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STUDY OF DIGITAL ELEVATION MODELS OF OBJECTS OF HISTORICAL AND CULTURAL HERITAGE CREATED OVER DIFFERENT YEARS

The purpose of the work is to investigate the digital elevation models of the mass grave of 1944, built on the basis of aerial and cartographic data of different times. The implementation of the task involves the construction of digital elevation models (DEM) on the territory of the Jewish mass grave in the city of Vynnyky and Italian prisoners of war near the city. On the territory of the Jewish mass grave in the city of Vynnyky, a DEM was created based on a stereo pair of archival aerial images obtained in 1944 and on the basis of aerial photography from a UAV conducted in 2015. Since archival aerial photographs did not contain orientation elements, they were geometrically transformed using the ErdasImagine software. After that, the stereo pair was processed in the program Digitals, where relief elements on the territory of the mass grave were obtained. Aerial photography from a UAV on the territory of the city of Vynnyky provided the data which was processed in the Agisoft PhotoScan software. It allowed us to create an orthophoto plan and an elevation map of the city territory. Elements of relief on the territory of the mass grave of 1944 and 2015 were imported into the Surfer software environment, where 3D digital elevation models were built. Since the territory of the grave did not have significant differences in height, and the relief was quite gentle, the method of constructing the DEM of the Natural Neighbor was chosen, which gave a positive result. Analyzing the digital elevation model and the vector map for 1944, the border of the mass grave is clearly distinguished, since the height difference between its edges and the rest of the territory is from 20 to 36 cm, depending on the section of the border. The analysis of the digital elevation models and the vector map for 2015 of the territory of the mass grave determined from the aerial image of 1944 showed that the characteristic height differences on the former border of the grave are observed only in the left-right corner of the grave and on a separate section of the right border. Height difference indicators range from 15 to 20 cm. It should be noted that height differences are also observed in the rest of the territory belonging to the mass grave and outside it. This can be explained by many years of human intervention and agricultural land use. With regard to the investigation of the mass graves of Italian prisoners of war near the city of Vynnyky, the modern territory is 100 % wooded, which makes it impossible to apply aerial photography. Therefore, in order to compare the modern DEM with the stereo pair of aerial images of 1944, it was decided to conduct a ground tacheometric survey of the area in 2011. Tacheometric survey data was exported to the dxf exchange format, after which it was opened in Surfer and the DEM was built. In this case, digital elevation models were built using the Kriging method, since the area where the mass graves are located is quite hilly with a significant difference in elevation. According to the digital elevation models, 54 pits with burials that have survived to this day have been identified. The scientific novelty of the work consists in the development of the concept of combining disparate data for the construction of digital elevation models and the creation of a complete picture of the study of the territory of the object of historical and cultural heritage. The received data can be used by the relevant cultural heritage preservation departments of the Ministry of Culture of Ukraine for their further study.

Key words: digital elevation models; orthophoto plan; elevation map; mass grave; archival aerial image

Introduction

During the last decade, one of the most actively developing areas of using digital technologies in historical research is related to the creation of virtual reconstructions of lost (completely or partially) objects of cultural heritage. Apparently, the focus is on research projects that use various three-dimensional modeling technologies in the tasks of virtual reconstruction of historical urban space – areas of lost urban development of past centuries, monastic complexes, buildings or even entire cities of one or another historical period. We can also talk about the growing interest in the development of virtual reconstructions of historical urban landscapes. Digital technologies and methods have led to radical changes in the study and preservation of cultural heritage. At the same time, digital approaches influence historical research, which is the basis of knowledge and understanding of cultural heritage. The most obvious effect is a kind of "public use" of history. The results of digital history are more accessible to a wide audience of cultural heritage connoisseurs – taking into account the spatio-temporal context. And if the "spatial turn" characterized recent historical research, the spatial localization of historical data preceded digital approaches. Since the 1970s, the concepts of urban space influenced the development of historical urbanism, and the use of digital 3D technologies gave a noticeable impetus to the study of the visual history of the city, and the virtual reconstruction of its lost elements. In addition, "architectural urban history" also emphasized the role of the visual factor. Significant attention in the article is paid to 3D methods, which are considered as "scientific technology". With the development of computer graphics in the 1960s and obviously, since the 1990s, more and more attention has been paid to virtual reconstruction. Today, 3D retro-digitization of existing artifacts obtained by 3D laser scanningphotogrammetry and digital 3D virtual reconstruction of lost objects, reproduced on the basis of sources, provides adequate access to objects of research in the field of archeology, art, architecture and urban history in the internet age. An important element of such projects is the contextualization of 3D models based on metadata. The authors see two reasons why 3D models have such great potential. First, it is an exact reproduction of the geometric and material properties of the reconstructed object. Second, deep interpretation of sources and hypothetical reproduction of the object give historians and users a deeper understanding of it.

