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DETECTION OF URBAN AND SPATIAL CHANGES IN A SELECTED AREA OF KRAKOW ON THE BASIS OF PHOTOGRAMMETRIC DATA

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Summary

This paper presents the process of detecting urban and spatial changes on the basis of photogrammetric data. The studied object was a fragment of the city of Krakow covering parts of the districts of Bronowice, Krowodrza and Prądnik Biały. The following photogrammetric data were used to perform the research: orthophotomaps of a fragment of the city of Krakow from 2009 and 2021; LIDAR data for the same area from 2017 available on the national geoportal. Based on manual classification done by vectorisation of the orthophotomap in the QGIS programme, the changes in the developed fragment of the city were detected. Meanwhile, based on the classified LIDAR data from aerial scanning, a digital elevation model DEM was generated, which was used to briefly characterise the elevation of the study area. The process of classifying the land cover elements together with an analysis of the urban and spatial changes in the study area is described in this publication.

Keywords

orthophotomap • LIDAR • urban and spatial changes • photogrammetric data

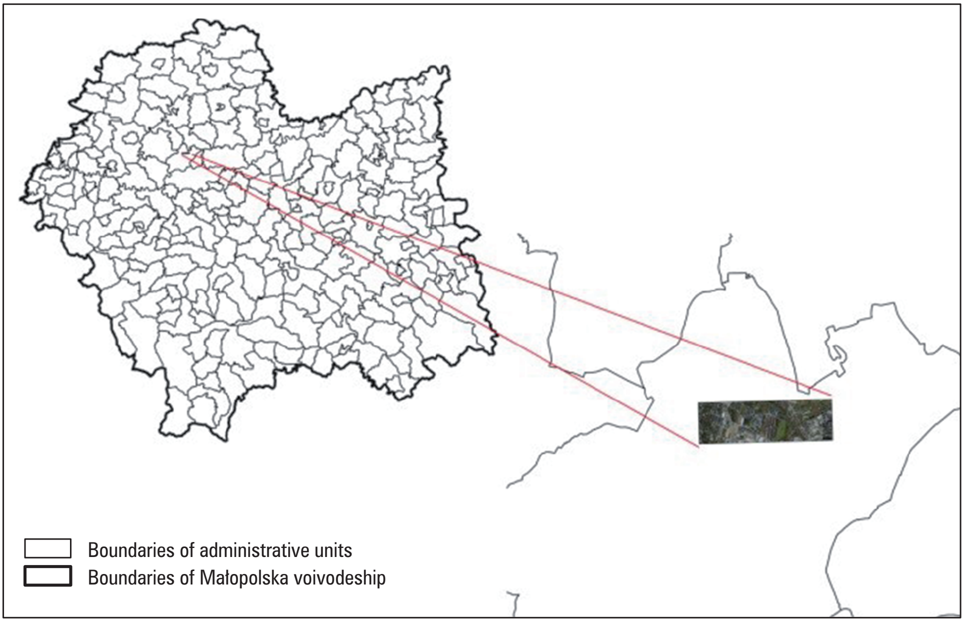
1. Introduction

The natural environment is changing and, as a result, the surrounding landscape is changing. The entire ecosystem of nature is evolving due to the impact of humans on nature. Changes in land use types and land cover classes are very important factors in this process [Wężyk et al. 2013]. The process of urban development is of no small importance in the transformation of the natural environment and land use. Land cover refers to the physical state of a specific area of the Earth's surface and is determined by the natural and anthropogenic objects on its surface. Determining the type of land cover and detecting changes in the urban and spatial shape of the Earth's surface can provide a basis for analysing the directions of development of a given area [Jaskulski et al. 2020, Jelonek and Wyczałek 2006]. This study aimed to show the directions of development in Krakow and the urban-spatial changes that have taken place in the study area. By indicating how the area under study is evolving and by examining what land use predominates in the selected fragment of the city, it is possible to infer its development directions, as well as to forecast what trends or tendencies have been observed in the area. An important aspect of carrying out this study was also to illustrate the extent to which urbanisation has an impact on the disappearance of the natural ecosystem due to human activities. Photogrammetric technologies are often used to detect land cover elements and have gained popularity over the past decade or so, embracing a wide market of applications, both commercially and in the public domain. They can be used both for the detection of land cover classes, such as vegetation, but also work well for the tasks of detecting elements of EGIB and BDOT databases [Plichta et al. 2017]. The issue of investigating land cover changes and providing information on the spatial location of an object is quite often addressed in the literature.

The research on land cover changes in a large city such as Łódź is presented in the paper *Land cover changes in selected areas on the southern outskirts of Łódź between 1973 and 2017: a case study*. The authors of this article used panchromatic photographs from 1973 and an orthophotomap from 2017 as source material, while the research methodology was based on the digitisation of the content of the photographs and the orthophotomap using the photo-interpretation method. As a result of the analyses performed, the authors found that the diversity of land cover types increased in the study areas. In addition, the dominant land cover types have also changed, and a clear increase in built-up and communication-related areas has been observed. Another paper on land cover changes is *Map of land cover changes in Małopolska 1986–2011 made on the basis of object classification of LANDSAT and RAPIDEYE satellite images* by Wężyk et al. [2015], Wężyk et al. [2013]. The authors are concerned with the diagnosis of the main trends of land cover transformations in the Małopolska voivodeship over the period 1986–2011. The article Plichta et al. [2017] *Developing the graphical part of the Land and Building Register based on UAV aerial photographs* addresses the issue of using image data as a data source for EGIB and BDOT databases. The authors of the publication state that such photogrammetric data can be used for developing the graphical part of the land and building register in terms of detecting the existing buildings, but also for showing accompanying elements, i.e. terraces, stairs or annexes. They stress, however, that not all objects can be conclusively identified on aerial surveys due to difficulties in determining the shape and size of the object due to obscuring slopes or the frequent occurrence of eaves next to buildings. The issue of land cover changes in terms of vegetation was also addressed by the authors of the publication *Changes in land cover in the Błędowska Desert between 1926 and 2005*. In this paper, an assessment of the extent of land cover changes was made based on archival and contemporary (at the time of the study) aerial and satellite imagery. It was based on photo interpretation of images (aerial photographs from 1926, satellite images CORONA from 1968 and orthophotomap from images recorded by satellite IKONOS from 2005) carried out in a GIS environment [Bryś and Gołuch 2015]. Photogrammetric data are currently used in many areas of the economy and are increasingly popular with various types of institutions, companies but also individuals [Kubalska and Preuss 2014]. Thanks to the widespread availability of these data, any person can use them to the extent that interests them. The information contained in photogrammetric data sources makes it possible to employ them to a very wide extent [Izdebski 2020]. Photogrammetric data should be understood as any graphical-descriptive information that can be obtained about the terrain and elements related to it, which was obtained by using any photogrammetric measurement methods, as well as the products of processing the results of these measurements. Among the most commonly used photogrammetric data, we can distinguish: orthophotomap, airborne laser scanning, Numerical Terrain Model, Numerical Land Cover Model [Forkuo 2008], satellite images [Piech and Drożdż 2010], terrestrial laser scanning [Zawieska et al. 2013].

