The application of remote sensing and IT in research of mass graves in the system of Jasenovac ustasha camps

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Abstract

Remote sensing enables a large amount of qualitative new data about the Earth's surface to be obtained. It also creates precise geodetic bases in a new, efficient and economic way. It can also be applied to the discovery of mass graves in the system of Croatian ustasha genocide camps. This research demands an interdisciplinary approach and a methodology by which we can find the precise location and make a detailed analysis of any individual grave. The data obtained from remote sensing are checked by georadar image acquisition, after which excavation and anthropological research are begun. A thematic information system that puts together all given and existing data along with a definition of their mutual position and connection, gives full meaning to the whole project. By this method, historical science gets a powerful research tool while data search, comparative analysis and conclusion making are accelerated and simplified.

Key words: Geographical Information System (GIS), Remote Sensing, georadar, research methodology, traces of mass graves.

1. Introduction

The horror of the total extermination of some ethnic groups because of the "prosperity" of others became reality during the Second World War. Bad inheritance from the past and plans of devastation grew rapidly in that environment. In the newly created Independent State of Croatia, the most deplorable methods of inquisition began to appear insignificant when compared to the cruel deeds being done to Serbs, Jews and Gypsies in the Croatian ustasha genocide camps.

Unfortunately, when the war finished, injustice, concealment of the truth and consequent acceptance of crime, has continued. Along with the passage of time and natural exogenous influences, graves have been cemented and levelled, documentation and records have disappeared, books have been forbidden and those who should have bowed to shadows of the dead, have never been held accountable.

There has been a rapid development of photogammetry, the technique and discipline of data collection and the study of the Earth and its surface. This initiated the hypothesis that with the help of photogammetry, graphic bases for the whole area of the Jasenovac ustasha camp can be made, and with the help of remote sensing, places where there may be mass graves, can be discovered. In this way, the frames for further searches by Ground Penetration Radar - GPR can be set, and by archaeological and anthropological methods a geographic information system can be built. In this way, historical science becomes more meaningful and data search, comparative analysis and conclusions making are accelerated and simplified. The final result is an efficient learning process and an increased volume of information, drawn out from the darkness of past and present.

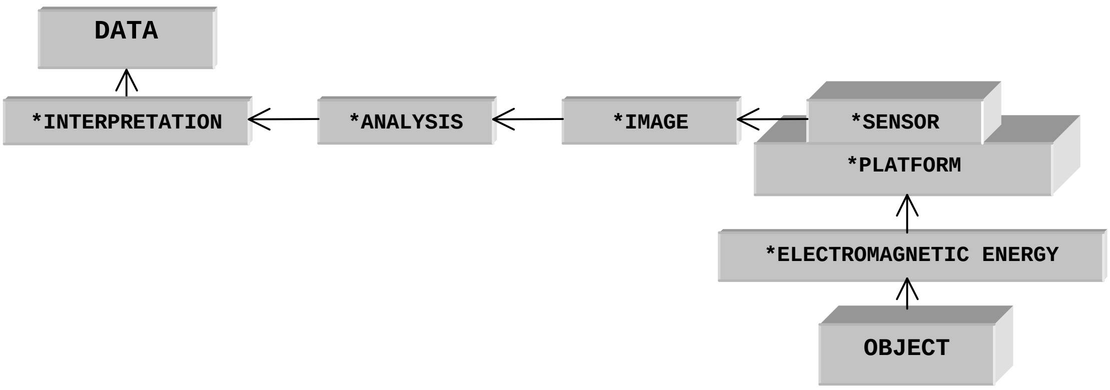
2. Remote sensing

According to Maxwell, electromagnetic radiation is: a "dynamic form of energy that manifests only in interaction with matter" (Reevers, 1975). Electromagnetic radiation is changeable in space and time, and it alternately connects electric and magnetic fields spreading in space. It spreads itself in the cosmos and in the atmosphere of the Earth, approximately by the speed of light in a vacuum. Man has only partial knowledge of this energy. Based on the fact that emitted or reflected electromagnetic radiation contains information about qualitative and quantitative characteristics of an object, it is possible to obtain this information indirectly, not by destructive methods.

Because of this, the "method of collecting information by the systems that are not in direct contact with the object or appearance which ought to be examined" (Markovic 1987, from Esters and Singer, 1974) is called remote sensing**.**

The development of most scientific and technical disciplines demands financial investment. Initially, remote sensing was used only for military purposes, but nowadays it is used in many areas. The wide range of remote sensing applications is also reflected in research of mass graves.

Objects, in this case mass graves that are being sought, emit and reflect electromagnetic energy. Electromagnetic energy is registered by a sensor positioned on a suitable portable platform. Electromagnetic energy converts itself into a visible registration/image, that is analysed and interpreted from the perspective - and according to the needs - of the search methodology. The final result of processing is new data about potential location, shape and size of mass graves, which represents a starting-point for further georadar and anthropological research. (Scheme 1).



