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FOREWORD

It is my pleasure to recommend the next issue of scientific quarterly “Geomatics, Landmanagement and Landscape” to our readers. Representing the neighbouring faculty of Mining Surveying and Environmental Engineering of the AGH University of Science and Technology, I am very glad that the journal managed by our colleagues and friends from the University of Agriculture have been created and is rapidly developing.

The practice shows that the competition in science is a very good thing. It enables exchanges of ideas and enriches research developments. The current issue responds to the good recognition of geodetic science.

The first paper demonstrates how architectural and landscape form of convent gardens can be restored. The authors highlights the need to conduct research on history and rules of compositions regarding such objects. The study and the recomposition project are based on the research carried out in the Bernardine monastery in Krakow.

The following paper presents the application of GIS tools for building spatial models for spatial planning purposes. The various data for building DTM were analysed there. The spatial models (including free ones, e.g. Google Earth) were compared in the study.

In the third paper, the formation of rainfall in the catchment of a mountain river in decades is described.

In the fourth publication the author proposes the use of non-metric cameras for 3D modelling and visualization. The project involves both technical and precision as well as economic optimization of this process.

The use of CAD platform for the consolidation works makes the content of the next article. The authors compare such operations with those based on GIS platform.

In the sixth article, the author proposes the application of original statistical-graphics method to evaluate the accuracy of the formation and the state of clone structure of forest herbs. Research was carried out in the ecosystems situated in the north-east of Ukraine.

Analysis of the conditions of occurrence of selected plant species is the content of the next paper. Research area is artificially created bayou area of the old river basin of Skawinka. The study provides a selection of species and varieties of plants to ensure their proper development and maintaining the recreational values of this place.
In the eighth article, the selected techniques and programming tools that enable the presentation of maps of statistical data are compared. Their functionality and usability from the point of view of the user is rated there.

Last publication points out to the need of improving the economic conditions of sub-Carpathian villages. The authors suggest how to overcome the difficulties resulting from the faulty village spatial structure, applying the known mutation procedures used in the rural areas.

I am sure that our readers will find in this issue interesting scientific inspirations and encouragement to the joint inter-university research.

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STUDIES OF HISTORICAL MODIFICATIONS TO THE BERNARDINE MONASTERY GARDEN IN KRAKÓW AS THE BASIS FOR ITS REDISIGN

Przemysław Baster

Summary

Characteristics rules of composition of the Polish monastic geometric gardens, combined with the information on the history and the spatial changes in the Bernardine monastery garden in Kraków and the iconographic research on the discussed garden design, show its clear architectural and landscape character. The study indicates that there are no de facto differences in the views on its original form and underlying principles of composition. The Bernardine monastery garden was similar to other such garden designs in Poland, and its composition was based on the earlier medieval idea of the division of space into quarters planted with trees. Although over the centuries, modifications were made to the course of the borders and the general form of the garden, it remains in the very same location and invariably presents its geometric layout. Currently, the original composition is less intelligible, and the land use is different from the historical one. This fact justifies the need to redesign the garden based on the spatial studies of its historical transformations.

Keywords

monastery • historical Kraków • monument conservation and protection • cultural heritage • geometric garden • garden redesign

1. Introduction

The aim of the research was to perform queries into the Bernardine monastery garden in Kraków, in order to provide grounds for the later execution of garden redesign within its current borders.

Founded in the fifteenth century, the oldest Bernardine monastery in Poland, along with its extensive gardens, lies at the foot of the Wawel Castle Hill, between the streets of Bernardyńska, Stradomska and Koletek. This location within the urban layout of Kraków, emphasized its importance for centuries, and made it one of the most recognizable landmarks of the city; thus it has been drawn repeatedly, and marked on historical drawings and maps of Kraków as one of the most important elements of the city’s landscape (Figure 1). Despite the continuous increase in the density of buildings in the
centre of Kraków, staking of new roads and changes to the course of the Vistula river, the size of the monastic garden has undergone only minor changes over the centuries. Currently, the entire compound is situated in the area of strict monument conservation zone, under the care of the Małopolska Regional Monument Conservation Authority, and it is a registered monument. Furthermore, it falls within the area of the “Kraków – historical city zone”, recognized in 1994 as a monument of history, and within the limits of the entry of the historic centre of Kraków in the UNESCO World Heritage list (1978).

Source: Banach 1983

![Fig. 1. Kraków from the south, seen from Krakus Mound, before 1600. Bernardine monastery – marked in the figure with the letter E. Author: E. van der Rye](image)

2. The object and methods of the study

The study aimed to analyse the historical transformation of the Bernardine monastery garden in Kraków, in order to develop the concept for the garden’s redesign. The research covered both the monastery garden itself, as well as the principle of composition of the geometric Polish monastic compounds in general; therefore it takes into account the historical character of the compound in question and theoretical design principles of similar sites, resulting from the principles of garden art. Complementing these considerations was the analysis of vegetation, its value and importance as an element of the whole garden compound.
The article presents the results of the research: the studies of historical and contemporary literature on the monastic garden, as well as the synthesis of the information available on this topic. Furthermore, an analysis was performed on the historical plans and principles of design. Information about the contemporary care of the trees was obtained through consultations with the Bernardine Order, and obtained during site visits by the author of the article.

3. Study results and discussion

3.1. Monastic garden composition in the historical context of the Polish garden art

Ever since the Middle Ages, Polish monastic gardens were designed and planned according to specific principles. One could say that the monastery garden is “in principle, not available to the public [...] intended for use by the monks, mostly characteristic for the mediaeval era” [Siewniak, Mitkowska 1978]. Garden was characteristically divided into different spaces, or quarters, and contained ever-present elements, which were the inherent parts of his layout: an orchard, a vegetable garden and a herbarium [Stępniewska 1977]. “The viridarium [...] was accompanied by a vegetable garden, and other gardens of purely practical function, as well as the herbarium. The orchards, which in their essence were the beginning of a later compositional idea of a park, gradually take the geometrized, chessboard form, broken down into quarters of a kind.” [Bogdanowski 2000]. This “chessboard form” was characteristic for the formal principles of monastic gardens composition; moreover, it was their domain also after the Middle Ages era has ended. “A chessboard garden is a composition based on geometric divisions of space, therefore it has regular quarters, with no clear marking of axes, or even an important communication course leading to the adjoining building. This simple form, derived no doubt directly from the design principles of medieval monasteries, showed remarkable durability. Even disregarding the different variations, it has survived in the same form until the end of the eighteenth century.” [Bogdanowski 2000].

The chessboard form of the monastic garden survived during the Renaissance and Baroque periods, drawing on the achievements of the Middle Ages, however, also rendering some garden elements more decorative. “Monastery gardens of the Baroque era exhibited a greater degree of arbitrariness and compositional diversity, resulting from a variety of religious rules and orders; having said that, usually they were still based on the concept of a viridarium, a pleasure garden, and orchard and checkerboard quarters of the outlay.” [Siewniak, Mitkowska 1998]. Seventeenth-century garden transformations entailed the tendency to bring out the compositional axes, and give the quarters a more ornate form. “The designers of chessboard gardens, above all, sought to accentuate the axes and give the quarters a new, dynamic, and ornate format – star-shapes were particularly popular, as well as introduction of different levels of greenery.” [Bogdanowski 2000] Furthermore: “the edges of the quadrangular or rectangular quarters were mostly planted with trees, thus creating walking alleys, or surrounded with a manicured hedge, while the middle of the quarters housed flower beds for the cultivation of flowers, herbs, vegeta-
bles and fruit trees, and sometimes a pond.” [Majdecki 2008] Gerard Ciołek notes that, in a modified form, this form of the historical layout – in addition to the “viridarium” garden and the “broad” garden, which also originated from medieval tradition – was still used in the nineteenth century. It should be noted that some researchers, including Longin Majdecki and Barbara Stępniewska, do not use the term “chessboard garden”. However, their descriptions of the composition of the monastic gardens are fully in line with the theses of Gerard Ciolek and Janusz Bogdanowski, who are using this concept.

3.2. Composition of the Bernardine monastery garden and its transformations throughout the centuries, in the light of historical and contemporary sources

Garden of the Bernardine monastery in Kraków, dating back to mid-fifteenth century, presented geometric forms, and its composition was based on a medieval orchard – just like in other Polish monastic compounds of this period. Uniform paths led along the borders of the square or rectangular quarters, planted with fruit trees. Gerard Ciolek and Janusz Bogdanowski, when describing the garden in question, are in agreement: they both define it as a “chessboard garden”. [Ciolek 1978, Bogdanowski 2000].

After the Swedish wars in the seventeenth century, the monastic compound was rebuilt following its complete destruction by the invaders. It was recreated in an area with irregular borders, approximating the current one (the present state of the garden). [Kantak, Szablowski, Żarnecki 1958, Sroczyńska 1989, Daranowska-Łukaszewska]. It was then that the garden acquired its Baroque character, while remaining a chessboard garden, and retaining all the medieval and Renaissance compositional principles; however, in the spirit of the Baroque, it was made more decorative. The garden retained its uniform, parallel quarters (divisions), which, however, have been given a more beautiful appearance – in the form of coaxial or star-shaped layout. [Rejduch-Samkowa, Samek 2000]. Increasing attention was paid to the alignment, or axial system, where the axis of the composition led from the monastery into the garden chapel or a gazebo [Bogdanowski 2000].

Historical descriptions of the Bernardine monastic garden in Kraków perfectly complement its historic plans. One can say that they provide the equivalent source of information on the composition of the discussed compound over the last two centuries and more. The most famous historical plan is called Plan Kollątajowski (Kollątaj’s Plan) and it dates to 1785 (Figure 2). It shows a garden of irregular shape, somewhat similar to today’s borders, divided with wide paths into several quarters. All paths are of the same width; all are also planted as identically labelled trees. The main axis of the composition follows a longitudinal path, leading through the centre of the garden. The designated quarters are hatched with diagonal lines, with a varying gradient and form, suggesting the existence of plants within the quarters (rather than just the lawn) – it may be presumed that the hatched areas on the drawing designate a vegetable garden and a herbarium. The quarters on the south side (at today’s Kołtek street) present irregular shapes – resulting from the layout of the garden, and the borderline that bends in this spot – and they play a complementary role within the garden system.
Further archival material confirming the designations of the Kołłątaj’s Plan, while providing further information on the changes in the land use within the garden, include: “Plan of the surroundings of the Vistula river bend near the Wawel Castle and Stradom” of 1796 (Figure 3), Förstl’s Plan of the same year (Figure 4) and the so-called Senate Plan, drafted in the years 1802–1805 (Figure 5). All these present the contemporary boundaries of the garden, its surroundings and the position relative to the buildings of the monastery. The first plan is the most precise, and it presents the layout of several quadrangular and rectangular quarters, designed so that they filled almost the entire area. At the same time, longitudinal axis of the composition is marked, coinciding with the course of the longest garden path, shaped by the quarters and accentuated with the trees growing mostly in the quarters’ corners. Importantly, this axis runs through the whole garden, and thus does not begin at the church, which is located on the side

Source: Kantak et al. 1958

Fig. 2. Kołłątaj’s Plan, 1785
of the whole compound. The importance of the monastery buildings is highlighted by another road, which leads out of these buildings and into the garden; parallel to the said, and axis passing with its distinctive compositional element.

![Plan of the surroundings of the Vistula river bend near the Wawel Castle and Stradom, 1796. Authors: Mosano i Chavanne](image)

**Fig. 3.** Plan of the surroundings of the Vistula river bend near the Wawel Castle and Stradom, 1796. Authors: Mosano i Chavanne

Förstl’s Plan confirms the existence of geometric layout of paths (the main path leading through the middle of the compound, and the peripheral path, running along the borders); the shape of quarters following regular geometric figures, and the aforementioned square; as well as the trees growing along the paths and in the corners of the quarters. However, it also points to a quite a different layout of quarters, and a different course of paths, compared to the “Plan of the surroundings of the Vistula river bend near the Wawel Castle and Stradom.”
Source: Pianowski 1991

Fig. 4. Förstl's Plan, 1796

Source: Pianowski 1991

Fig. 5. So-called Senat Plan, 1802–1805
The third of the aforementioned plans shows the area of the garden planted with trees, most of which grow irregularly, and only some forming alleyways – including one major avenue, leading from the monastery’s corner to the opposite borders of the compound. Why such differences on plans drawn within the space of just ten years? The analysis of the development of adjacent plots indicates that the authors do not strive to faithfully reproduce the form of greenery on individual estates, and only its character, while maintaining uniform graphic presentation for the entire part of the city as depicted in the drawing. After all, the first one of the discussed plans accurately shows the green areas around the depicted area (in the vast majority, it is geometrical in character), while the third shows it the least precisely (mostly depicting freely planted trees). Therefore – in this author’s opinion – what we witness here isn’t inconsistencies or contrast of the information presented, but rather the degree of precision resulting from the manner of drawing and the considered importance of the adequate mapping of the composition layout and the significance of the location of individual trees.

Subsequent historical changes of the monastic buildings and their surroundings are widely described in the manuscript by the already mentioned Joanna Daranowska-Łukaszewska. As part of her historical research – based largely on the archives of the monastery – she paid much attention to the description of border changes and the appearance of the fence around the compound of the monastery, as well as the demarcation of new streets, which surrounded it. She explains, among other things, the thickening of the wall, seen on the plan on the side of Koletek street: “Wall fragment between the corner of the Koletek nunnery, and the Bernardine church, marked on the Kołłątaj’s Plan as an arcade wall, probably corresponds to the passage existing between 1727–1830, which allowed the nuns to walk from the nunnery to the church.” [Daranowska-Łukaszewska]. She also mentions that in the later years of the nineteenth century, the Order agreed to give up a fragment of the garden in order to extend the Koletek street.

Joanna Daranowska-Łukaszewska also describes the changes and the shrinkage of the monastic compound, which took place on the other end, from the side of the Wawel Castle. “In the 1920s, the ‘way around the castle’ was set out – this is today’s Bernardyńska street; the new road was planted with Italian black poplars, fashionable at the time, but in 1868 they were replaced with clipped acacias.” [Daranowska-Łukaszewska]. The description of that same area is also found in “Gazeta Krakowska” daily paper from the year 1830, cited by Jan Banach: “beautifications to the eastern side of the castle by the plantations continue. Soon the most wonderful view shall open between the Bernardine church and the said edifice. Beautiful road of macadam with sidewalks, lined with poplars around the castle, is forming a dazzling harmony of this serious retreat.” [Banach 1980].

The above information on the garden, at the turn of the late eighteenth and the early nineteenth century, and particularly the presence of trees within it, is complemented by two figures presented in the “Historical transformations of the Wawel Castle surroundings”, where they are described as “The plan of the Bernardine Church surroundings” (Figure 6) and “The Slopes of the Wawel Hill and the Bernardine church, seen from the west” (Figure 7). The first plan shows the northern part of the compound with the afore-
Fig. 6. The plan of the Bernardine Church surroundings, around 1825. Unsigned

Source: Banach 1953

Fig. 7. The Slopes of the Wawel Hill and the Bernardine church, seen from the west, around 1830. Author: Józef Brodowski

Source: Banach 1953
mentioned new road (the so-called Planty around the Castle), with a string of additional demolition of the existing buildings. At the same time, it depicts many trees belonging to the Bernardine compound, planted partly regularly. The second figure – a perspective drawing – shows the view of Bernardyńska street with single trees along the road, as well as numerous, low trees in the garden of the monastery. This would confirm the claims that the garden was planted in the form of an orchard, which still existed in the first half of the nineteenth century, and referred to the earlier historical form of the medieval garden.

Another interesting document, pertaining to the form of the garden in question around mid-nineteenth century, is a plan drawn by Jan Kurkiewicz (Figure 8). It is tempting to analyse it more closely. Just like on the Kołłątaj’s Plan, the two paths leading along the entire compound of the monastery deeper into the garden are clearly marked, which facilitated the main compositional axis to be maintained. The location of quarters and paths on the north side – symmetrically to the building – retains the earlier, transverse compositional axis, mentioned by Gerard Ciołek. The overall chessboard plan, with quarter divisions, has been somewhat blurred, because the paths no longer divided the garden into quarters of identical, modular plan.

![Plan of the monastic garden, second half of 19th century. Author: Jan Kurkiewicz](source: Daranowska-Lukaszewska)

Fig. 8. Plan of the monastic garden, second half of 19th century. Author: Jan Kurkiewicz

Jan Kurkiewicz’s plan clearly confirms the designations of the Kołłątaj’s Plan in terms of planting trees along all garden paths (two types of trees are visible – with spherical and conical shape of the crown). It can therefore be concluded with the high-
est probability that fruit trees of various species grew along all garden paths. Symbols of the plan also confirm, that at least in some quarters, low greenery was planted (rather than lawn) – the hatching in these quarters is much more explicit and detailed than on the 1785 plan. With almost certainty, it can be concluded that one of the two types of hatch used in the drawing denotes a vegetable garden.

It is also worth mentioning that the plan here described envisaged piercing of a route, through the Bernardine gardens, connecting the Bernardyńska street and the then-called Kopernika (today’s Kołek) street, but this was not realized.

The turn of the nineteenth and twentieth century brought with it changes to the boundaries of the garden from the side of Kołek street. “...Along the Kołek street there stood a tall, brick plastered wall; after it was breached by the flood of 1903, it was built from scratch, which is confirmed by the chronicles of the monastery. [...] Surviving is a design for the demolition of the wall on the Kołek street, and to raise its further part higher, also dating from 1910. [...] Adjoining the wall is a stone grotto with a statue of Our Lady of Lourdes.” [Daranowska-Łukaszewska].

4. Conclusions

Summary of the information about the geometric Polish monastic gardens, and descriptions of the composition and history of the Bernardine garden as well as iconographic materials pertaining to that compound, demonstrate its consistent architectural and landscape character. Although over the centuries, the garden underwent transformations, its appearance – called “chessboard” by some – remained one of the most popular and unchanging forms in the history of Polish monastic gardens. Currently, the garden under discussion still retains its function as an orchard, although the number of fruit trees growing there significantly decreased, and the former compositional layout is difficult to read afield. Hence the necessity of performing the study described herein, which will serve for the development of the redesign concept for the compound in question.

References

USING GIS TOOLS TO OBTAIN ELEVATION MODELS FOR THE PURPOSE OF SPATIAL PLANNING¹, ²

Piotr Bożek, Agnieszka Głowacka, Urszula Litwin, Magda Pluta

Summary

The paper presents the possibilities of applying GIS tools in order to obtain elevation models for spatial planning. Digital Elevation Model (DEM) or Digital Terrain Model (DTM) can be created based on direct field measurements, vectorization of existing cartographic materials, observations from the air, or data obtained from radar systems placed on the Earth's orbit, using radar interferometry. The research methodology was based on the use of GIS tools in the process of obtaining public (generally available) elevation data, and assessing suitability of that data, for instance, in the context of spatial planning. In the study, we have used data from airborne laser scanning, free data provided by CODGiK (Central Documentation Centre of Geodesy and Cartography) and data acquired from Google Earth software, among others. Data analysis was divided into 4 stages: the first was to estimate how large are the differences when creating a grid elevation model out of a cloud of points, using aggregation algorithms. The second stage of the analysis consisted in the comparison of the amount of the received free data, and the elevation model established based on the cloud of points – the LIDAR model. The next stage of the analysis was aimed at a mutual comparison of the elevation models created with free data. The last stage of the analysis concerned the comparison of the DSM (Digital Surface Model) with the free data acquired from the Google Earth.

Keywords

Digital Elevation Model (DEM) • Digital Terrain Model (DTM) • DSM (Digital Surface Model) • LIDAR • spatial planning

1. Introduction

The Digital Elevation Model (DEM) is a numerical discrete (point-based) representation of the topographic heights of the terrain, together with the interpolation algorithm, which allows for restoring its shape in a specific area [Kurczyński 2014]. As

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noted by authors Burdziej and Kunz [2006], DEM is one the most common sources of data concerning terrain, while according to Przybyła and Pyszny [2013], the model can be created based on direct field measurements, vectorization of existing cartographic materials, aerial observations, or data obtained from radar systems placed on the Earth's orbit, using radar interferometry. According to Burdziej and Kunz [2006], the accuracy of DEM determines the possibility of its use for specific purposes, while Hejmanowska et al. [2008] note that it affects the outcome of the analyses carried out with the consideration thereof, as well as derivative maps such as grade map, map of exposures, or map of visibility. Accuracy of the DEM will depend on the data sources used for its construction, as well as the density of points, measured object definitions, and the chosen type and parameters of the grid (TIN, GRID) [Hejmanowska et al. 2008]. Moreover, according to Burdziej and Kunz [2006], the source of errors in the DEM, which has been developed on the basis of raster data, lies in the size of the smallest fields (pixels), which store the information about the heights. Image resolution determines the accuracy of DEM, and the decrease in resolution causes the decrease in the amount of detail within the entire model. Despite these limitations, the use of raster data enables fast processing of large data sets, and therefore, according to Rusli et al. [2014], it is recommended for the construction of DEMs in small and medium scale.