Formalization and structuring of knowledge allow for efficient use of data and contribute to the acquisition of knowledge in the digital environment, as well as the creation of knowledge networks based on Internet technologies. As for source-based historical reconstruction, we can underline projects that make web visualization comprehensible, interpretable, demonstrate the potential of sustainable process registration and linking 3D data to events, sources, and actors as linked data.

In Ukraine, among the works related to the study of digital models of relief and terrain for the study of objects of historical and cultural heritage, it is necessary to the works of scientists H. Burshtynska, I. Vasylikha, S. Vovkodav, P. Koval, B. Chetverikov, Z. Kuzyk and O. Tumska [Burshtynska et al., 2007; Vovkodav, 2008; Kuzyk, 2013; Burshtynska & Tumska, 2000; Chetverikov et al., 2017; Chetverikov & Babiy, 2016].

It is to foreign scientific works related to 3D modeling of objects of historical and cultural heritage. The general role of studying objects of historical and cultural heritage based on the construction of 3D models is highlighted in works [Agosto & Bornaz, 2017; Ubik and al., 2015; Liu and al., 2022]. For creation of 3D models of architectural structures or monuments, short-baseline photogrammetry methods are widely used (Alsadik, 2014; Remondino & Menna, 2008). Also, photogrammetric methods of superimposed survey or radial survey of buildings or monuments are very popular in the study of architectural objects [Bolognesi et al., 2014; Hou & Cheng, 2021; Moisan et al., 2021; Solem & Nau, 2020, Mostafavi et al., 2019]. General basics of building 3D models of objects of historical and cultural heritage using photogrammetric processing of images is presented in works [Vilceanu and al., 2014; Zhao and al., 2018]. An interesting direction of studying 3D models of such objects includes methods based on computer vision and machine learning libraries [Barrile & Bilotta, 2018; Gelnar & Zegzulka, 2019]. Also, in the foreign scientific literature there are articles dedicated to the actual study of the places of mass burials during the Second World War using aerial photographs, however the toolkit of methods for processing aerial photographs in these works is rather limited [Fiedler and al., 2009; Ossowski and al., 2018]. Before the Second World War, there was a very developed Jewish community in the town of Vynnyky near Lviv, as well as throughout Galicia. Therefore, it is quite understandable that during the Nazi occupation most of them were taken to concentration camps, and the rest were shot in the city and its surroundings and buried in mass graves.

During the Second World War, the Germans fenced off part of the forest between Lysynychy and the Lviv – Vynnyky road with barbed wire – they forbade anyone to approach it. But some people, risking their lives, came by there. They saw that Jews, and sometimes Ukrainians and Poles, were brought here in cars. The column of the doomed was led to the place of the former sand quarry, to deep pits prepared in advance. People were ordered to undress, and then they were led in groups to the pit under the sights of a machine gun. The shooting was carried out by a special Gestapo team. In order to muffle the screams of the masked people, dance music was played at full power from several gramophones at once. At this place, prisoners of war who were transported from the concentration camp "Stalag-328" (Citadel) were brutally massacred.

The territory covers the area stretching along the Sichova street, which is bounded by residential buildings in the south and west, by the border of the forest in the north, and by a ravine in the east.

Mass graves located in the forest are limited by forest plantations on all sides and are located on hilly terrain. The territory of mass graves is not specially marked. There is no fence.