2. Study area

The object analysed in this study is a fragment of the Prądnik Biały, Krowodrza and Bronowice districts located in the Małopolska voivodeship in the municipality of Krakow. The study area covers an area of approximately 320 ha and its location is shown in Figure 1.



Source: Authors' own study

Fig. 1. Location of the analysed object

The study area of Krakow includes a fragment of three of its districts: Prądnik Biały (IV), Krowodrza (V) and Bronowice (VI). These districts are the most north-western districts of Krakow city. The analysed area of Krowodrza district is very strongly urbanised, with the majority of its area covered by residential buildings and road infrastructure. The other two districts, due to their proximity to neighbouring municipalities, are more diverse in terms of land cover.

3. Data preparation and methodology

Orthophotomaps of the study area from the two time periods, 2009 and 2021, were used in this analysis. The images were obtained from the national geoportal and are publicly available for download data. One orthophotomap has dimensions of 32000 × 20000 pixels. Two maps were used for the analyses. The materials from 2021 are characterised by a horizontal and vertical resolution of 96 dpi (96 points per inch of image) and a depth of 24 bits, which corresponds to the amount of colour information available for each image pixel. In contrast, the 2009 ortophotomaps have dimensions of 9046 × 9367 pixels and a resolution of 1 dpi. The field pixel size was 0.25 m for the 2009 map and 0.05 m for the 2021 map, respectively. The depth in bits is the same for both map primers. Land cover elements were detected on both digital maps, for which areas were then calculated based on plotted vector polygons characterising specific classes and changes in their extent were examined. QGIS software was used for this purpose. The elements were indicated with the ‘Draw Polygon’ tool. It allows to draw closed polygons, which can be given a chosen colour and shape. Based on the land cover elements on the orthophotomap, the entire area designated for analysis was classed using this tool. Each land cover class in QGIS corresponded to one vector layer, which was assumed for both the 2009 and 2021 maps. The areas of each class were calculated using the ‘Group Stats’ tool, which can perform automatic calculations and simple analyses for objects on vector layers. The calculations resulted in the areas of each class of cover in hectares with an accuracy of 1 m^2. Other data used for the study was a LIDAR point cloud from aerial laser scanning from 2017. This data was also obtained from the national geoportal. LIDAR survey data are used, among other things, to create and update NMT and NMPT, but they also provide useful analytical material on their own. In Poland, ALS data with point densities varying from 4 pts/m^2 even up to 20 pts/m^2 (for cities) are available for the whole country. The study area includes urban areas, so the point density for the data compiled is 20 pts/m^2. The acquired scanning data were classified. Then, additionally, a second, this time manual point cloud classification was performed on the basis of the LIDAR data. The ‘Free-Form Selection’ tool was used for this purpose, allowing the desired part of the point cloud, in any shape, to be selected and then assigned a land cover class from those available in the software. Based on these two types of classification, Digital Elevation Models (DEMs) were generated. The differences between the two classifications and an analysis of the results obtained are presented. The work with the point cloud was done in Agisoft Metashape Professional software.

4. Analysis of spatial data

4.1. Using an orthophotomap to detect urban and spatial changes in the study area of the city of Krakow

On the 2009 orthophotomap, it is clear that these areas were greenfields with buildings covering a negligible part, whereas in 2021 the area is more urbanised (Fig. 2).

Orthophotomap 2009 | Orthophotomap 2021

Source: Authors' own study

Fig. 2. Difference in land cover (2009–2021, fragment of the study area)

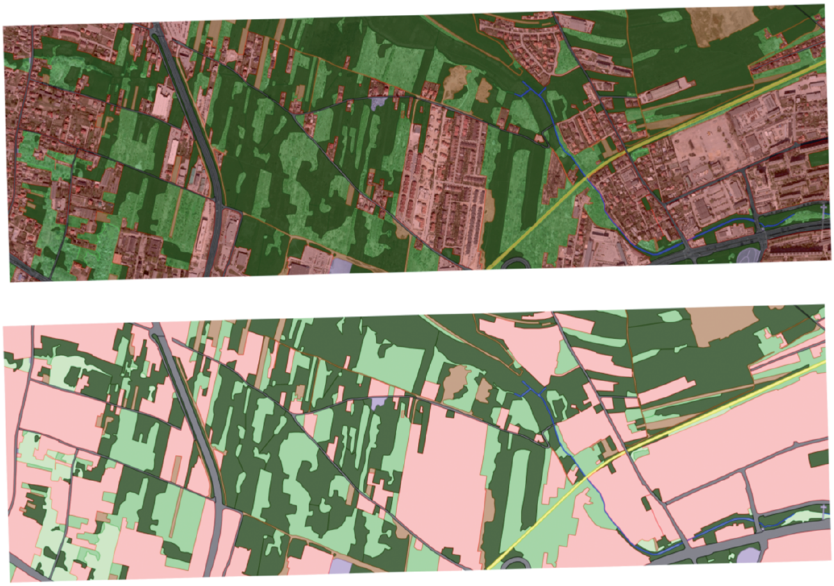
Orthophotomap 2009 | Orthophotomap 2021

Source: Authors' own study

Fig. 3. Land cover difference (2009–2021)

From the example shown, we can see how strongly this part of the city has developed into a built-up area. We can make similar observations in Figure 3. We observe an increase in the proportion of medium and tall vegetation in the land cover.

