approximately 200 m) with the State Forest areas (Forest District in Milicz), administered by the Polish State Forest National Holding (Figure 2). Usually these are the grounds where agricultural production is stopped and uncontrolled forest succession starts. For this area, earlier studies were performed in the usage of ALS data for the monitoring of LULC changes (Szostak et al., 2014). The area of study consisted of 68 cadastral parcels (total area equal to 68.57 ha; a mean parcel area of 1.01 ha). The built-up areas were excluded from the study.

**Materials and methods**

In this paper, we used the following materials:

- Satellite imagery Sentinel-2A of 23 May 2016 (source: ESA), coordinates system: WGS84/UTM 34N. Channels: 4 (Red), 3 (Green), 2 (Blue) and 8 (NIR) were used (pixel 10m). Free

![Figure 1. The study area: The general map of Poland (a), the Lower Silesia Province with the part of Milicz commune (b) – the study area marked red.](image1)

![Figure 2. The analysed parcels – marked red, the parcels of State Forest – hatched area (background: orthophotomap; 2015; coordinates system: PL-PUWG1992).](image2)
Sentinel-2A imagery was downloaded from the ESA Sentinel data hub (https://scihub.copernicus.eu).

- Aerial orthophotomap of 2015 (source: Main Office of Geodesy and Cartography – pl. Główny Urząd Geodezji i Kartografii; GUGiK), coordinates system: PL-PUWG1992, pixel 0.25m.
- ALS point clouds (2012; source: GUGiK), transformed to the form of DTM (Digital Terrain Model), DSM (Digital Surface Model) and nDSM (normalized DSM). ALS data were used only for support manual vectorization orthophotomap. ALS data there were not reference data in this paper because of the actual year 2012.
- Cadastral data (2015; parcels + land use; source: GEOPORTAL and webEWID portal), coordinates system: PL-PUWG1992.

Preliminary image processing (define the range of the area and export to *tiff format) was executed in programme SNAP 3.0.0 (free software ESA). The main processing of Sentinel-2A spectral channels was performed in free software ILWIS 3.3 (academic version). First, linear stretching of histograms in Stretch function was applied and compositions were made: RGB and CIR (Colour InfraRed) with Colour Composite function.

The main task was to do image classification. In this study, the most popular classification method – supervised classification – was used. The Object-Based Image Analysis (OBIA) was the subject of the previous studies (Szostak, Wężyk, Hawryło, & Pietrzykowski, 2015; Szostak, Wężyk, Hawryło, & Puchala, 2016; Szostak et al., 2014). OBIA provides better results, but requires specialized software and user’s knowledge. The essence of this study was to indicate the methodology for the common and widespread detection of abandonment areas based on the newest and generally available satellite imagery – Sentinel-2. For these reasons, the supervised (pixel-based) classification was used. Of course, OBIA and other methods could also be applied.

Pixel-based classification was done using different algorithms – maximum likelihood and minimum distance algorithms (ILWIS). The minimum distance algorithm gave the best results. The classification was based on the photo-interpretation key, prepared during the field visit, for composition RGB and CIR (Figure 3). During the field visit for each class, several training fields were chosen (GPS measurements). In ILWIS software, these training fields were defined as single pixels or groups of pixels. The examples and patterns of the training fields (group of pixels) for the process of the pixel-based classification are given in Figure 3. The following classes of land cover were defined: deciduous forest, coniferous forest, meadows and pastures (one class), arable land and waters. Built-up areas were not analysed. In this study, there was not defined class of forest succession because essence of the study was to detect where the abandonment of agricultural land exists rather than define the different stages of forest succession.

The assessment of the results of classification was performed in ILWIS 3.3 using function Confusion Matrix, defining accuracy as: Average Accuracy (AA), Average Reliability (AR) and Overall Accuracy (OA). The error matrix simply compares the reference pixels to the classified points. The reference pixels were based on validation points from the field terrain (other group than training fields). For each class, several of validation points were collected.

The next stage was GIS processing. Function Majority Filter (the generalization process, Arc Map 10.4. ESRI) was applied for the results of pixel-based classification of Sentinel-2A imagery. Then the results were converted from raster into polygon, in order to refer to the data contained in the ground cadastre. This step allowed selecting the parcels, where the process of forest succession occurs.

