INFLUENCE OF CANOPY HEIGHT MODEL METHODOLOGY ON DETERMINING ABANDONED AGRICULTURAL AREAS

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Abstract. Determining areas affected by forest succession is one of the main tasks aimed at shaping rural areas. Effective determination of the parameters of the dynamics of forest succession in areas used for agriculture is the basis for understanding the phenomenon of land cultivation abandonment. Understanding it allows to implement a proper policy limiting the negative effects of giving up agricultural production. There are many methods to determine forested areas. The most popular group of the methods includes those that rely on the use of LiDAR data. LiDAR data are processed to build the Canopy Height Model. The use of the data from aerial laser scanning (ALS) enables obtaining information on the area of afforestation as well as parameters of individual trees, such as their height or surface area. The use of different methods of acquiring the Canopy Height Model affects the obtained results of environmental analyses. The article is an analysis of methods allowing to determine the parameters of the dynamics of forest succession in areas used for agriculture. High accuracy aerial laser scanning (ALS) data as well as cadastral databases were used. The research area was located in Southern Poland, where the phenomenon of land abandonment occurs with high intensity. The obtained results allowed to draw conclusions useful during the construction of the Canopy Height Model. They are helpful when determining the parameters of the dynamics of forest succession and allow to develop the Canopy Height Model methodology including parameters related to the location of the research.

Keywords: GIS, LiDAR, land-use.

Introduction

The change in land use is one of the dynamic processes occurring almost all over the world [1]. It is an effect of a number of interacting factors of economic, social, and demographic nature. The most noticeable effect of these changes are those associated with forest cover related both to the processes of cutting down forests, especially the tropical ones, and afforestation of land previously used for agriculture [2]. The occurrence of afforestation in areas traditionally used for agriculture is often the result of implementing programs supporting this process financially, but in many cases it is the result of permanent abandonment of land cultivation.

Permanent abandonment of land cultivation is observed in many countries characterized by a relatively high level of economic development and stable or negative natural increase related to the flow of people from rural areas to cities. This phenomenon has affected or is affecting most European countries, with the highest intensity observed in Eastern European countries [3], which agriculture had to adapt quickly to the market conditions after political transformation in the early 90s of the last century. Southern Poland is one of the regions, where abandonment of land cultivation is recorded with the highest intensity. This is related to the impact of a number of factors affecting the reduction of agricultural profitability: dominance of small area farms, poor soil quality, unfavorable land fragmentation parameters [4] or low quality and insufficient density of agricultural transport network [5]. The abandonment of agricultural production contributes to the appearance of forest vegetation, which transforms arable land into forests over time. The process of changing the use of arable land into a forest is one of dynamic processes, and determining whether given arable land has already changed into a forest or whether it is still an afforested area is very difficult. There are many conditions (related to legal regulations or physical parameters of trees communities) that must be met before an area can be regarded as a forest. Due to the nature of the work, which aims to compare the methods of creating the Canopy Height Model, an area with forest vegetation exceeding 2 m above the ground covering arable land is regarded as a forest area.

Uncontrolled cessation of agricultural production on land with good soil quality is a serious problem of modern agriculture, as it results in permanent reduction of areas capable of agricultural production. The restoration of abandoned areas, already occupied by forest vegetation, is very difficult, time-consuming, and expensive. There are cases, where temporal afforestation allows to improve the soil conditions. In order to obtain positive results, the process of temporary exclusion from agricultural production must be properly supervised. The cases where the resumption of agricultural production took place are very rare and they are related to programs that improve the conditions for shaping agricultural areas. For this reason, national programs and legal regulations that, on the one hand, aim to facilitate the afforestation of land with the lowest agricultural usefulness, and on the other, protect from these activities areas with good quality soils, are of significant importance. The basis for the development of effective tools in this area is the fast and reliable monitoring of areas which are a subject to controlled forms of afforestation and natural forest succession. It may be based on the analysis of satellite or airborne images [6], however, the greatest possibilities are given by techniques that not only assess the extent of afforestation, but also its height structure, as in the case of techniques based on airborne laser scanning [7; 8]. Data acquired with the use of remote sensing techniques combined with classification algorithms or statistical models allow monitoring changes in land use. The use of the LiDAR technology allows to obtain data on terrain and its cover. Thanks to the ALS technology, it is possible to construct the Canopy Height Model (CHM). It provides information on the surface area of afforestation and the parameters of individual trees, such as their height and surface area [9,10]. Remote sensing data in combination with classification algorithms and statistical models allow to monitor changes in land use [11,12].