In order to obtain detailed data on the studied fragment of Krakow based on the orthophotomap, a manual (manual) classification of land cover elements was performed. Within the framework of the study, 9 land cover 'classes' were distinguished for both orthophotomaps: built-up areas – for this analysis, buildings with accompanying infrastructure (car parks, yards, pavements, internal roads, etc.) were considered built-up areas, roads – main communication routes, low vegetation, medium vegetation, high vegetation, points on the ground surface (ground points), waters, railways and tramways, other elements of land cover. Once the process of classifying the elements on the orthophotomap was completed, a map was created containing land cover data in the form of 'coloured polygons', in which each corresponded exactly to one specific land cover element. In Figure 4, the 2009 orthophotomap mainly contains green areas: low, medium and high vegetation, which occupy the vast majority of the central and northern areas. Buildings are mainly located in the western and southeastern parts of the study area. There is also a small concentration of buildings in the centre. Communication areas are partly asphalted (classified as roads) and one can notice that in this fragment there are sections of two main roads of Krakow (Jasnogórska Street and Opolska Street) and other side roads. There are also a lot of dirt roads classified as ground points. Also visible is a section of a watercourse running from the east towards the centre of the study area, as well as railway and tramway tracks in the southeastern part.



Source: Authors' own study

Fig. 4. Classified land cover elements on the ortophotomap from 2009

Analysing Figure 4, it can be seen that the fragments of the development especially in its central part, are small and scattered. This implies the presence of individual buildings or courtyards (Fig. 5) and not a complex of buildings as in the case of Figure 6.

Source: Authors' own study

Fig. 5. Individual buildings on the orthophotomap 2009

Source: Authors' own study

Fig. 6. Complex of buildings on the orthophotomap 2009

By sorting the area using polygons, the surface area of the individual land cover classes was calculated. The areas of the individual cover classes in hectares with an accuracy of 1 m^2 were obtained, which for the 2009 map are summarised in Table 1.

Table 1. Areas of land cover classes classified for the 2009 orthophotomap

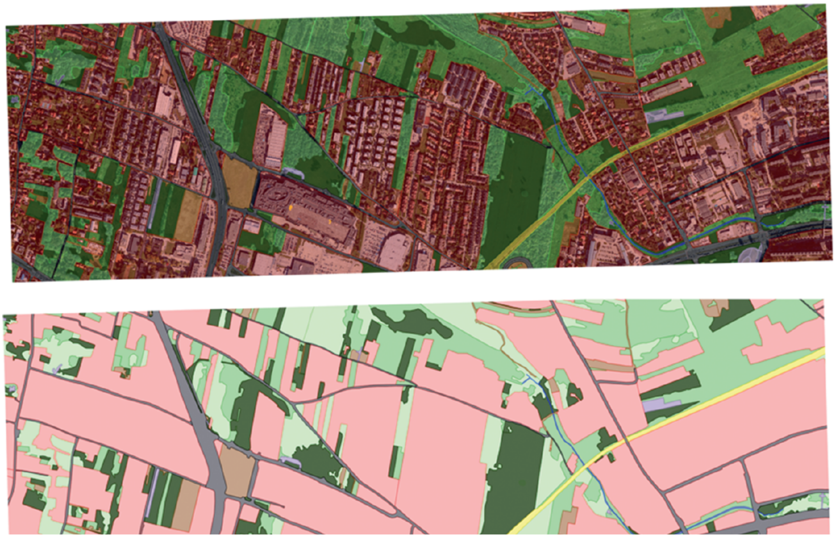
Land cover class	Area [ha]
Built-up areas	120.9086
Roads	14.1905
Ground points	13.7862
Low vegetation	101.1685
Medium vegetation	56.6656
High vegetation	9.4153
Railway and tramway tracks	1.7016
Other elements of land cover	1.1553
Waters	0.5974

As noted in Table 1, by far the largest area is occupied by built-up areas and low vegetation, 120.9086 ha and 101.1685 ha, respectively. The smallest area is occupied by water (0.5974 ha) and other land cover elements (1.1553 ha). Built-up areas account for 37.8% of the total area of the study area and have the largest share in the area of the analysed fragment of Krakow city. Water has the smallest percentage share, only 0.2%. Therefore, it can be concluded that already in 2009 these areas were quite heavily built-up, but considering that all vegetation (low, medium and high) constitutes more than half of the total area of the study site (52.3% – 167.2494 ha) they were still mostly green.

When analysing the land cover on the orthophoto from 2021 (Fig. 7), it can be seen that the vast majority of the area is covered by buildings. It is present to a greater or lesser extent across the entire analysis area. An abundance of low, medium and high vegetation can also be observed. Most of this is found in the northern and northeastern parts of the study area. In addition, the presence of a large number of asphalt roads ('road' class) can easily be noted, while there are few elements classified as ground points. Elements of land cover can be seen on the map, i.e. railways, tramways, water (south-east) and other highly dispersed areas. It is clear from Figure 7 that tightly clustered development predominates, with only small parts of the area being loose, dispersed development.

After the classification of the 2021 orthophotomap, the areas of the different land cover classes in the area were calculated as in the case of the orthophotomap of 12 years ago. These are summarised in Table 2 (in hectares with an accuracy of 1 m^2).