One of the data sets used to build the DEM is the satellite imagery stored in the form of raster images. Particularly noteworthy are the images taken by the Aster scanner, which captures images in 14 spectral channels of different spatial resolution, where the system of registration of near-infrared was equipped with the capability to perform reverse images, at an angle of 27.7°, as a result of which it is possible to perform stereoscopic imaging [Przybyła and Pyszny 2013]. The scanner is mounted on board of the satellite, which performs nadir imaging and reverse imaging, within area coverage between 83°N–83°S. Based on satellite images, a DEM was created called AsterGRID, developed in cooperation with NASA, and the Japanese Ministry of Economy, Trade and Industry. Implementation of the project started in 1999, and it lasted for 10 years. Data development comprised processing of some 1.5 million images, creating 1.2 million stereo-pairs, removing clouds, and allocating the DEM (Digital Elevation Model) onto 22,600 tiles sized 1° × 1°. The Aster model is a GRID model, in which each cell (pixel) has a specific x, y coordinates as well as the averaged coordinate z [Przybyła and Pyszny 2013]. According to Rusli et al. [2014], AsterGRID is available under an open license (open source), and the resolution of the DEM is 30 m. In addition, the average accuracy of the DEM, estimated by its creators, is 10 m, and the prevalence of negative errors is noted, i.e. undervaluation of heights [Rusli et al. 2014]. Moreover, as noted by Mukherjee et al. [2013], the accuracy of the vertical model that is based on Aster stereo pairs is impacted by the morphological characteristics and the roughness of the terrain; additionally, the error increases significantly with the increase in the slope grade above 10°.

In the context of using DEM for specific purposes, its accuracy is an important issue. According to Litwin et al. [2015], accuracy depends on the errors of point positioning, which result from the selected measurement method, the size of the mesh cells, and
the configuration of the terrain. According to Burdziej and Kunz [2006], assessment of the DEM accuracy is performed by comparing the size of the RMSE (Root Mean Square Error) calculated on the basis of a comparison of selected model points with control points. According to Fisher [1999], DEM can be well defined, and in that case, the uncertainty of measurement is expressed by the RMSE error; or it can be poorly defined, in which case indeterminacy or ambiguity occurs (Figure 1).

![Characteristics of Digital Elevation Model definition](image)

Source: Fisher 1999

**Fig. 1.** Characteristics of Digital Elevation Model definition

According to Hejmanowska et al. [2008], the ambiguity arises when during the measurement, various criteria are adopted different, as well as various methods and interpolation parameters. Indeterminacy occurs when the adopted criteria are not known during the measurement, or when there is no information as to whether these criteria were met. Moreover, the consideration of the quality of the model should take into account the measurement technique used, the criteria adopted during the measurement, and the technology to generate the DEM. DEM error distribution may be determined by analytical or empirical methods, or the increasingly frequently applied Monte Carlo method. Analytical methods, due to the difficulty in the formulation of the function describing the propagation of an error, are rarely used in practice. Empirical method, on the other hand, requires the knowledge of error for selected points throughout the area. Monte Carlo method involves placing random errors of the given distribution within the model, and then performing spatial analysis with regard to these errors. Repeating the procedure several times allows us to determine the spatial distribution of errors [Hejmanowska et al. 2008]. According Burdziej and Kunz [2006] a reduction in the resolution causes generalization of the model, including the loss of extreme values, which translates into an increase in the value of the error where grade models of land correspond to the forms with the greatest inclination.
2. Materials and methods

The research methodology was based on the use of GIS tools, the process of obtaining generally available elevation data, and assessing suitability of that data, for spatial planning, among others. The study used data from airborne laser scanning, free data provided by CODGiK (Central Documentation Centre of Geodesy and Cartography), and data acquired thanks to the Google Earth software, among others. The methodology can be divided into two parts: first, pertaining to data acquisition and processing, and second, pertaining to collating and comparing the data, in order to assess accuracy.

The first stage was related to the acquisition of data. The study used two types of data: free public data, and elevation data obtained by the technology of airborne laser scanning. The first free data was obtained from the CODGiK website, and it was represented by the DEM. As of 12 July 2014, this data was made available free of charge, and data coverage spanned the entire area of Poland. The maximum distance between adjacent points in the CODGiK data is 100 m. Free data also included the data obtained via Google Earth. Elevation data was imported from this platform, using the free TCX Converter software.

The generally available data was compared with the information obtained from the air laser scanning. LIDAR data provided the accuracy of point location at the level of 0.2 m, with 8 points per 1 m². The study covered two areas: one located in Zabierzów municipality (Figure 2a) and the other, in Nowy Targ municipality (Figure 2b). The areas of study were selected because of their configuration. The first area is characterized by a great diversity of use: it is a built-up area, directly adjoining a woodland area, shrubbery, and grassland. The other area, located in the municipality of Nowy Targ contains mostly open spaces, undeveloped, and without trees or shrubs. Only in the south-west portion of the region, there is a densely built-up fragment – a housing estate. The selection of these areas allowed the assessment of the suitability of the free elevation data, both in urban areas and in the open area (such as agricultural land).

In order to obtain consistent elevation data formats, GIS software was used: SAGA GIS (version 2.1.2) and QGIS (version 2.12.0). The first step consisted in processing the cloud of point into a raster format. Thus classified, the cloud of points represented Numerical Terrain Model (DTM). Using the Saga GIS software, a cloud was distinguished, containing only those points that were classified as terrain (GROUND). This was followed by the conversion from the files of point clouds (.las) into raster format (.geotiff). As a result, GRID models were obtained with a mesh of 1 m. The SAGA offers the capability to create the geotiff format by using one of the five algorithms for aggregation: the creation of a grid based on the first, or the last point in the mesh cell, the largest and smallest values in the individual cell of the mesh, and on the basis of calculating the average height of the points contained in the mesh cell. The study used all these algorithms, thus creating five separate grid files. Identical operations were performed.

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2 Based on art. 40a ust. 2 pkt 1 ustawy Prawo geodezyjne i kartograficzne z dnia 17 maja 1989 r., Dz. U. z 2014 r. poz. 897 (tekst jednolity). Until 12 July 2014 no fees are charged for making data sets available.
performed with respect to the point cloud containing DTM, however, in this case only the algorithm creating the grid based on the highest value in the individual mesh cell was applied. In both studied areas, the methodology of processing point clouds to raster form was applied. Free data provided by CODGiK was converted from .XYZ format to raster format with a grid cell of 100 m. The last phase of data acquisition consisted in using free software called TCX Converter. This facilitated obtaining heights for points with the given grid coordinates (WGS 84 frame of reference). This was done based on the .kml file format, containing the so-called “route paths.” The program updates the information on the heights of the points, and then allows you to export that to the desired format (e.g. Csv). As the source of the plane data, coordinates of points were used found in the free CODGiK data (spaced 100 m). For the area located in Zabierzów municipality, 132 points were assigned, and 144 points for the area in the municipality of Nowy Targ.

The developed data (both raster and vector) has been imported into QGIS software, which prepared it for analysis. Within the program, vector layer was created containing a regular grid of points (Figure 3). The points constituted the markers, which imported elevation data from individual raster layers, and from the vector layer containing the heights thanks to the TCX Converter software. For this purpose, the QGIS Point Sampling Tools plug-in was used, which offers the ability to retrieve values from a raster layer, and then assign them to any vector layer. The heights of the individual rasters were summarized in one table of attributes, and then using the calculator of fields, deviations were calculated from the elevation model created out of the cloud of points (raster created using an algorithm that calculates the average altitude of points
within 1 m²). The data obtained was exported to .csv format. Using Microsoft Excel and Surfer software, we have analysed the results.

![Layer showing DEM with marked locations of altitude measurements for the areas in Zabierzów and Nowy Targ municipalities](image)

Source: author’s study

**Fig. 3.** Layer showing DEM with marked locations of altitude measurements for the areas in Zabierzów and Nowy Targ municipalities

### 3. Results

The analysis of elevation data has been subdivided into several stages. The first stage consisted in estimating, how large the differences are, when developing the grid elevation model out of point cloud, using aggregation algorithms. When creating the GRID, only those points were included, which were classified as terrain (GROUND). The mesh cell size was 1 m. An assessment was made of the way the algorithms, which aggregate the cloud of points, affect the accuracy of the square grid model (Table 1, Table 2).

<table>
<thead>
<tr>
<th>The area located in Zabierzów municipality</th>
<th>LIDAR mean – LIDAR low</th>
<th>LIDAR mean – LIDAR high</th>
<th>LIDAR mean – LIDAR first</th>
<th>LIDAR mean – LIDAR last</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum difference</td>
<td>0.000</td>
<td>0.005</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Maximum difference</td>
<td>0.160</td>
<td>5.880</td>
<td>0.160</td>
<td>0.120</td>
</tr>
<tr>
<td>Average difference</td>
<td><strong>0.029</strong></td>
<td><strong>0.223</strong></td>
<td><strong>0.017</strong></td>
<td><strong>0.020</strong></td>
</tr>
<tr>
<td>Mean value of differences</td>
<td></td>
<td></td>
<td></td>
<td><strong>0.072</strong></td>
</tr>
</tbody>
</table>

Source: authors’ study
Table 2. Analysing the differences between the GRIDs created using aggregation algorithms in the SAGA GIS software for Nowy Targ municipality

<table>
<thead>
<tr>
<th>The area located in Nowy Targ municipality</th>
<th>LIDAR mean – LIDAR low</th>
<th>LIDAR mean – LIDAR high</th>
<th>LIDAR mean – LIDAR first</th>
<th>LIDAR mean – LIDAR last</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum difference</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Maximum difference</td>
<td>0.100</td>
<td>0.137</td>
<td>0.137</td>
<td>0.090</td>
</tr>
<tr>
<td>Average difference</td>
<td>0.036</td>
<td>0.033</td>
<td>0.020</td>
<td>0.022</td>
</tr>
<tr>
<td>Mean value of differences</td>
<td></td>
<td></td>
<td></td>
<td>0.028</td>
</tr>
</tbody>
</table>

Source: authors’ study

Both in the first and second area studied, with an exception of one case, the maximum difference in the values did not exceed 0.16 m, and the average height difference for all the test points was 0.036 m.

In the area located in Zabierzów municipality, the average difference in height for all models in relation to the output model reached 0.029 m, which should be considered a very good result.

In open spaces with uniform slope, similar result was obtained regardless of the aggregation method applied. Along with the increase of the individual GRID cell, differences may increase, but let us keep in mind that this is also connected to the generalization of results, and does not only depend on the aggregation algorithm. For the area located in Zabierzów municipality, the biggest height difference occurred between the model created on the basis of the average value, and the model using the maximum value in the cell – that difference amounted to 5.880 m. This resulted in a decrease in the accuracy of the entire model. Reasons for such a large difference should be seen in the data source, rather than in erroneous execution of the elevation model. The algorithm takes into account all the points contained in one area of the mesh cell, including noise or the points in the cloud that were wrongly classified. The algorithm, which creates the GRID, while taking into account the maximum value of points in the area of 1 m, used the maximum value (in this case the noise of the points cloud).

The second stage of the analysis was based on a comparison between the altitudes obtained from the free data, and the elevation model established based on the cloud of points – the LIDAR model. Analysis of the height differences compared to the LIDAR model data in both areas, clearly demonstrated that the differences are less significant in the model, which uses free data provided by the CODGiK.

In the elevation model for the area located in Zabierzów municipality, the maximum difference for CODGiK data amounted to 1.578 m, while in the case of the model retrieving data from Google Earth, to as much as 20.857 m. For the area located in the municipality of Nowy Targ, the maximum difference for CODGiK data amounted to 4.950 m, whereas for the model retrieving data from Google Earth, to 6.346 m (Table 3). For both areas, the difference between the LIDAR model and the free CODGiK model
amounted to 0.16 m, while in the case of the data obtained from the Google Earth model, this difference amounted to 3.211 m (Table 4).

Table 3. Height differences for the models developed using free data

<table>
<thead>
<tr>
<th>Area/location</th>
<th>The area located in Zabierzów municipality</th>
<th>The area located in Nowy Targ municipality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis of the models</td>
<td>LIDAR mean – CODGiK data</td>
<td>LIDAR mean – Google data</td>
</tr>
<tr>
<td>Minimum difference</td>
<td>0.000</td>
<td>0.088</td>
</tr>
<tr>
<td>Maximum difference</td>
<td>1.578</td>
<td>20.857</td>
</tr>
<tr>
<td>Average difference</td>
<td>0.216</td>
<td>3.494</td>
</tr>
</tbody>
</table>

Source: authors’ study

Table 4. Differences between free data and LIDAR data

<table>
<thead>
<tr>
<th>Data source</th>
<th>CODGiK</th>
<th>Google Earth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean value of differences from the two areas</td>
<td>0.160</td>
<td>3.211</td>
</tr>
</tbody>
</table>

Source: authors’ study

The models, which use free data, are better suited for open areas; and here also lower differences in values were noted for the models created on the basis of free data. Elevation models developed on the basis of free data cope better in the case of less complicated surfaces, with a uniform grade (slope). In areas that are heavily urbanized, with varied terrain and varied surfaces, it is impossible to achieve satisfactory results.

The next stage of the analysis was to conduct a mutual comparison of elevation models created on the basis of free data. We were hoping that the comparison would answer the question whether it is possible to merge and use the data to build one joint elevation model.

Average differences between the points in the area of Zabierzów municipality reached the value of 3.603 m, and in Nowy Targ municipality, 3.263 m. The free data provided by CODGiK has a low density (about 100 m). If the accuracy of both elevation models had similar characteristics, it would have been possible to supplement the CODGiK data and render it denser, using the data acquired from the Google Earth. In both areas, the difference of heights assumes the largest value in built-up areas, and in border areas. In the area of Zabierzów municipality, height differences were smaller; and in those locations where there are strongly urbanized areas, the values were similar. Visualization of the point distribution of differences, or mutual interdependencies between measurement points, is shown on the map (Figure 4), which was developed using the Surfer software. The resulting differences were plotted on the map using the interpolation, or Kriging.
The last analyses concerned the comparisons of the DEM with the data acquired from the free Google Earth service. Configuration of the terrain, along with the vegetation or buildings, is of particular importance in the analysis of the impact of potential investments (both construction investments and linear infrastructure) on the existing environment.

The changes, which investment projects within the landscape will cause, can be assessed best (i.e. in the easiest, and yet the most effective manner) by means of their visualization. Thanks to using the appropriate elevation model, first we are able to designate the area (subject to visibility changes, shading, or the course of airways), which the given investment will affect, and then assess the extent to which the investment will affect the environment.

As in previous cases, there are discrepancies between the two elevation models. The maximum difference in the Zabierzów municipality location amounted to 20.857 m, and in the Nowy Targ municipality location, 6.120 m. The average height differences for all points in Zabierzów municipality reached 3.494 m, and in the Nowy Targ municipality, 3.027 m (Table 5).

### Table 5. Comparison of height differences between the Google Earth elevation model and the DEM (LIDAR)

<table>
<thead>
<tr>
<th>Area/location</th>
<th>The area located in Zabierzów municipality</th>
<th>The area located in Nowy Targ municipality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum difference</td>
<td>0.088</td>
<td>0.150</td>
</tr>
<tr>
<td>Maximum difference</td>
<td>20.857</td>
<td>6.120</td>
</tr>
<tr>
<td>Average difference</td>
<td><strong>3.494</strong></td>
<td><strong>3.027</strong></td>
</tr>
</tbody>
</table>

Source: authors’ study

**Fig. 4.** Height differences between the model based on the CODGiK data, and elevation model acquired from Google Earth for Zabierzów and Nowy Targ locations
4. Conclusions

The spatial planning today requires the use of modern technologies that support the planning process. Already at the designing stage, many aspects must be considered, present within every investment project. Regardless of the size of the investment project, each one project makes an impact on the surrounding environment. With the latest technology, it is possible to predict some of that impact. The use of elevation models improves the very process of investment project design, but it also allows its users to assess how the investment will affect the environment after its completion. In order to create elevation models, one can use GIS software, which allows the acquisition and processing of the elevation data available. In the planning process, free data can be used. We should bear in mind that the accuracy of such data differs, and it largely depends on the studied area. The present study used two types of free data. The first type of data, obtained from CODGiK, had good accuracy, but low density of coverage points (approximately 100 m), and the other type of data, obtained, among others, from Google Earth, left much to be desired in terms of precision. The data used in the Google Earth software demonstrates an elevation model (obtained using SAR technology) for large areas (e.g. the whole continent). Accuracy for small areas (such as the ones analysed in the present work) is therefore lower. Therefore this type of data cannot be used where high accuracy of material is required. In such cases, one should use data with greater accuracy (LIDAR). Free data, however, can be useful at the stage of planning. It has one important feature: that of being generally available. We can using it in order to carry out preliminary analyses, to designate areas where a more detailed analysis (using more precise data) is needed, which can save time when processing the data with greater accuracy.

References


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The aim of the study is to evaluate the mean annual precipitation in the mountain river catchment area, in the period between 1984–2012. Data on daily rainfall totals was obtained from IMGW PIB in Warsaw, and it came from two weather stations: one in Nowy Sącz, and the other in Krynica. It has been demonstrated that during the multi-year period covered by the study, there were variations in terms of precipitation levels; the year 1987 should be considered extremely dry, while 2010, extremely wet – in the latter year, extreme rainfall was noted. In the analysed multi-year period, within the total annual precipitation, rain dominated during the first half year, which undoubtedly affects the hydrological regime of the Kamienica river.

Keywords
precipitation • extreme rainfall • annual precipitation • mountain river catchment (basin)

1. Introduction
The issue of water systems is a very important for the management of river basin districts. To a large extent, the nature of the catchment area determines the physical and chemical characteristics of rivers. When analysing these features, we can get an idea of the hydrological processes occurring within a given catchment area and riverbed. Observations of a series of hydrological and meteorological data, over the multi-year period, permits developing a description of the formation of the runoff and the assessment of water resources of the region concerned [Banasik and Hejduk 2011]. Furthermore, these observations provide the basis for the assessment of the dynamics of water flow in some periods of the year. For this purpose, trend analysis and the analysis of cyclical nature in the occurrence hydro-meteorological phenomena are typically applied [Skowera et al. 2014].

Precipitation is the main source of rivers’ water feed, and it is the rainfall, which largely shapes the hydrological regime. A number of factors influence the occurrence of precipitation, including altitude, atmospheric circulation and orographic conditions. It is extremely important from the point of view of the analysis of water resources, and the analysis of extreme hydro-meteorological phenomena, to recognize the progress of
rainfall in the aspects of time and space. For the area of Polish, of all natural hazards caused by natural factors, the biggest threat is posed by high precipitation and maximum wind speed. Intensive outpours of rain lasting for many days cover large areas and are often cause flooding, while the short heavy rains and torrential rains cause flooding and local flash flood [Lorenc et al. 2012].

Precipitation in times of floods constitutes a direct source of the water streams supply. According to Wrzesiński [2014], in the case of rivers outside the areas subjected to strong human pressures (urbanization), climatic conditions have a greater impact on modifying the characteristics of the hydrological regime. Research by Bartczak et al. [2014] also confirms this. Precipitation events of extreme character cause serious hydrological effects such as floods, which pose a threat to humans, and to many sectors of the economy [Szalińska and Otop 2012]. Dong et al. [2015], on the other hand, claim that the variability of the direct runoff from direct catchment areas is not only affected by the changes in land use, but also by the changes in the progress of precipitation, especially in catchment areas of medium size.

The purpose of this study is to evaluate the characteristics of the formation of annual precipitation in the area of Kamienica (a mountain river), in the period 1984–2012. The analysis was performed based on the sequences of daily precipitation totals for Krynica and Nowy Sącz weather stations.