Materials and methods

The research area covered parts of the Biecz commune, located in the Gorlice county, in the Małopolska Voivodeship, in the southern part of Poland (Fig. 1).

The ALS data and data from land use cadastral databases were used. The plots, which according to cadastral data were regarded as arable land, but on which high vegetation occurred, were identified. Areas occupied by high vegetation were determined with the use of the LiDAR data. The data are characterized by 0.2 m accuracy of a point location.

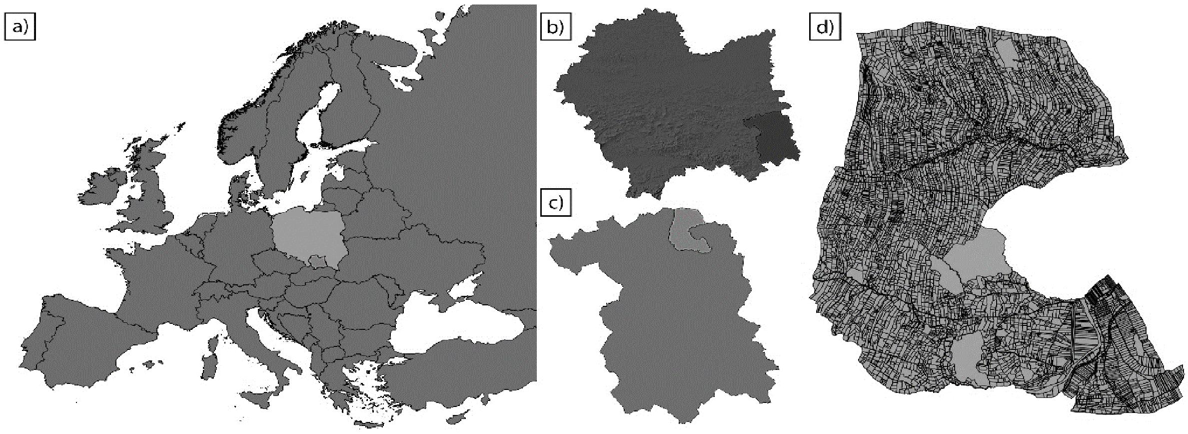

Fig. 1. **Location of study area(d) in Europe, Poland (a), Małopolska(b), and Gorlice county(c)**

The methodology used was to determine the arable land, on which the cessation of agricultural production occurred, which, in turn, resulted in the emergence of high vegetation. The methodology also allowed to determine whether the method of data processing affects the results and whether it is possible to improve the process of building the CHM. For this purpose, two methods of obtaining the CHM model were incorporated.

The first method of building the CHM was based on subtracting the DSM (Digital Surface Model) from the DTM (Digital Terrain Model) [13; 14]. A classified point cloud was used to create rasters representing the DTM and DSM, which contained only points representing high vegetation. The value of the DTM model was created on the basis of the average height of points in a raster grid. The DSM model took into account the greatest height of a point belonging to the high vegetation for each raster grid. The subtraction of the DSM from the DTM raster model resulted in the CHM. ArcGIS tools were used in building the CHM, what allowed to create two raster models (DSM and DTM) from point clouds and to calculate their difference. Las Dataset containing a point cloud consisting of ground and high vegetation layers was created in ArcGIS. Using Las Dataset to Raster tool, two raster models were created: the first one from the ground layer, the second one containing the high vegetation layer.

Next, using the Raster Calculator tool, a raster model was created as a difference between the first (DTM) and the second (DSM) raster. Default settings of ArcGIS were used during the process.

The second method was based on creating the CHM without the construction of the DSM and DTM. It assumed conversion of the point cloud to CHM raster model. First, a normalized point cloud was created, that is a cloud for which new heights were calculated relative to the ground layer. All points representing the ground layer received heights equal to 0 and for the remaining points the height relative to the ground layer was calculated. The horizontal coordinates (x, y) of the point clouds remained unchanged.

In the process of creating the CHM model the created point cloud was converted to a raster form and the following tools of the LasTools program were used: Lasheight to calculate the height of high vegetation relative to the ground layer; Las2las to create a cloud containing only high vegetation; and Las2dem to create a CHM raster model. All tools used default settings of LasTools program. Both of the CHM raster models had a grid size equal to 1 m (Fig. 2).

