

CASE STUDY OF ON-THE-SPOT AND SURFACE MEDIEVAL OBJECTS - VERIFYING CURRENT REMOTE METHODS OF DOCUMENTING ARCHAEOLOGICAL SITES

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Abstract

One of the limitations of satellite techniques in archaeological investigations is the land cover. Heritage objects may be more or less visible depending on the land cover type. Low vegetation, such as grass or small shrubs, will usually allow us to determine the location of archaeological objects if the difference in height between the object and vegetation is not significant enough. Forest or high vegetation cover makes it more challenging to determine the location of potentially artificial structures. This project's study area covered 50×70 km of the lower reaches of the Vistula River, Poland. The authors searched for anthropogenic objects close to watercourses and analysed nine different (point, line and surface type) objects having a defensive, sepulchral or settlement function. Circular objects, ditches and earth embankments, burial mounds and strongholds of regular forms were found during this research. Based on nine different models processed with LiDAR-based DEMs, several characteristics and relationships of various types of objects were demonstrated. Moreover, optimal models for searching for archaeological objects in forest areas were defined.

Keywords: Archaeology; LiDAR; Spectrometry; Thermal images

Introduction

This paper describes newfound archaeological sites in the Chełmno region. First, we briefly describe our methods; for more details, please see the first part of this 2-part series, and then we describe the study area in great detail. The next part of the paper describes each recognized site separately. This description includes remote sensing and historical data analysis, geophysics research (where explicable), fieldwork and a summary of results for each site. Finally, we present the results of our works, the effectiveness of the method and future work descriptions.

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The authors of this paper adopted a concept based on an interdisciplinary research approach that would allow for the non-destructive identification of archaeological sites [1–3]. The method described in this paper consists of three steps to find new and undiscovered archaeological sites and create extensive documentation for the authorities about the recognized archaeological sites. The methodology also provides enough 2D and 3D spatial data to develop a GIS-based database with information about these protected, investigated and prospected archeologic sites.

- a. Remote sensing data analysis.** Methods and data from disciplines such as geomorphometry, remote sensing, geomorphology, and geophysics were used in a complementary way to identify heritage monuments hidden in the natural landscape forms [4–7].
- b. Field verification.** Preparation of photographic documentation for individual objects and GPS measurement, simultaneously surveying the research areas to register movable archaeological monuments [1,8].
- c. Digital GIS-based documentation.** Digitization and importation of field- and remote sensing-based data into a geospatial database.

Due to the spatial data integration into the GIS environment, it is possible to analyze the data and create a dataset based on a wide range of information derived from the obtained results. Non-invasive methods allow the creation of modern digital conservation documentation to assist in taking action to protect discovered monuments [9–11].

The secondary contribution of this paper is the description of newly recognized archaeological sites. However, the main contribution is the fact that recognition of those sites has proven that it is possible to use ALS derivatives as a basis for remote recognition of undiscovered archaeological sites in forested areas [12].

Results

Nine sites were selected for verification based on field inspection within the thirteen study areas recognized with remote sensing methods mentioned in the first column of figure 1. The verification included detailed archaeological surveys and field measurements, and geophysical surveys. From the verified areas, only those whose field form is clear and dominant were selected to be presented (

Fig. 1). The sites selected were those with the following IDs:

- No. 1: Paparzyn in Stolno region.
- No. 3: Katarzynki in Ryńsk region.
- No. 7: Zamek Bierzgowski in Łubianka region.
- No. 8: Nowe Dobra in Chełmno region.
- No. 13: Katarzynki in Ryńsk region.

Study area 1

General characteristics of the object

The LiDAR-based analysis of the terrain in the village of Paparzynin, Stolno commune and Chełmno powiat revealed an object. This object most likely served as a defensive structure; however, it was impossible to determine its chronology. Study area, located on the edge of the Vistula River valley, consists of three circular concentric ditches surrounding the hill, towering over the ravine. The diameter of the outer ring is about 70m, the intermediate ring is about 40 m, and the inner ring is 10m. The analysis of historical archival data - Schroeter maps, indicates forest growth in this area since at least the 18th century. The analysis of the Messtischblatt map shows continuous afforestation from then until the present time (Fig. 2).

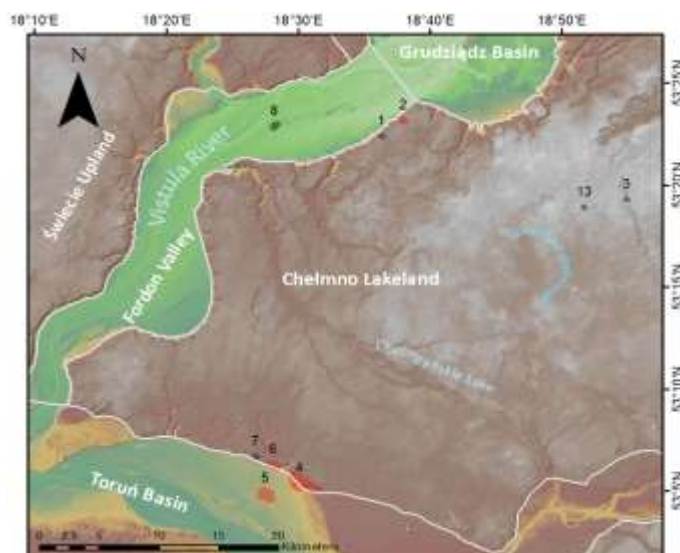


Fig. 1. Map of the extent of archaeological and field investigation areas, presented on the background of the shaded hypsometry map (source: geportal.gov.pl access date: 01.02.2022), with borders of the physical and geographic mesoregions (source: geportal.gov.pl, access date: 01.07.2019). Grey marks are the areas described in this publication and the red marks are the areas omitted in the publication