In Table 2, by far the largest area in 2021 is occupied by built-up areas 181.2943 ha, which is 56.7% of the total area of the developed part of Krakow. Green areas occupy a total of 106.5795 ha and most of the greenery is medium vegetation, high and low vegetation is about 31 ha each. The smallest areas are occupied by water (0.3657 ha) and other land cover elements (1.5222 ha). The first noticeable component is the strong predominance of buildings over the rest of the land cover classes. Another highly distinctive component is the vegetation (low, medium and high), which together make up 33.3% of the total land area. Medium vegetation has the highest percentage, while low vegetation has the lowest. More than 6% is occupied by roads, while the other classes make up less than 3% of the area share.



Source: Authors' own study

Fig. 7. Classified land cover elements on the 2021 ortophotomap

Table 2. Areas of land cover classes included in the 2021 orthophotomap

Land cover class	Area [ha]
Built-up areas	181.2943
Roads	19.4726
Ground points	7.3117
Low vegetation	31.0288
Medium vegetation	44.0965
High vegetation	31.4542
Railways and tramways	3.0434
Other elements of land cover	1.5222
Waters	0.3657

4.2. Analysis of land cover changes based on classified orthophotomaps from 2009 and 2021

The analysis of land cover changes between 2009 and 2021 in the fragment of Krakow was made on the basis of classified land cover elements on orthophotomaps. Figure 8 compares orthophotomaps from two different time periods. One can notice a definite increase in the amount of built-up areas, at the expense of green areas. The other thing that can be observed is an increase in high and medium vegetation and a dramatic decrease in low greenery.

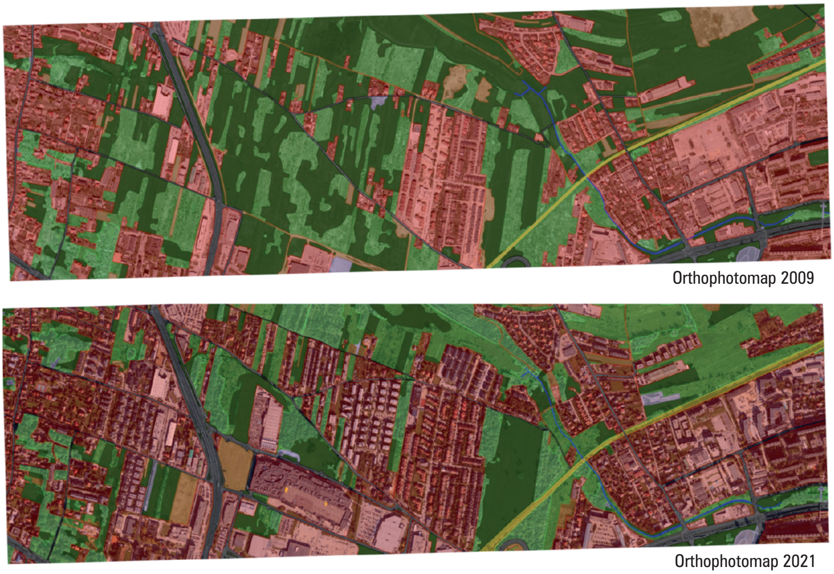


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Fig. 8. Comparison of classified ortophotomaps from 2009 and 2021

Table 3 compares the area of land cover classes from 2009 and 2021. The last column shows the difference in area (2021 minus 2009). There was an increase in built-up areas by as much as 60.4578 ha, high vegetation by 22.1110 ha and roads by 5.3542 ha. These are the three main land cover elements that have increased over the 12 years. The largest decrease in area was in low vegetation, by as much as 70.0676 ha, and in medium vegetation, by 12.4970 ha. These changes can mainly be attributed to human activity and the take-up of areas with a 'low vegetation' class by built-up areas, tree planting and natural growth of greenery over the years. The amount of ground points has also decreased, while the number of roads has increased, which may be explained by the gradual improvement of the transport network and systematic improvement of road conditions, by increasing the number of asphalt roads, in place of the former dirt roads.

Table 3. Comparison of areas of land cover class in 2009 and 2021

Land cover class	Area in 2021 [ha]	Area in 2009 [ha]	Difference in area (2021–2009)
Built-up areas	181.2943	120.9086	60.4578
Roads	19.4726	14.1905	5.3542
Ground points	7.3117	13.7862	–6.4024
Low vegetation	31.0288	101.1685	–70.0676
Medium vegetation	44.0965	56.6656	–12.4970
High vegetation	31.4542	9.4153	22.1110
Railways and tramways	3.0434	1.7016	1.4139
Other elements of land cover	1.5222	1.1553	0.4390
Waters	0.3657	0.5974	–0.1596

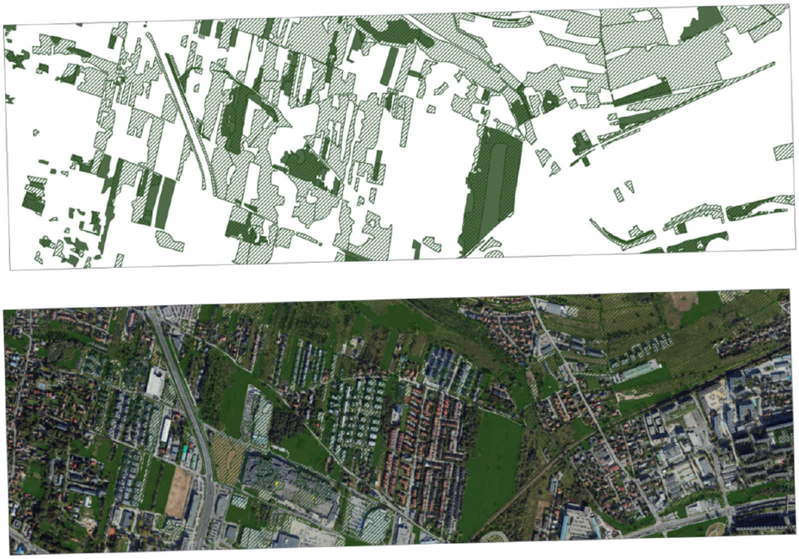
Figures 9–15 present the land cover classes highlighted for 2009 and 2021. They also show the fragments that have not changed their use since 2009. The elements classified on the basis of the 2009 orthophotomap, in order to distinguish them from the 2021 orthophotomap, are represented in hatched form.