Aim

The purpose of the work is to investigate the digital elevation models of the mass graves of 1944, built on the basis of aerial and cartographic data of various times. The task of the work is to investigate two different areas of the territory of the town of Vynnyky and its surroundings, where mass graves are located. The types of territory of the graves are also different, one object is in an open area, and the other is in a wooded area. In this regard, it is necessary to choose appropriate and effective methods of building the DEM.

Methodology and work results

The first object of research is located in the northern part of Vynnyky near Lviv. This is a Jewish mass grave, which, according to eyewitnesses of the mass shootings, had an elongated shape close to rectangular.

For the identification of the mass grave, a stereo pair of German aerial photographs from 1944 with a longitudinal overlap of 70 % (determined analytically) was used as input data. The transverse overlap could not be determined, since only one stereo pair was available. The height of aerial photography of the territory is 8000 m, the survey scale is 1:10500. Orientation elements are missing, as the pictures were in the US National Archives in the form of scanned negatives. The pictures were transformed in Erdas Imagine software and saved in GeoTIFF format, which allowed them to be imported and processed in Digitals software. Fig. 1 shows a fragment of the overlap zone of a stereo pair of aerial photographs with a marked area on which, according to the testimony of eyewitnesses, there was a mass grave.

Fig. 1. Overlap area of a stereo pair of aerial photographs from 1944 with the marked pre-defined mass grave area

Indeed, when interpreting this territory, a disturbed section of an elongated shape, close to rectangular, can be seen. The detected disturbance differs in its structure from disturbed land due to plowing for agricultural needs. The disturbance is not uniform over the entire area of the plot, which indicates more the structure of the buried pit than the plowed upper layer of the soil (Fig. 2). According to the aerial photograph, it was determined that the area of the mass grave has an irregular shape and is 939.6 m^2.

Interpretation of aerial photographs of 1944 allowed displaying the territory of the mass grave located within modern urban development. Its analysis helped to create an orthophoto plan and a height map based on the data of the aerial survey of the territory of the town of Vynnyky from a UAV in 2015.

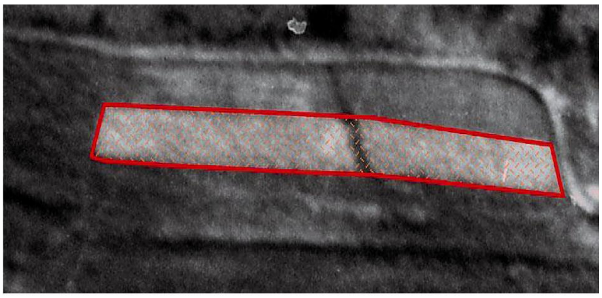

Fig. 2. The territory of the mass grave in Vynnyky, interpreted from aerial photographs of 1944

With the help of Agisoft Photoscan software, an orthophoto plan and a height map of the territory of the town of Vynnyky, near Lviv, were constructed based on 119 photographs. When forming the orthophoto plan, we used 37 contour points with known coordinates determined in advance by applying GNSS surveying.

When performing the image alignment operation to build the scene, medium accuracy was chosen. The “Accuracy parameter” in the Agisoft Photoscan program includes “very high”, “high”, “medium”, “low”, “very low”. An increase in accuracy leads to an increase in processing time. Since the survey area was large enough, and the area of interest was long enough, we were satisfied with the average accuracy of the model construction.

After the completed operation there is:

- a sparse point model of the terrain consisting of common points;
- calculated coordinates and orientation parameters of pictures;
- specified (in a first approximation) camera calibration parameters.

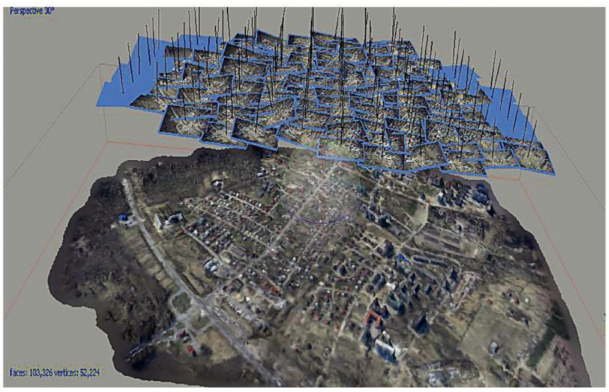

Fig. 3. Creation of an orthophoto plan and elevation map of the territory of Vynnyky

The next stage after aligning the photos is marking the reference points and setting their coordinates, and then – optimizing the referencing. The final stage of the processing of aerial photography data for the creation of an orthophoto plan of the area is the construction and export of the orthophoto plan. Fig. 3 shows an example of creating an orthophoto plan of Vynnyky in the Agisoft Photoscan program.