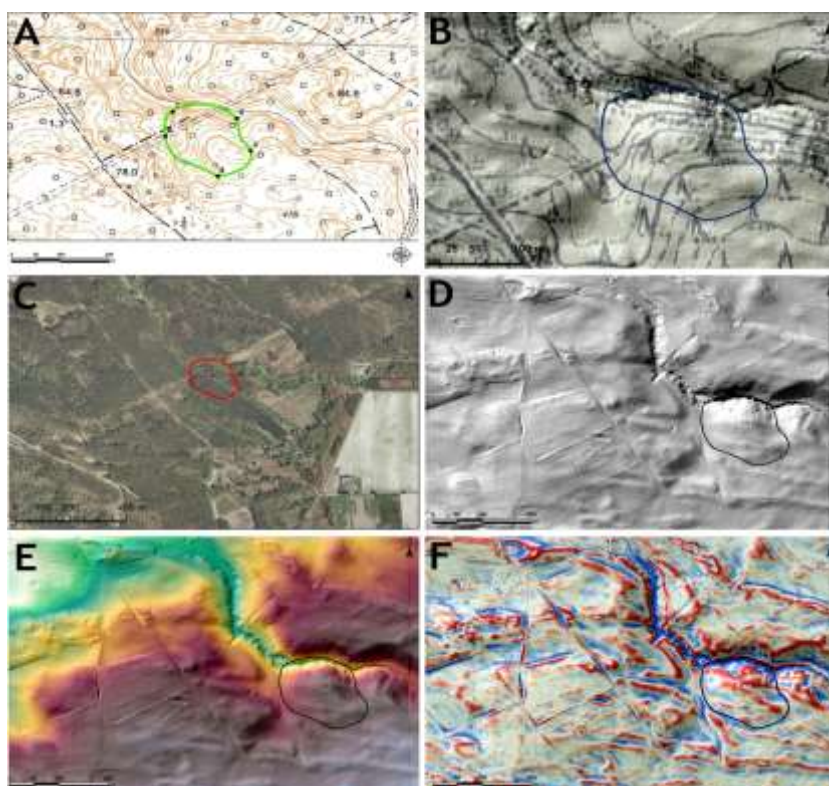


Fig. 2. Study area no. 1 'Paparzyn' in Stolno region: A – with points representing its estimated borders, background, the topographic map, B – background superposition of the shaded model and the Messtischblatt topographic map, C – orthophoto map background (dot in the middle – placement of terrestrial images), D – shaded DEM model background, E – shaded model and hypsometry background, F – shaded model background and SLRM

An interesting observation derived from those maps is a natural terrain feature, an aeolian composition, part of a dune, located half a kilometer south of study area 1, referred to as "Alte Shanze" - old rampart. Based on the AZP data analysis, the presence of Neolithic and Halsztacko-lateński period settlements was found. Study area 1 has not been previously described in any archaeological works; however, it is located close to sites in the Vistula River Valley, 2 km south and 4km north. Those comprise the famous cemetery of the Oksywie culture in Podwiesk [13]. Recently, similar objects dated to the Iron Age were discovered in Warmia [14].

Geomorphological study

From the geomorphological point of view, study area 1 is located in the Chełmno Lakeland, in the vicinity of the Lower Vistula Valley, at the edge zone of the moraine plateau, rising 80–90m above sea level. The upland is a typical flat ground moraine, but the edge zone is characterised by a presence of a complex of arched and parabolic dunes and aeolian covers. The highest dune forms reach just over 100m above sea level. The bottom of the Vistula valley, formed by a flood plain, lying at the altitude of 20–25m above sea level, directly adjoins the plateau's slopes. Lateral erosive valleys, denudation and erosive valleys, and spring niches related to the activity of groundwater flowing to the surface and water flowing down the slopes diversify the slope zone.

The study area includes the remains of three low, poorly preserved concentric dikes that form a system of concentric circles. The dikes are arranged stepwise on the plateau and slopes of the hill constituting the top of the moraine plateau, connected most prominently from the south-east side by slopes subsiding towards the denudation-erosion valley. The top part of the headland is most prominent as it is covered by aeolian sands, which form the northern arm of a low parabolic dune, providing a more spectacular view. The dike zone is about 70 m in diameter, and the individual dikes and the space inside the smallest one are about 10 m wide. The highest and smallest dike has been preserved as a complete circle. The other two, lower-lying ones, are visible only in the southern and eastern parts. They were probably blurred from the west and north due to the denudation processes on the steep slopes of the erosive valley. The regularity of the form and the geometrically precise arrangement of the shafts exclude its natural origin and allows it to be associated with human activity.

The anthropogenic object was successfully verified in the form of three circular concentric ditches. The object was selected for geophysical research. The site is covered with mixed pine and birch forest. Visible traces of forest ploughing in the area make it difficult to identify the circumferential ditches. In the form of a rampart and an inner circle, the central part of the site is the most easily identifiable part of the object. No heritage objects were found during the field survey.

Geophysical study

The test site consisted of a hilltop with a steep northern slope and a gentle southern slope. At the top, there are concentric embankments practically invisible in the field, but possible to be identified on the LiDAR images. The research area was poorly accessible due to dense forest and undergrowth. Based on the research performed, it is impossible to unequivocally assess the usefulness of the magnetic method in researching the past of this area due to significant limitations imposed by the terrain. It was impossible to cover the entire area of concentric embankments, depriving the results of a broader interpretative context. Preliminary assessment shows that the small concentric embankments visible in LiDAR data do not have significant magnetic properties. In addition, no potential archaeological excavations have been identified (Fig. 3).

Fieldwork results

Study area 1 is the only such object recorded in the Chełmno region, but it resembles objects listed in the Warmia region [14]. This similarity may indicate cultural ties between these areas. The object is characterized by the presence of circumferential ditches located concentrically around the highest point of the hill. As this is the most prominent part of the terrain, the object most likely served defensive functions. Usually, the goal was to create a defense system that used existing dominant area features. Therefore, the dominance of the terrain was permanently isolated, giving it a distinction consisting of circumferential ditches. This is indicated by the results of the geophysical surveys, which show only slight traces of human activity in the form of stone or wooden artefacts or furnaces. Thus, a function other than defensive for such an object, e.g. symbolic, is possible. In the future, geophysical surveys covering the entire site area should be performed, and the results should be verified through a series of boreholes. More information is needed regarding the chronology and cultural affiliation of this object. The site should be a part of the confirmed archaeological monuments documentation.