Source: Authors' own study

Fig. 9. Comparison of the 'built-up area' class in both time periods

The built-up area has grown to a very large extent. Previously, the main concentrations of built-up areas were in the southeast and west, and to a small extent also in the central part. By 2021 the built-up area has expanded over the entire study area and it is difficult to determine which areas are the least built-up. Only the north and northeast parts seem to be less densely built up. The development of single, detached buildings that were common in 2009 have also disappeared, and large building complexes have emerged, most of which are new housing estates or public facilities.

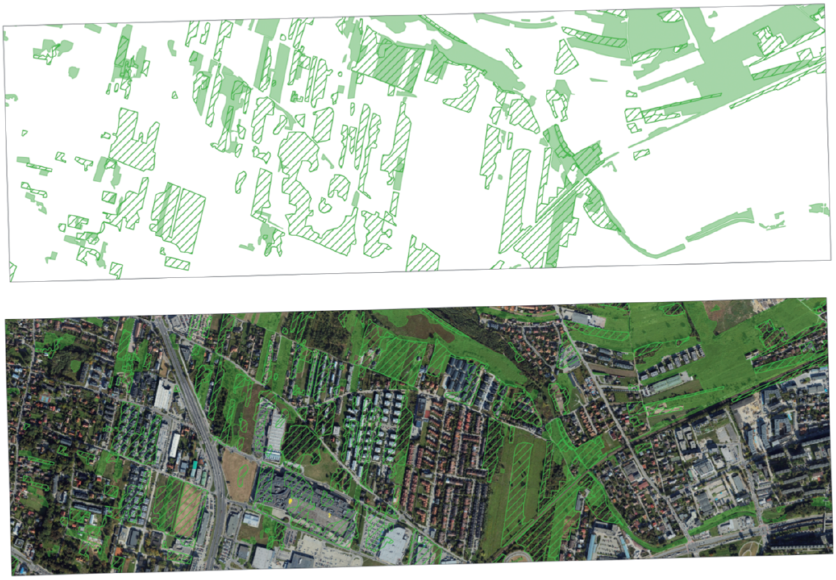
In the case of low vegetation, the situation is the opposite compared to built-up areas. Previously it was one of the predominant classes, covering a large area throughout the study field, but after 12 years there has been a reduction by over 70 ha in these areas. Figure 10 shows a year-by-year comparison of the class, which shows that there is very little low vegetation in 2021 and it only occurs in a few larger clusters.



Source: Authors' own study

Fig. 10. Comparison of the 'low vegetation' class in both time periods

The terrain component of medium vegetation can be considered relatively permanent, in contrast to the built-up areas and low vegetation. Despite maintaining a similar area, the locations of this terrain component have changed (Fig. 11). In 2009, most of the medium vegetation overgrew the central areas, whereas in 2021 it mainly covered the northern and northeastern areas. Unlike the other vegetation-related classes, it is characterised by an increase in area over the years. In 2021 it increased its area by just over 22 ha relative to 2009. One can observe in Figure 12 that the hatched elements, i.e. presenting the land cover for the 2009 orthophoto, are mostly concentrated in the western part of the analysed area of the city and small fragments in the south-eastern part. In contrast, high vegetation in 2021 was scattered throughout the area.