Fig. 4 shows the created orthophoto plan of the town of Vynnyky with the found area where, according to data from 1944, the mass grave is located. The territory with the grave is outlined in red.

Fig. 4. Orthophoto plan of the city of Vynnyky with a selected fragment of the location of the mass grave

The next step was to save a fragment of the 2015 elevation map for this area and the relief elements of 1944 in separate files for their further import into the Surfer software package for modeling. The 2015 elevation map fragment was saved as point coordinates with elevation data in a format with the *.txt extension, and the 1944 relief elements were decided to be saved in the *dxf exchangeable format as the most suitable for subsequent import into the Surfer software.

Surfer software package tools helped to construct the DEM of the territory of the mass grave based on the data from the stereo pair of aerial photographs of 1944 and the heightmap of 2015. Since we needed the most accurate interpolation without unnecessary anomalous surface distortions, we chose the Natural Neighbor construction method. The “Natural Neighbor” interpolation method uses the weighted average value of local data, which is based on the concept of natural neighborhood coordinates determined by Thyssen polygons. The method makes it possible to obtain good isoline maps based on data sets containing a cluster of sampling points in some sub-sectors of the studied territory and sparse sampling points in other sub-sectors. An estimate obtained at an arbitrary point will always be within the range of values at the nearest points.There will be no “peaks”, “pits”, “ridges”, “valleys” in the built model, which would not be represented by the original data. The algorithm used by the “Natural Neighbor” interpolation tool finds the subset of input samples closest to the desired point and applies weights based on proportional regions to them to interpolate the values. In this method, the estimate of the variable Z at some point of the research area is defined as the weighted average of the values of this variable at sampling points (in fact, at the nearest sampling points):

$$Z_0 = \sum_{i=1}^{n} w_{i0} \cdot z_i, \quad (1)$$

where the weights w_{i0} are determined using Voronoi diagrams. Voronoi diagrams are also called Thyssen polygons or Dirichlet cells.

The results of the construction of the DEM and vector maps of the territory of the mass grave for 1944 and 2015 are presented in Figs. 5–8.

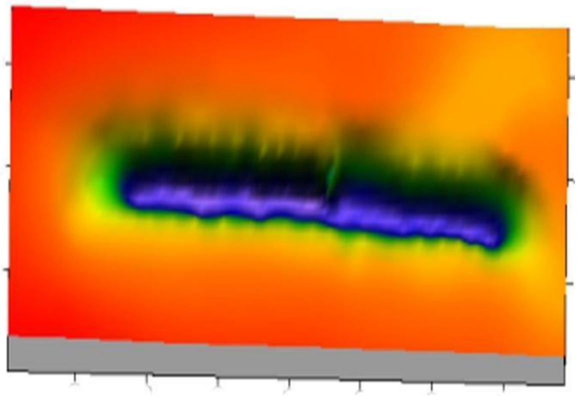

Fig. 5. DEM of the territory of the mass grave, created based on a stereo pair of aerial photographs of 1944

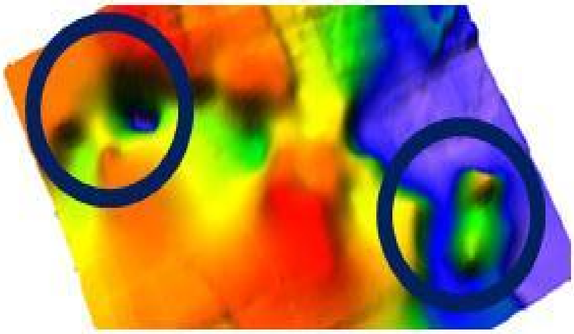

Fig. 6. The DEM of the mass grave area, created based on the 2015 aerial elevation map