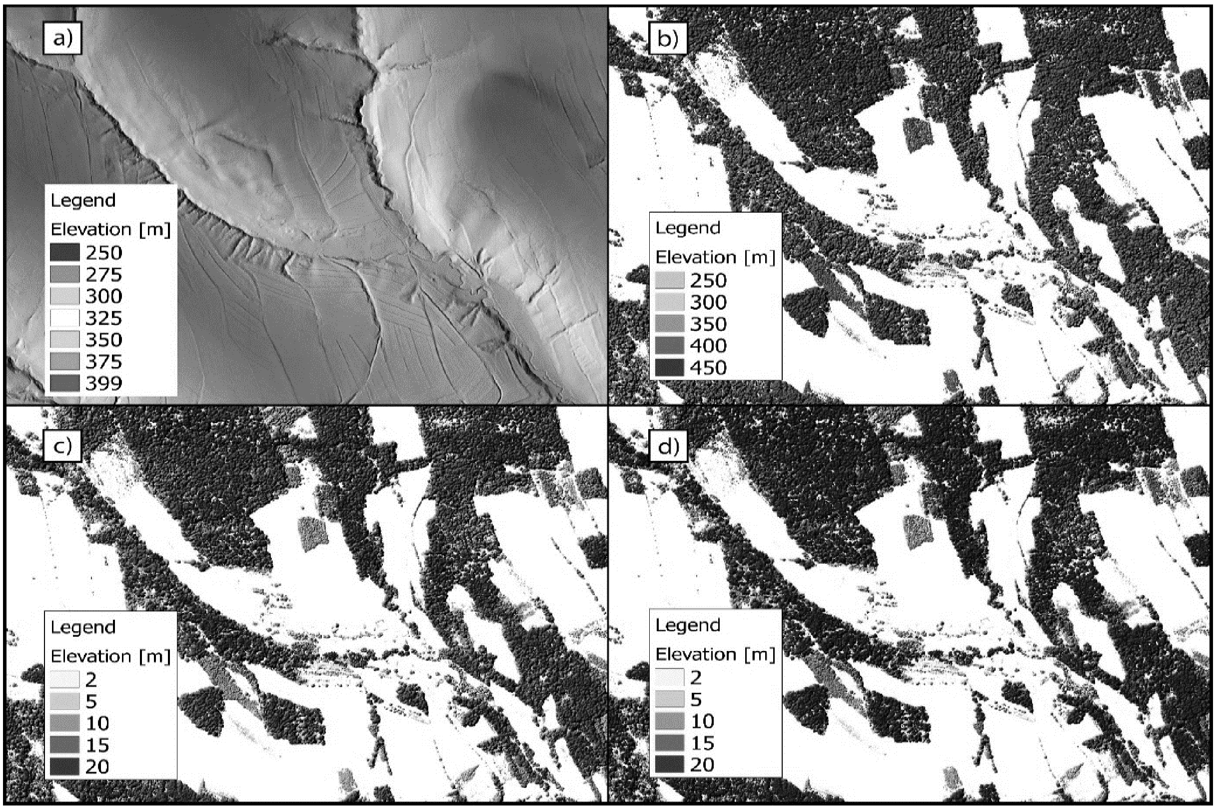

Fig. 2. **Two methods for creating CHM as differences between DSM and DTM were used in study (a); The second model was generated directly from the normalized point cloud (d)**

The methodology assumed to determine the arable land, where forest vegetation appeared. The CHM model created for the analyzed sections was reduced by plots that did not belong to arable land. Then, the obtained rasters were reclassified. The first class included vegetation with the height from 2 to 3 m. The second class included vegetation with the height from 3 to 4 m. The third class was represented by vegetation with the height of 4 to 5 m above ground. The remaining classification of vegetation was conducted in the same way, until reaching the 20th class. Vegetation included in the 20th class was of 21 to 22 m height above the ground. The methodology was designed to determine the range and dynamics of the emergence of forest vegetation, which is why the height classes above 20 were omitted. The studied area is included in the areas, where the change of land use was recorded, therefore the changes are most evident in the initial classes.

The last stage of data processing was related to the spatial analysis. The obtained data on afforestation were used to update information on afforestation and to determine its structure [15]. For this purpose the Zonal Statistics tools of the ArcGIS software were used.