Source: Authors' own study

Fig. 11. Comparison of the 'medium vegetation' class from both time periods

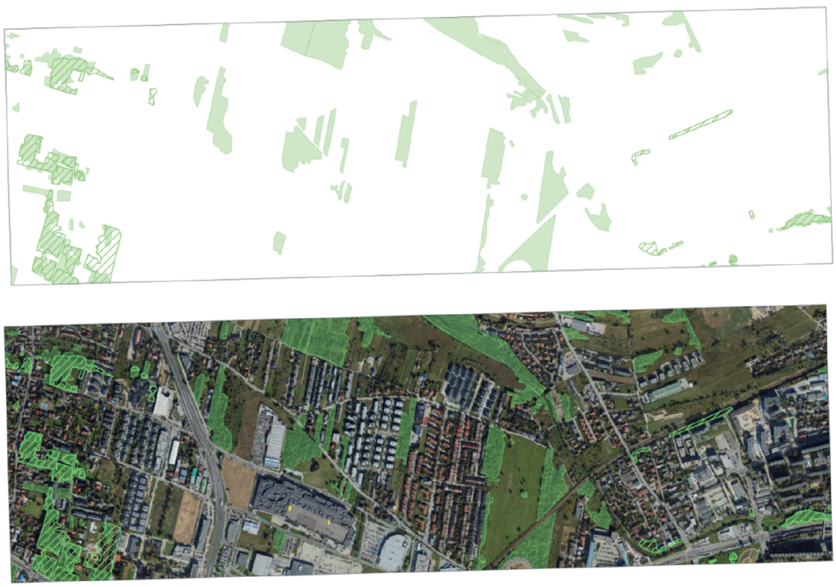


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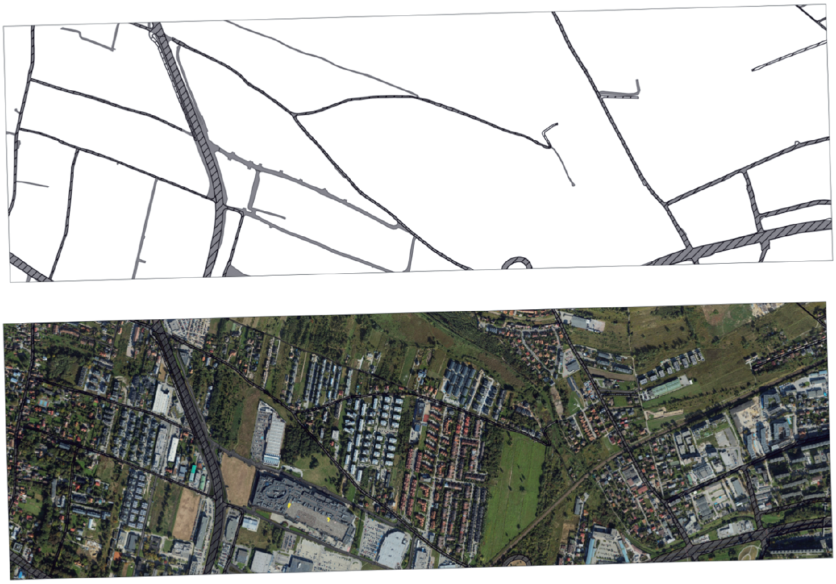
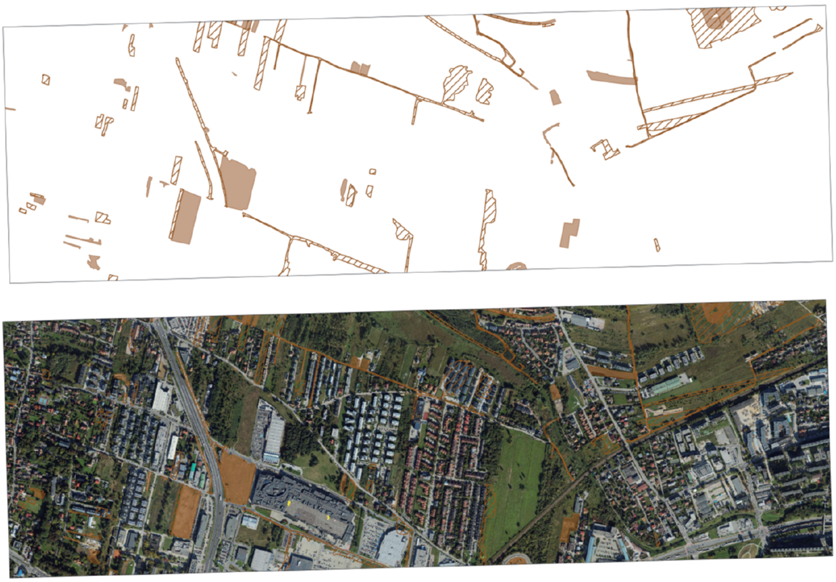
Fig. 12. Comparison of the 'high vegetation' class from two time periods



Source: Authors' own study

Fig. 13. Comparison of the 'road' class between both time periods



Source: Authors' own study

Fig. 14. Comparison of the 'ground points' class between both time periods

Roads were also a class that recorded an increase in area from 14.1905 ha in 2009 to 19.4726 ha in 2021. This is due to the development of transport and road infrastructure, including the construction of new roads and the repair of old ones, such as the replacement of dirt roads with asphalt roads. In Figure 13, the main transport routes from 2009 have remained unchanged or have been widened, while minor roads – access roads – have been added. This has led to a decrease in the proportion of dirt roads and thus in the ground point class, which has almost doubled in area. The differences in the ground point class between 2009 and 2021 are shown in Fig. 14. When analysing Figures 13 and 14, it can be seen that the new areas of the 'roads' class are the former areas of land. In 2009, ground points were often elongated elements (dirt roads) and could be found throughout the entire analysed section of Krakow, whereas in 2021 this class was less numerous and concentrated in a few larger fragments.

The most common issue causing errors in classification is the overlapping of elements from different land cover classes. Usually, this situation concerns elements classified as high vegetation, which obscures other objects located directly below it.

4.3. Processing of LIDAR data in Agisoft Metashape Professional

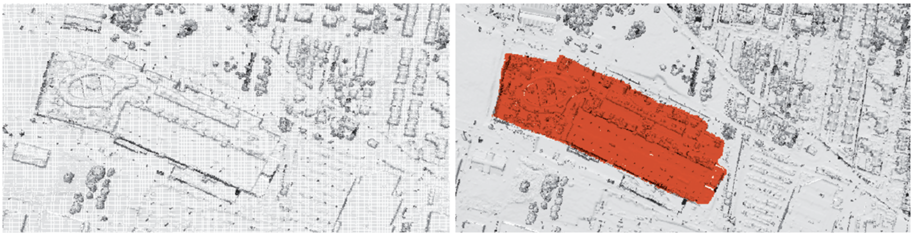
LIDAR data from laser scanning provides information on the spatial position of the object and elevation data. The cloud derived directly from the geoportal was already classified and contained the identified classes. However, Figure 15 shows that it has a lot of imperfections and many points on the cloud do not have a class assigned.

Source: Authors' own study

Fig. 15. Classified point cloud from the national geoportal

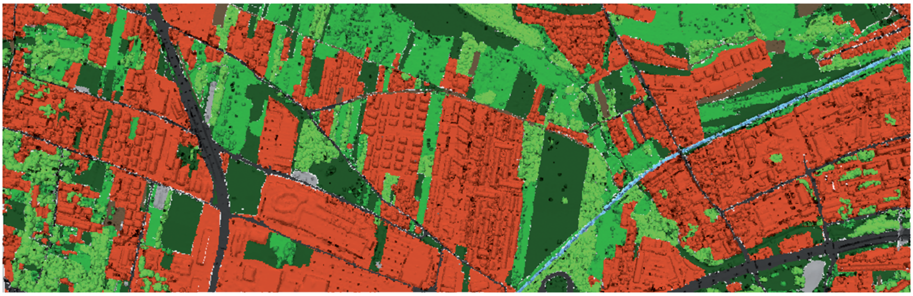
It was therefore decided to create a second classification, this time manually, giving the operator full control over the assignment of a particular class to the cloud points. The unclassified cloud is grey in colour, but once a class is assigned to the selected area, its colour changes to correspond to the assignment to a specific object class. This situation is illustrated in Figure 16 for the object 'buildings'.