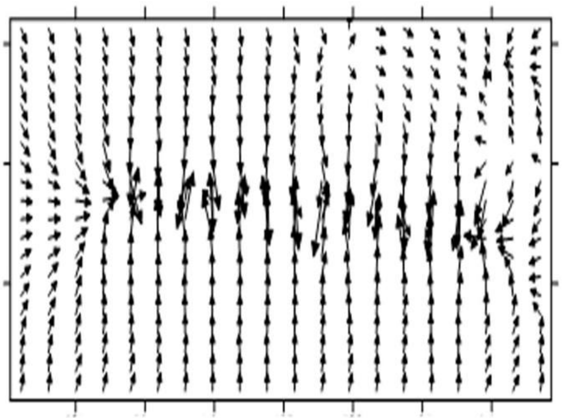

Fig. 7. The vector map of the mass grave, created based on a stereo pair of aerial photographs from 1944

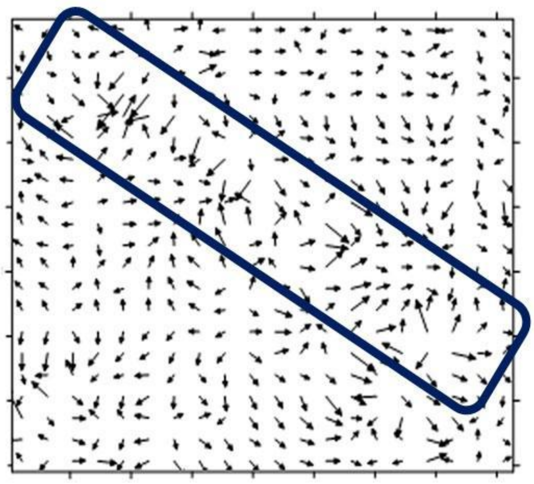

Fig. 8. The vector map of the mass grave, created based on the 2015 aerial elevation map

Analyzing the digital relief model and the vector map for 1944, the border of the mass grave is clearly distinguished, since the height difference between its edges and the rest of the territory is from 20 to 36 cm, depending on the section of the border.

The analysis of the digital elevation models and the vector map for 2015 of the mass grave territory determined from the aerial photograph of 1944 showed that the characteristic height differences on the former border of the grave are observed only in the left-right corner of the grave and on a separate section of the right border. Height difference indicators range from 15 to 20 cm. It should be noted that height differences are also observed in the rest of the territory belonging to the mass grave and outside it. This can be explained by many years of human intervention and agricultural use of the land.

The second object of research is located in the forest near the Lviv – Vynnyky highway, or rather between the highway and the village of Lysynychi. The object is a cluster of mass graves of Jews and Italian prisoners of war who were taken to execution from the "Stalag-328" (Citadel) concentration camp during World War II.

Since the research area is wooded, it is impractical to carry out aerial photography from a UAV as in the first option. Therefore, the main input data for research were a stereo pair of German aerial photographs from 1944, as in the first case, and a topographical plan of the research area on a scale of 1:1000, created in 2011.

A stereo pair of archival German aerial photographs was obtained from the US National Archives as scanned negatives. Aerial photographs were taken on July 29, 1944. Aerial photography was carried out from a height of 8170 meters, the survey scale is 1:11000. It is analytically determined that the zone of longitudinal overlap is 70 %, as in the first case. The images were transformed by 11 reference points in ErdasImagine software, and imported into the Digitals environment for further processing.

Fig. 9 shows the overlap zone of the stereo pair of German aerial photographs of 1944 on the research territory. It can be seen from the picture that the territory of the current forest was not afforested in 1944, in fact, afforestation was just beginning. There was a sand quarry between the forest and the Lviv-Vynnyky road. Mass graves of different shapes and sizes are interpreted along the paths in the present forest area.

To compare the 1944 DEM with the modern model, we used a topographic plan created in 2011 based on a tacheometric survey on a scale of 1:1000. The contour interval is 1 m. Subsequently, this plan was loaded into the Surfer software package and the contours were digitized to construct the DEM.