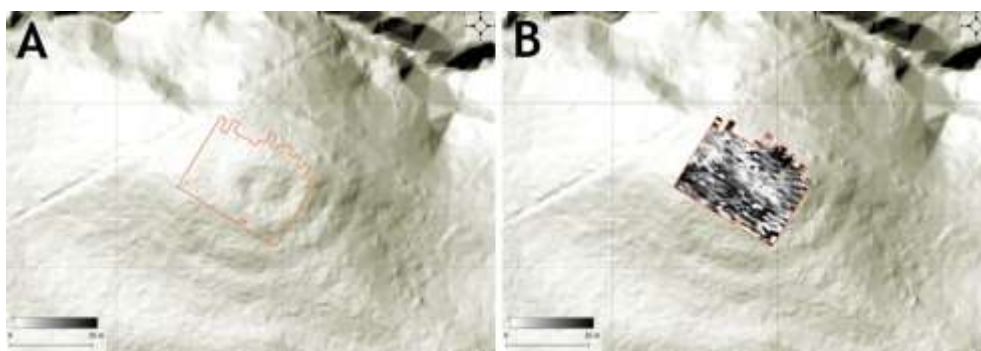


Fig. 3. Study area no. 1 Paparzyn, Małe Łunawy, Stolno region: A – The scope of geophysical research, B – The results of geophysical surveys with the interpretation of Piotr Wroniecki – Montefortino Prospekcja Digitalizacja, Warsaw

*Study area 3**General characteristics of the object*

The LiDAR-based analysis of the terrain in the village of Katarzynki, Ryńsk commune and Wąbrze powiat revealed a typical archaeological site with a specific landscape form covering the area of 2ha. It has a form of a settlement with a regular round shape. Visible relics of the embankment and defensive ditch surround the maian. The diameter, including the embankment, is 40m. In the center of the square, there is a relic of a quadrilateral earth ditch with a side length of about 7m. Study area 2 presents many features of an early medieval chronology, such as defensive structures and a fortified town (

Fig. 4).

Continuous afforestation of this area dates back to 1803 and is evident from the 18th century onwards. The content of the Messtischblatt map also shows the afforestation and the lack of early modern traces of settlement in the area. It is worth mentioning that a typical system of forest separations from the 19th century (part of the forest composed of a type of tree or used in a specific way) is marked on the map. Their placement and direction tend to follow the landscape features. However, this separation must have been long abandoned since it is neither visible on the DTM models nor was observed during fieldwork. The early 20th-century map shows the object as a system of contours with a regularly circular top shape. The analysis

of the AZP data revealed the presence of a large settlement from the early Middle Ages, about 1500m N-direction from the site in Jarantowice. Study area 3 has not been listed to date in any available archaeological record.

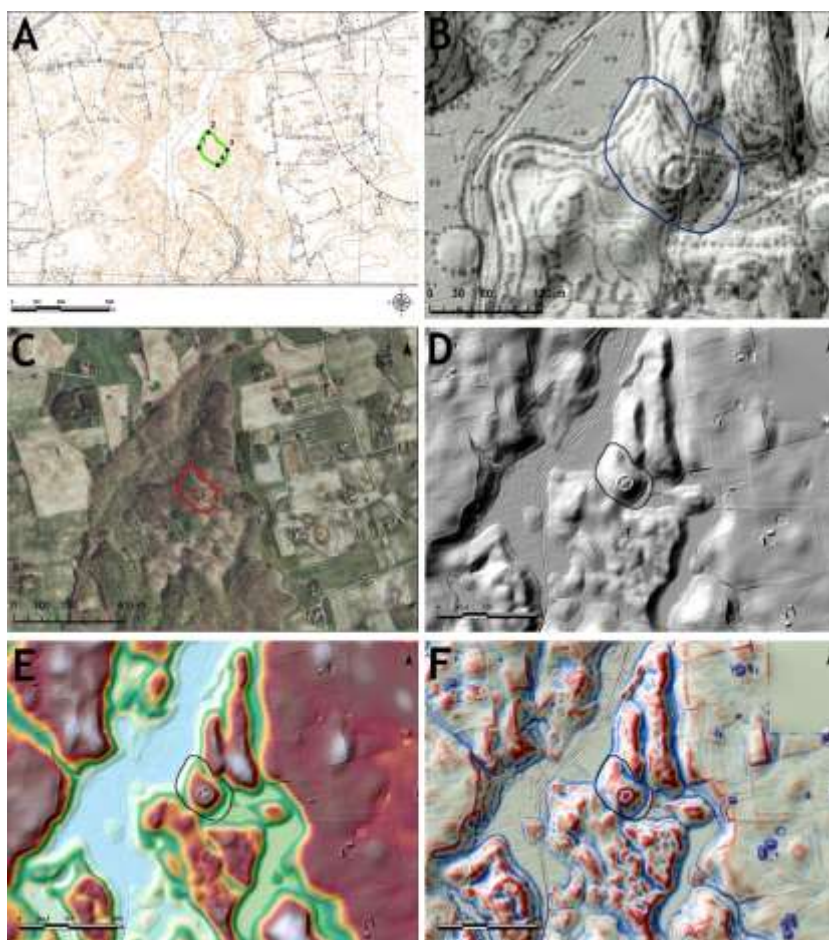


Fig. 4. Study area no. 3 ‘Katarzynki’ in Ryńsk region: A – points representing its estimated borders, background, the topographic map, B – background superposition of the shaded model and the Messischblatt topographic map, C – orthophoto map background (dot in the middle – placement of terrestrial images), D – shaded DEM model background, E – shaded model background and hypsometry, F – shaded model background and SLRM

Geomorphological study

Site no. 3 in Katarzynki is located near the village of Jarantowice, within the Chełmiński Lake District, in the zone of the terminal moraines of the Krajeńskie-Wąbrzeska subphase. In terms of geomorphology, it is an area of an uneven moraine plateau with a height of about 110–115m above sea level, strongly fragmented by subglacial gutters with N–S direction. Study area 3 is represented as a circular embankment with a diameter of about 45–50m, located at the top of one of the island-like elevations situated in the historical glacial gutter system. The hill on which the embankment is located is 113–114m above sea level, and its relative height in relation to the surrounding depressions (part of the bottom of the gutters) ranges from 10 to 15m. This type of terrain surrounding the top of the island-like hill is strongly exposed to the

processes of erosive destruction; thus, it cannot have a natural origin. It resembles an anthropogenic structure, with the form characteristic of medieval fortified settlements.

This object was easily identified during fieldwork. Currently, it is covered with old oak and beech forest. A well-preserved part of the yard with a clear central form of an embankment, a regular quadrangle, is particularly visible. The relic of the embankment surrounding the fortress is also visible. No heritage objects were found during the field verification. This object was selected for geophysical research.

Geophysical study

The side hill was covered with a moderately dense forest that did not cause significant problems during the geophysical investigations. However, steep slopes and uneven terrain associated with the remains of the embankments of the ramparts made the site quite challenging to be accessed for the geophysical survey (Fig. 6).