2. Research area

Research area covers the Kamienica river – also known as Kamienica Nawojowska, but henceforth referred to simply as Kamienica – flowing through the Nowy Sącz district in the Małopolska province. The length of the river is 33.079 km, and the catchment area equals 237.83 km² [Szafarska 2015]. Sources of Kamienica river are located on the north side of the Jaworzyna Krynicka mountain range, where mountain streams of Krzyżówka and Roztoka flow in, while its outlet is located in the Dunajec river, which flows on the east in Nowy Sącz. The studied catchment area is located in the area of two climatic regions of the upper basin of the Vistula river: the mountain climate and climate the Carpathian foothills [Cebulska et al. 2013].

Predominant form of the natural landscape in the district of Nowy Sącz is the Carpathian flysch in the form of stratified clastic sediments, which have been folded in the Neogene, and then in the Miocene. Flysch sediments occurring in this area are mainly sandstone, shale and conglomerates. In terms of land use, the predominant part of the basin – 58.7% is covered with forests, which determine the types of soil conditions, topography and climatic conditions. Other uses include: built-up areas 11.8%, grassland 7.4%, arable land 6.5%, and wasteland 15.6% [Szafarska 2015].

3. Material and methods

The basis for the study was provided by the daily precipitation totals from the period of 1984–2012, measured at two weather stations in Nowy Sącz (geographic coordi-
nates N: 49°37’38.29”; E: 20°41’19.3”) and Krynica near Muszyna (geographic coordinates N: 49°26’58.79”; E: 20°58’10.23”). The data was obtained from the Institute of Meteorology and Water Management of the National Research Institute in Warsaw. In the study, we have calculated the total precipitation on the annual and monthly basis, we classified mean annual precipitation according to Kaczorowska’s [1962] classification, we calculated the amount of the sum of intense daily rainfall events for the summer season (half year), in individual years of the studied period, for the following ranges: P ≥ 30 mm (threatening rainfall), P ≥ 50 mm (dangerous rainfall), P ≥ 70 mm (flooding rainfall), P ≥ 100 mm (catastrophic rainfall). Classification of rainfall was applied as per [Climate 2009].

4. Presentation and discussion of results

In the analysed period (1984–2012), annual rainfall for the Nowy Sącz weather station ranged from 561.8 mm in the hydrological year 1986 to 1,183.1 in the hydrological year 2010. At the Krynica weather station, the lowest rainfall occurred in 1987 (637.3 mm), while the highest rainfall was noted in 2010 (1,164.3 mm). For comparison, in the region of the upper Vistula river catchment area, the average rainfall for the period 1951-1970 amounted to 749 mm, and for the 1952–1981, 769 mm.

The average atmospheric precipitation in the catchment area of Dunajec river amounted to 874 mm for the period 1951–1970, and 1014 mm for the period 1952–1981 [Cebulska et al. 2013]. Precipitation totals in individual years, analysed within the discussed multi-year period, exhibit considerable variation. In general, indications in the Krynica station are higher than in the Nowy Sącz station – see Figure 1. The opposite situation occurred only 4 times (1987, 1996, 1997 and 2010). Precipitation totals in individual hydrological years, however, show a certain cyclic nature – with alternating periods of growth and decline, generally involving simultaneously both of the test stations. In the Polish Carpathians, precipitation is affected mainly by circulation and geographical factors – such as varied terrain and high altitude [Woźniak in 2013]. In Nowy Sącz, wet years occurred in 1989, 1997 and 2009, a very humid year, in 2001 and extremely humid, in 2010, when it the highest rainfall was recorded. In Krynica, the following years were considered humid: 1985, 2001, 2002, 2005, and very humid: 2007 and 2010. Dry seasons in Nowy Sącz coincided with the years: 1986, 1988, 1993–1996, 2003, and 2012; in Krynica: 1988 1990, 1991, 1993, 1994, 2003 and 2012. One year, 1987, can be classified as very dry. Long-term trend of annual precipitation at both stations was growing and statistically insignificant.

In the analysed period, in the summer season (half year), rainfall for the weather station in Nowy Sącz ranged from 364.6 mm in 1992 to 915.4 mm in 2010. At the weather station in Krynica, the lowest rainfall occurred in 2003 (419.3 mm), while the highest, as in the case of Nowy Sącz, in 2010 (905.5 mm). Summer season (half years) with low rainfall (< 400 mm) was noted at the Nowy Sącz station in 1986, 1988, 1992–1994, while humid summer seasons (> 700 mm) occurred in 1997 and 2010. In turn, at the station in Krynica, there were no summer seasons (half-years) noted in which precipitation totals
Fig. 1. Total rainfall at a) Nowy Sącz station and b) Krynica station in the period 1984–2012

Source: authors’ study
would be below 400 mm. Relatively low rainfall (< 500 mm) occurred in the years 1987, 1988, 1993, 1994, and 2003. The high amount of rainfall (> 700 mm) was recorded four times: in 1985, 2001, 2002, and 2010. In the case of winter seasons (half-year, November-April), the lowest amount of rainfall at the weather station in Nowy Sącz was recorded in the hydrological year 2012 (153.8 mm), while the highest, in 2010 (328.3 mm). At the Krynica weather station, the lowest rainfall occurred in 1987 (186.4 mm), and the highest in 2000 (393 mm). In Nowy Sącz, exceptionally dry winter seasons (precipitation < 200 mm) occurred in the years 1985, 1986, 1991, 1997, 2002, 2009, 2011, and 2012. The winter seasons with a relatively large amount of rainfall (> 300 mm) occurred in the years: 1987, 1989, and 2000. In Krynica, winters with low rainfall (< 200 mm) were recorded in the years 1987, 1991, and 1996, whereas the high amount of rainfall (> 300 mm) was noted in years 1989, 1990, 1992, 1995, 1998, 2000, 2005 and 2007.

There is a statistically significant correlation between the annual precipitation totals at the weather station in Krynica (upper part of the river catchment) and Nowy Sącz (lower part of the river catchment) – see: Figure 2. The calculated correlation coefficient of $r = 0.719$ is statistically significant.

**Fig. 2.** Comparison between annual total rainfall in Krynica and Nowy Sącz stations between 1985–2012

In both studied stations, rainfall in the winter season was much lower than in the summer seasons. In Nowy Sącz, the share of winter season precipitation in annual total rainfall ranges from 20% (1997) to 43% (2000). At the Krynica weather station, the
respective figures were from 22% (2010) to 44% (2000). The average share of precipitation for the two stations, in the analysed period, in the winter season was 31% and in the summer season, 69%. Woźniak reaches similar conclusions as to the share of rainfall in each season are for the region of the Carpathians [2013]. Figures 3 and 4 shows the contribution of the individual seasonal (half-year) precipitation in relation to the total annual rainfall.

![Graph showing contribution of individual half-year precipitation](image)

**Fig. 3.** Share of precipitation in individual half-year periods compared to annual totals for the Nowy Sącz station in the period 1984–2012

At the weather station in Nowy Sącz, the minimum value of daily precipitation totals in each year amounted to 0.1 mm. The highest maximum precipitation occurred in the year 2009 and amounted to 82.2 mm. A high total was also observed in 2001 (74.8 mm). Also at the weather station in Krynica, minimum values of rainfall each year amounted to 0.1 mm. The maximum daily totals were recorded in 1999 (94.5 mm) and in 2008 (82.2 mm). A relatively high total of the highest daily rainfall was also noted in 2012 (72.8 mm).

In the Kamienica river catchment area, days with very strong precipitation occur very rarely. Threatening rainfall in analysed period lasted for, on average, 1.6 days as recorded at the weather station in Nowy Sącz and 2.2 days as recorded in Krynica. Most of precipitation days (4 days) in excess of 30 mm in the summer half-year in Nowy Sącz took place in the years 1997, 2007 and 2010. In 2002 and 2005, threatening precipitation occurred each year 3 times.
The highest number of days (4) with a rainfall that exceeded 30 mm in the summer season, in Nowy Sącz, occurred in the years 1997, 2007, and 2010. In 2002 and 2005, threatening rainfall occurred 3 times in each year. Throughout the whole period, only in 4 years, no threatening rainfall was recorded. In other years it occurred at least once. At the weather station in Nowy Sącz, dangerous rainfall (P ≥ 50 mm) was recorded 5 times (1987, 2001, 2006, 2009–2011), and flooding rainfall (P ≥ 70 mm) occurred 4 times (2001, 2009–2011). However, there was no incidence of precipitation in excess of 100 mm. Most days of intense precipitation were recorded in 2010 (6 days). Dangerous rainfall and flooding were more frequent at the end of the analysed period (Table 1). In Krynica, most days with precipitation exceeding 30 mm in the summer season were recorded in 2011 (6 days). Also in 2001, their number was significant (5 days), while 4 days with threatening rainfall was observed in 1986, 1992 and 2010. In other years, the summer seasons had an average of 1–3 days with precipitation above 30 mm. In the years 1985, 1999 and 2005 the precipitation P ≥ 70 mm was recorded one time in each year. Most days of intense precipitation were recorded in 2010 and 2011 (6 days). However, there was no incidence of precipitation in 1990, 1991 and 2003 (Table 1). Dangerous precipitation in Krynica occurred more frequently than in Nowy Sącz. In 1995, it was observed for 2 days, it was recorded for 1 day each year in 1984–1986, 1994, 1999, 2006 and 2007. Also, two days of flooding rainfall were recorded in 2010.
In 1985, 1999 and 2005, the rainfall in the amount of P ≥ 70 mm occurred once each year. Most days of intense precipitation were found in 2010 and 2011 (6 days). However, it did not occur at all in 1990, 1991 and 2003 (Table 1).

Table 1. Number of total events of intensive daily rainfall in the summer season (half year), in the analysed period for the Nowy Sącz and Krynica stations

<table>
<thead>
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<td>P ≥ 50</td>
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<th>2011</th>
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<td>2</td>
<td>3</td>
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<td>0</td>
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<td>6</td>
<td>3</td>
<td>1</td>
<td>3.0</td>
</tr>
</tbody>
</table>

5. Conclusions

The paper presents the analysis of the selected characteristics of mean annual precipitation in the period between 1984–2012, in the catchment area of Kamienica, a mountain river. In the analysed period, the year 2010 has been classified as extremely humid, and 1987 as extremely dry. In the case of both weather stations, average of six years of wet and seven dry years were recorded in the studied period. We have also observed cyclical nature of the annual precipitation totals. In both studied weather stations, rainfall in
the winter season (half year) was much lower than in the summer seasons (half years). The average share of precipitation in the analysed period, in the winter season was 31%, and in the summer season, 69%. In the analysed period rainfall that would qualify as a natural disaster (P ≥ 100 mm) did not occur. In the case of both stations, particularly common instances of extreme rainfall occurred in 2001 and 2010.

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EXAMINING THE IMPACT OF RECORDING LONG-SERIES IMAGES TAKEN FROM NON-METRIC CAMERAS ON OPTIMISATION OF MODELLING PROCESS AND 3D VISUALISATIONS

Bogdan Jankowicz

Summary

In spite of the diversity of methods used in acquiring data images and later in the modelling process and spatial visualisation it is worthwhile to seek for alternative methods of optimizing the applied technique and processing method. Adopting costly solutions is not always necessary. For the purposes of terrain analysis and local assessments of landscape the author suggest to use the modelling method based on recording series images taken by non-metric cameras, guaranteeing economical, technically optimal and accurate solution of the problem. This claim is proven by the accuracy analyses of generated spatial visualisations and the results of calibration of chosen non-metric cameras.

The study confirmed the consistency of the results of control measurements – carried out by means of analyses of calibration reports in chosen non-metric cameras and an exemplary object’s spatial model created by a separate software – with the predictions made in the stage of theoretical considerations.

Keywords

recording of long-series images • non-metric cameras • calibration • 3D modelling

1. Introduction

High development dynamics of image information systems together with Internet as a means of communication and source of information is still on the rise [Gryboś et al. 2013].

Constantly improved non-metric cameras are more and more popular and in some well-grounded cases they can replace costly, more professional devices. New solutions for generating 3D models in the cloud computing environment emerge, allowing for the data processing largely without the participation of the project’s author. The activity of famous firms like Google, Microsoft and Autodesk considerably contribute to the development of this domain.
This paper is aimed at presenting the results of a study of calibration of chosen non-metric cameras and outcomes of an accuracy analysis of a spatial model generated by these cameras in two modes of taking pictures: single shot mode and continuous one. The goal of this comparison is to optimise functioning of the cameras in the process of spatial visualisation, and to broaden the scope of discussion on the application of long-series mode.

The methodology of modelling based on series or long-series record of images can contribute significantly to improvement of quality and accuracy of objects’ models created by applications based on algorithm of scale invariant feature transform (SIFT).

2. Research methodology

As the author’s study showed, good results in improvement of accuracy of 3D models in applications based on SIFT algorithm can be achieved by using continuous and long-series technique. That is why in the presented research (one of many studies of this kind) on calibration of non-metric cameras by means of pictures of a test board, the use of continuous mode was aimed at demonstrating its superiority – practical and accuracy-wise – over single shot mode. This superiority results from the fact that in the continuous recording the exposition time of photodetectors is regulated only electronically by reading with a definite frequency of accumulated electric charges. That is why this mode does not effect image orientation.

Long-series image recording technique is an extension of continuous mode with the following conditions:

- the pictures are taken in relatively long series (e.g. a few hundred shots),
- the memory card of the camera must be sufficiently large (it follows from the first condition),
- the image recording is regular (with a fixed time interval) and sufficiently fast,
- the images are best recorded in a series as “frozen”, to avoid blur.

In case of single shooting mode the photo-mechanics of the camera plays an essential role, which impairs image stability. Among conditions that significantly influence the zoom lens stability of a digital (non-metric) compact camera is the movement of zoom lens – sliding and rotary motion while taking single pictures, when the uniqueness of the lens position causes instability of image distance.

That is why recording of images was done with camera calibration and an exemplary object’s model was generated (Figure 1) together with its measurement in the field – in variants that enable the discussion of results, developed by software ensuring simple and clear accuracy analysis.

The study of models created by using long-series image recording indicate that they are more accurate, have less distortions, contain more than twice as many correct results in a set of control measurements and are faster to record than the method based on a single shot mode.
Another difference in the results between these two modes of recording images lies in determining the orientation of pictures and positions of the camera. In a long-series method the configuration of images was correctly determined. In the second method the order of images was incorrect even when the corresponding points on the subsequent pictures have been manually determined, which has been shown in earlier studies of modelling and spatial visualisations carried out by the author [Jankowicz 2015].

The calibration of the camera is a procedure by which interior orientation elements (IOE) can be determined with a specific error, the value of which shows the dispersion in their determination. The results of studies of selected cameras are presented below.

The results of calibration of chosen non-metric cameras include five picture sessions of a calibration board in Agisoft Lens software.

Generally, comparison of results of series recordings of images (Figure 2) and single ones (Figure 3) proved that in the first method the lower standard errors regarding the following parameters:

- focal length (x), (y),
- coordinates of picture's principal point (x), (y),

had better stability in the process of taking pictures.

Fig. 1. Positions of the Canon camera (above) and measurement of control tie distances in modelling from series pictures (left) and single ones (right). The exemplary visualisation of the Florian Straszewski monument in Kraków was created by 123D Catch software. In visualisations made from single shots distortions are more visible than in the continuous mode.
Fig. 2. The results of an exemplary calibration of a Panasonic DMC-FS3 camera – series pictures. Values of standard errors for focal lengths and principal points are visibly lower than in Figure 3.

This advantage translates further into accuracy parameters of an object’s 3D model, generated in the next stage from the series pictures.

The report of calibration (made by Agisoft Lens software) of the Panasonic DMC-FS3 camera presented above includes estimated values of specific parameters, some of which with their errors (Figures 2 and 3):

- image width / height [pix],
- horizontal and vertical focal length (x), (y) [pix],
- coordinates of principal point (x), (y) [pix],
- radial distortion value K1, K2, K3, K4 and tangential distortion value P1, P2 [pix],
- skew of axes X and Y.

Next, the calculations determine the transformation of coordinates in a local configuration of a camera to a pixel coordinates in an image frame.

Local system of coordinates of a camera starts in the middle of a projection. Z axis takes a direction of look, X axis points to the right, Y axis – downward.
The system of coordinates starts in a left upper image pixel, precisely in its middle, with coordinates (0.5, 0.5). Y axis of an image system coordinates points to the right, Y axis – downward.

For a given point M (X, Y, Z) in a local coordination system of a camera, predicted coordinates in an image frame can be calculated by the following equations:

\[
x = \frac{X}{Z}
\]

\[
y = \frac{Y}{Z}
\]

\[
x' = x(1 + K_1r^2 + K_2r^4 + K_3r^6) + P_2(r^2 + 2x^2) + 2P_1xy
\]

\[
y' = y(1 + K_1r^2 + K_2r^4 + K_3r^6) + P_1(r^2 + 2y^2) + 2P_2xy
\]

\[
u = c_x + x'f_x + y'skew
\]

\[
v = c_y + y'f_y
\]
where:

- \( r = \sqrt{x^2 + y^2} \),
- \( X, Y, Z \) – points’ coordinates in the local coordinates of the camera,
- \((u, v)\) – predicted coordinates of points in the system of coordinates of an image [pix],
- \((f_x, f_y)\) – focal lengths,
- \((c_x, c_y)\) – principal point coordinates,
- \(K_1, K_2, K_3\) – coefficients of radial distortions,
- \(P_1, P_2\) – coefficients of tangential distortions,
- Skew – skew coefficient of axis x and y.

Moreover, graphs are presenting values (in pixels) of radial and tangential distortions, as a relation of distortion on its radius (Brown's model).

Similar research was carried out for other non-metric cameras (Sony Cybershot DSC-T-5, Canon EOS 400D), confirming that standard errors in determining horizontal focal length \(F_x\) and vertical \(F_y\) and coordinates of principal point \(O(x, y)\) are significantly lower in series pictures than in single ones.

Comparison of the results is presented in Table 1.

<table>
<thead>
<tr>
<th>Camera</th>
<th>Continuous mode</th>
<th>Single shot mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(F(x)<em>{err} / F(y)</em>{err})</td>
<td>(O(x)<em>{err} / O(y)</em>{err})</td>
</tr>
<tr>
<td>Panasonic FS3</td>
<td>48.79 / 48.88</td>
<td>7.03 / 7.57</td>
</tr>
<tr>
<td></td>
<td>(3216 / 3223)</td>
<td>(1661 / 1105)</td>
</tr>
<tr>
<td>Sony DSC-T5</td>
<td>125.29 / 125.09</td>
<td>5.95 / 4.03</td>
</tr>
<tr>
<td></td>
<td>(2932 / 2931)</td>
<td>(1338 / 814)</td>
</tr>
<tr>
<td>Canon EOS 400D</td>
<td>0.017 / 0.032</td>
<td>6.35 / 1.63</td>
</tr>
</tbody>
</table>

Source: author’s study

3. Conclusions

The calibrations of chosen non-metric cameras showed that the continuous mode of recording pictures is more accurate. The standard error values of focal length and position of the principal point of a picture in all continuous mode sessions have lower values than in single shot sessions.
Moreover, on the basis of the research carried out in the field [Kwoczyńska 2013] and with the help of 123D Catch software, it was confirmed that models and 3D visualisations from terrestrial pictures (Figure 1) and aerial ones, taken by unmanned aerial vehicles (UAV) by a long-series image recording method, are characterized by greater accuracy, which is proven by studies carried out by others [Litwin and Piech 2013, Litwin and Pijanowski 2013].

Apart from that, series method of recording, in comparison with the single shot one is: faster, a generated model has less distortions, “Error-free” measurements of a generated model is 70% of database in continuous mode and 30% in single shot mode.

Therefore, having the above results in mind, one can say that 3D visualisations generated from series of pictures have better accuracy parameters, which is also confirmed by the outcomes of calibration chosen non-metric cameras.

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MKSCAL – SYSTEM FOR LAND CONSOLIDATION PROJECT BASED ON CAD PLATFORM

Jarosław Janus, Mariusz Zygmunt

Summary
Consolidation works are a complicated and lengthy set of legal, technical and administrative operations. IT tools used in this process are developed in many countries, and the scope of their functions is very wide: from a decision-making aid, through support in solving technical aspects, to assisting the evaluation of the effects of consolidation projects. Practically all existing solutions are based on GIS systems, which has many advantages but also imposes some limitations related to supporting typically geodetic aspects of these works. The article presents a different approach to implementing this kind of projects, which is based on CAD platform. It is used as an aid in various stages of land consolidation works in more or less half of the area of Poland.