At the end, manual vectorization of the orthophotomap was done. The aim of this step was to compare results from the pixel-based classification of the Sentinel-2A imagery with the results of traditionally applied manual vectorization aerial orthophotomap. The operator vectorized vegetation as the outlines of

Figure 3. Sentinel-2A: RGB and CIR composition for the study area, with the marked examples of land use classes.
trees and shrubs using traditional means of photo-
interpretation. Vectorization was performed to define
the range of wooded areas and areas overgrown by
shrubs (class Forest). The manual vectorization pro-
cess was supported by the information about the
height of vegetation (visual interpretation) obtained
from nDSM (normalized Digital Surface Model,
derived from the ALS data). The example of applying
vectorization process was presented in Figure 4,
whereas in Figure 5, nDSM for the whole study area
was shown.

Results
As a result of the pixel-based classification of
Sentinel-2A imagery, it was possible to select the
parcels (from 68 parcels – total area 68.57 ha)
where agricultural use was stopped. This referred to
35 parcels, of total area 45.11 ha. For these parcels, LULC changes were detected – forestation of the area.

In Figure 6, the parcels where the process of forest succession occurred were presented. There were 35 parcels selected in the pixel-based image analysis on Sentinel-2A imagery (Figure 6(a)). For these parcels, the land use registered in the ground cadastre was also shown (Figure 6(b)).

In the subsequent stage of work, these 35 parcels were analysed in detail. The results of manual vectorization were referred to the earlier applied pixel-based classification Sentinel-2A imagery (Figure 7).

Confusion matrix table for the result of the pixel-based classification of Sentinel-2A imagery (OA classification was 98%) was shown in Figure 8 (CF – Coniferous Forest, DF – Deciduous Forest, M and P – Meadow and Pasture, A – Arable Land, W – Water).

The total area of agricultural land use and its distribution in the analysed parcels according to state of the ground cadastre and the results of the manual vectorization and pixel-based classification of Sentinel-2A imagery were shown in Table 1. Differences between these methods (for 35 parcels) were shown in Table 2.

The land listed in the ground cadastre as forests and the areas identified as forest succession areas, i.e. wooded areas and the areas covered with shrubs, were in the table combined as one class Forest. The meadows and pastures were also one class Meadow.
The total area of land use classes for 35 parcels analysed in detail (total area 45.11 ha).

| Land use          | Cadastral data | Ortho | Sentinel |
|-------------------|---------------|-------|----------|
|                   | Area [ha]     | Percentage [%] | Area [ha]     | Percentage [%] | Area [ha]     | Percentage [%] |
| Arable land       | 31.27         | 69.30  | 17.43    | 38.64         | 16.57        | 36.74       |
| Meadow and pasture| 6.38          | 14.14  | 3.88     | 8.6           | 3.13         | 6.93        |
| Forest            | 5.73          | 12.71  | 22.59    | 50.08         | 24.33        | 53.93       |
| Other classes     | 1.73          | 3.85   | 1.21     | 2.68          | 1.08         | 2.40        |
| Total             | 45.11 ha (100%) |       |          |               |             |             |

| Land use          | Cadastral data | Ortho | Sentinel |
|-------------------|---------------|-------|----------|
|                   | Area [ha]     | Percentage [%] | Area [ha]     | Percentage [%] | Area [ha]     | Percentage [%] |
| Arable land       | 13.83         | 30.66  | 0.86     | 1.67          | 0.28         | 0.52       |
| Meadow and pasture| 2.50          | 5.54   | 0.75     | 1.54          | 0.52         | 0.17       |
| Forest            | −16.86        | −37.37 | 1.74     | 3.85          | 0.52         | 0.17       |
| Other classes     | 0.52          | 1.17   | −0.12    | −0.28         | 0.52         | 0.17       |

Table 1. The total area of land use classes for 35 parcels analysed in detail (total area 45.11 ha).

Table 2. Differences between land use classes areas based on the results of manual vectorization, pixel-based image classification and cadastral data.

and Pasture. The land classified as Other classes included: recreational areas (R), wastelands (Ws), communication areas (C) and waters (W).

At the beginning, one should emphasize a big difference in the results of a manual vectorization and a pixel-based classification of Sentinel-2A imagery in the relation to the official data – land use, contained in the ground cadastre. Nearly 37.37% of the area of the analysed parcels, which are wooded or overgrown by shrubs, are inventoried in the ground cadastre as agricultural land. Similar results were indicated by the earlier papers (Szostak et al., 2014) and the reports of the field check-ups in terms of subsidies for farming and agriculture. In the paper by Szostak et al. (2014), the result of manual vectorization orthophotomap (2007) indicated 33.66% more area covered by trees or shrubs than it was indicated by the status in the ground cadastre for the analysed area. This points to the progress in the succession processes of the analysed area and the fact that these grounds within the period of the recent 10 years (they were not monitored earlier) have not been agriculturally used, although the state in ground cadastre shows the opposite.