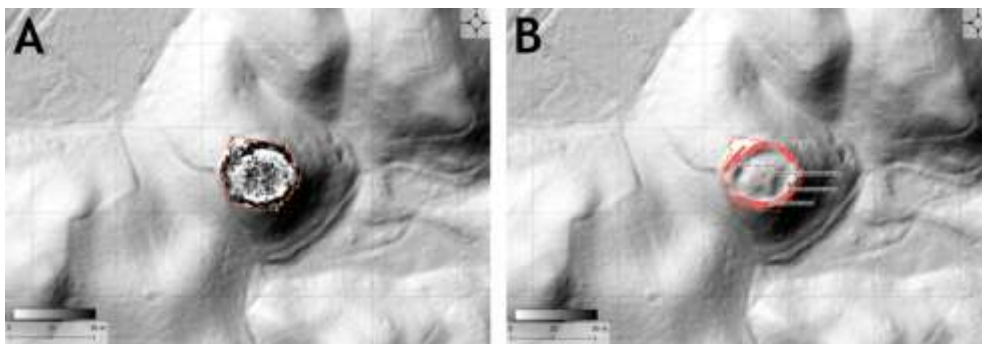


Fig. 5. Study area no. 3 'Katarzynki' in Ryńsk region: A – The scope of geophysical research and pre-processing results, B - The results of geophysical surveys with the interpretation made by Piotr Wroniecki - Montefortino Prospekcja Digitalizacja, Warsaw

The research was devised as a preliminary investigation, a non-invasive diagnosis, to verify the method's effectiveness in this area. Magnetic tests showed the method's effectiveness in detecting anomalies. Due to the very steep forested slopes, the research area was significantly limited. Despite this, it was possible to capture anomalies around the top of the embankment clearly visible in the visualizations, characterized by an increase in the magnetic field. Due to their shape, characteristics, and location, it can be assumed that they attest to the presence of embankment relics. However, there is no information in the magnetic data to indicate that they are relics of wooden, stone, brick or burned structures. Also, in the central part of the embankment, the measuring device detected a slight increase in the magnetic field. The entire examined area of the embankment is characterized by an increase in the magnetic field, indicating the presence of cultural remains in this area (

Fig. 5).

Fieldwork results

Study area 3 presents exceptional historical values, which are visible in the form of a remarkably well-preserved shape of a settlement with medieval features. Both the geophysical survey results and other analyses provide the basis for the need to protect this site.

The studied object has a characteristic form of early medieval fortified settlements from the 12th and 13th centuries. This type of structure was previously discovered in the Chelmino Region and is connected with the 5th - the last stage of the formation of the strongholds of this type [15]. Its appearance is very characteristic and is associated with the development of the

castle-castellan construction type. The castles of that time essentially played the role of knightly settlements or the so-called watch/guard towers/castles. In the latter case, they were uninhabited fortresses whose function was limited only to temporarily manning and were guarded by knights or, during their absence, by peasants, i.e. free peasants. The fortress at Katarzynki was conceived as a guard castle; therefore, it was built in a place not previously inhabited. This assumption is based on the fact that there is no written information about the granting the rule of this area by any of the local noblemen, nor has the right to build a settlement-type fortress been recorded. Thus, the object's function was not residential but only defensive.

In order to unambiguously establish the origin, it is postulated that small excavation-type surveys should be carried out in the locations based on the results of the geophysical surveys. Small probing excavations or a series of boreholes should be made to obtain historical material on the basis of which the affiliation of this monument will be determined.

Study area 7

General characteristics of the object

LiDAR-based analysis of the terrain in the Zamek Bierzgowski of Lubianka commune and Toruń powiat revealed an object (study area 7) consisting of a complex of anthropogenic landforms in the form of earth embankment covering an area of 24ha. The forms are arranged in an orderly manner and do not disturb the mutual arrangement. The structures of the embankments run linearly, often parallel to each other, and are arranged in the general direction of the meridian with a slight deviation towards the NNW. Only a few are arranged latitudinal. The embankments are 90m long and 6m wide. It was not possible to determine the function and age of the structure.

Analysis of the Schreotter map shows that this area was deforested in the 18th century. There are no signs of any settlements, buildings, or farm buildings in this area. At that time, it was most likely considered a fallow land due to the sandy soils. The Messtischblatt map illustrates the afforestation of this area. Due to current terrain transformations, it was impossible to identify forest roads using DTM derivative models (

Fig. 6). Based on the AZP query, an Iron Age site was found 160m north of the site. Study area 7 has not been listed in any available archaeological record.

Geomorphological study

Study area 7 in Zamek Bierzgowski is situated on the edge of the moraine plateau of the Chełmno Lakeland and at the edge of the Toruń Basin. Study area 7 is interestingly located at the end of a complex of dunes drifted from the Toruń Basin to the upland, at the point of contact of a group of aeolian forms with the undeveloped surface of the moraine upland, adjacent to the north. There is a group of about 8 to 12 forms not very distinguishable in this area, although undoubtedly, the parallel embankments cover approximately 270m in length. The embankments are 40 to 100m long and are oriented NNW-SSE. On this surface, no distinct mounds were observed. On the northwest edge of the site and west of it, there are several single and indistinct hills, which could be such mounds. All the embankments and mound-shaped landforms that occur in the watered near-edge fragments of the moraine plateau at the site in the Bierzgowski Castle have an anthropogenic origin. Their characteristics are unusual for aeolian objects and the regularity of shapes and arrangement in space proves that they are not naturally formed.

A complex of objects with poor legibility was observed during fieldwork. Currently, the study area is covered by a 60-year-old pine forest. The survey was carried out right after the logging, which made it difficult to properly observe due to the area being covered with the remnants of branches and dense bushes. Only in the western part were the discontinued

embankments visible. No heritage objects were found during the field verification. Due to field conditions, the field survey in this area was abandoned.