Keywords
land consolidation • land reallocation • expert systems

1. Introduction
Land fragmentation is one of the key factors that negatively affect the profitability of agricultural production [King 1982]. Many countries around the world and in Europe, especially those in Central and Eastern Europe, are confronted with this problem, which continues to be the subject of numerous recent studies [Hartvigsen 2014]. The most important aspect of land fragmentation is the division of farms into many small plots scattered on a large area, which often makes farming costs higher than potential profits. To improve this ratio land fragmentation process is most commonly used [Pašakarnis and Maliene 2010]. Its aim is to reorganize the layout of plots on a large area of a whole village or – more rarely – its part, or a compact area covering a few neighbouring villages.

Land consolidation procedure is a complicated and costly operation, and the duration of such projects depends on solutions adopted in a particular country and varies from a few to a dozen or so years [Hartvigsen 2015]. This period includes both the implementation of the land consolidation project and time necessary for carrying out essential accompanying investments, including especially building new agricultural roads. The process has largely administrative and legal character, however due to major share
of typically technical elements, including those related to measurements and calculations, development of information technology has proven effective in aiding specific aspects of these works. The model of consolidation works differs greatly depending on a country where the works are carried out, from highly centralized, based on state or local government units, to a strictly commercial one, with private companies acting as part of public works contracting system. Carrying out land consolidation works is in most cases an element of rural areas development politics implemented in specific countries [van Dijk 2007], or even, as it is in the EU member countries, the politics realized in the whole region [Sonnenberg 1996].

The most popular IT solutions adopted to assist in the land consolidation procedure are based on GIS type platforms [Martínez 2013, Junfang et al. 2006, Tourino et al. 2003, Semlali 2001] and are used as help in typically technical operations, in planning elements of these works [Changjiang 2011], as well as in estimation of their effects [Coelho et al. 2001, Gonzalea et al. 2004], while the project implementation can be supported by propositions of land plots layouts generated by optimizing algorithms [Wang 2010, Demetriou et al. 2014, Cay and Iscan 2011]. More and more often they take the form of integrated systems covering broad scope of operations related to consolidation works [Demetriou 2014].

The paper presents a different approach to aiding consolidation works, based on CAD type platform. It is executed by a software package called MKSCAL, which is widely used in Poland. The approach based on CAD has its origins in the historical aspects of its development. The main task of the early versions of this software was to help to create a consolidation project based on the results of geodetic surveys and available geodetic and cartographic data. However, at the time when the MKSCAL was developed – namely at the beginning of the 21st century – the basic tool used by many firms carrying out consolidation works in Poland was a family of MicroStation software by Bentley. The advantages of CAD-oriented approach to designing consolidation works are still significant, as they give much greater freedom in designing, offer more drawing tools and broader scope of using various data formats than GIS platform. Yet undoubtedly both approaches to storing and processing data are increasingly convergent, also due to the development of conversion methods of these two types of data, especially from CAD to GIS environment [He 2011, Al Rawashdeh 2013]. For this reason, in a dozen or so years a division between tools based on CAD and GIS model may disappear.

2. Technical and legal conditions of consolidation works in Poland

IT solutions supporting transformation process of lands spatial structure are largely determined by legal and organizational conditions existing in a specific country. When describing the structure and functionality of the MKSCAL system it seems reasonable to outline the model of how consolidation works are carried out in Poland. Such projects are run by specialized units of voivodeships governments. In almost each of 16 voivodeships in Poland there is usually one geodetic unit which carries out such works and which, in some voivodeships, has its local branches. Only in a few voivode-
ships there are no units of this kind, because of relatively low demand for that kind of works in the area. In such cases consolidation works are done by units from other parts of Poland under agreements of appropriate local governments.

In Poland there are no technical requirements related to IT tools that can be used in land consolidation works. Up until the beginning of the 21st century each institution developed its own IT tools aiding consolidation works, of mostly fragmentary rather than comprehensive character. Of major significance was a choice of a principal IT platform for most geodetic works in a voivodeship. Two types of software dominated and still dominate in this respect: the first one consists mainly of CAD software of Microstation line by Intergraph and by Bentley Systems, the second is based on Polish device integrating functionalities typical of CAD, GIS platforms, complying with the specificity of the Polish cadastral data model and including contents of separate categories of geodetic maps – software package developed by Geobid since the nineties up to this day. Other tools, including those based on typical GIS platforms (and on ArcGIS, MapInfo, Geomedia and others), are in small minority, though recently they are becoming more popular in some regions of Poland – and a good example of that is a system designed and put into implementation at the beginning of 2016, aiding consolidation works in the Lubelskie voivodeship, based on ESRI ArcGis platform.

3. The genesis of MKSCAL system

At the beginning of the 21 century the scale of consolidation works in Poland was relatively low because of two principal reasons. First, there was no effective tools to help their financing. The binding provisions of law limited the ways of financing these works almost exclusively to resources of the Treasury. This apparently safe method was in practice very problematic, as this kind of expenditures was not included in consecutive budget plans, which was the condition for the works to be done. Second reason was a relatively low interest of lands’ owners. Negative perception of local communities stemmed from their experiences of consolidation works carried out according to the law of 1969 on consolidation and exchange of lands, which was in force up to 1982. Its provisions allowed for consolidation works to be done regardless of or even against the owners’ will (manifested in applications). Moreover, the works often boiled down to approving the project on new layout of plots and to outlining it in the field, while access roads to arable lands were not built for a long time after the consolidation had been completed.

In Poland the consolidation works, in contrast to majority of other categories of geodetic works, were never an element of free market game, and they were reserved, with rare exceptions, first to state units and then, after the reform of 1999, to local government units. The result was a limited number of institutions responsible for consolidation works. Together with an almost total disappearance of consolidation works at the beginning of the 21st century, it diminished the interest of software firms in developing tools for consolidation works. Also, at the level of local and central government, there were no solutions enabling uniform IT standard encompassing common data model, tools and procedures.
The first attempt at comprehensive approach to implementing IT solutions to consolidation works was made in 2001 in the Małopolskie voivodeship on the occasion of resuming, after many years of suspension, consolidation works in Wojków. The works were continued up till 2014 and it was during that period when the MKSCAL system was conceived and implemented. Its first form [Janus and Zygmunt 2005, Litwin et al. 2006] consisted of two elements: project part, integrated with MicroStation graphic platform by Bentley Systems, and a module for assisting the process of balancing consolidation works in accordance with requirements of the law on consolidation and exchange of lands, the software created with the use of Visual Studio package and independently of CAD platform (Figure 1).

The innovativeness and potential of the package were soon noticed by and then implemented in many centres responsible for carrying out consolidation works in Poland. In 2006 the system and its two authors were awarded a prize by the Ministry of Construction in recognition of outstanding achievements in geodesy and cartography that consisted in designing and implementing this system in nearly half of Poland.

Since its market launch the software package has undergone many changes, related to both the development of original modules and adding new functionalities, including those assisting the study stage and evaluation of consolidation works. Today it can be regarded as a fully integrated system assisting both the decision processes and implementation stages of consolidation works.
4. The functional scope of the system – from analysis of the needs to evaluation of results

Today, that is in 2016, the MKSCAL system consists of a number of elements, aiding the following categories of works related to the process of consolidation of lands:

- analysis of land and building register (LBR, in Polish: EGiB) databases in order to identify the areas with unfavourable parameters of lands’ spatial structure that qualify them for consolidation works,
- assisting the study works proceeding the proper consolidation works,
- automating appraisal map creation based on LBR data and on comparative estimation of lands,
- automating appraisal registers generation before and after consolidation,
- assisting the creation of transitional register,
- automating the process of designing land plots of intended value, size and width,
- assisting the generation of geodetic documentation,
- assisting the process of balancing and control of the project in accordance with the provisions of the law on consolidation and exchange of lands,
- assisting the process of establishing new land register after consolidation,
- evaluation of effects of completed consolidation works,
- experimental module of optimizing plots layout, based on the methods of linear programming using binary variables and external computational package GLPK [Makhorin 2008].

The functional chart of MKSCAL system is presented in Figure 2.

![Functional Chart of MKSCAL System](image_url)
5. Automation of some stages of consolidation process

This article is aimed at presenting these elements of the programme that while using the best aspects of CAD platform can be of help in some technical operations. These elements are presented in consecutive subsections below.

5.1. The preparation of land value map

One of the key elements of consolidation procedure is defining the principles of appraising lands intended for consolidation, because in Poland, as a rule, individual owners are allotted the same (with some tolerance) value of lands before and after the consolidation. These principles should than be applied in the process of creating the land appraisal map of the consolidation area. The content of the map is in turn used in the process of generating comparisons defining the value of each participant's lands divided into particular plots.

These operations are usually based on maps of land quality classification and soil and agricultural maps, while the additional aspects taken into account in the appraisal process are records of local development plans, distance zones and local corrections proposed by representatives of local community.

5.2. Generating register of comparative appraisal before consolidation

Completed appraisal map, after geometric cutting of a layer which it represents with a layer of plots, enables generation of adequate comparisons, formally called “register of comparative appraisal”. This operation is performed in the consolidation procedure twice, at its beginning and at the end, which allows for essential comparisons in the evaluation of consolidation correctness and financial settlements related to enlargement or reduction of farms’ areas.

5.3. Division of object on project complexes

After the appraisal register is generated, the works on the essential elements of the project can be stared. The design process must be proceeded by a division of a village area into complexes, often limited by existing or newly designed roads, external borders, borders of compact forest areas, built-up areas, rivers, railways and any significant terrain obstacles. The boarders of these areas have their counterparts on the comparative appraisal map, in the form of borders of proper appraisal contours and areas excluded from the appraisal. On this basis, in an automatic or semi-automatic way, a first version of division into project complexes can be created, which then can by an object of further corrections based mainly on data from geodetic measurements taken directly in the field.
5.4. Designing plots

Assisting the process of designing plots (Figure 3) is made in many ways: as designing plots of intended value, while taking into consideration the content of appraisal map, as designing plots of intended size or intended width. The algorithms used accept any complexity of appraisal map and any shapes of complexes. The tools to help the designing process are combining the advantages of CAD approach to free creation of vector drawing with requirements of current control of topological correctness of structure of created area spatial objects. To this purpose technology of virtual objects was used [Siejka et al. 2014].

Fig. 3. An example of module of the MKSCAL package, responsible for designing plots

The designing process is enhanced by an information immediately conveyed to the user on a current state of the project for a given farm, on the plots layout before and after consolidation and on comparisons of values and sizes of lands (Figure 4).

Equally important aspect of preparing a consolidation project is a control over its correctness from the point of view of legal provisions regulating this procedure. They impose a number of conditions and limitations on a created project that have to be controlled during outlining the borders of consecutive plots. One of the most important requirements of correctness is the control of size and value divergence of plots in a specific farm, before and after consolidation, and compliance of proposed locations
Fig. 4. An example of module of the MKSCAL package, responsible for visualizing progress of works in the MicroStation software family

Source: author's study

Fig. 5. Some elements of the MKSCAL package, presenting the progress of works over the project of consolidation in a tabular form

Source: author's study
with an owner’s application. It is verified by a separate group of system’s tools, and some elements of them are presented in Figure 5.

The final form of the project is a basis for generating geodetic and cartographic documentation, or lists of coordinates, outlines of plots’ layouts and documentation maps. The last stage of works consists in generating digital cadastral databases showing new plots layout and documentation, essential to upgrading land and mortgage register.

6. Conclusions

The elements of software package described in the article showed their great potential in assisting the technical aspects of consolidation works procedure, and their usefulness has been confirmed in numerous implementations overseen by appropriate units over the last dozen or so years. It is especially noteworthy that there are actually no limitations as to the size of objects, their number (up to tens of thousands) and area (even a few thousand hectares). By involving CAD platform it is possible to simultaneously use many other dedicated tools and overlays for geodetic design development, including those for creation of situational-elevation layers or related to utility infrastructure. Using the algorithm of virtual topography provides the possibility of taking advantage of object-oriented approach to map development, while keeping the convenience of graphics editing typical of CAD platforms. Among the disadvantages of the presented approach is limited scope of spatial analysis (defined by a user and not explicitly anticipated by the system’s developers) and less convenient data exchange with other systems, regarding both geometry and all objects’ attributes stored in the system. In the process of its development the presented software has been supplemented with numerous analytical modes related to evaluation and optimization of plots’ layout, including algorithms of automatic division. These features make him a comprehensive (though not integrated in one platform) assisting system useful not only in consolidation works but also in analytical and decision processes related with them.

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THE FORMATION AND STRUCTURE
OF CLONES OF FOREST HERBS IN ECOSYSTEMS
OF NORTH-EASTERN UKRAINE

Ihor Mykolayovych Kovalenko

Summary

The clonal structure of forest herbs of north-eastern Ukraine, such as Aegopodium podagraria L., Asarum europaeum L., Carex pilosa Scop., Stellaria holostea L., has been examined using the total mapping method. The regularities of changes within the radii of clones, density of partial bushes and their age have been found out. The author has suggested an original statistical and graphical method which allows to estimate age state of each clone and make its land zoning.

Keywords

forest herbs • populations • clones • partial bush • age state

1. Introduction

There are three main types of reproduction in forest plants: sexual, asexual and vegetative. Sexual and vegetative reproduction can occur in seed plants. There are often specific situations where certain types of plants are dominated by one of these two types of reproduction. Vegetative reproduction often predominates in forest herbs.

Vegetative reproduction is common among forest herbs. It compensates for possible low efficiency of sexual reproduction in forest ecosystems with high species saturation and intense competition. Vegetative reproduction evolutionary proved to be useful in connection with immobility of vegetative organisms and frequent cases of alienation of their aerial parts by any phytophagous. Under these conditions, the ability to re-growth turned to be an important adaptation for survival. In this regard, G.Y. Levina [1981] noted that vegetative reproduction in plants essentially performs two functions: firstly, it ensures the longevity of the species existence due to re-growth and, secondly, increases the number of species in ecosystem (actually reproduction). Vegetative reproduction has other progressive feature as well. Young new species in vegetative reproduction are better provided with all kinds of resources through relations with the parent plants, and therefore their survival is much higher than in young plants, originating from diaspores of sexual reproduction.
Length of the respective structures (rhizomes, roots with tillers, tendrils and the like), their ability to branching and depth [Bell 1980] are of importance, when evaluating vegetative reproduction.

All kinds of vegetative mobile plants are characterized by the formation of clones, which are a population of ramets – descendants of one genet. Due to the clonal formation, these plants are more competitively sustainable, capable of capturing the space and holding it for long, preventing other plant species from populating the clone area. Cloning benefits from succession changes in forest phytocenoses. The stability of clones is largely determined by the fact that in the early stages of the ramet formation they receive the necessary organic matters from genet, and therefore are much more stable than regular shoots and sprouts. Thus, the structure of clones, the rate of their formation and stability are not the same [Korovkin 2002] in clone plants with different ways of vegetative reproduction (rhizomes, mustache, stolons, root sprouts, etc.).

2. Objects and methods of the study

The studies were conducted in forest ecosystems of the north-east of Ukraine. A detailed analysis of the clone formation and structure was made for the following model group of grasses: *Aegopodium podagraria* L., *Asarum europaeum* L., *Carex pilosa* Scop., *Stellaria holostea* L. The list and main features of the phytocoenoses in which the clones of the model plants of grass and subshrub layer have been studied, are shown in Table 1.

Table 1. Brief geobotanical characteristics of forest associations with participation of herb and shrub layer dominants

<table>
<thead>
<tr>
<th>Number and name of association</th>
<th>Stand composition</th>
<th>Stand density</th>
<th>Average stand age [year]</th>
<th>Average stand height [m]</th>
<th>Average projective cover of dominant [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aegopodium podagraria</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I. Quercetum coryloso-aegopodiosum</td>
<td>6Q4P</td>
<td>0.7</td>
<td>79</td>
<td>27</td>
<td>55</td>
</tr>
<tr>
<td>II. Querceto-Pinetum coryloso-aegopodiosum</td>
<td>7P3Q</td>
<td>0.6</td>
<td>61</td>
<td>27</td>
<td>60</td>
</tr>
<tr>
<td>III. Betuleto-Pinetum coryloso-aegopodiosum</td>
<td>6P4B+Q</td>
<td>0.8</td>
<td>53</td>
<td>24</td>
<td>55</td>
</tr>
<tr>
<td><strong>Asarum europaeum</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I. Quercetum coryloso-asarosum</td>
<td>8Q2P+B</td>
<td>0.7</td>
<td>65</td>
<td>23</td>
<td>60</td>
</tr>
<tr>
<td>II. Pinetum coryloso-asarosum</td>
<td>9P1Q+B</td>
<td>0.8</td>
<td>68</td>
<td>24</td>
<td>50</td>
</tr>
<tr>
<td>III. Querceto-Pinetum asarosum</td>
<td>6P4Q</td>
<td>0.5</td>
<td>59</td>
<td>22</td>
<td>65</td>
</tr>
<tr>
<td><strong>Carex pilosa</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I. Querceto-Pinetum caricosum (pilosae)</td>
<td>6P4Q</td>
<td>0.6</td>
<td>48</td>
<td>20</td>
<td>65</td>
</tr>
<tr>
<td>II. Quercetum coryloso-caricosum (pilosae)</td>
<td>8Q2P</td>
<td>0.7</td>
<td>53</td>
<td>21</td>
<td>60</td>
</tr>
<tr>
<td>III. Betuleto-Quercetum coryloso-caricosum (pilosae)</td>
<td>6Q4B</td>
<td>0.8</td>
<td>55</td>
<td>23</td>
<td>50</td>
</tr>
</tbody>
</table>
**Stellaria holostea**

| I. Querceto-Pinetum coryloso-stellariosum | 7P3Q+B | 0.6 | 52 | 22 | 55 |
| II. Quercetum coryloso-caricoso (pilosae)-stellariosum | 8Q2P | 0.7 | 55 | 24 | 50 |
| III. Querceto-Pinetum stellariosum | 6P4Q | 0.5 | 51 | 21 | 60 |


Source: author’s study

Source: https://yandex.ua/images

**Fig. 1.** The territory of the investigations
Overall, from 20 to 30 clones were investigated for each species (Figure 1). From four to six clones of each species (Figure 2) were selected as the most typical ones of the region of the studies.

The study of the clones of plant populations of forest herbs in north-eastern Ukraine was conducted by total mapping of the area occupied by clone. The area was divided into squares (50 × 50 cm). For each square horizontal projection was made, on which the location of partial bushes of the investigated species, their number and age state of each were indicated. After that, the litter and surface soil were removed, and the position of rhizomes was marked in the scheme being made.

Clones are significantly different from each other by the ratio of partial bushes of different age, and location of bushes of different age is not accidental within each clone. To estimate the total age state of clones the author has developed three new indexes: the index of recovery ($I_{rec}$), the index of aging ($I_{ag}$) and the index of generativity ($I_{gener}$),
based on the theory of M.V. Glotova [1998]. They were calculated according to the following formulas:

The index of recovery as the ratio of pre-generative partial bushes to their total number:

\[
I_{rec.} = \frac{\sum_{i=1}^{p-v} n_i}{\sum_{i=1}^{p-s} n_i} \cdot 100
\]

where:

\( p..s \) – age state of partial bushes in standard designations.

The index of aging as the ratio of partial bushes of age state \( g3, ss \) and \( s \) to their total number:

\[
I_{ag.} = \frac{\sum_{i=1}^{g3-s} n_i}{\sum_{i=1}^{p-s} n_i} \cdot 100
\]

The index of generativity as the ratio of number of generative partial bushes to their total number:

\[
I_{generat.} = \frac{\sum_{i=1}^{g1-g3} n_i}{\sum_{i=1}^{p-s} n_i} \cdot 100
\]

3. Results of the study and their discussion

3.1. Aegopodium podagraria

The study of A. podagraria clones was made in three associations (Table 1).

Vegetative reproduction plays the main role in self-recovery of A. podagraria populations in the forests of north-eastern Ukraine. The result is a spatial arrangement of partial shoots around female parent. A special structural element (clone) is consequently created. A. podagraria clone consists of ramets that represent rosette-like partial shoots, parts of which are connected by living rhizomes, and the rest are independent after rhizome digestion.