Based on the classification of Sentinel-2A imagery and the manual vectorization of the orthophotomap, the following areas and percentage distribution of main land use categories occurring on the analysed parcels were identified: forested and shrub (class Forest)-covered land was according to Sentinel-2A 24.33 ha (53.93% of the study area) and in the orthophotomap vectorization it was 22.59 ha (50.08%); arable land was 16.57 ha (36.74%) and 17.43 ha (38.64%), respectively; meadows and pastures covered 3.13 ha (6.93%) and 3.88 ha (8.60%). Other land use classes covered 1.08 ha (2.40%) according to Sentinel-2A and 1.21 ha (2.68%) for manual vectorization.

The difference between the results of the classification of Sentinel-2A imagery and the manual vectorization of the orthophotomap (SENTINEL – ORTHO) was formed in the following way: for forest and wooded or shrub-covered ground (class Forest), it was 1.74 ha (which is 3.85% of the area of the analysed parcels), for arable land –0.86 ha (−1.90%) and for meadows and pastures −0.75 ha (−1.67%), respectively. The mean difference in the absolute value of the total area of participation in individual land use plots was about 1.54% (0.69 ha) of the analysed area.

Analysing the results of the pixel-based classification by Sentinel-2A and the manual vectorization orthophotomap for individual land use (according to the cadastral data) for each 35 parcels, for which the process of succession occurred, the mean difference (SENTINEL – ORTHO) in defining the area covered by trees and/or shrub (class Forest) on all the land use of the analysed parcels is 0.03 ha, which is 0.06% of the total analysed area of the parcels (45.11 ha). Taking into account the mean area of the parcel, in the land affected by forest succession, which was 1.29 ha, this difference is on average 2.25% for one parcel.

To sum up, the presented results, one can state that processing of Sentinel-2A imagery gave good results compared to traditionally applied vectorization of orthophotomap. Earlier studies performed for this area (Szostak et al., 2014) indicated, for areas covered by trees and shrubs (class Forest), the difference of 2% (0.79 ha) determined based on the vectorization of the orthophotomap (in composition RBG) and the analysis of ALS data. Thanks to free and universal access, satellite images Sentinel-2 can be an alternative for the monitoring of LULC changes, mainly the area of forest succession. Contrary to relatively rare ALS flights and slow updating of orthophotomaps, all the time available satellite images Sentinel-2 can definitely be used for detection of the areas of uncontrolled forest succession. Referring to the papers on the use of Landsat images for monitoring of LULC changes and monitoring of agricultural land abandonment (Baker, Lawrence, Montagne, & Patten, 2006; Hall, Botkin, Strebel, Woods, & Goets, 1991; Prishchepov, Volker, Dubinin, & Alcantara, 2012; Reschke & Hüttich, 2014; Szostak et al., 2015) Townsend et al., 2009), images Sentinel-2 (Bontemps et al., 2015) provide new possibilities of application, mainly due to better terrain resolution of spectral channels R, G, B and NIR.
Conclusions

In this paper, the discrepancies were shown in the range of the forested and wooded areas, between the official cadastral data and a definite use of the manual vectorization and pixel-based classification satellite images Sentinel-2. It provides legitimate reasons for automation of the process of detection of the areas of uncontrolled forest succession. Cadastral databases are outdated and do not reflect the scale of the process of tree and shrub invasion on the land where the agricultural use has stopped.

Only a small difference in general total area and within the borders of individual land use plots, defined according to the classification of Sentinel-2 imagery and as a result of the manual vectorization of the orthophotomap, indicates the possibility of replacing the process of manual determination of the range of forest succession based on aerial orthophotomaps – by processing, generally available, newest satellite images Sentinel-2 with the application of image classification methods: supervised classification or more advanced OBIAs.

The study showed the possibility of updating land use classes in the aspect of forest succession, with the processing of modern satellite images Sentinel-2. This will allow for much faster and cheaper (based on free geodata) inventory of LULC changes, which is important in the aspect of the implementation of EU programmes, and can significantly improve the updating of the cadastral databases. The remote-sensing technology provides accurate information on the spatial and temporal distribution of land cover/land use classes and shows the spatial range of vegetation.

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