Contours in the Surfer software package helped to construct the DEM based on a modern topographic plan and a stereo pair of archival aerial photographs from 1944. Taking into account that the topography of the research area is rather steep, it was decided to choose the Kriging method as the most optimal for designing this type of topography.

Fig. 9. Overlapping zone of a stereo pair of aerial photographs from 1944 on the territory of mass graves of Italian prisoners of war near the village of Lysynychi

Kriging is an advanced geostatistical method that allows you to construct a predicted surface from a set of *z*-valued points. Unlike other interpolation methods, the Kriging tool provides an interactive study of the spatial behavior of the phenomenon represented by *z*-values before choosing the optimal estimation method for constructing the resulting surface.

The basic formula for interpolation by the Kriging method is formed as a weighted sum of data:

$$\widehat{Z}(s_0) = \sum_{i=1}^{n} \lambda_i z(s_i), \qquad (2)$$

where $Z(s_i)$ is the value measured at location i; λ_i – unknown weight for the measured value at location i; s_0 – location of the forecast; N is the number of measured values.

Here, the weight, λ_i, depends only on the distance to the location of the forecast. However, when using the Kriging method, weights are applied not only to the distance between the measured points and the forecast locations, but also to the overall spatial location of the measured points. To use spatial location in the weights, you need to define the amount of spatial autocorrelation. Thus, in conventional Kriging, the weight, λ_i, depends on the established model for the measured points, on the distance to the location of the forecast, and on the spatial relationships between the values measured around the location of the forecast.

Figs. 10–13 show the constructed DEM and vector maps of mass graves in the Lysynychi forest for 1944 and 2011.

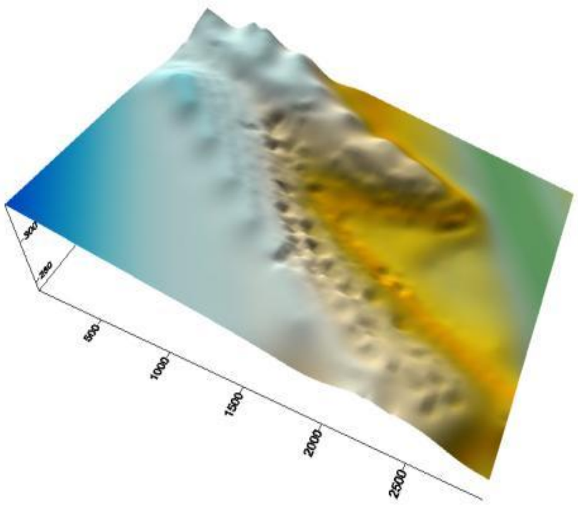

Fig. 10. The DEM of the territory of the mass graves, created based on a stereo pair of aerial photographs of 1944

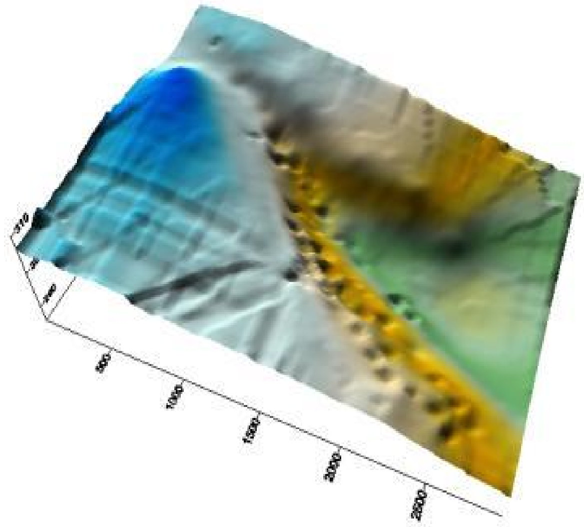

Fig. 11. DEM of the territory of mass graves, created according to the topographical plan of 2011