*electromagnetic energy → own or reflected, solar energy and/or artificial energy
*platform → sensor carrier: man, vehicle, aircraft, spaceship, satellite
*sensor → energy registration device: camera, TV camera, scanner, radar etc.
*analysis → image research: visual or instrumental
*interpretation → image interpretation

Scheme 1. The principle of the remote sensing method (Markovic, 1987)

Electromagnetic radiation covers a wide range of wavelengths. Remote sensing is interested only in the parts of the electromagnetic spectrum for which atmosphere is leaky to a great extent (visible, near infrared, thermal infrared and microwave).

With the help of satellite images of high spatial resolution, it is today possible to collect the most varied data. IKONOS images are an example of commercial space imaging, with its panchromatic images having a spatial resolution of one metre and its multispectral images having a resolution of four metres (Picture 1). In combination with radar images containing information about characteristics of terrain beneath the Earth’s surface, it is possible, with a certain probability, to collect data about the potential location, shape and size of mass graves, by classification methods.

High spatial resolution allows the formation of geodetic bases of a scale of up to 1:2500, with previously precise setting of the co-ordinates of orientated points (using the Global Positioning System - GPS) and also the generation of a digital elevation model (DEM).


Picture 1. Part of multispectral IKONOS satellite image of Donja Gradina
Left - RGB colour composite; Right - visible and near infrared colour composite

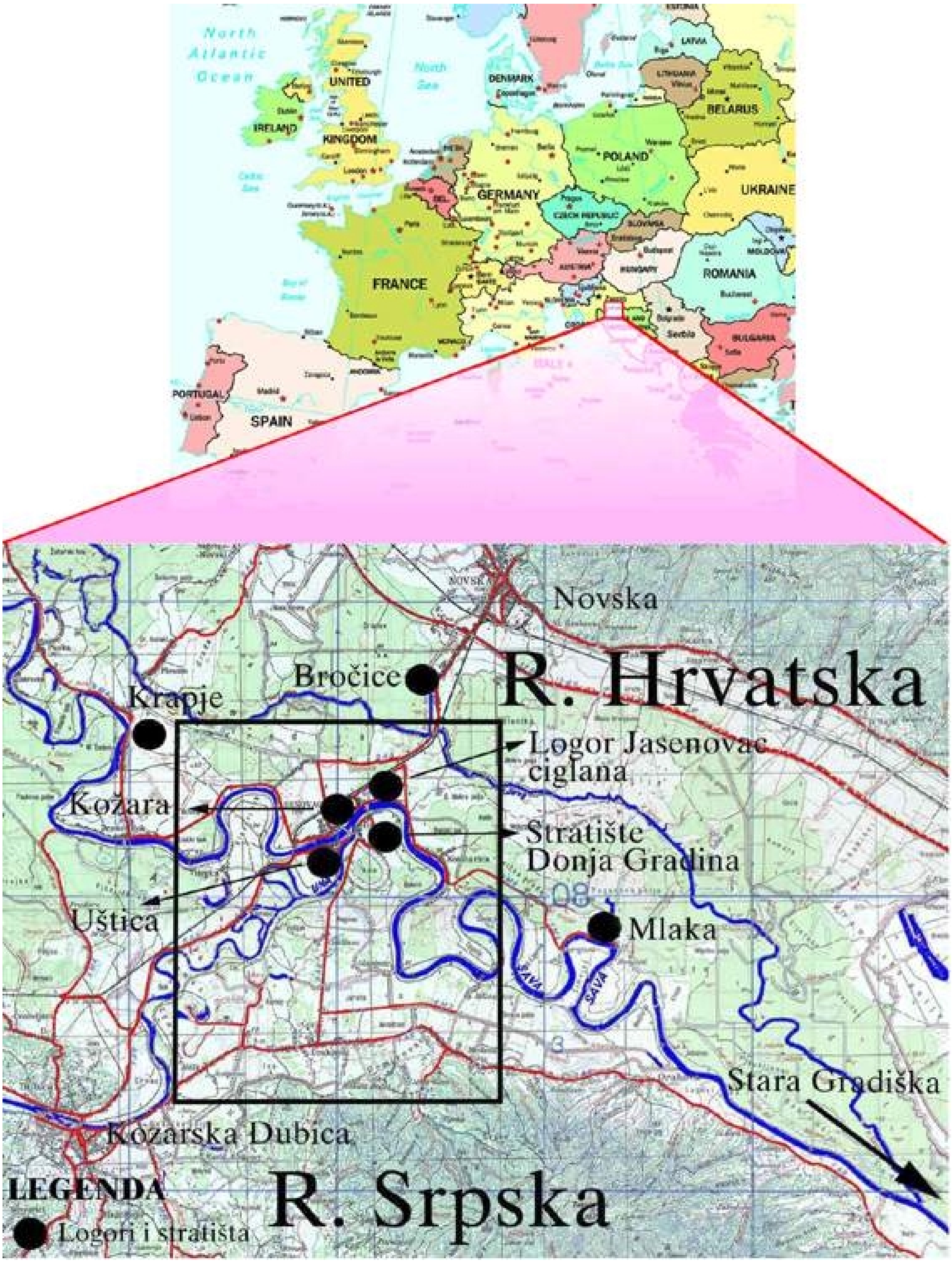
3. Geographical position and general geological and geomorphological characteristics of experimental area

The Jasenovac camp and one of its main execution areas, Donja Gradina, is located at the mouth of the rivers Una and Sava. The area of Jasenovac, like the areas of other camps from the system of ustasha genocide camps, is today within the borders of the Republic of Croatia. Donja Gradina, which is bordered by the right banks of both rivers at three sides, is in the Republic of Srpska. In this way, the Memorial Complex of Jasenovac is divided and therefore inaccessible to direct research as a whole.