The manual classification process distinguished 8 classes, which were automatically assigned an appropriate colour by the software: buildings – red, low vegetation – dark green, medium vegetation – green, high vegetation – light green, road surface – dark grey, ground points – brown, railways – light blue, other (unclassified) – light grey. The final result of the manual classification is shown in Figure 17.



Source: Authors' own study

Fig. 16. Object in the class 'buildings' before and after classification



Source: Authors' own study

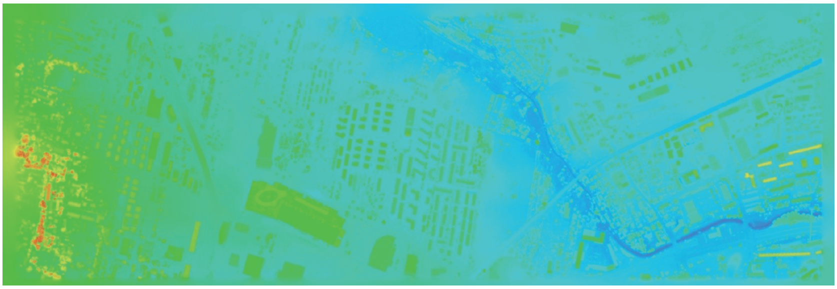
Fig. 17. Manually classified point cloud

The main difference between the classifications is already noted at the stage of class designation, which depends on the method adopted. A comparative overview is presented in Table 4.

The manual classification is considered to be more accurate since it leaves no points without a class assigned (never classified). Furthermore, the geoportal data does not include classes such as road surface or railway, which are very important, especially for urbanised areas, such as the study area. The classified point clouds were used to create Numerical Terrain Models (NMT), which give us with information on the elevation of the relief. Figures 18 and 19 show the elevation models for the two methods of LIDAR data development, NMT of manual classification data and geoportal data, respectively. They show that the models differ very little. The geoportal data did not have classified roads and railways and also had a large number of unclassified points. This resulted in a slight discrepancy between the areas. For the NMT from the manual classification, the elevation values range from 209 to 276 m, while for the second data it is between 209 and 276 m.

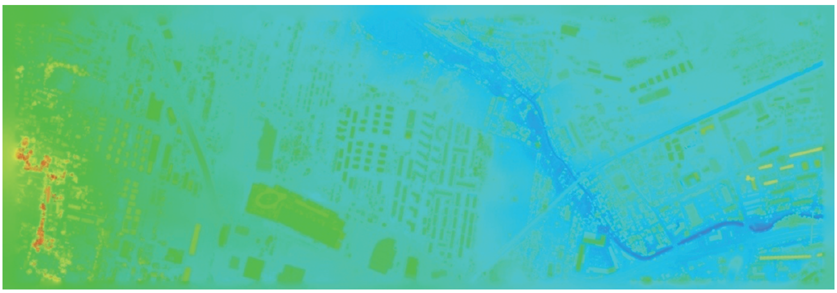
Table 4. Comparison of the occurrence of classes in the two different classification methods

Land cover class		
Geoportal classification		**Manual classification**
Building		Building
Low vegetation		Low vegetation
Medium vegetation		Medium vegetation
High vegetation		High vegetation
Low points (noise)		
Ground		Ground
Water		
		Road surface
Overlap points		
		Rail
		Unclassified
Created (never classified)		



Source: Authors' own study

Fig. 18. DEM model based on manual point cloud classification



Source: Authors' own study

Fig. 19. DEM model based on classified cloud from geoportal

LIDAR data can be used to determine the height of the terrain, and to study slopes and gradients of the ground surface. The elevation model data that we can retrieve from the geoportal are different from those obtained by processing different types of photogrammetric material, i.e. LIDAR. Although the scanning data were also retrieved from the national geoportal, the manual classification resulted in a more accurate and precise representation of the altitudinal variation of the study area. The analysed area is characterised by an altitudinal variation of approximately 67–68 m. The highest points, i.e. those shown in red on the NMT, comprise the vast majority of elements representing high vegetation. Elements oscillating in the medium height range are mostly buildings or medium vegetation. In contrast, the lowest heights have roads, ground points and low vegetation. Analysing Figures 18 and 19, it can be concluded that the terrain decreases from west to east in a fairly uniform manner. Only buildings dominate the other land cover classes in the eastern parts of the study area.

5. Summary, conclusions and discussion of the results

The aim of this publication was to present changes in the urban and spatial structure of a fragment of the city of Krakow that included parts of the districts of Bronowice, Krowodrza and Prądnik Biały. It also indicated the possibilities of using orthophotomaps and LIDAR data in the detection of land cover elements as well as in the study of spatial changes. The use of photogrammetric data to study changes in a given area and to detect land cover elements is becoming increasingly common. Thanks to the wealth of spatial information available in such materials, we can infer possible directions of development of an area, study land cover and discuss the elevation of an area.

The results of the analyses show that photogrammetric data such as orthophotomaps and LIDAR measurement data are a good source of information on the urban and spatial organisation of a given area. The study of the orthophotomaps from 2009 and 2021 indicates a development of the built-up areas in the analysed fragment of Krakow – their area has increased by more than 60 hectares over a period of 12 years. Another class of land cover that has registered an increase between 2009 and 2021, by about 25%, is transport routes.

The results of this analysis clearly show a trend in the study area, namely the loss of natural habitat to anthropogenic habitat caused by intensive human activity. This entails very heavy losses related to the disruption of the natural ecosystem that existed in the area prior to a series of construction projects. The huge increase in building development in the surveyed part of the city of Krakow translates into an increase in the number of people living in the neighbouring districts of Krakow. This in turn indicates an urbanisation trend called suburbanisation, which means leaving the central areas of the city and moving to the outskirts. People are more willing to live in such areas for peace and quiet, while the improving road infrastructure allows quick access to the centre. On the other hand, this brings a loss of vegetation and results in the destruction of vegetation in places where further investment is made. According to the study, the area of all vegetation (low, medium or high) has decreased by just over 60 ha.