In all investigated forest types, glague cover is solid due to the closure and convergence of clones. But in some places it was possible to find A. Podagraria clones, fairly isolated
from each other. They had a round or ameboid form. The five clones were described in various associations of about the same size within a radius of 8 to 14 m each.

The analysis of counting the number of *A. podagraria* partial bushes on the investigated patches within a radius of clone from its centre to the periphery has shown (Figure 1a, b) that the density of partial bushes throughout the clone area is about the same with a slight tendency of its decline from 58 to 53 bushes per square meter to the periphery of clone, which corresponds to the regression equation, given by: $y = 57.7 - 0.2x$. Thus, *A. podagraria* clones by structure are, in the understanding of A. Zlobin [1997], clones-fields. These clones are evenly filled with partial bushes. The average density of partial bushes, characteristic of the investigated forest associations, is at a level of 45–70 pieces $\cdot$ m$^{-2}$.

The results of these calculations are shown in Table 2.

Clones No. 4 and No. 1 can be estimated as young: they are absolutely dominated by partial bushes of pre-generative age state that constitute more than 50%. Clones No. 2 and No. 3 are middle-aged. These two clones have the highest generativity (over 60%), and pre-generative and post-generative bushes in equal parts. Of all studied clones, Clone No. 5 is the oldest one: it has the highest index of aging, and reduced generativity in comparison with the middle-aged clones.

**Table 2. Age state of *A. podagraria* clones in forest associations of north-eastern Ukraine**

<table>
<thead>
<tr>
<th>Clones</th>
<th>$I_{rec.}$</th>
<th>$I_{ag.}$</th>
<th>$I_{generat.}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>61.3</td>
<td>12.5</td>
<td>31.8</td>
</tr>
<tr>
<td>2</td>
<td>29.9</td>
<td>20.8</td>
<td>65.3</td>
</tr>
<tr>
<td>3</td>
<td>26.2</td>
<td>16.5</td>
<td>65.4</td>
</tr>
<tr>
<td>4</td>
<td>67.8</td>
<td>7.3</td>
<td>29.8</td>
</tr>
<tr>
<td>5</td>
<td>28.9</td>
<td>37.5</td>
<td>54.2</td>
</tr>
</tbody>
</table>

Source: author’s study

A certain regularity was observed in distribution of partial bushes of *A. podagraria* in clones area. Young clones (clone No. 4 is taken as an example, Figure 3) are dominated by pre-generative partial bushes, the regression line for the index of recovery is higher than the regression line for the index of aging. Pre-generative partial bushes, in comparison with partial bushes of other age-related conditions, mostly occur throughout the area of clone, and they obviously predominate in the peripheral area of a clone. Bushes of age status $g_3$ (subsenile and senile) are not available at the periphery of a clone. They occur in small numbers only in the central zone of clone.

The older clones that can be evaluated as middle-aged (clone No. 2, Figure 3d) are characterized by intersection of the regression lines for the index of recovery and the index of aging in the intermediate part of a clone, so that in the very centre of a clone, subpopulation of partial bushes of *A. podagraria* is composed mainly of generative and post-generative partial bushes of glague, whereas post-generative partial bushes hardly
Fig. 3. A. podagraria: a) change in the number of partial bushes on the investigated patches from the centre (on the left) to the periphery of clones (1–5 numbers of clones); b) change in the average number of partial bushes on patches from the centre (on the left) to the periphery of a clone; c) value change in the index of recovery and the index of aging of partial bushes in clone No. 4; d) value change in the index of recovery and the index of aging of partial bushes in clone No. 2; e) value change in the index of recovery and the index of aging of partial bushes in clone No. 5; (f) diagram of the structural models of A. podagraria clones at different stages of development: A – clone, in the creation of which pre-generative partial bushes are involved; B – clone, in the creation of which pre-generative, virginal, generative and post-generative partial bushes are involved; C – clone, in the creation of which virginal, generative and post-generative partial bushes are involved. 1 – a population of partial bushes of invasive type; 2 – a population of partial bushes of normal type; 3 – a population of partial bushes of regressive type.
ever occur at the periphery. Pre-generative partial bushes dominate here. In much older clones (clone No. 5, Figure 3e) the value of the index of aging is, on average, higher than the value of the index of recovery at all patches within a radius of clone. The first of these regression lines is higher than the second one. Pre-generative partial bushes are absent in the very centre of this clone, but they both occur in the intermediate and peripheral zones of a clone. It can assumed that older clones of *A. podagraria*, which in the forests of the northern-eastern Ukraine have not been found, are dominated by aging partial bushes, and clone is gradually dying off completely.

The author developed the method of evaluating clone aging with the calculation of the indexes of recovery and aging, which allows for internal clone zoning with the separation of the clone area into three concentric zones: central, intermediate and peripheral. The boundaries among them, of course, have a fuzzy nature, but the areas are significantly different from each other.

As a result of generalization of the conducted population studies of *A. podagraria* in forest ecosystems, the three structural models of clones were created which differed in the ratio of partial bushes of different age state and their position (Figure 3f). On average, the rate of expansion of *A. podagraria* clones under the conditions of the National Nature Park “Desniansko-Starogutsky” is about 20 cm per year. The length of the perennial underground shoots of one plant greatly varies depending on the growth conditions and is up to 2–2,5 m.

A number of structural features of *A. podagraria* clones are determined by the density of ramets: it has been found that separate ramets are smaller in size and have poor flowering in dense clones. This effect has previously been described by Y.V. Lavrychenko [1985]. In general, the clones of this species grow well only under the conditions of highlight [Mikhaylova 2006].

### 3.2. Asarum europaeum

The study of *A. europaeum* clones, was conducted in the three associations (Table 1).

Vegetative reproduction plays the main role in self-recovery of *A. europaeum* populations in the forest ecosystems. It results in spatial distribution of monocarpic shoots (partial bushes) around the primary partial bush. The thickets of wild ginger (clones) are consequently created. *A. europaeum* clone consists of partial bushes that are monocyclic shoots, growing acrosympodially.

The six isolated clones of *A. europaeum* were described in various associations. They have a round or oval-elongated shape.

The analysis of counting the number of *A.europeaeum* partial bushes on the investigated patches within a radius of clone from its centre to the periphery has shown (Figure 4a) that it is individual and depends on the size and age of a clone. In contrast to the clonal structure of glague, wild ginger is characterized by tends to decrease the density of partial bushes within a radius of a clone from the centre to its periphery. This pattern corresponds on average to the linear regression, given by: $y = 28.5 – 1.2 x$ (Figure 4b). In the clones with a diameter of 6–9 meters from the centre of a clone to
the periphery the density of partial bushes is reduced from about 90–100 to 28–30 pieces · m⁻². This difference in regularities of clone assemblage, as in *A. podagraria*, may be due to significant differences in the morphology and anatomy of leaves. In *A. europaeum*, unlike *A. podagraria*, they are thick, leathery and almost light-proof.

In the ratio of partial bushes of different age, clones are significantly different from each other, and location of bushes of different age is not accidental within each clone. In order to estimate the total age state of *A. europaeum* clones, the author used the index of recovery \( (I_{rec}) \), the index of aging \( (I_{ag}) \) and the index of generativity \( (I_{generat}) \), the formula for computation of which had been mentioned above.

Clones No. 1 and No. 3 can be estimated as young: they are absolutely dominated by more than 70–80% of partial bushes of pre-generative age state. Clones No. 2, 4 and 6 are middle-aged. These three clones have the highest generativity (over 50%) and pre-generative and post-generative bushes in equal parts. Of all studied clones, Clone No. 6 is the oldest one: it has the highest index of aging (37.5%), and reduced generativity in comparison with the middle-aged clones. (Table 3).

The assignment of clone *A. europaeum* into the category of young, middle-aged or old clones is conditional. Aging of each clone is determined by the ratio of two indexes – the index of recovery and the index of aging, and by this ratio clones constitute the entire continuum of aging.

**Table 3. Age state of *A. europaeum* clones in forest associations of north-eastern Ukraine**

<table>
<thead>
<tr>
<th>Clones</th>
<th>( I_{rec} )</th>
<th>( I_{ag} )</th>
<th>( I_{generat} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>86.7</td>
<td>3.9</td>
<td>11.7</td>
</tr>
<tr>
<td>2</td>
<td>34.1</td>
<td>1.6</td>
<td>65.4</td>
</tr>
<tr>
<td>3</td>
<td>69.3</td>
<td>6.7</td>
<td>27.4</td>
</tr>
<tr>
<td>4</td>
<td>38.6</td>
<td>3.9</td>
<td>60.1</td>
</tr>
<tr>
<td>5</td>
<td>28.9</td>
<td>37.5</td>
<td>54.2</td>
</tr>
<tr>
<td>6</td>
<td>26.4</td>
<td>17.1</td>
<td>71.1</td>
</tr>
</tbody>
</table>

Depending on the age of wild ginger clone, there are regular changes as to the spatial distribution of partial bushes in it. In young clones (clone No. 1, Figure 4) the entire area is dominated by pre-generative partial bushes, the regression line of the index of recovery is much higher than the regression line of index of aging. Pre-generative partial bushes, in comparison with the partial bushes of other age-related conditions, are more common throughout the clone area. Bushes of age status \( g3 \), \( ss \) and \( s \) are not marked.

The middle-aged (clone No. 6, Figure 4d) clone is characterized by a decrease in the intensity of the process of new partial bushes formation and an increase in the aging process of partial bushes.

The regression line of the index of recovery is on the level of 15–10% that is considerably below the regression line of the index of aging, on average, it has the value of 50%.
In older clones (clone No. 5, Figure 4e), the value of the index of aging is, on average, higher than the value of the index of recovery at all patches within a radius of a clone. It can be assumed that in much older clones of wild ginger, which have not been found in the forests of north-eastern Ukraine, aging partial bushes predominate, and clone is gradually dying out completely.

The author have developed the method of evaluation of clone aging which allows, as in the case of clones of *A. podagraria*, for internal zoning of wild ginger clones with the separation of the clone area into three concentric zones: central, intermediate and peripheral.

As a result of generalization of the conducted population studies of *A. europaeum* clone formation in forest ecosystems, the three structural models of clones were created which differed in the ratio of partial bushes of different age state and their position (Figure 4f). The capture of a new area by means of *A. europaeum* clone formation is slow. The main thing in this case is seed propagation.

### 3.3. Carex pilosa

The study of *C. pilosa* clones was conducted in the three associations (Table 1).

In self-recovery of *C. pilosa* in the forests of Ukrainian Polissya vegetative reproduction plays the main role, which is a division of multi-bushy female parent into several filials. No isolated partial bushes, but systems of partial bushes, interconnected by underground shoots, are separated. Collectively such individuals are clones.

The five isolated clones of *C. pilosa* are identified in various associations. From the centre to the periphery, whether in case of individual clones of sedge (Figure 5a) or, on average, for all investigated clones (Figure 5b), the density of partial bushes is sharply (3–4 times) reduced. These clones would take an intermediate position between the clones-fields and clones-individuals.

The regularity of reduction in the density of partial bushes of sedge within a radius of a clone can approximate equation of the form: \[ y = 12.2 - 0.4x \]. The average density of partial bushes are 12–65 pieces \( \cdot \) m\(^{-2}\).

In accordance with the values of the indexes of aging, recovery and generativity of partial bushes, clone No. 3 can be regarded as young (Table 4). It has the highest index of recovery (65.6%) and the lowest index of aging (11.2 %). Clone No. 1, by contrast, is the oldest one. It has the highest index of aging and the lowest index of recovery (63.3% and 10.2%, respectively). Other clones are middle-aged. They are characterized by high generativity.

Pre-generative partial bushes prevail in young clones. The regression line for the index of recovery within a radius of a clone is significantly higher than the regression line for the index of aging (Figure 5c). In the middle-aged clones, these two regression lines overlap, because the aging process of partial bushes clearly dominates in the central part of a clone (Figure 5d). In the older clones, the regression line for the index of aging is higher than the regression line for the index of recovery (Figure 5e). In such clones the aging of partial bushes covers the periphery of a clone.
Fig. 4. *A. europaeum*: a) change in the number of partial bushes on the investigated patches from the centre (on the left) to the periphery of clones (1–6 – numbers of clones); b) change in the average number of partial bushes on patches from the centre (on the left) to the periphery of clone; c) value change in the index of recovery and the index of aging of partial bushes in clone No. 1; d) value change in the index of recovery and the index of aging of partial bushes in clone No. 6; e) value change in the index of recovery and the index of aging of partial bushes in clone No. 5; f) diagram of the structural models of *A. europaeum* clones at different stages of development: A – clone, in the creation of which pre-generative partial bushes are involved; B – clone, in the creation of which pre-generative, virginal, generative partial bushes are involved; C – clone, in the creation of which pre-generative, virginal, generative and post-generative partial bushes are involved; D – clone, in the creation of which virginal, generative and post-generative partial bushes are involved. 1 – a population of partial bushes of invasive type; 2 – a population of partial bushes of normal type; 3 – a population of partial bushes of regressive type
Fig. 5. *C. pilosa*: a) change in the number of partial bushes on the studied patches from the centre (on the left) to the periphery of clones (1–5 – numbers of clones); b) change in the average number of partial bushes on patches from the centre (on the left) to the periphery of clone; c) value change in the index of recovery and the index of aging of partial bushes in clone No. 3; d) value change in the index of recovery and the index of aging of partial bushes in clone No. 2; e) value change in the index of recovery and the index of aging of partial bushes in clone No. 5; f) diagram of the structural models of *C. pilosa* clones at different stages of development: A – clone, in the creation of which pre-generative partial bushes are involved; B – clone, in the creation of which pre-generative, virginal and generative partial bushes are involved; C – clone, in the creation of which post-generative partial bushes are involved. 1 – a population of partial bushes of invasive type; 2 – a population of partial bushes of normal type; 3 – a population of partial bushes of regressive type
Based on changes in the density of partial bushes and their age state, the specific zones have been distinguished in *C. pilosa* clones: the central zone is mainly occupied by senile ramets; the intermediate zone is inhabited by ramets that form the subpopulation of partial bushes of normal age type, and the peripheral (invasive) zone, presented by ramets of young vegetative and sometimes generative state. Details of the distribution of *C. pilosa* partial bushes of different age state depend on its age after the clone zoning.

As a result of generalization of conducted population studies of *C. pilosa* clone structure in forest phytocenoses, three models of clonal structure were created that differed in the ratio of partial bushes of different age state and their location (Figure 5f).

### 3.4. *Stellaria holostea*

The study of *S. holostea* clones was conducted in the three forest associations (Table 1). Vegetative reproduction plays the leading role in dispersal of *S. holostea* in forests. This is also confirmed by the clonal expansion model of this plant species, developed by N.V. Mikhailova et al. [2006]. Its consequence is the placement of partial bushes around the primary partial bush. The result is the formation of *S. holostea* clones.

The four isolated clones of *S. Holostea* have been distinguished. They have a diameter of 15 to 20 m, and often interpenetrate one another. In isolated clones, 40–135 partial bushes of *S. holostea* occur per square meter. They are unevenly distributed (Figure 6a, b): their number in the centre of clones is 5–6 times greater. The regression equation for changes in the number of partial bushes within a radius of a clone is given by: \( y = 27.3 - 0.98 \times \).

Clones of *S. holostea* differ from each other by the ratio of partial bushes of different age state and, accordingly, by values of the indexes of recovery, aging, generativity (Table 5). In young clone No. 3 the index of recovery is equal to 64.4% with low indexes of aging and generativity (respectively 13.8 and 28.6 %). On the general graphs the changes in values of the indexes of recovery and aging within a radius of a clone the regression line of the index of recovery is always above the regression line of the index of aging (Figure 6c). During aging of clones the value of the index of recovery is reduced, and the index of aging is growing. In the middle-aged clones No. 1

---

**Table 4.** Age state of *C. pilosa* clones in forest associations of north-eastern Ukraine

<table>
<thead>
<tr>
<th>Clones</th>
<th>( I_{rec.} )</th>
<th>( I_{ag.} )</th>
<th>( I_{generat.} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.2</td>
<td>63.3</td>
<td>57.9</td>
</tr>
<tr>
<td>2</td>
<td>38.3</td>
<td>11.6</td>
<td>59.9</td>
</tr>
<tr>
<td>3</td>
<td>65.6</td>
<td>11.2</td>
<td>28.0</td>
</tr>
<tr>
<td>4</td>
<td>16.4</td>
<td>45.9</td>
<td>69.4</td>
</tr>
<tr>
<td>5</td>
<td>13.1</td>
<td>48.2</td>
<td>66.6</td>
</tr>
</tbody>
</table>

Source: author's study

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**Fig. 6.** *S. holostea*: a) change in the number of partial bushes on the studied patches from the centre (on the left) to the periphery of clones (1–4 numbers of clones); b) change in the average number of partial bushes on patches from the centre (on the left) to the periphery of clone; c) value change in the index of recovery and the index of aging of partial bushes in clone No.3; d) value change in the index of recovery and the index of aging of partial bushes in clone No. 4; e) diagram of the structural models of *S. holostea* clones at different stages of development: A – clone, in the creation of which pre-generative, virginal and generative partial bushes are involved; B – clone, in the creation of which pre-generative and post-generative partial bushes are involved. 1 – a population of partial bushes of invasive type; 2 – a population of partial bushes of normal type; 3 – a population of partial bushes of regressive type.
and 2 (Figure 6d) the index of recovery goes down to 30–35%, and the index of aging increases by 15–16%. Index of generativity reaches its maximum (60–65%) in such clones. In older clones (clone No. 4, Figure 6e) the index of recovery is about 10%, and the index of aging exceeds 50%.

Table 5. Age state of S. holostea clones in forest associations of north-eastern Ukraine

<table>
<thead>
<tr>
<th>Clones</th>
<th>I_{rec.}</th>
<th>I_{ag.}</th>
<th>I_{generat.}</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>34.5</td>
<td>16.2</td>
<td>60.5</td>
</tr>
<tr>
<td>2</td>
<td>31.9</td>
<td>15.4</td>
<td>65.4</td>
</tr>
<tr>
<td>3</td>
<td>64.4</td>
<td>13.8</td>
<td>28.6</td>
</tr>
<tr>
<td>4</td>
<td>9.9</td>
<td>55.6</td>
<td>66.6</td>
</tr>
</tbody>
</table>

Source: author’s study

The three types of allocation of partial bushes subpopulations have been distinguished in the structure of S. holostea clone: invasive, normal and regressive. Subpopulations of partial bushes of invasive type are mainly formed by pre-generative and adult vegetative bushes: the normal type is formed by bushes of normal age-related condition, the regressive type is mainly formed by bushes of post-generative age state.

As a result of generalization of the conducted population studies of S. holostea in forest ecosystems of Ukrainian Polissya, the two structural models of clones were created which differed in the ratio of partial bushes of different age status and their location (Figure 6f).

Clones dominated by pre-generative partial bushes and existence of post-generative partial bushes in the centre of clone (A) are typical for association of Quer cetum coryl oso-caricoso-stellariosum; clones with a higher proportion of pre-generative, adult vegetative and generative partial bushes (B) are typical for associations of Quercet o-Pinetum coryl oso-stellariosum and Querceto-Pinetum stellariosum.

4. Conclusions

The use of the methods of plant population ecology combined with the original statistical and graphical modeling approach has allowed us to establish regularities of formation and spatial arrangement of clones of four species of forest herbs: Aegopodium podagraria L., Asarum europaeum L., Carex pilosa Scop., Stellaria holostea L., which are the main species in some forest ecosystems of north-eastern Ukraine.

References


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CONDITIONS FOR THE OCCURRENCE OF SELECTED AQUATIC PLANT SPECIES IN THE WATER BODIES OF THE MUNICIPAL PARK IN SKAWINA

Zbigniew Koziara

Summary
The study was conducted in an artificially formed fen, within the old basin of Skawinka river, in a municipal park located in the southwest part of Skawina town. The location and the conditions of the occurrence of selected species were characterized, by means of describing their positions and plotting them on the land survey and height map in the scale of 1 : 500 [Czarnota 1997]. The pH and salinity of the water were examined, the percentage of light reaching the plants was determined, and the organic matter content in the soil was measured. Understanding these conditions will make it possible to select the right species and varieties of plants, having the requirements compliant with the conditions existing in the tested water basin, which will enable their further development and maintaining attractive appearance.

Keywords
aquatic plants • salinity • organic matter • sunlight exposure

1. Introduction
In a unique way, water enlivens and enriches each environment in which it occurs, either natural or artificial.