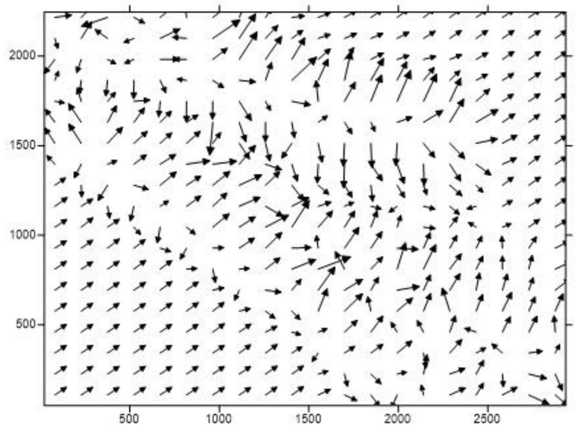

Fig. 12. The vector map of mass graves, created based on a stereo pair of aerial photographs from 1944

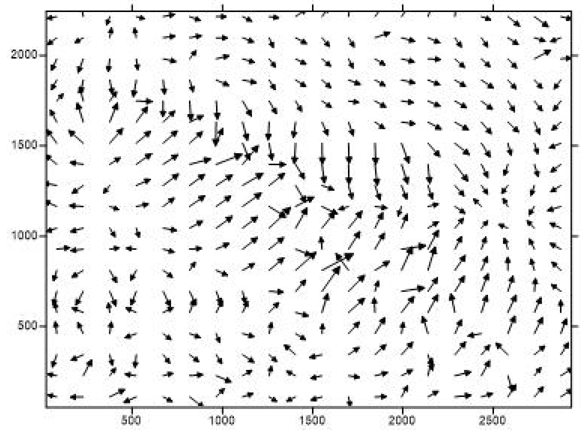

Fig. 13. The vector map of mass graves, created according to the 2011 topographical plan

The results of the identification of mass graves in the Lysynychi Forest according to the German aerial photographs of 1944 were plotted on the modern topographical plan of the territory in 2011. Aerial photographs allowed us to identify 54 pits with burials distributed mainly along the country road. Currently, 46 pits have been preserved, which repeat the location of the graves of 1944. The depth of the pits in 1944, according to the built DEM, varied from 30 to 60 cm depending on the area, as of 2011, the depth varies from 50 to 110 cm. This can be explained by the subsidence of the soil due to the decomposition of biological substances and the layering of the soil around the graves. The remaining 8 pits, which have not been preserved, were most likely filled in as a result of a possible change in the topography of the area where they were located over time, probably, as a result of human intervention.

Fig. 14 shows a fragment of the topographical plan of the research area in 2011 with marked (in red) mass burial pits of 1944.

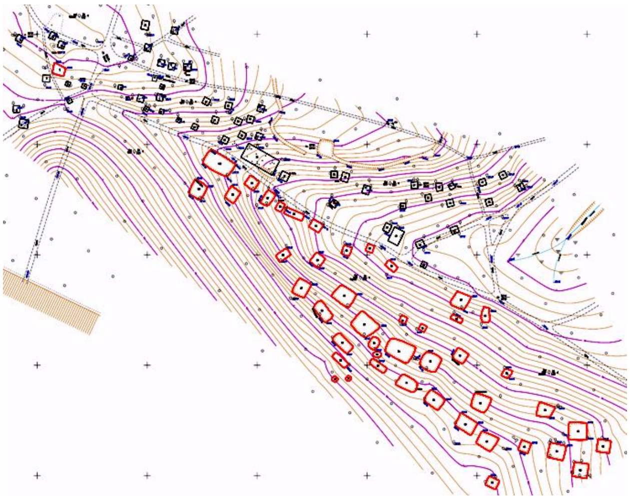

Fig. 14. A fragment of a topographic plan on a scale of 1:1000, created in 2011, with the pits of mass graves transferred from the Central Military District of 1944 applied (reduced image)

Scientific novelty and practical significance

The scientific novelty of the work consists in the development of the concept of combining disparate data for the construction of digital elevation models and the creation of a complete picture of the study of the territory of the historical and cultural heritage object. The received data can be used by the relevant cultural heritage preservation departments of the Ministry of Culture of Ukraine for their further study.

Conclusions

As a result of the realization of the aim, by analyzing the digital model of the relief and the vector map for 1944, the border of the mass grave was determined. The height difference between its edges and the rest of the territory is from 20 to 36 cm, depending on the section of the border. The analysis of the digital elevation models and the vector map for 2015 of the territory of the mass grave showed that the characteristic height differences on the former border of the grave are observed only in the left-right corner and on a separate section of the right border. Height difference indicators range from 15 to 20 cm. It should be noted that height differences are also observed in the rest of the territory belonging to the mass grave and outside it. This can be explained by many years of human intervention and agricultural use of the land. According to aerial photographs of 1944, the area of the grave is 939.6 m^2.