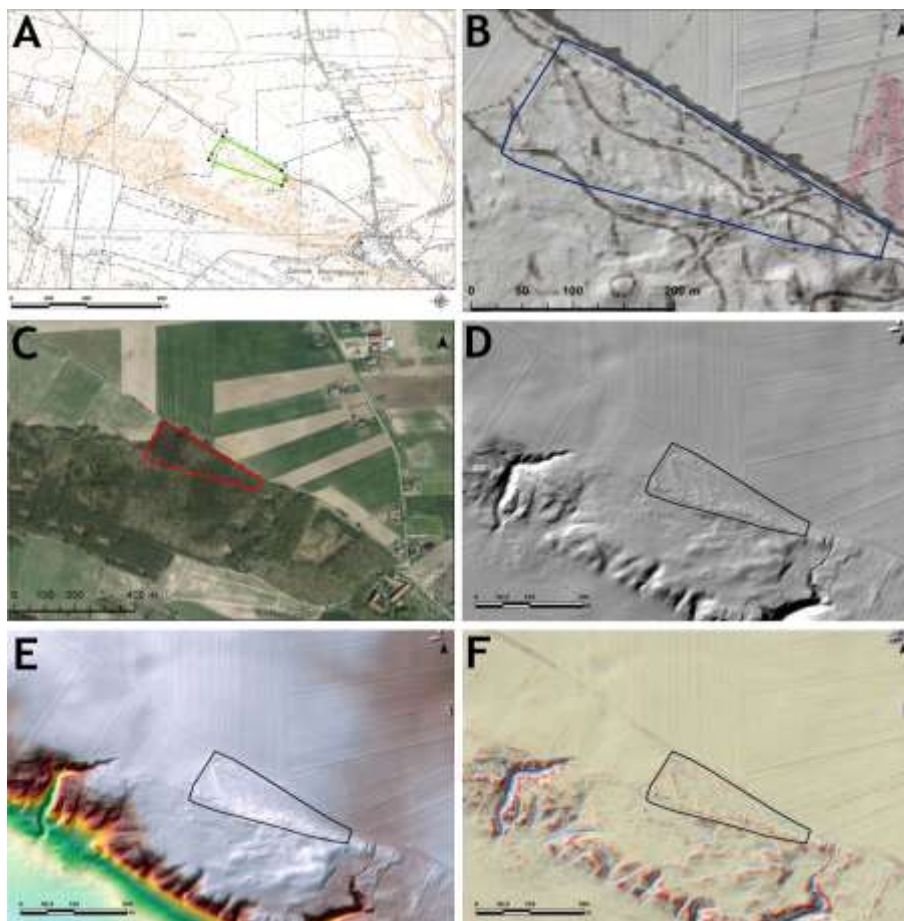


Fig. 6. Study area no. 7 ‘Zamek Bierzłowski’ in the Lubianka region:

- A – points representing its estimated borders, background, and the topographic map,
- B – background superposition of the shaded model and the Messtischblatt topographic map,
- C – orthophoto map background (dot in the middle – placement of terrestrial images),
- D – shaded DEM model background, E – shaded model background and hypsometry,
- F – shaded model background and SLRM

Fieldwork results

Study area 7 consists of a smaller group of embankments representing a unique landscape. From the point of view of research experience to date, no such complex anthropogenic form has been recorded so far in the Chełmno region. The site constitutes of a group of anthropogenic objects in the form of an embankment forming a row of parallel lines with NNW–SEE orientation, whose size and course may indicate economic functions. The embankment may be the remains of graves or livestock systems. The chronology of the object is impossible to establish based on current data; it probably dates back to the Middle Ages or earlier periods. Due to limited availability, the site was not subject to a geophysical survey. Such studies should be carried out in the future. Further research should also be carried out at

the site to perform geophysical surveys. The survey should consist of small probing excavations or boreholes. This would allow obtaining historic material or samples to analyse the objects' chronological framework further. Ultimately, the site should be under conservation protection.

Study area 8

General characteristics of the object

LiDAR-based analysis of study area 8, in the Nowe Dobra village of Chelmino commune and Toruń powiat, revealed an object of diverse landscape forms of anthropogenic origin. They formed mounds-barrows and earth embankments covering the area of 13ha. The observed forms are arranged in an orderly manner and do not disturb the mutual arrangement. The mounds are located in the north part of the complex and may have been erected simultaneously or secondary to the embankments, which is indicated by their location "respecting" the arrangement of the embankments. The embankment structures run linearly, parallel to each other and follow the direction of the meridian with a deviation towards the NNE. The embankments are badly damaged but still identifiable. The embankments are 90m long and 6 m wide. They are of unknown function or age.

Analysis of the Schroeter map shows that this area has been afforested at least since the 18th century. The contents of the Messtischblatt map show the area as a fallow land with thickets. Both maps do not show traces of modern settlement that could be related to this location. Analysis of the AZP data revealed traces of rich settlement in the site's immediate vicinity. Approximately 350m to the northeast, there is a Pomeranian culture cemetery [4, 5]. About 500m to the west, there is a settlement from the Hallstatt and La Lae period. A box grave of the Pomeranian culture was discovered in the immediate vicinity during the 2012 rescue survey. Study area 8 can be associated with the Nowe Dobra No. 20 archival site, which is listed as a cremation graveyard from the ancient pre-Roman period. This site was examined in the early 20th century (

Fig. 7). As a result of the survey, 420 pit graves and one urn grave were discovered [13].

Geomorphological study

The Nowe Dobra site is located in the Lower Vistula Valley, at the valley bottom of the valley called Fordońska. It forms part of a large Vistula floodplain lying at an altitude of about 22–24m above sea level. The analysed section is divided into two wide belts by a higher terrace level, formed by dune forms. These forms reach a maximum height of 37m above sea level, rising about 15m above the main valley bottom level. The dunes form irregular hills, although they are clearly arched in places. The typological and habitat diagnosis classified the soils in this area as arenosols. These types of soils are usually formed by strong transformation of the land surface, probably caused by human use in recent centuries.

In the area of Nowa Dobra and Dolne Wymiarów, the terrain of the dune complex, a grouping of about a dozen regular linear forms located in a flat area about 32m above sea level, was observed. These forms are low dikes with a length of about 60 to 150–200m and a width of several meters. The ten dikes are arranged parallel and oriented towards the NNE-SSW. The next two-three dikes are orientated approximately W-E. The dikes are barely visible and appear to be heavily damaged remnants of more expressive forms, clearly visible only on NMT imagery. Natural aeolian processes cannot explain the formation of such regular, simple, linear dike forms within the dune complex. They are definitely artificial forms.

Study area 8 can be described as a complex of objects in various state of preservation. The area is covered by a pine forest with a varied age structure. Younger forest areas are dominant. Some of the objects verified were embankments with a slight difference in the height of up to 40 cm and a length of about 100–130m. Their identification was difficult due to the existence of young forests covering the research area. Near the embankments, there are mounds

of various heights, which occur individually or in small clusters. Field verification confirmed the anthropogenic nature of the objects. The area is in the immediate vicinity of currently inhabited housing zones, which are a direct cause of the presence of litter and minor interference of the study area in the form of trenches. No heritage objects were found during field verification. As a result of the field survey, no direct threats to the identified objects were found.