Wanting to make his environment more varied and attractive, man often attempts to create enclaves of water, introducing selected accompanying species of fauna and flora, examples of which are found in park and garden design. In urban parks and gardens, large bodies of water not only add to the landscape, but they also provide a place for recreation and relaxation, where beautiful aquatic plants and animals living in an aqueous environment are no doubt the biggest attraction for visitors.

Aquatic plants and marshland plants demonstrate numerous morphological, anatomical and physiological adaptation traits to the specific physical and chemical properties of the aquatic environment. Water is about 775 times denser than air and nearly 100 times more viscous, thus the mechanical action of the mass of water in motion is more powerful than that of air (wind) in an aerial and terrestrial environment. Furthermore, the water has large specific heat, and therefore a high thermal
capacity, whereby thermal changes occur slowly, while large bodies of water have a soothing effect on the microclimate. Compared to other liquids, water exhibits anomalous density changes due to temperature – it has the highest density at 4°C, and when passing into the solid state (ice), it becomes less dense, lighter and increases in volume. This phenomenon is the cause of thermal stratification of stagnant water, mostly in deeper reservoirs.

As stated by Kłosowski and Kłosowski [2001], the properties of a given aquatic environment have a huge impact on the plants living therein. Surrounding of a plant organism with water gives it the ability to receive the nutrients with the whole surface of its body. In many aquatic species, therefore, we observe an increase of the absorption and assimilation surface of the leaves located underwater, by their fragmentation into a number of small sections (for instance, in thread-leaved water-crowfoot – *Ranunculus trichophyllus*; whorl-leaf water-milfoil – *Myriophyllum verticillatum*; and hornwort – *Ceratophyllum demersum*); formation of long, ribbon-like leaves (for instance, arrowhead – *Sagittaria sagittifolia* (Figure 1); European water-plantain – *Alisma plantago-aquatica* (Figure 2); reduction of the ground tissue and its lack of differentiation [Broda and Mowszowicz 1979] (for example, in waterweed Canadian pondweed - *Elodea canadensis* Michx.; blue water-speedwell – *Veronica anagalis-aquatica*); as well as loss of cuticle and wax on the skin (mostly in the case of submerged plants). In floating species, common features include the reduction or absence of root system (for example, spotless watermeal - *Wolffia arrhiza* L.; hornwort – *Ceratophyllum demersum* L.), as well as the disappearance of the system for conducting water and mineral salts.

![Arrowhead](image)

**Fig. 1.** Arrowhead (*Sagittaria sagittifolia* L.)
Appropriate selection of plants for water planting will depend primarily on the location of the given body of water, its sunlight exposure and the soil type. When knowing the requirements of individual plant species, we can create favourable conditions for the healthy growth of aquatic plants.

2. Materials and methods

The aim of this study was to locate the positions of the groupings of aquatic plants, and to describe the characteristics of selected species in the artificial body of water within the municipal leisure park in Skawina, as well as to learn about the conditions for their occurrence.

These studies will allow the development of methods for the cultivation of various species, and they will show the current status of the aquatic biological environment in question.

The fen consists of two separate bodies of water (the smaller one, with an area of about 1,700 square meters, and the larger one, with an area of over 2,600 square meters), connected by a narrow lock, and fed by streams flowing thereto (Figure 3). Excess water flows via an artificial canal into the nearby Skawinka river.
LEGEND:
* red colour signifies existing aquatic and marshland plant groupings in the studied bodies of water

1. Alisma plantago-aquatica L.
2. Caltha palustris L.
3. Iris pseudacorus L.
4. Lythrum salicaria L.
5. Myosotis scorpioides L.
6. Nymphaea alba L.
7. Acorus calamus L.
8. Typha latifolia L.
9. Typha angustifolia L.
10. Myriophyllum spicatum
11. Phragmites australis (Cav.)Trin. ex Steud

Source: registered land surveyor Marek Czarnota. Existing groupings of aquatic and marshland plant species are marked (May 2004)

Studies have been carried out in the period from January 2003 to November 2003. During the studies, locations were determined and the species, which occurred there, were labelled. Measurements of light intensity, water pH level and water salinity were conducted, as well as the measurement of the organic matter content in the soil. To identify individual species and their characteristics, we have benefited from the guides – keys to the plants identification by eminent Polish botanists, including: Rostafiński and Seidel [1967], Mowszowicz [1979], Szafer et al. [1988], as well as the atlas of aquatic and wetland plants, developed by Kłosowski and Kłosowski [2001].

Samples of water (about 50 ml each) were obtained from the selected locations of the tested bodies of water, and subsequently analysed in the laboratory at the Department
of Biochemistry, University of Silesia, where pH was determined using the electric pH meter type CP-401 produced by Elmetron, and salinity was measured using resistivity meter CC-401, also by Elmetron. The results obtained were summarized in Table 1, in the format of arithmetic means.

Organic matter was identified using thermal method, in the laboratory of the Agrochemical Station in Poznań. The results in the form of arithmetic means are summarized in Table 2.

The intensity of light exposure was measured with a Sonopan light meter type L-100.

The study was conducted twice, in June 2003, and in August 2003, during cloudless weather, in the afternoon. Having selected multiple locations, we determined illumination levels at the height of the lamina of the studied plants, and these were compared with the light intensity in the open, while our control (100%) was provided by the illumination conditions in the particular location in the given day of measurement. This served to determine the degree of shading of selected plants (%) relative to open space. The results of the arithmetic means of the measurements are summarized in Table 3.

3. The results

In the area covered by the study, several interesting groupings of aquatic and marshland vegetation were found. Among these plants, only those were selected and described, which possessed special decorative qualities, while the others, as common and typical for natural bodies of water, have not been covered by this study.

The reservoir No. 1 (Figure 2) is not very deep (about 1.5–2 m); it is smaller of the two, and it constitutes an artificial pond. From the south, it is partially shaded by several deciduous trees and a flood embankment, from the north, it adjoins a thick trees stand, and an extensive free space, which forms a meadow overgrown with various species of grasses. There is a pathway leading around the perimeter of the reservoir. The edges of the pond are not overgrown with lush marshland vegetation, however, we encountered tufts of broadleaf cattail (Typha latifolia, Figure 4) and narrowleaf cattail (Typha angustifolia L.), sweet flag (Acorus calamus L., Figure 5), and common reed (Phragmites australis, Figure 6). There were isolated cases of true forget-me-not (Myosotis palustris, Figure 7), purple loosestrife (Lythrum salicaria) and marsh-marigold (Caltha palustris, Figure 9). The reservoir also features, in a well-lit position, a group of European white water-lily (Nymphaea alba, Figure 8) and yellow iris (Iris pseudacorus, Figure 10). Similarly as in the reservoir No. 2, a relatively large area of water surface was covered with spiked water-milfoil (Myriophyllum spicatum), which blooms with pink flowers during the flowering period.

The reservoir No. 2 (Figure 1) is a bigger, artificially shaped pond. From the northeast, it borders on the park with trees, while from the south, the bankside is partially exposed to the sun, and in some places sheltered by birch (Betula) and willow (Salix) trees. Here we found common reed (Phragmites australis), sweet flag (Acorus calamus L.), broadleaf cattail (Typha latifolia) and tufts of yellow iris (Iris pseudacorus).
**Fig. 4.** Broadleaf cattail (*Typha latifolia*)

**Fig. 5.** Sweet flag (*Acorus calamus* L.)
Photo by Z. Koziara

**Fig. 6.** Common reed (*Phragmites australis*)

Photo by Z. Koziara

**Fig. 7.** True forget-me-not (*Myosotis palustris*)
3.1. Description of the characteristics of studied species

European white water-lily (*Nymphaea alba*), family: *Nymphaeaceae*

![European white water-lily (*Nymphaea alba*)](image)

This species was observed only in the reservoir No. 2, in locations at the depth of up to 170 cm. The plants were concentrated in a small clump, not yet spread. Perennial plant with thick, branching rhizome of 1 to 3 meters long, it sunk into the mud bottom. Leaf blades are mounted on long, cylindrical stalks. The floating leaves are circular or oval, nearly half indented at the root (double folding), from 8 to 25 cm long (Figure 8). Underwater leaves (occurring only in the initial phase of the plant’s development) are ovate, smaller than the floating ones, and curled under the water. The dark green leaves have a distinctive maroon tint. The flowers are dioicous, white in colour. The fruit is a berry with a circular or angular thimble. The plant blooms from June to September [Szafer et al. 1988].

**Marsh marigold** (*Caltha palustris*), family: *Ranunculaceae*

This species occurs in two places in the reservoir No. 2. We have found just small tufts, clearly of a species that was only a recent arrival.

The leaves are dark green, kidney shaped (Figure 9); smaller at the time of flowering, and later enlarging to a width of 12–15 cm [Rostafinski and Seidl 1967]. The height of flowering plants ranged from 14 to 27 cm.

Flowers appeared at the beginning of April, and the full flowering lasted for a half of that month. The plants were blooming profusely, although briefly, because two weeks later, the complex seed heads began forming, in the shape of star-shaped follicles.
Yellow iris (*Irys pseudacorus*), family: *Iridaceae*

The species appeared in small tufts on the banks of reservoirs No. 1 and 2. It is a perennial plant with thick, strongly branching rhizome and multiflorous stems up to 1 m [Koziara 2015] (Figure 10). The leaves are green (width 3 cm), sword-shaped. The flowers are dioecious, with long pedicles, and they turn yellow. The fruit is a capsule. The plant blooms from May to July [Mowszowicz 1979].
Purple loosestrife (*Lythrum salicaria*), family: *Lythraceae*

Single plants growing in a group of rushes were located in reservoirs No. 1 and 2. This robust perennial plant grows up to 1 m in height. The rhizome is woody, well developed. The stem is straight and poorly branched, in green-brown colour. Dark green leaves, lanceolate, alternate, are gathered in whorls, 3 each. Pink and violet flowers are dioecious, dorsiventral, gathered in a spiked inflorescence. The fruit is a capsule, which cracks open into two flaps. The plant blooms from July to August [Mowszowicz 1979].

Spiked water-milfoil (*Myriophyllum spicatum*), family: *Halorrhagidaceae*

This species was encountered in the reservoirs No. 1 and 2, creating a dense, though fragile, underwater carpets. The stems, submerged or floating-branched, were about 100 cm long. Underwater leaves, pinnatisectum, with almost thread-like sections, are gathered in whorls, 4 to 6 each. Inflorescences usually grow above the water surface. Flowers are collected in a clear, peaking ear of several centimetres, monoicous and dioecious, and they are usually gathered by 4 in one whorl. In the bottom of the inflorescence, female flowers are placed, and above, there are male flowers [Szafer et al. 1988]. Reddish – pink ears appeared above the water surface at the beginning of July, and they remained on the plants until the end of August.

3.2. Characteristics of the conditions for the occurrence of the studied species

The pH and salinity of the water

Table 1. The pH and salinity in the locations of the studied plants

<table>
<thead>
<tr>
<th>No.</th>
<th>Species</th>
<th>pH</th>
<th>Salinity mS·cm⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>European white water-lily</td>
<td>6.8–6.9</td>
<td>0.20</td>
</tr>
<tr>
<td>2</td>
<td>Marsh-marlgold</td>
<td>6.8</td>
<td>0.18</td>
</tr>
<tr>
<td>3</td>
<td>Yellow iris (reservoir no. 1)</td>
<td>6.4–6.8</td>
<td>0.18</td>
</tr>
<tr>
<td>4</td>
<td>Yellow iris (reservoir no. 2)</td>
<td>6.3–6.9</td>
<td>0.16–0.20</td>
</tr>
<tr>
<td>5</td>
<td>Purple loosestrife</td>
<td>6.8</td>
<td>0.18</td>
</tr>
<tr>
<td>6</td>
<td>Spiked water-milfoil</td>
<td>6.8–6.9</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Source: author's study

From the measurements, it follows that these plants occupied positions in the slightly acidic environment (pH 6.3–6.9). Differences arising from the determined pH range are not high, and nowhere was a strongly acidic or alkaline environment determined.

The lowest pH results were found in the location of the yellow iris, and the highest, in the location of European white water-lily, spiked water-milfoil, and yellow iris.

As is apparent from Table 1, most of the plants selected for the study grew in an environment with an average salinity in the range of 0.16–0.20 mS·cm⁻¹.
Content of organic matter in the substrate, in the locations of the studied plants

The content of organic matter in locations of the studied plants ranged from 64.2 to 85.9% (Table 2).

Table 2. Organic matter content in the locations of the studied plants

<table>
<thead>
<tr>
<th>No.</th>
<th>Species</th>
<th>[%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>European white water-lily</td>
<td>85.9</td>
</tr>
<tr>
<td>2</td>
<td>Marsh-marigold</td>
<td>71.4</td>
</tr>
<tr>
<td>3</td>
<td>Yellow iris (reservoir no. 1)</td>
<td>71.9</td>
</tr>
<tr>
<td>4</td>
<td>Yellow iris (reservoir no. 2)</td>
<td>73.8</td>
</tr>
<tr>
<td>5</td>
<td>Purple loosestrife</td>
<td>64.2</td>
</tr>
<tr>
<td>6</td>
<td>Spiked water-milfoil</td>
<td>66.2</td>
</tr>
</tbody>
</table>

Source: author’s study

These values indicate that the tested environment, in most cases, contained a small amount of nutrients. Purple loosestrife grew on slightly more sandy soil, which is characterized by a lower organic matter content. The content of organic matter in the remaining locations ranged from 66.2 to 85.9%. The highest value was found in the European white water-lily environment.

Intensity of sunlight

Table 3. Percentage of sunlight reaching the studied plants

<table>
<thead>
<tr>
<th>No.</th>
<th>Species</th>
<th>Amount of sunlight reaching the plant [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Measurement 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 June</td>
</tr>
<tr>
<td>1</td>
<td>European white water-lily</td>
<td>90</td>
</tr>
<tr>
<td>2</td>
<td>Marsh-marigold</td>
<td>88</td>
</tr>
<tr>
<td>3</td>
<td>Yellow iris (reservoir no. 1)</td>
<td>65</td>
</tr>
<tr>
<td>4</td>
<td>Yellow iris (reservoir no. 2)</td>
<td>82</td>
</tr>
<tr>
<td>5</td>
<td>Purple loosestrife</td>
<td>86</td>
</tr>
<tr>
<td>6</td>
<td>Spiked water-milfoil</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: author’s study

Based on the data presented in Table 3, we can draw conclusions as to the requirements of individual species in terms of sunlight, which in the future will facilitate making the selection of species with a similar demand for light. Plants living on the
border between aquatic and terrestrial environments have a high demand for solar radiation. Very high light requirements (up to 100% of the incoming light) is typical for aquatic species with leaves floating on the surface (for example, European white water-lily), or near the water surface (for example, spiked water-milfoil), with inflorescences rising above the water surface. These plants grow abundantly in shallow, sunny and well-heated bodies of water.

Although about 100% of the light in fact reached the plants whose leaves float on the water surface, the species that were submerged in water received much less light than it would result from measurements made above the water surface. Less demand for light (at the level of 70–90%) is typical for species such as marsh marigold or purple loosestrife. These plants grow in positions with good sunlight exposure, but in mixed species clusters, with plants, which shadow each other.

Yellow iris is presented in the table twice, because the conditions in which it occurred in the two reservoirs were slightly different. In reservoir No. 2, where more light reached the plants, the latter were more compact, they had darker leaves, and bloomed much more intensively than in reservoir 1.

The area under study is located in the periphery of Skawina town. This is a park where town residents often spend their free time, walking along the paths and observing the surrounding nature. Farming in the immediate vicinity of the park and the studied reservoirs is not intense, and the presence of modernized factories also should not directly interfere with or disrupt of hydrophytes' growth in the basin in question.

4. Conclusions

Within the body of water, we have found locations of plants, which are protected by law (European white water-lily).

The pH in the studied location was in the range of 6.3 to 6.9, therefore, most of the studied plants grew under the conditions of slightly acidic pH.

Salinity of the water reservoirs showed no extreme values, oscillating around the average of 0.20 mS · cm⁻¹.

The highest light intensity (specified in %) arrived to aquatic plants with large leaf blades floating on the surface of the water, and inflorescences, which were raised about the water surface (for example, white water-lily).

Lower light intensity (in %) fell on partially shaded species, e.g. marsh marigold and purple loosestrife, while specimens of yellow iris growing in intensely lit locations developed more luxuriantly, and the flowers were larger.

A Summary of all the measurements and observations is a guideline to making the appropriate selection of vegetation for the studied area, while it also provides valuable guidance on how to cultivate these plants.
References


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DATA PRESENTATION ON THE MAP IN GOOGLE CHARTS AND JQUERY JAVASCRIPT TECHNOLOGIES

Karol Król

Summary

The article presents selected software development tools and technologies that enable the presentation of statistical data on digital maps in the browser. The aim of the study was to describe them, and to conduct their comparative evaluation. In our studies, we have used ad-hoc tests, performed on the basis of usability and functionality, using the technique of self-evaluation. Based on the criteria of global popularity and availability, the following were subjected to ad-hoc tests: Google Visualization – Geomap and Geo Chart, as well as selected solutions developed on the basis of the jQuery JavaScript.

In conclusion, it has been demonstrated that the tested design and development technologies are complementary, while the selection of tools to carry out the design principles assumed remains at the discretion of the user.

Keywords
data visualisation • mashup • web cartography

1. Introduction

In recent years, we can observe rapid development of Internet-based technologies. It is accompanied with the increasing availability and variety of design techniques and tools [Gotlib 2008, Halik 2011, Kukułka 2011, Król 2015a]. Creating visually attractive data visualizations in the browser window, with the use of digital maps, is no longer reserved exclusively for advanced computer users. Developers put increasing emphasis on the software's versatility, universal accessibility, and availability. Therefore, increasingly, the software is developed in two parallel ways. On the one hand, advanced and specialized solutions are created, and on the other hand, simpler ones, intended for users without an IT background, and serving, among other things, to popularize the technology. In addition, software is issued in versions for web-based or mobile devices.

This trend can also be observed in the use of geodata. The suppliers thereof, in the light of increasing competition, seek to attract the users – and the majority of the latter still have rather little knowledge of geo-data. With those users in mind, sets of accessible design tools and techniques are developed, which enable the use of geo-data, often
in an automated manner [Bitner et al. 2014, Król 2015c, Król 2015d]. All this means that more and more sites of “mashup” type appear on the Internet, which combine selected thematic content with the map background [Benslimane et al. 2008, Yu et al. 2008]. Many techniques and tools are conceived in such a way, that the application thereof requires only entering the source data and selected configuration parameters of the map. Others, in turn, are made available in the form of “wizards”, or map generators, which produce maps of spatial phenomena in an automated way to.

Interactive cartographic tools made available on the Internet have many advantages. Spatial (geographical) perspective on information management, which uses digital surveying and mapping, supports the interpretation of data, and the maps are clear and intuitive way of presenting that data. Compilation of thematic maps makes it easy to see and demonstrate the relationships hidden in the numbers. Furthermore, the information provided in the form of interactive maps is attractive for the customer, and more easily remembered.

The aim of this study is to review, describe, and conduct a comparative evaluation of selected techniques for data presentation on general world maps and administrative maps.

2. Materials, methods and data sources

The aforementioned techniques and design tools, and the maps created by means thereof, were tested using exploratory “ad-hoc” testing, also referred to as “Expert Testing or Monkey Testing” [Chhabra 2012, Kölling and Patterson 2004]. It is one of the least formal methods of software testing. Exploratory studies are performed without pre-planned user cases (test cases); however, the aim of testing is specified. Ad-hoc tests are preliminary in character. Often they precede tests proper, they may support the planning of the test proper, or, because of limited resources or time constraints, may replace them completely. They allow you to predict critical points, to which you should devote more attention when conducting further, more formal testing. In the case described herein, ad-hoc tests were carried out on the basis of usability, from the point of view of an average user, while self-assessment technique was applied, which is based on self-registration of experiences and observations made.

The advantage of ad-hoc testing is their cognitive function. They allow you to become familiar with the application being tested, which may not be accurately reflected in the design documentation. The scenario of testing carried out in this manner provides for observing and recording the behaviour of the program in typical conditions in which it operates, i.e. during the implementation of project objectives or activities performed by the user.