Results and discussion

The analyzed part of the Biecz commune is an agricultural area. Arable land occupies 73.05 % of the area of the commune and 67.47 % of all plots in the studied area. All of the arable land is dominated by plots, which range from 0.25 ha to 0.50 ha, and their number equals to 31.1 % of all plots. The average area of an arable land plot is equal to 0.51 ha, what proves that the land is very fragmented. By analyzing the data contained in cadastral databases, it can be concluded that arable land is located on small area plots, and their number suggests that the spatial structure of registered plots used for agriculture is fragmented (Fig. 3).

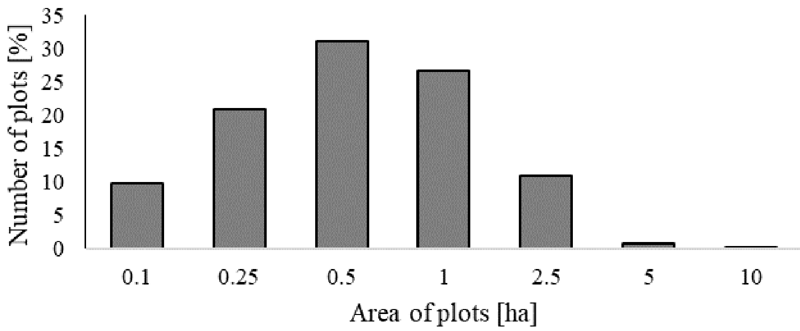

Fig. 3. **Surface area structure of arable land on cadastral plots where high vegetation was identified**

The areas covered with forests are in the second place both in terms of the surface area (17.3 %) and the number of plots (14.07 %). The average area of a forest plot is equal to 0.58 ha. The remaining plots are characterized by a wide variety of use and the number of plots. The plots are used as pastures, roads, built-up areas, and orchards (Fig. 4).

Type of land use	area [m]	%
residential areas - B	61955	0.16
other built-up areas - Bi	115742	0.30
built-up agricultural areas - Br	469601	1.20
grasslands - L	401963	1.03
forests - Ls	6811886	17.39
wooded and shrubbed areas - Lz	134705	0.34
wastelands - N	15980	0.04
pastures - Ps	1250167	3.19
arable lands - R	28617066	73.05
orchards - S	170618	0.44
lands under the water - W	361073	0.92
roads - dr	765422	1.95
Total	39176178.74	100

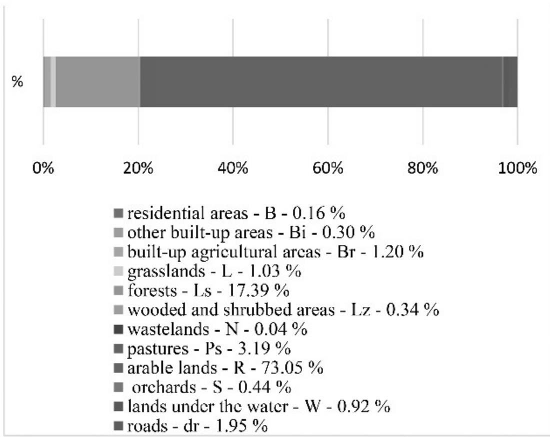

Fig. 4. **Land use structure in analysed area**

Creating the CHM allowed to obtain information on the surface area of afforestation and its height structure [16]. All analyses of afforestation were based on the CHM model, obtained as the difference between the DSM and DTM. Typically, high vegetation occupied the area of 10 to 20 % of arable land (42.44 %). Plots with afforestation below 10 % of the area accounted for 20.65 % of all plots registered as arable lands in the cadastre. The analyses provided data for the plots, where the information about their use should be updated. The total of 506 cadastral plots, with above 50 % of afforestation area, were identified in the study area. The plots constituted 9.64 % of all arable land plots.The height structure of afforestation in the studied area was dominated by classes representing vegetation lower than 10 m (Fig. 5).

Vegetation lower that 10 m amounted to 65 % of afforestation identified with the use of the LiDAR technology. The analysis of afforestation parameters allows to conclude that the forest structure is in the initial stage of development. Afforested areas cover a small fraction of registered plots, and the height structure is dominated by areas, where vegetation does not exceed 10 m. The choice of the methodology did not affect the results. The data provided by the two CHM models were almost the same. Differences in the results of the height structure were noticed only for the first height class (2-3 m), but their value was equal to 0.83 % of the total afforestation identified with the CHM model (Fig. 6).