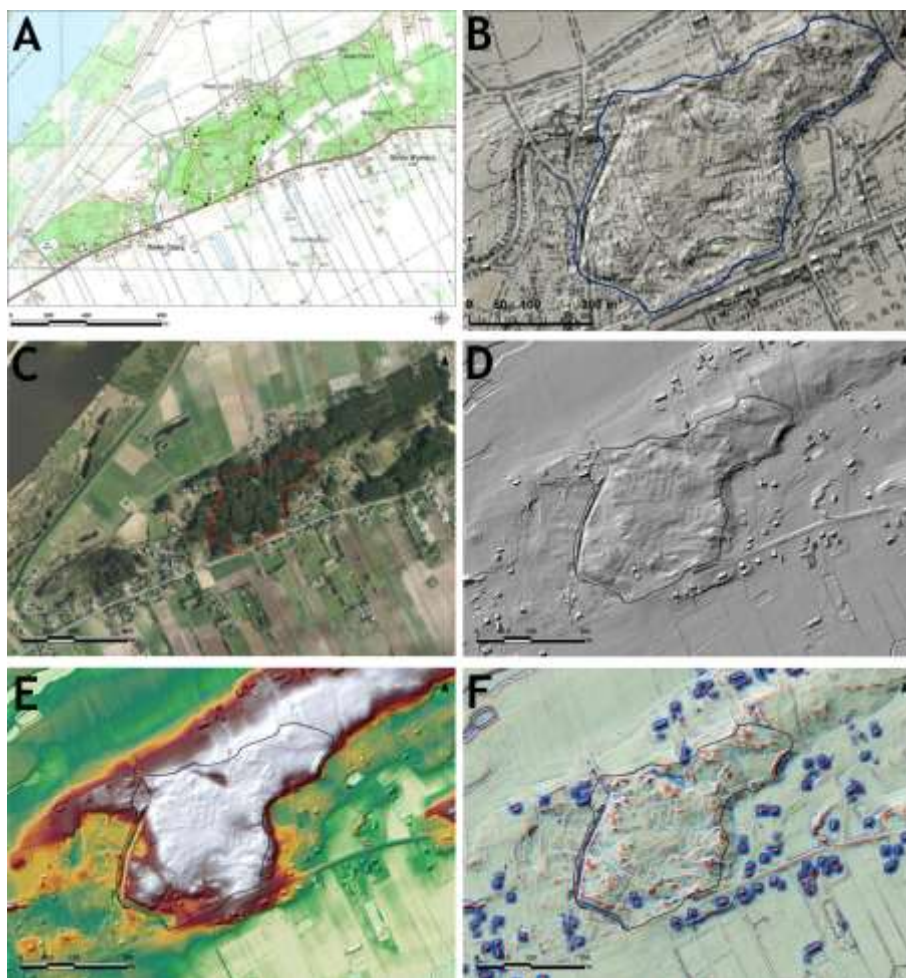


Fig. 7. Study area no. 8 ‘Nowe Dobra’ in Chełmno region:

- A – points representing its estimated borders, background, the topographic map,
- B – background superposition of the shaded model and the Messtischblatt topographic map,
- C – background orthophoto map (dot in the middle – placement of terrestrial images),
- D – background shaded DEM model, E – background shaded model and hypsometry,
- F – background shaded model and SLRM

Fieldwork results

Study area 8 is a vast complex of various forms with unique landscape values. In the Chełmno region, an embankment complex of this nature has not been registered so far. The results of the research carried out clearly confirm, at least, the historical nature of the objects.

The group of anthropogenic forms of dikes in the castor system indicates their intentional nature. Objects are an example of using a large-scale planned spatial layout. Linear course structures with NNE–SSW orientation indicate a farm system of unknown function. Although the chronology of the object is unknown, it should be assumed that its origin is at least medieval, if not earlier. It is necessary to carry out geophysical surveys in the area. The survey should also consist of small probing excavations or boreholes to obtain historical material or samples that allow analysing the chronological framework of the objects. Ultimately, the site must be under conservation protection.

Study area 13

General characteristics of the object

LiDAR-based analysis of the study area 13, the terrain in the Katarzynki village of Ryńsk commune and Wąbrzesk powiat, revealed an object of diverse landscape forms of anthropogenic origin covering an area of 1.0ha. Study area 13 consists of a regular round shape of a fortress with a diameter of 40m. No embankment relics were detected. The age of the structure is not determined.

Analysis of the Schroeter map shows that this area has been afforested since at least the 18th century. Messtischblatt map also indicates the forest covering the site and a settlement system with roads corresponding to the current build-up situation. The superposition of the maps shows how the road built at the beginning of the 20th century destroyed the western part of the study site. AZP data analysis revealed the presence of a single settlement from the Hallstatt or Laen period, 560 m towards the northeast, that had not been recorded before.

Geomorphological study

Katarzynka village is in the Chełmiński Lake District and geomorphologically in the zone of the terminal moraines of the north-wąbrzeskie moraines. Study area 13 is a single, isolated, regular circular hill located within an enclosed, outflow-free, drained out kettle-type depression. The depression is occupied by a peat plain, the surface of which is 105m above sea level. The hill rises above its level at about 4m, reaching a height of almost 109m above sea level. The diameter of the base of the hill is about 100m. The regular circular shape suggests an anthropogenic origin. However, based only on data obtained from analysis of chamber materials and non-invasive field reconnaissance, its genesis cannot be unequivocally determined. An isolated hill towering over the biogenic plain and a melt pit may also be a type of Kem hill, typical for Chełmno Lakeland. In the case of the Katarzynki site, excavations seem necessary for the accurate diagnosis of the genesis of this landform.

During the field survey, it was observed that the study area has a characteristic landscape form, which manifests itself on the terrain as a local landmark (Fig. 8).

A decades-old oak forest currently covers it. Numerous traces of soil disturbances were observed, which might be related to the activity of wild boars looking for acorns. No heritage objects were found during the field survey. As a result of the field survey, no direct threats to the identified objects were found.

Geophysical study

Geophysical surveys carried out with the magnetic method have proven their effectiveness in study area 13 in Katarzynki. The magnetic survey allowed the detection of anomalies, some of which may be associated with anthropogenic disturbances of the stratigraphy (e.g. excavations) or the presence of modern garbage and ferromagnetic materials. A part of study area 13 that was selected for geophysical study was located on a small hill, difficult to access due to the density of trees and shrubs.