The main goal of the design was to create an online map illustrating the numeric or text data, including statistics related to a specific administrative area, or a point phenomenon. Ad-hoc tests (of usability and functionality) were administered to test techniques and design tools, which were selected on the basis of global popularity and availability. Some of the selected techniques and tools are based on geo-data, which is provided by Google (Visualization: Geomap and Geo Chart). In others (jQuery
JavaScript), map primer must be created from scratch (e.g. vector map drawing), or a ready-made map must be obtained from external sources.

The project of the Web application included the creation of a model presentation of statistical data, including the number of inhabitants and the area of the largest cities in Małopolska (Poland), as well as data related to the characteristics of individual provinces. The project assumes that the presentation must take on a multimedia, interactive character, and that it is intended as a component of a website. In addition, the main carriers of information must take the form of either POIs (points of interest), lines or polygons, whose graphic form and principle of operation may vary, depending on the development techniques applied. Further, attempts were made to create a presentation (as described), using various technologies, and their respective design potentials were subsequently rated.

3. Characteristics of design and development techniques applied

The study was preceded by a review of the network services provided free of charge, enabling the presentation of data on the map primer. Analysis of various tools showed that, in general, these services apply out in the four technologies (the classification of which was made according to the type of map primer and the manner of programming interactivity):

1. Static – presentation of statistical data on the raster map (no interactivity). The map is generated in the browser window as a graphic file;
2. Interactive, raster map-based – presentation is a component of a website, based on raster foundation. Interactivity is achieved with selected programming techniques and tools;
3. Interactive, based on vector graphics. Interactivity is achieved with selected programming techniques and tools;
4. Other (mixed), e.g. in presentations using Adobe Flash technology, applying selected programming techniques and development tools (Table 1).

<table>
<thead>
<tr>
<th>Format of map presentation</th>
<th>Features of presentation and technical remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raster</td>
<td>Presentation of statistical data as a raster (static computer graphics). The map is not interactive.</td>
</tr>
<tr>
<td>Raster, extended</td>
<td>Based on raster (graphic) files, such as PNG, JPG and others, which are the foundation for the data embedded dynamically, using programming scripts.</td>
</tr>
<tr>
<td>Vector</td>
<td>Cartograms and map diagrams are rendered in the web browser, in vector format – SVG or VML (line drawing).</td>
</tr>
<tr>
<td>Other</td>
<td>Combinations of various designing techniques, for instance Adobe Flash and script-based languages.</td>
</tr>
</tbody>
</table>

Source: author’s study
Based on a review of available design tools, Google Chart API and jQuery JavaScript, among others (Table 2) were selected for exploratory ad-hoc testing. These technologies provide tools and techniques for creating interactive presentations, which can be a component of your web site, and they are among the most popular throughout the world.

Table 2. Selected methods and techniques of interactive data presentations

<table>
<thead>
<tr>
<th>Development technology</th>
<th>Designing techniques and tools</th>
<th>Data source</th>
<th>Licence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Google Charts API (Image Charts)</td>
<td>Parametrization of the address of the URL web resource</td>
<td>Basic text format</td>
<td>Completely free*</td>
</tr>
<tr>
<td>Visualization API: Geomap • regions display style • markers display style</td>
<td>DHTML: HTML, CSS, Adobe Flash, JavaScript, Google Visualization API</td>
<td>Google Chart libraries (jsapi and loader) DataTable</td>
<td>Completely free*</td>
</tr>
<tr>
<td>Visualization API: Geo Chart • Region GeoCharts • Marker GeoCharts • Text GeoCharts</td>
<td>DHTML: HTML, CSS, SVG, VML, JavaScript, Google Visualization API</td>
<td>Google Chart libraries (jsapi and loader) DataTable</td>
<td>Completely free*</td>
</tr>
<tr>
<td>jQuery JavaScript SVG • jVectorMap</td>
<td>DHTML: HTML, CSS, SVG, VML, jQuery JavaScript</td>
<td>SVG foundation. Free vector and raster map data*</td>
<td>Dual-licenses – GNU GPL and Commercial License</td>
</tr>
<tr>
<td>jQuery JavaScript • CSSMap • CraftMap • MouseWheel • MapBox • ZoomBox</td>
<td>DHTML: HTML, CSS, jQuery JavaScript</td>
<td>Raster foundation. Requires acquisition of data</td>
<td>Open Source, Royalty free</td>
</tr>
<tr>
<td>GIS and JavaScript • ImageMapster • Maplight</td>
<td>QGIS, HTML Image Map Plugin – Map Area DHTML: HTML, CSS, jQuery JavaScript</td>
<td>Raster foundation. Requires acquisition of data</td>
<td>Open Source</td>
</tr>
</tbody>
</table>

* Completely free for all uses: commercial, governmental, personal or educational

Source: author’s study

3.1. Static charts – “Google Image Charts”

Google Image Charts service can generate static charts in the browser. These charts can take the form of bar graphs, pie charts, but also the character cartograms [Ratajski and Lipinski 1973]. Presentation of data is elicited from the server of the service provider on the basis of a URL address (Uniform Resource Locator), in which the parameters of the map are stored, in addition to other elements. Access to the service is free and unlimited.
3.2. Interactive charts – “Visualization API: Geomap, Geo Chart”

Google Charts is an extended service available within the Google Developers, which allows you to create varied graphical, interactive charts, diagrams and other formats of data presentation [Gesmann and Castillo 2011]. Using the service, you can create both traditional pie charts, bar (column) charts, or line charts, as well as charts with a spatial reference (Geomap, Geo Chart). Charts are generated as part of a hypertext document in Adobe Flash technology and SVG or VML format.¹

The SVG format (Scalable Vector Graphics) allows you to combine vector graphics, raster graphics and text. It is characterized by a high degree of integration with hypertext documents. It allows you to handle events (using scripting languages), which in turn facilitates the programming of smooth scaling and moving image functionality, as well as changing the presentation of layers or access to the data assigned to graphic objects [Madej 2003]. The testing focused on the possibility of applying numerical data to the digital map (Visualization API: Geo Chart and Geomap).

3.3. Vector maps in SVG format

The technique of creating interactive maps using jVectorMap [Lebedev 2016] does not provide for the use of raster graphics. The whole image is generated based on HTML, CSS and jQuery JavaScript using SVG or VML. This solution facilitates presentation of statistical data for different administrative units (states, regions, etc.). In order to present data on the map other than the one provided by jVectorMap, you must first create a vector (e.g. GIS formats – Shapefile SHP, Inkscape – SVG formats), and then convert it using a converter prepared in Python programming language. It is available on the jVectorMap website (http://jvectormap.com). JVectorMap constitutes the basis for vector maps downloaded from Natural Earth [2016], available under the “public domain” license.²

3.4. Maps created using “jQuery JavaScript”

jQuery is a comprehensive library of JavaScript programming, first published on 26 August 2006 (the first stable release), which provides a relatively simple way of creating dynamic components of websites and web applications [jQuery 2015].

Among the many solutions based on jQuery, those selected for testing include CraftMap jQuery Plugin [Dziewulski 2013, Król and Bedla 2013, Król 2015b]. This

¹ Vector Markup Language – language of the XML family, serving to generate vector graphics, created by Microsoft company. Standard VML is used for the presentation of charts in older versions of the Internet Explorer browser (adopting VML for old IE versions), which ensures compatibility with various browsers and devices such as iPhone, iPad and Android-type software.
² To simplify, “public domain” signifies creations, which can be used without limitations. This unlimited use may result from the expiry of copyright, or from the fact that the given work has never been or is not subject to copyright.
component is available for free under the Creative Commons NonCommercial Use license (NC), which means that it can be used free of charge only in non-commercial projects.\footnote{The CC NC license allows for copying, distribution, displaying and using the work and all its derivatives, but only for non-commercial purpose.}

The component facilitates viewing static raster graphics, which – via the script – take over the function of a map of coordinates, so to speak. Each pixel here is localized, based on the attributes of length and width of the image (Figure 1). Based on that, an interactive marker is positioned on the map so, which can be a carrier of textual or pictorial information, or the two simultaneously. The information accompanying the points is revoked at the user’s request in the form of a pop-up window.

![Pixel Grid Diagram](image)

Source: author’s study

Fig. 1. Indication of marker location in point 602 × 402 px of the raster image

The second version, based on jQuery script, provides for the execution of the base of map using software such as “desktop GIS” which applies QGIS (open source GIS software license). Map source is stored in a vector format, and then transformed, using QGIS, into a raster file. Its interactive presentation in a browser window is made possible via the following scripts: mouseWheel Extension jQuery Plugin [Aaron 2012] and MapBox Zoomable Maps jQuery Plugin [Abel 2012].

Another jQuery script that allows you to display data on the map base is jQuery ZoomBox [Sutherland 2009]. The script performs mainly the function of navigation, i.e. it facilitates data viewing. In addition to the map, interactive markers are also the
carriers of information. The script also makes it possible to zoom in the map view. The effects of the zoom-in and the drag are simulated; they are based on a raster maps, superimposed layer upon layer onto one other. At the user’s request, individual layers are displayed, and the others are hidden, which resembles the effect of zooming in the map image.

Also analysed was the possibility of presenting data using the CSSMap script [Popardowski 2016]. Interactivity of the map thus created is executed almost entirely by using cascading sheets of CSS styles, with a minor contribution of jQuery scripts. The whole presentation is based on a raster basis. The solution is available with royalty free licence.4

3.5. Maps created using “JavaScript – map area”

Another analysed technology involves the use of “desktop GIS” type software to create the base of the map (vector layer), which is then converted to raster using HTML Image Maps Plugin [Salata and Król 2012]. The map thus created is accompanied by a hypertext document containing, among others, the coordinates of the vertices of objects previously plotted on the vector layer. Interactivity of the applications can be programmed using jQuery ImageMapster script [Treworgy 2013], which allows graded (stepped) zooming in of the map view. After selecting the zoom, polygons depicted on the map are scaled (reduced or enlarged).

The basis of an applications thus created is provided by raster maps. For practical reasons and for reasons of the application’s utility, large image files can be divided into sectors. Each raster map is covered with an interactive layer, generated by the jQuery Maplight script [Lynch 2013]. Mapped graphics is displayed in the IFRAME, commonly called a “floating frame”. The frame allows mutual inclusion of the hypertext documents.

4. Test results

Solutions based on Google Chart are relatively simple to implement and they require no additional extensions, however, they have a closed form, i.e. the user has access to the defined scope of the presentations and to selected graphic attributes; also, he must agree to such terms of use (Table 3). They lack the possibility of extending the functionality of e.g. the option to capture and drag the map area, for example by implementing an appropriate script, or adding module. Attempts to modify or interfere with the format of charts’ presentation can also be inconsistent with the stated terms of use. However, this is compensated by high quality of visuals and seamless service.

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4 The licensing model is based on a one-off fee, paid by the license buyer, upon which he gains the right to repeated, free use of the intellectual property, with no need to make repeated payments.
Table 3. Summary of observations made during exploratory testing\textsuperscript{5}

<table>
<thead>
<tr>
<th>Development technology</th>
<th>Google Charts (Visualization API: Geomap, Geo Charts)</th>
<th>jQuery JavaScript, SVG</th>
<th>GIS and JavaScript</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time of development</td>
<td>+</td>
<td>++</td>
<td>+++</td>
</tr>
<tr>
<td>Complication level of the implementation of a functionality</td>
<td>+</td>
<td>++</td>
<td>+++</td>
</tr>
<tr>
<td>Possibility to personalize the map</td>
<td>++</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>Format of the map base</td>
<td>Adobe Flash, SVG/VML</td>
<td>Raster PNG, JPG, or another, SVG</td>
<td>Raster PNG, JPG, or another</td>
</tr>
<tr>
<td>Format of presentation of numerical data</td>
<td>Fixed, defined</td>
<td>Free, possible to program</td>
<td>Free, possible to program</td>
</tr>
<tr>
<td>Amount of data presented</td>
<td>Limited by the form of presentation</td>
<td>Depending on the script solution</td>
<td>Depending on the script solution</td>
</tr>
<tr>
<td>Form of implementation</td>
<td>Direct implementation in the HTML code (embed a map) or implementation using iframe</td>
<td>Direct implementation in the HTML code (embed a map) or implementation using iframe</td>
<td>Direct implementation in the HTML code (embed a map) or implementation using iframe</td>
</tr>
<tr>
<td>Modification of map base</td>
<td>No access, based on Google Maps</td>
<td>Full access, if based on custom map</td>
<td>Full access, if based on custom map</td>
</tr>
</tbody>
</table>

\textsuperscript{5} In Table 2, no assessment of the technique for generating static charts was presented, as it has been replaced with solutions facilitating the creation of dynamic and interactive presentations.
In contrast, in the case of solutions based on jQuery JavaScript, the basis for the presentation is provided by the raster, which can be created from scratch using programs such as desktop GIS or other vector graphics applications. The source file, resulting from the conversion, provides foundation of a kind for further work. Implementation of external scripts can give it an interactive character (of a dynamic presentation). In this case, statistical data can be presented in any form and quantity, without limitations. However, for the user, the lack of expertise may be an obstacle, as some expert knowledge is necessary to be able to program or implement the functionality of the map. Maps prepared in a variety of technologies, presenting one and the same phenomenon, may share a similar or even identical form of presentation. The technology, in which they have been developed, can be identified based on the analysis of the source code, subtle differences in graphic design, or functionality testing.

Ad-hoc tests have demonstrated that subsequently, it is advisable to conduct testing of interactions of the solutions described herein with other components of the site, for example, other jQuery scripts (interaction of selected scripts within a hypertext document), as well as performance testing, in order to assess the impact of the presentation on overall comfort of using the service, in which they are included as components.

4.1. Google Image Charts

The advantage of maps and charts generated using Google Image Charts is the simplicity and lack of limitations to use. Parameterization of the address of network resources does not cause many problems, however, this technique allows you to generate presentations of data on a limited basis. The disadvantage of the maps thus prepared is the lack of possibility to plot numerical data or text onto them. In the web browser window, they assume a chorochromatic format.

The service allows you to generate maps only in a defined spatial range (records of map parameters: africa, asia, europe, middle_east, south_america, usa, world). The form of encoding of the map’s parameters is not very intuitive, nor is the range of their values (Table 4). A certain advantage comes from the option to save them in any order relative to each other. Another limitation is the relatively small size of the generated map (440 x 220 px).

Numerous restrictions as to the form and scope of the generated maps and charts, coupled with the development of dynamic presentation technologies, led to the closing of the Google Image Charts project in 2012. The official announcement by Google pertaining to this case is that the service may be turned off completely, without prior notice, although the service provider is not currently planning to do so [Google 2016]. The question of the cessation of work on the project may be debatable, because the maps thus generated could find their place in the projects of websites and web applications for mobile devices.
Table 4. Example of parametrization of URL address of a static map of Europe

<table>
<thead>
<tr>
<th>URL address</th>
<th>Significance of parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><a href="http://chart.apis.google.com/chart">http://chart.apis.google.com/chart</a>?</td>
<td>Basic address of the service</td>
</tr>
<tr>
<td>cht=t</td>
<td>Defines the type of chart</td>
</tr>
<tr>
<td>chs=440x220</td>
<td>Chart size in pixels</td>
</tr>
<tr>
<td>chd=t:0,60,100</td>
<td>Defines the data of the chart</td>
</tr>
<tr>
<td>chco= FFFFFF,B3FFB3,008000</td>
<td>Parameter which decides on the colour of the states plotted on</td>
</tr>
<tr>
<td></td>
<td>the map</td>
</tr>
<tr>
<td>chld=FRDEPL</td>
<td>Codes of the states, which shall be marked with a colour on the</td>
</tr>
<tr>
<td></td>
<td>map, Poland (PL), Germany (DE), France (FR)</td>
</tr>
<tr>
<td>chtm=europe</td>
<td>Base area of presentation (Europe)</td>
</tr>
<tr>
<td>chf=bg,s,EAF7FE</td>
<td>Colour of water basins</td>
</tr>
<tr>
<td>&amp;</td>
<td>Character dividing individual parameters</td>
</tr>
</tbody>
</table>

The record of URL address in whole, to be entered in the browser window

http://chart.apis.google.com/chart?cht=t&chs=440x220&chd=t:0,60,100&chco=FFFFFF,B3FFB3,008000&chld=FRDEPL&chtm=europe&chf=bg,s,EAF7FE

Source: author’s study

4.2. Google Visualization API

Of all the analysed technologies, Google Visualization API is relatively the easiest to use, the most effective and impressive. It does not require the user to install any additional software. The basic configuration and implementation of maps require only a minimum of expertise.

The advantages of Google Visualization: Geomap include the availability of two design options: the presentation of data based on interactive polygons (a map made using surface method, and quality background, it shows geographical range – i.e. regions display style) and points (markers display styles, a map made using map diagram method – simple, graded point map diagram). A map thus prepared is automatically equipped with a legend, and the user is pre-equipped with a ready map and mapping software. Moreover, this technique is versatile, it is recommended by Google (locations are geocoded by Google Maps), and it is accompanied by an extensive system of training and technical support. Visualization: Geomap facilitates publication of visually appealing presentations of data on a map, divided into continents, countries or regions. Figure 2 shows an example of an interactive map prepared on the basis of Visualisation: Geomap, in the markers display style version (Małopolska region: the area of the largest cities) and in the regions display style version (Poland: population by province).

The service can be used free of charge, in both personal and educational projects, as well as commercial. Terms of use do not allow you to download and store on your computer the base server code: google.load or google.visualization. It follows that the assembly of all the components of the presentation in any medium of digital data, and
Fig. 2. Screenshot of interactive maps – presentation of statistical data using Visualization: Geomap. 1. Presentation with spatial reference, of the areas of selected cities of the Małopolska region; upon marking a selected point, previously defined information is presented. 2. Presentation of population density; the region selected by the user with a mouse cursor is marked (highlighted) in orange.
using them without access to the Internet, is incompatible with the terms of use. At the same time, it is permissible to generate a screenshot and insert it as a component of a website.

The disadvantages of presentations prepared using the “Visualization: Geomap” include the limited area of the map, i.e. inability to capture and drag with the mouse cursor, and look at the map of the entire globe. Furthermore, Visualization: Geomap utilizes Adobe Flash – Flash-based visualizations (also known as Macromedia Flash). The map is displayed in a browser window using the Flash player (Adobe Flash Player).6

4.3. SVG vector maps

The main advantage of maps developed in SVG format is their flexibility. Thus created maps are generated in the browser in real time (e.g. on the basis of coordinates stored in JavaScript files), which does not require the use of raster graphics. This reduces the time associated with loading the map in the browser window and the amount of data transmitted by the network. Interference with the application code allows you to modify forms of presentation and the scope of the presented data. The effect of drag and zoom of the map view is usually performed using the jQuery JavaScript scripts.

4.4. Components of jQuery JavaScript

Overview of the jQuery Java scripts for presenting data on maps in the browser window, and testing of the selected scripts demonstrate that, in general they are based on raster. Opportunity to explore the map, and its very presentation can be similar to the functionality specific to geoportals, however, the effects achieved using jQuery are usually the simulation of the latter, hence the limited possibilities for their application.

Simulation of the map zoom-in view is the result of the “vertical” overlapping of the previously developed raster maps, one upon the other. The effect can be described as “passive zoom”. Each layer has a different raster size in pixels. Varying sizes of raster grids are levelled by the window of map presentation, where only a fragment is displayed, e.g. the size of 600 × 500 px. Using navigation elements, successive layers are selected and presented in a vertical hierarchy, which the user perceives as zooming in or zooming out of the map. In this case, the degree of mapping the terrain is always the same. The number of objects depicted on the map is fixed. The only thing that changes is the magnification (visibility). The effect of changing the map scale would be possible to achieve only through adequate preparation of raster bases, i.e. every one of them should be prepared so that it would depict the given area or phenomenon in a different scale.

6 Simply speaking, Adobe Flash is a technology of creating animations using vector graphics. At this point we should note that the presentation of a map using Flash technology may depend on individual settings. If the browser extension (that is, Adobe Flash Player) is switched off, damaged or not installed, the map will not be displayed. Furthermore, there is a group of users who deliberately refrain from using Flash technology, because it is often described as “consuming too many resources”, that is, overloading and slowing down the browser.
Limitations to mapping applications created using jQuery are mainly due to the restrictions of the raster base, whose size should be relatively small (it can be assumed that it should be no larger than 1 MB, as otherwise it might result in a lack of usability of the presentation thus developed). Geocoding is lacking, i.e. the points are plotted on the map not based on geographical coordinates, but based on the pixel location on the raster base. All components of the presentation can be gathered in one place (saving the files from the website to be used off-line), and so they can be used without Internet access.