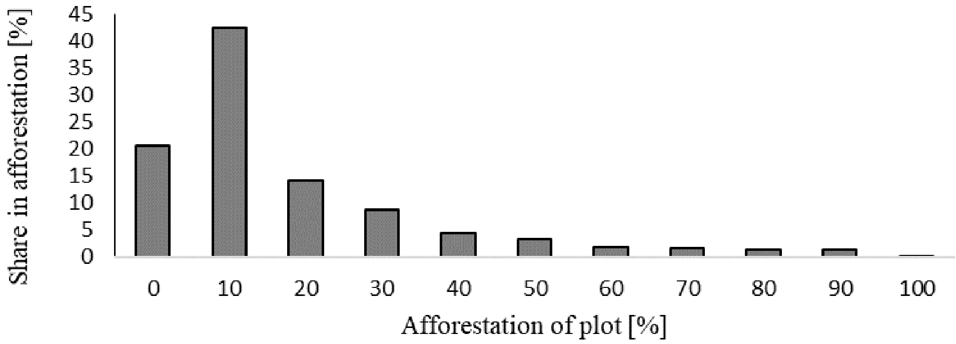

Fig. 5. **Surface area of plots occupied by high vegetation**

Afforested areas calculated with the CHM model, derived directly from the point cloud, were larger. Nevertheless, they reached the differences in the results up to only 0.07 % of the arable land area. Therefore, it should be assumed that the method of generating the CHM model on surface results is negligible. The increase in the afforested area in the CHM model generated from a point cloud resulted in an increase of the height class by 1. The discrepancies in the results were caused by the different ways of calculating the height in relation to the terrain. The first CHM model calculates the height of points relative to the terrain basing on the cell size. The CHM model created from the point cloud calculates the height basing on the nearest points, what resulted in the inconsistencies of the results. However, as it is in the case of surface area calculations, the influence is very small and it does not affect the final results.

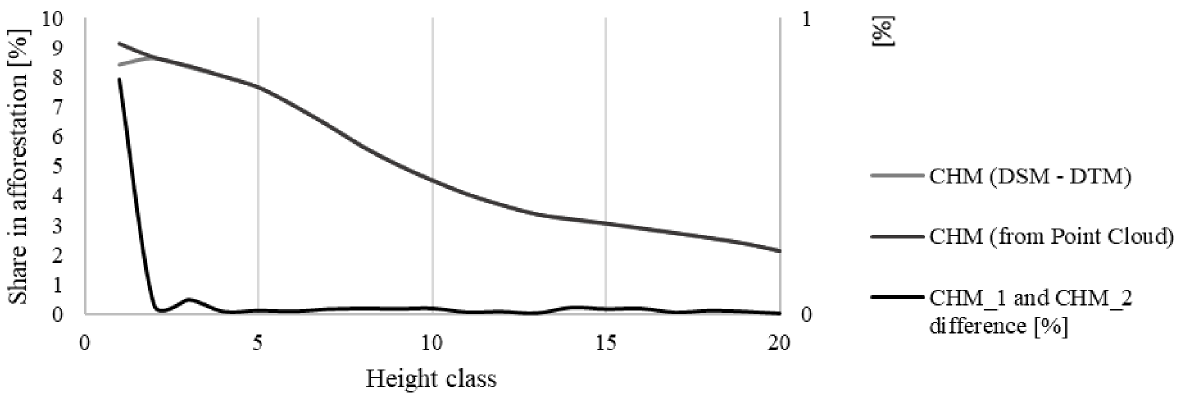

Fig. 6. **Height structure of forest areas identified with CHM model**

Conclusions

The use of the LiDAR technology allows to determine the areas, which were affected by forest succession and to determine the dynamics. The influence of the CHM methodology on determining abandoned agricultural areas is negligible. The results, regardless of the chosen method, are almost identical. At the same time, the chosen methodology has an impact on the process: thanks to the use of the method based on generating the CHM directly from the point cloud, it is possible to improve and expedite the process of identifying abandoned agricultural areas.

Acknowledgements

This research was financed by the Ministry of Science and Higher Education of the Republic of Poland, grant number BM – 4321/KGRKiF/2017.

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