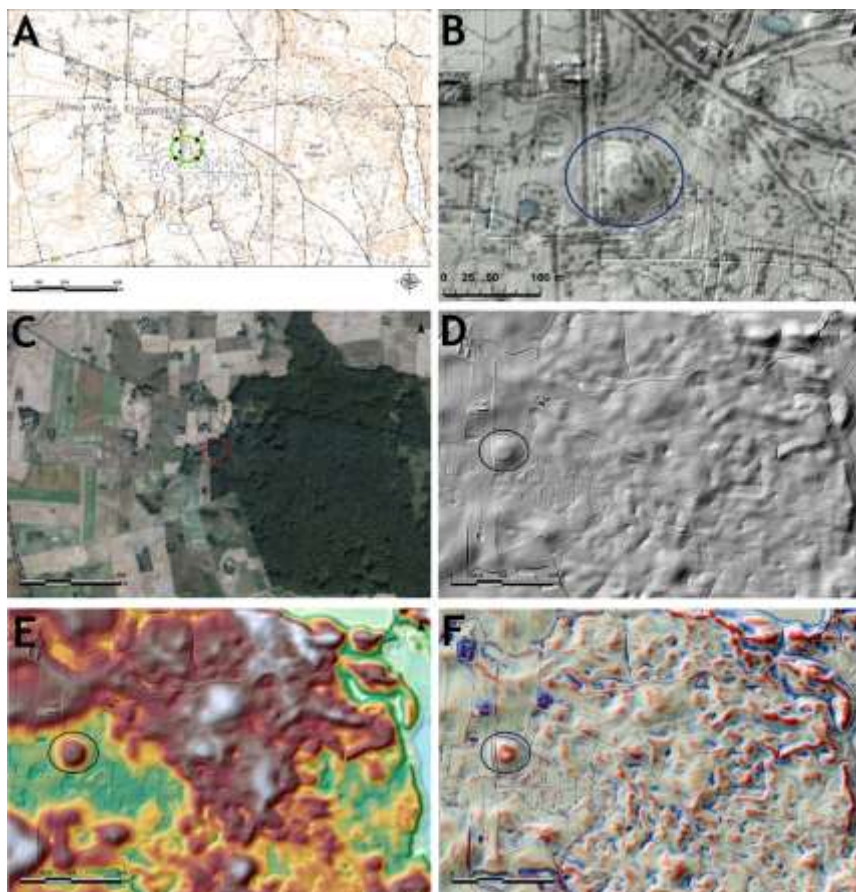


Fig. 8. Study area no. 13 'Katarzynki' in Ryńsk region:

- A – Study area estimated borders, background, the topographic map,
- B – background superposition of the shaded model and the Messtischblatt topographic map,
- C – background orthophoto map (dot in the middle – placement of terrestrial images),
- D – background shaded DEM model, E – background shaded model and hypsometry,
- F – background shaded model and SLRM

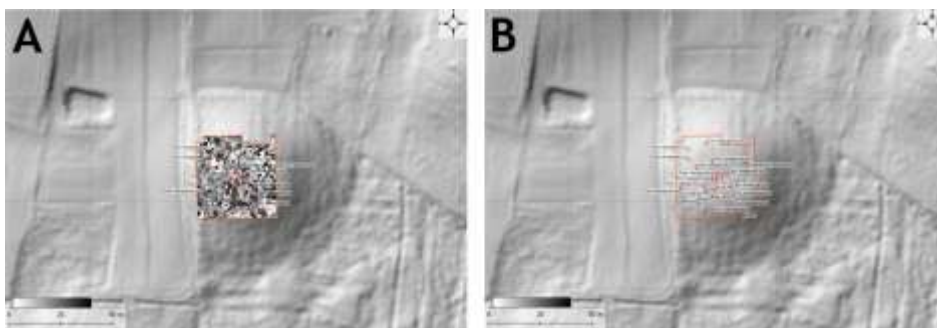


Fig. 9. Study area no. 13 'Katarzynki' in Ryńsk:

- A – the scope of geophysical research and pre-processing results,
- B - the results of geophysical surveys with the interpretation made by Piotr Wroniecki - Montefortino Prospekcja Digitalizacja, Warsaw

In the east-northern part of the study area, a dense cluster of dipole anomalies is clearly visible. Visualizations of magnetic measurements in the southern part of the study area also show a fuzzy circular structure (

Fig. 9). On the other hand, measurements did not show the presence of typical settlement structures. As this was a preliminary study within a limited survey area, this was to be expected.

Fieldwork results

Study area 13 is most likely a relic of defensive function structure. The lack of embankment relics and the undisturbed shape of the hill's plateau probably exclude the medieval chronology of this object. More information on the chronology and cultural affiliation of this object is needed. The geophysical surveys brought positive results in terms of recording possible layers or cultural remains. However, the results of geophysical surveys may indicate the presence of layers or cultural objects of an earlier or later chronology. The planning of further survey steps should consider the performance of limited excavation surveys in the form of small surveys or boreholes in the presence of anomalies that show potential cultural objects. It is worth highlighting that the site should be under conservation protection.

Conclusions

Verification tests brought positive results in terms of the identification of landscape forms for all nine analyzed sites. According to the PAR (Polish Archaeological Record, polish Archeologiczne Zdjecia Polski - AZP) methodology, the results based on surface studies proved negative for selected areas [6, 7]. This was caused by the limitations of the so-called availability of land for research based on the AZP methodology, where forest complexes are defined as inaccessible areas due to the lack of visibility caused by vegetation [3,12]. Field studies were carried out within areas with exposed land cover, including forest roads, fallen trees, and places with disturbed forest litter. Despite the methodology, no isolated masses or monuments were identified during conducted surface survey [20–22].

The features that connect all of the newly discovered archaeological sites are:

- Location in the edge zones of large geomorphological forms (moraine plateau and ice-marginal valley or subglacial gutter) - except for the Cegielnik site, located on the ice-marginal terrace.
- Location within dry areas covered by poorly fertile soils, soils unsuitable for agricultural activities built of loose, permeable and nutrient-poor aeolian sands - except for Katarzyna's site no. 3 and 13, which are located on a clay moraine plateau.

Typical sites such as Cegielnik, Różankowo or Zamek Bierzgowski are located at a short distance from each other. The geomorphological features within their location suggest that their occurrence in these landscape zones is not accidental. Most likely, they constitute a wider complex of relics of anthropogenic forms, with a degree of relief transformation that can be considered monumental. In Europe, objects of this type are so far unknown. They require special attention and commitment to further research as a new category. For the time being, they also need protection.

This project contributed to developing new research standards and methods, which can be successfully used while searching for sites similar to those in the Chełmno region. As far as the authors are aware, this study is the first that this type of work has been carried out on such a scale. The implementation of the tasks described during this project made it possible to create a spatial information resource, which became the scientific result of this study and will also be the

starting point for further research and conservation activities. Undoubtedly, it is necessary to carry out a field survey, i.e., boreholes. Chronology and cultural affiliation have not been satisfactorily specified for all identified sites. The reason for this is the lack of historical material acquired, based on which necessary clarifications can be made. Hence, another conclusion obtained from the project is that this type of research should include a minimum scope of destructive tests in the future. Nor should it be limited to the search for monuments alone but should be complemented with specialized analyses in the field of soil science and the radiocarbon method.