CSSMap tests show that this is a flexible tool, which is largely due to the fact that it has been developed, practically in its entirety, based on CSS styles (this provides a lot of flexibility in modifying the presentation of content). Maps have been developed carefully and they are visually appealing. However, the CSSMap solution is not free. The availability of numerous, alternative free scripts does not encourage its use.

4.5. Testing the map created using “JavaScript – map area”

Presentation of statistical data on the administrative map requires the preparation of the map and the database in full (vectorization of raster bases), or downloading data from unlimited use sources. Vectorization of the map is associated with the installation of GIS desktop software and its additional extensions, enabling the transformation of a vector map into a raster map, covered with a mosaic of active objects in a hypertext document using the <map> marker. They are formed during the conversion, based on the vertices constituting the vector map.

The base in the form of a set of coordinates stored in the hypertext document can serve as a foundation for providing interactivity scripts, e.g. JQuery Map Hilight [Lynch 2013] or ImageMapster [Treworgy 2013]. The latter work on the basis of the <map> marker, which defines the map's address for a given element, telling the Web browser that the graphics (raster) is covered with a grid of active links, which in turn form the map of links (Figure 3). The map of links is an accurate representation of all the objects shown in the grid. Each reference (link) may be a carrier of information, text, graphics, or both simultaneously.

What is typical for the application thus created is the limited area of the map and limited functionality range, i.e. inability to capture and drag with the mouse cursor, and look at the map of the entire globe. In addition, the map’s form is static. A greater range of interactivity, similar to the opportunities offered by Visualization: Geomap, can only be achieved through the implementation of additional scripts.

The advantages of the applications developed in this way include the ability to operate offline, i.e. without access to the Internet. This method involves the preparation of the map from scratch in vector format, hence the lack of restrictions in terms of

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7 In the jargon of coders (programmers), the static character of a website is described as “dry format of application.” This means, among other things, for “floating” frames, no smooth transitions or animations, no curves and no shadowing of objects whatsoever. The effect is that of certain coarseness, in the sense of no smooth cooperation between various functionalities.
the form of the presented objects. Selected jQuery scripts, which create the effect of interactivity (including ImageMapster) do not work if the raster base consists of one hundred or more objects (polygons), especially on computers with a slower Internet connection. Scaling of these objects in the browser window takes too long, which may discourage the user from using the application.

Fig. 3. Active map of links generated in the form of a layer, over the raster base

5. Conclusions

Presentations of statistical data in the form of interactive digital maps, which take the form of cartograms and map diagrams, created by people without basic knowledge of the field, may be incompatible with the principles of cartography. Therefore, it is advisable that presentations thus created be consulted with cartographers or experts in the field of geo-informatics.

Generally available designing techniques enable the users (who lack foundations in the field of geo-informatics) to present statistical data in the browser window, in the form of various diagrams, cartograms and map diagrams. The techniques and tools we have analysed are well-developed and relatively simple to use. Their use usually requires only a basic knowledge of embedding the objects in the structure of a hypertext document. The configuration of map parameters, the choice of the presentation format, and the database input depend on the user.

The technologies and techniques and design tools, which were described in the present study, and which enable the presentation of data in the form of an interactive map, are only a selection from the wide range available on the market. It is difficult to determine, which of the tested sets of tools and techniques is the best. Practice shows indeed that they are complementary. Complementarity is reflected in the selection of an appropriate set of tools for the implementation of a given project assumptions. A specific task will determine the selection of a suitable tool. The differences between the tools are mainly due to programming techniques and data sources used. All this
gives each of them a unique character. The properties resulting therefrom translate into the possibility of design and application in a given project.

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ANALYSIS OF THE FLAWED SPATIAL STRUCTURE OF LAND IN SELECTED VILLAGES OF THE SOUTH-EASTERN POLAND

Przemysław Leń, Monika Mika

Summary
Faulty spatial structure of villages in south-eastern Poland is a result of historical, socio-economic and demographic processes. They are responsible for many long-lived inconsistencies and errors in the Register of Land and Buildings (EGiB) acting as the Cadastre in Poland. The article discusses the problem of the flawed structure of the possession of land, land use and the fragmentation of cadastral parcels in the villages Konieczkowa and Lutcza in the Strzyżów District (powiat), Podkarpackie Voivodeship. Correction of the flawed spatial structure of rural areas, through the known agricultural arrangement treatments such as consolidation and exchange of land, is a chance to improve the economic conditions of the Subcarpathian villages. This process is long-lasting, requiring the cooperation of local authorities with inhabitants and proper legal safeguards. The advantage of carrying out this process would provide a basis for EGiB reforms in order to transform it into the real estate cadastre.

Keywords
fragmentation of land • wielding structure • use structure • plot • parcel • cadastre

1. Introduction
The original settlement systems influenced by human activities have been constantly evolving. Morphogenesis, which occurred in the first spatial systems of villages land, led to high fragmentation of making up farms cadastral plots and their dispersion. Small registration plots characterized by irregular and elongated shape often do not meet the requirements of carrying out field works in agriculture. The fragmentation of plots was not followed by building the access roads for their direct service, which meant that a significant part of plots does not have a direct road connection with the host habitat [Noga 1977].

In the south-eastern Poland the spatial structure of villages was formed in historical, socio-economic and demographic processes. A significant problem for rural areas in this part of Poland is a low level of agricultural development, which is largely due to the topography. The area with the diverse terrain relief is not conducive to the development of
agriculture both in terms of the structure of use and of the mechanization of farm works. In Podkarpacie farms are characterized by a large number plots of irregular shape and relatively small areas. This is demonstrated by scientific research presented in a number of publications [Leń and Noga 2010, Leń 2010, Leń et al. 2015a, b, c; Janus and Taszakowski 2013a, b, 2014]. Due to the high fragmentation and dispersion of farms, farmers are exposed to significant costs of cultivation. The high degree of the development of mechanization, automation and robotization of agricultural machines in these difficult conditions is not applicable. An additional problem is the poor condition of the roads causing difficult or impossible access to the service of fields. These factors adversely affect the state of real estate cadastre in Poland and prevent its further development [Mika 2007, Mika and Siejka 2014]. The chance to improve the economic conditions of the Subcarpathian villages is the correction of the flawed spatial structure of rural areas through the known agricultural arrangement treatments such as consolidation and exchange of land. This process is long-lasting, requiring the cooperation of local authorities with inhabitants and proper legal safeguards. The advantage of carrying out this process would provide the basis for EGiB reforms in order to transform it into the real estate cadastre.

In the article the analysis of the flawed spatial structure of the plots in Lutcza and Konieczkowa villages was carried out. The study determined the structures of use, possession and land fragmentation. The study was conducted to illustrate the configuration of the borders of register plots and capturing areas showing significant failure of the spatial structure of the plots. Quantum GIS program was applied as a tool for presenting the results. The analysis was made on the basis of materials EGiB, obtained from the District Office in Strzyżów.

2. Analysis of the spatial structure of the investigated villages

2.1. The structure of the land use in investigated villages

The structure of land use is a result of presence of multiple factors. These include the terrain relief, soil and climatic conditions. Table 1 shows a comparative tabular listing of the land use in the studied villages.

Table 1. Use of the land in the studied villages

<table>
<thead>
<tr>
<th>The type of agricultural use</th>
<th>Konieczkowa</th>
<th>Area [ha]</th>
<th>[%]</th>
<th>Lutcza</th>
<th>Area [ha]</th>
<th>[%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arable land</td>
<td>452.52</td>
<td>41.22</td>
<td></td>
<td>1341.01</td>
<td>47.63</td>
<td></td>
</tr>
<tr>
<td>Orchards</td>
<td>6.4</td>
<td>0.58</td>
<td></td>
<td>30.9</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>Meadows</td>
<td>27.09</td>
<td>2.47</td>
<td></td>
<td>212.57</td>
<td>7.55</td>
<td></td>
</tr>
<tr>
<td>Pastures</td>
<td>116.01</td>
<td>10.57</td>
<td></td>
<td>195.41</td>
<td>6.94</td>
<td></td>
</tr>
<tr>
<td>Built-up agricultural land</td>
<td>55.53</td>
<td>5.06</td>
<td></td>
<td>80.42</td>
<td>2.86</td>
<td></td>
</tr>
</tbody>
</table>
The analysis of the land use structure in the village Konieczkowa (Table 1) indicated that the largest area was occupied by agricultural lands. They cover 657.66 ha, or 59.91% of the total area of Konieczkowa. The predominant method of the use is arable lands, which cover 508.04 ha, making up 46.28% of the total land area. The second largest group of agricultural lands are pastures that occupy 116.01 ha, or 10.57% of the total land area in the analyzed village. The forest land, shrubs and trees as a whole occupy 405.87 ha, of which 36.56% is covered by forests, and the remaining 0.41% are wooded lands and shrublands. Built-up and urbanized areas represent 2.60% of the total area of Konieczkowa, and the road surface is 28.06 ha, or 2.56% of the studied area. A relatively small area, in the village Konieczkowa, is occupied by the lands under water of 0.48% and a wasteland of 0.05% of the total land use structure. The spatial picture of land use in the studied village is illustrated in Figure 1.

The similar analyses were conducted based on data from the EGiB for the Lutcza village. These studies showed that the largest area in the use structure of the village occupy agricultural lands, which occupy 1866.48 hectares, that is 66.29% of the total area. Similarly to the Konieczkowa village, the area is dominated by arable lands, which take 1341.01 ha and represents 47.63% of the total land area. The next group of agricultural land in relation to the surface of the whole village are meadows, representing 7.55% of the analyzed area. Pastures occupy 195.41 ha, or 6.94% of the total area of the village. Agricultural lands amount to 80.42 ha built, which makes 2.86% of the studied area. Orchards and ditches altogether constitute only 1.32% of Lutcza. Forest lands, bushes and plantings occupy 834.48 hectares, of which 29.03% is covered by forests, and the remaining 0.61% are wooded lands and shrublands. Built-up and urbanized areas represent 3.02% of the total area of Lutcza, of which road area occupy 2.56% of the surface of the land, that is 28.06 ha. The relatively small area is occupied by the lands under water of

<table>
<thead>
<tr>
<th>Ditches</th>
<th>0.11</th>
<th>0.01</th>
<th>6.17</th>
<th>0.22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forests</td>
<td>401.32</td>
<td>36.56</td>
<td>817.36</td>
<td>29.03</td>
</tr>
<tr>
<td>Wooded land and shrubland</td>
<td>4.55</td>
<td>0.41</td>
<td>17.13</td>
<td>0.61</td>
</tr>
<tr>
<td>Residential areas</td>
<td>0.31</td>
<td>0.03</td>
<td>1.67</td>
<td>0.06</td>
</tr>
<tr>
<td>Industrial areas</td>
<td>–</td>
<td>–</td>
<td>0.96</td>
<td>0.03</td>
</tr>
<tr>
<td>Other built-up areas</td>
<td>0.11</td>
<td>0.01</td>
<td>3.66</td>
<td>0.13</td>
</tr>
<tr>
<td>Urbanized undeveloped areas</td>
<td>–</td>
<td>–</td>
<td>0.27</td>
<td>0.01</td>
</tr>
<tr>
<td>Recreation areas</td>
<td>–</td>
<td>–</td>
<td>3.43</td>
<td>0.12</td>
</tr>
<tr>
<td>Roads</td>
<td>28.06</td>
<td>2.56</td>
<td>74.9</td>
<td>2.66</td>
</tr>
<tr>
<td>Waters</td>
<td>5.24</td>
<td>0.48</td>
<td>23.41</td>
<td>0.83</td>
</tr>
<tr>
<td>Fallow lands</td>
<td>0.54</td>
<td>0.05</td>
<td>6.01</td>
<td>0.21</td>
</tr>
<tr>
<td>Various areas</td>
<td>–</td>
<td>–</td>
<td>0.43</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>1097.79</td>
<td>100.00</td>
<td>2815.71</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Source: authors’ study based on Szewczyk 2016
0.83%, wasteland 0.21% and different areas 0.43% of the total land use structure in Lutczza village. The spatial structure of land use in the studied village is presented in Figure 2.
Fig. 2. Land use structure in Lutcza
2.2. Analysis of the structure of possession of land

As it is clear from the analysis (Table 2) of the structure of land possession, from 3057 parcels with total area of 1097.79 hectares, the largest percentage in the surveyed village falls to natural persons, which is as much as 75.98% of the total area of the Konieczkowa village. The area of the land is 834.11 hectares and counts 2 700 parcels. The Treasury is another big owner of these lands. As for the size of the land area, the State Treasury lands occupy an area of 213.27 hectares, i.e. 19.43% of the studied village. On the other hand, the area of land in the hands of companies is 20.13 ha, which is at 1.83% of the total area of the village. Land municipalities and inter-municipal associations own 94 register plots, and they occupy 8.58 ha, which represents 0.78% of the total studied area. The next group of land owners in the village are cooperatives. They own 11 plots with a total area of 8.35 ha. In turn, the land of churches and religious associations occupy 5 plots with a total area of 8.37 ha. The cooperatives and churches and religious associations have the same percentage of the total area of the analyzed village.

<table>
<thead>
<tr>
<th>Number of register group</th>
<th>Land</th>
<th>Konieczkowa</th>
<th></th>
<th>Lutcza</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Number of plots</td>
<td>Area [ha]</td>
<td>[%]</td>
</tr>
<tr>
<td>1</td>
<td>Land of Treasury</td>
<td>117</td>
<td>213.27</td>
<td>19.43</td>
</tr>
<tr>
<td>2</td>
<td>Land of Treasury let for perpetual usufruct</td>
<td>12</td>
<td>1.02</td>
<td>0.09</td>
</tr>
<tr>
<td>4</td>
<td>Land of municipalities and intercommunal unions</td>
<td>94</td>
<td>8.58</td>
<td>0.78</td>
</tr>
<tr>
<td>5</td>
<td>Municipalities land in perpetual usufruct</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>7</td>
<td>Natural persons land</td>
<td>2700</td>
<td>834.11</td>
<td>75.98</td>
</tr>
<tr>
<td>8</td>
<td>Cooperatives land</td>
<td>11</td>
<td>8.35</td>
<td>0.76</td>
</tr>
<tr>
<td>9</td>
<td>Churches land</td>
<td>5</td>
<td>8.37</td>
<td>0.76</td>
</tr>
<tr>
<td>11</td>
<td>Districts land</td>
<td>16</td>
<td>3.96</td>
<td>0.36</td>
</tr>
<tr>
<td>13</td>
<td>Voivodeships land</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>15</td>
<td>Companies land</td>
<td>102</td>
<td>20.13</td>
<td>1.83</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>3057</td>
<td>1097.79</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Source: authors’ study based on Szewczyk 2016

Lands belonging to the district occupy 0.36% of the total area. Negligible percentage in the possession of land has the land of the Treasury let for perpetual usufruct. They occupy 1.02 hectares which is only about 0.09% of the area of the studied village. The spatial image of the possession of land in the Konieczkowa village is presented in Figure 3.
As the analysis shows, for the Lutza village, the structure of the land possession, among 6838 parcels with total area of 2815.71 ha, the largest percentage in the studied
village falls to natural persons, which is as much as 78.19% of the total area of the village. The area of the land is 2201.47 ha in 6116 register plots. Land belonging to the State Treasury is another group in terms of the areas under its possession. They occupy an area of 519.95 hectares, representing 18.47% of the studied village. Companies have 34.83 ha of land, what makes 1.24% of the village area. Municipalities and their associations possess 148 register plots of land, covering an area of 30.19 hectares and representing 1.07% of the total area of the village. Land of churches and religious associations occupies 29 plots with a total area of 16.19 hectares. Lands belonging to the district authorities occupy 0.23% of the total area. The voivodeships lands cover 5.77 hectares which is 0.20% of the area of the studied village. Negligible percentage in the possession structure are 4 plots of municipalities land in perpetual usufruct. The area of this land is 0.77 ha representing only 0.03% of the Lutcza area (Figure 4).

2.3. Analysis of land fragmentation

The studies of Konieczkowa village demonstrated that out of 3057 register plots, the most numerous are the plots within the area range from 0.11 ha to 0.20 ha. Their number is 774, which represent 25.32% of the total number of plots. In the analyzed village 739 plots smaller than 0.10 ha was found, which represents 24.17% of all parcels. On the other hand, within the range 0.21–0.30 ha there are 559 parcels representing 18.29% of all parcels. Size of plots representing 22.18% of the total number of plots is between 0.31 and 0.60 ha, including 678 parcels. Percentage of the number of parcels in the group ranging between 0.61 and 1.00 ha area is 6.18%. The smallest group of 118 parcels, is a group of area above the 1.01 ha. It represents 3.86% of the total number of plots and 34.49% of the total area of analyzed village. The spatial image of the fragmentation of land in the Konieczkowa village illustrates Figure 5.

Table 3. Fragmentation of individual farms land in the studied villages

<table>
<thead>
<tr>
<th>Area range [ha]</th>
<th>Konieczkowa</th>
<th>Lutcza</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of plots</td>
<td>Percentage of plots number [%]</td>
</tr>
<tr>
<td>0.00–10.00</td>
<td>739</td>
<td>24.17</td>
</tr>
<tr>
<td>0.11–0.20</td>
<td>774</td>
<td>25.32</td>
</tr>
<tr>
<td>0.21–0.31</td>
<td>559</td>
<td>18.29</td>
</tr>
<tr>
<td>0.31–0.60</td>
<td>678</td>
<td>22.18</td>
</tr>
<tr>
<td>0.61–1.00</td>
<td>189</td>
<td>6.18</td>
</tr>
<tr>
<td>&gt;1.01</td>
<td>118</td>
<td>3.86</td>
</tr>
<tr>
<td>–</td>
<td>3057</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Source: authors’ study based on Szewczyk 2016
Fig. 4. The structure of possession in Lutcza
Fig. 5. Fragmentation structure in Konieczkowa

Source: Szewczyk 2016
Source: Szewczyk 2016

**Fig. 6.** Fragmentation structure in Lutcza
The research of fragmentation of land in the second village (Lutcza) showed that among the 6838 parcels, the most numerous are plots within the range of 0.31–0.60 ha (Figure 6). Their number is 1668 representing 24.39% of the total number of plots. In the analyzed village 1341 plots do not exceed the area of 0.10 ha, which represents 19.61% of all parcels. In the area range from 0.11 to 0.20 ha there are 1542 parcels representing 22.55% of the total number of plots. On the other hand 20.20% of the total number of plots in the studied village have between 0.21 and 0.30 ha, representing 1381 register plots. Percentage of the number of register plots in the group between 0.61 and 1.00 ha is 8.20%. The smallest number of parcels is found in a group of more than 1.01 ha (5.05% of the total number of plots which represents 36.46% of the total area of analyzed village). Number of plots in this group is 345.

3. Conclusions

The analysis carried out on the basis of the EGiB materials showed that in both locations the greatest area in the spatial structure in terms of land use are arable lands. In the first of the analyzed villages (in Konieczkowa) they occupy an area of 657.66 ha, which represents 59.91% of the total area of the village. On the other hand, in the second village (in Lutcza) agricultural land has an area of 1866.48 hectares which makes up 66.29% of the village.

Both in Konieczkowa and Lutcza the dominant group in the structure of possession of land are natural persons. This indicates a further possibility of growing of the fragmentation in the near future, due to the legal consequences of inheritance of land. In Konieczkowa natural persons are in possession of 834.11 ha, which is at 75.98% of its area and includes 2700 register plots. In Lutcza natural persons are in possession of 6116 plots, with a total area of 2201.47 hectares, which represents 78.19% of the total area of the village.

Analysis of the fragmentation performed in both locations indicated that in Konieczkowa the most numerous are plots within the area range from 0.11 to 0.20 ha, including 774 plots, while in Lutcza the largest number of plots is between 0.31 and 0.60 ha and includes the 1668 register plots.

The scale of the fragmentation in the studied area can be described as large and typical of its region. The results of analyses confirm the outcomes of other studies carried out in southern and south-eastern Poland. They show clearly that the analyzed area is characterized by large imperfection of the spatial structure, adversely affecting not only the level of development and comfort of the inhabitants work, but also contribute to the deterioration of cadastral data. The characteristics of the studied area makes them suitable for carrying out comprehensive consolidations works and exchange of land.
References


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