Digital elevation models of mass graves of Italian prisoners of war in the forest near the village of Lysynychi were built on the basis of a stereo pair of archival aerial photographs from 1944 and the data of tacheometric surveying of 2011. They allowed identifying 54 pits with burials that have survived to this day.

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ДОСЛІДЖЕННЯ ЦИФРОВИХ МОДЕЛЕЙ РЕЛЬЄФУ НЕРУХОМИХ ОБ'ЄКТІВ ІСТОРИКО-КУЛЬТУРНОЇ СПАДЩИНИ, СТВОРЕНИХ ЗА РІЗНІ РОКИ

Мета роботи – дослідити цифрові моделі рельєфу братської могили 1944 р., побудовані за різночасовими аеро- і картографічними матеріалами. Реалізація завдання передбачає побудову цифрових моделей рельєфу (ЦМР) GRID-методом на території єврейської братської могили в м. Винники та італійських військовополонених поблизу міста. На територію єврейської братської могили у м. Винники створено ЦМР за стереопарою архівних аерознімків, отриманих у 1944 р., та за матеріалами аерознімання з БПЛА, виконаного у 2015 р. Оскільки для архівних аерознімків не збереглись елементи орієнтування, їх геометрично трансформовано за допомогою програмного пакета ErdasImagine. Після цього стереопару опрацьовано в програмі Digitals й отримано елементи рельєфу на територію братської могили. Матеріали аерознімання з БПЛА на територію м. Винники, виконаного у 2015 р., опрацьовано в програмному пакеті Agisoft PhotoScan. Створено ортофотоплан та карту висот на територію міста. Елементи рельєфу на територію братської могили 1944 і 2015 рр. імпортовано в програмне середовище Surfer, де побудовано 3D цифрові моделі рельєфу. Оскільки територія могили не мала значних перепадів висот, а рельєф був доволі пологий, вибрано метод побудови ЦМР природної околиці, що дало позитивний результат. Під час аналізу цифрової моделі рельєфу і карти векторів за 1944 р. чітко виділено межу братської могили, оскільки перепад висот між її краями й іншою територією 20–36 см залежно від ділянки межі. Аналіз цифрової моделі рельєфу і карти векторів за 2015 р. території братської могили, визначеної за аерознімком 1944 р., показав, що характерні перепади висот на колишній межі могили спостерігаються лише в лівому правому куті могили і на окремій ділянці правої межі. Показники перепаду висот від 15 до 20 см. Зазначимо, що перепади висот є і на решті території, яка належить братській могилі та поза нею. Це можна пояснити багаторічним людським втручанням і сільськогосподарським розорюванням земель. Дослідження ЦМР братських могил італійських військовополонених біля м. Винники показало, що сучасна територія на 100 % заліснена, що унеможливлює виконання аерознімання. Отже, для порівняння сучасної ЦМР зі створеною за стереопарою аерознімків 1944 р. виконано наземне тахеометричне знімання місцевості у 2011 р. Дані тахеометричного знімання експортовано в обмінний формат dxf, після чого відкрито в ПП Surfer і побудовано ЦМР. У цьому випадку цифрові моделі рельєфу побудовано із застосуванням методу Крайгінга, оскільки ділянка, на якій розташовані братські могили, доволі горбиста, із великим перепадом висот. За цифровими моделями рельєфу визначено 54 ями з похованнями, що збереглись до сьогодн. Наукова новизна роботи полягає у доопрацюванні методики поєднання різнорідних даних для побудови цифрових моделей рельєфу та створення цілісної картини дослідження території об'єкта історико-культурної спадщини. Отриманими даними можуть скористатися відділи зі збереження культурної спадщини Міністерства культури України для їх подальшого вивчення.

Ключові слова: цифрові моделі рельєфу; ортофотоплан; карта висот; братська могила; архівний аерознімок.

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