References

- [1] P.Z. Banasiak, P.L. Berezowski, R. Zapłata, M. Mielcarek, K. Duraj, K. Stereńczak, *Semantic Segmentation (U-Net) of Archaeological Features in Airborne Laser Scanning—Example of the Białowieża Forest*, **Remote Sensing**, 14, 2022,. <https://doi.org/10.3390/rs14040995>.
- [2] Ł. Banaszek, *It takes all kinds of trees to make a forest. Using historic maps and forestry data to inform airborne laser scanning based archaeological prospection in woodland*, **Archaeological Prospection**, 27, 2020, pp. 377–392. <https://doi.org/https://doi.org/10.1002/arp.1780>.
- [3] M. Apollo, V. Andreychouk, *Trampling Intensity and Vegetation Response and Recovery according to Altitude: An Experimental Study from the Himalayan Miyar Valley*, **Resources**, 9, 2020,. <https://doi.org/10.3390/resources9080098>.
- [4] D.A. Gura, *Airborne Laser Scanning Technology in Archeology*, 1, 2019, pp. 776–779.
- [5] B. Štular, E. Lozić, S. Eichert, *Airborne LiDAR-Derived Digital Elevation Model for Archaeology*, **Remote Sensing**, 13, 2021,. <https://doi.org/10.3390/rs13091855>.
- [6] G. Haryuatmanto, *Analysis of Airborne LiDAR Data for Archaeology Study Case: Sriwijaya Muaro Jambi Site*, **IOP Conference Series: Earth and Environmental Science**, 1127, 2023, pp. 12012. <https://doi.org/10.1088/1755-1315/1127/1/012012>.
- [7] A. Gałaś, J. Majka, A. Włodek, *Origin of andradite in the Quaternary volcanic Andahua Group, Central Volcanic Zone, Peruvian Andes*, **Mineralogy and Petrology**, 115, 2021, pp. 257–269. <https://doi.org/10.1007/s00710-021-00744-0>.
- [8] K. Maciuk, M. Apollo, J. Mostowska, T. Lepeška, M. Poklar, T. Noszczyk, P. Kroh, A. Krawczyk, Ł. Borowski, P. Pavlovčič-Prešeren, *Altitude on Cartographic Materials and Its Correction According to New Measurement Techniques*, **Remote Sensing**, 13, 2021,. <https://doi.org/10.3390/rs13030444>.
- [9] A. Campos, S. GM, M. FD, E. Butassi, S. Zacchino, F. VC, *Antifungal Activity of Pyranonaphthoquinones Obtained from Cipura paludosa Bulbs.*, **Natural Product Communications**, 10, 2015, pp. 1589–1592.
- [10] E. Alby, *Point cloud vs drawing on archaeological site*, **International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives**, 40, 2015, pp. 7–11. <https://doi.org/10.5194/isprsarchives-XL-5-W7-7-2015>.
- [11] A. Guyot, M. Lennon, T. Lorho, L. Hubert-Moy, *Combined Detection and Segmentation of Archeological Structures from LiDAR Data Using a Deep Learning Approach*, **Journal of Computer Applications in Archaeology**, 4, 2021, pp. 1. <https://doi.org/10.5334/jcaa.64>.
- [12] G. Norstedt, A.-L. Axelsson, H. Laudon, L. Östlund, *Detecting Cultural Remains in Boreal Forests in Sweden Using Airborne Laser Scanning Data of Different Resolutions*, **Journal of Field Archaeology**, 45, 2020, pp. 16–28. <https://doi.org/10.1080/00934690.2019.1677424>.
- [13] E. Bokiniec, Podwiesiek, Fundstelle 2. Ein Gräberfeld der Oksywie-Kultur im Kulmer

- Land, Warszawa-Torun, 2005.
- [14] F. Welc, J. Nitychoruk, R. Solecki, K. Rabięga, J. Wysocki, *Results of integrated geoarchaeological prospection of unique iron age hillfort located on radomno lake island in north-eastern Poland*, **Studia Quaternaria**, 35, 2018, pp. 55–71. <https://doi.org/10.2478/squa-2018-0004>.
- [15] W. Chudziak, *Osadnictwo grodowe na Kujawach i ziemi chełmińskiej w okresie wczesnego średniowiecza w świetle tradycji miejsca centralnego*, **Archaeologia Historica Polona**, 24, 2017, pp. 41. <https://doi.org/10.12775/ahp.2016.003>.
- [16] T. Malinowski, *Katalog cmentarzysk ludności kultury pomorskiej*, T2 ed., Słupsk, 1981.
- [17] O. Romanowska-Grabowska, *Badania archeologiczne na st.1 w Nowych Dobrach pow. Chełmno*, Bydgoszcz, 1978.
- [18] S. Czerwiński, P. Guzowski, M. Lamentowicz, M. Gałka, M. Karpińska-Kończak, R. Poniak, E. Łokas, A.C. Diaconu, J. Schwarzer, M. Miecznik, P. Kończak, *Environmental implications of past socioeconomic events in Greater Poland during the last 1200 years. Synthesis of paleoecological and historical data*, **Quaternary Science Reviews**, 259, 2021, pp. 106902. <https://doi.org/10.1016/j.quascirev.2021.106902>.
- [19] K. Niedziółka, *The prospect of digitization of Polish Archaeological Record on an example of materials from the turn of Bronze and Iron Age from the area of Pomeranian Voivodeship (Northern Poland)*, **Sprawozdania Archeologiczne**, 68, 2016, pp. 121–144. <https://doi.org/10.23858/SA68.2016.007>.
- [20] M. Doneus, Ł. Banaszek, G.J. Verhoeven, *The Impact of Vegetation on the Visibility of Archaeological Features in Airborne Laser Scanning Datasets from Different Acquisition Dates*, **Remote Sensing**, 14, 2022, <https://doi.org/10.3390/rs14040858>.
- [21] P. Kryczka, K. Chrobak, *Contemporary challenges of spatial development of local service centres in the suburban areas of Wrocław – example of Czernica, Poland*, **Budownictwo i Architektura**, 19, 2020, pp. 53–72. <https://doi.org/10.35784/bud-arch.1678>.
- [22] M. Apollo, *Dual Pricing – Two Points of View (Citizen and Non-citizen) Case of Entrance Fees in Tourist Facilities in Nepal*, **Procedia - Social and Behavioral Sciences**, 120, 2014, pp. 414–422. <https://doi.org/https://doi.org/10.1016/j.sbspro.2014.02.119>.

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