Therefore, it can be concluded that there is a certain analogy in the fact that the area of built-up areas has increased by the amount by which the vegetation has decreased.

Expanding urban sprawl is also driven by the lack of space for new development in the central areas of cities, which are already largely built up. However, when settling the outskirts, it is necessary to keep in mind that the negative impact on the environment should be reduced as much as possible in order to preserve as much biologically active land as possible, keeping it natural and undisturbed.

The authors of the article *Land cover changes in selected areas on the southern outskirts of Łódź between 1973 and 2017: a case study* [Jaskulski et al. 2020] came to similar conclusions. According to the study, the dominant land cover type became built-up and communication areas, whose increase in area was caused by losses mainly in grassland vegetation and agricultural land. The authors of the publication *Map of land cover changes in Małopolska 1986–2011 made on the basis of object classification of LANDSAT and RAPIDEYE satellite images* [Wężyk et al. 2013] assert the usefulness of photogrammetric data for studying changes and presenting the spatial situation of an area. As a result of the study, it was found that there was a loss in arable land, afforestation and woodland. An increase in development was noted in these areas. The article Plichta et al. [2017]: *Developing the graphical part of the Land and Building Register based on UAV aerial photographs* claims that such photogrammetric data can be used to provide graphical information about the land and building register, but it is impossible to avoid some errors caused, for example, by roof eaves. Similarly to the analysis carried out in this study. Some of the classifiable elements, both on the orthophotomaps and on the LIDAR data, were hard to interpret due to the overlap of objects from different land cover classes. In the article *Changes in land cover in the Błędowska Desert between 1926 and 2005*, the authors concluded that based on aerial and satellite imagery the changes in the study area are mostly caused by human activity. According to the research presented in this publication, the situation is similar. As a result of human activity, natural areas are lost and become anthropogenic.

In conclusion, the use of orthophotomaps and LIDAR data for the study of urban and spatial changes brings satisfactory results. Surveys carried out on their basis are a unique source of information about the study area, in terms of the coverage of a given area and the detection of its spatial elements. The materials available on the national geoportal are characterised by an increasing accuracy over the years and can now provide a ground for this type of research. Therefore, taking into account all the analysed aspects, it can be said that the detection of urban and spatial changes, of a fragment of the city of Krakow, with the use of photogrammetric data is possible and gives results allowing for the inference of possible directions of development of the selected area.

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References

Bryś H., Gołuch P. 2011. Pustynia Błędowska dawniej i dziś – interpretacja wieloczasowych zdjęć lotniczych i obrazów satelitarnych. Acta Sci. Pol., Geodesia et Descriptio Terrarum, 10 (2), 5–16.

Forkuo E.K. 2008. Digital terrain modeling in a GIS environment. Remote Sensing and Spatial Information Sciences, XXXVII, B2, Pekin.

Izdebski W. 2020. Infrastruktura danych przestrzennych w Polsce, Geo-System Sp. z o.o., Warszawa.

Jaskulski M., Lechowski Ł., Nalej M. 2020. Zmiany pokrycia terenu na wybranych obszarach południowych obrzeży Łodzi w latach 1973–2017: studium przypadku. Uniwersytet Łódzki, Wydział Nauk Geograficznych, Instytut Geografii Miast, Turyzmu i Geoinformacji, Konwersatorium Wiedzy o Mieście, 5 (33).

Jelonek J., Wyczałek I. 2006. Automatyczna detekcja zmian urbanistycznych na zdjęciach lotniczych. Archiwum Fotogrametrii, Kartografii i Teledetekcji, 26, Kraków, 249–258.

Kubalska J.L., Preuss R. 2014. Wykorzystanie danych fotogrametrycznych do inwentaryzacji zieleni na terenach zurbanizowanych. Archiwum Fotogrametrii, Kartografii i Teledetekcji, 26, Kraków, 75–86.

Piech I., Drożdż B. 2010. Obrazy satelitarne jako źródło informacji o krajobrazie. Infrastruktura i Ekologia Terenów Wiejskich, 3. Polska Akademia Nauk, Oddział w Krakowie, 41–54.

Plichta A., Wyczałek M., Wyczałek I. 2017. Opracowanie części graficznej ewidencji gruntów i budynków w oparciu o zdjęcia lotnicze z pokładu UAV. Uniwersytet Zielonogórski, Zeszyty Naukowe, 165.

Wężyk P. 2105. Podręcznik dla uczestników szkoleń z wykorzystania produktów LiDAR. Główny Urząd Geodezji i Kartografii, Warszawa.

Wężyk P., Gęca T. 2013. Weryfikacja i aktualizacja bazy klaso-użytków egib w oparciu o analizy chmury punktów z lotniczego skanowania laserowego na przykładzie wsi Tuklęcz w województwie świętokrzyskim. Archiwum Fotogrametrii, Kartografii i Teledetekcji, wyd. specjalne: Geodezyjne Technologie Pomiarowe, 97–108.

Wężyk P., Wójtowicz-Nowakowska A., Pierzchalski M., Mlost J., Szafrańska B. 2013. Mapa zmian pokrycia terenu Małopolski 1986–2011 wykonana w oparciu o klasyfikację obiektową obrazów satelitarnych LANDSAT oraz RAPIDEYE. Archiwum Fotogrametrii, Kartografii i Teledetekcji, 25, 273–284.

Zawieska D., Ostrowski W., Antoszewski M. 2103. Wykorzystywanie danych lotniczego skaningu laserowego w metodyce badawczej zespołów fortyfikacji nowszej w Polsce. Archiwum Fotogrametrii, Kartografii i Teledetekcji, 25, Kraków, 303–314.

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