As an experiment the area 10×12 km with the following angles, is taken:

- NW $\varphi = 45^{o}\ 18'\ 2.75''$, $\lambda = 16^{o}\ 51'\ 8.18''$
- SE $\varphi = 45^{o}\ 11'\ 38.38''$, $\lambda = 16^{o}\ 58'\ 54.15''$

The area includes the northern slopes of the Prosara mountain, Draksenic village and the following camps: Jasenovac (brick plant), Kozara (tannery), Ustica and Donja Gradina (Picture2).



Picture 2. Geographical position of camps from Croatian ustasha camps of genocide and selected area of research

3.1. Description of general geological structure

Within the examined area, rocks from the Mesozoic and the Quaternary ages were extracted (Picture3).

Sediments of Mesozoic are represented by different metamorphic rocks. They were discovered at the southern part of the terrain and they are not diffusive.

Desultory sediments of Mesozoic Quaternary age compose almost the entire examined area. As the oldest sediments of the Quaternary period, redeposited loess sediments of Pleistocene were extracted; they are represented by clayey, yellow-brown, fine grained sand. Sediments of terrestrial loess are mostly developed north of the river Sava and on the large area of Ustica. These sediments are up to tens of metres or more in depth.

Sediments of the earlier Quaternary period, the Holocene, belong to different genetic types of sediments. The following units can be extracted:

Proluvial sediments developed in the area of Demirovac and in the south. They are represented by unclassified and mostly angular material. As for the macroscopic field, these sediments respond to dappled clayey alevrolites filled with limonite and gravel.

Organogenic swamp sediments are extracted in the area of Kosutarice, north-east of Jasenovac, and also in small, isolated parts of the areas of Bar, Daman and the west of Cuklinac. They are represented by fine grained silt with the remains of organic components (plants) and with tiny grained sand.

Sediments of oxbow lakes, genetically, belong to flood features and they are characteristic of the area of deserted meanders of the river Sava and partially the Una. They are made of sand, fine sand and silt.

As a special unit within flood facies, the extensions of the alluvial plains of the rivers Sava and Una, were extracted. They consist of muddy and sandy sediments and gravel. They are up to 5m or more in depth, but this decreases going further across the riverbeds. The sediments of floods are consistent with the regimes of the rivers Sava and Una. This can be seen by the presence of unconsolidated, desultory sediments of various spread, depending on the morphology of the terrain.

The biggest part of the examined area is occupied by alluvial plains, which are genetically similar with riverbed facies. The alluvium of the rivers Sava and Una is made of gravel, sands and alevrolites. The depth of the alluvium in some places, is up to a few tens of metres.

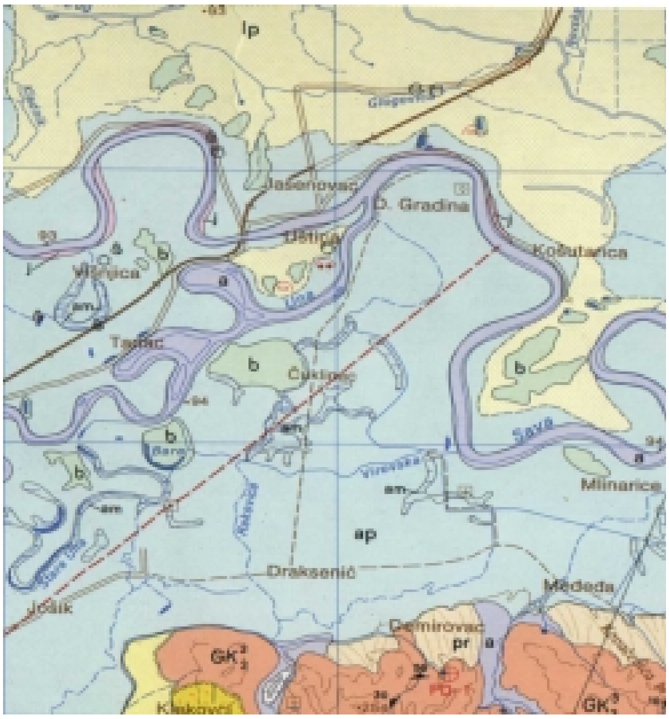
In the broader sense, in its western parts, the examined area belongs to the Panonian depression as tectonic unit of a higher order. But the origin and development of this area is connected with the existence of the river Sava's graben. The river Sava's graben was formed by strong activity in the upper Miocene period when the terrain started descending along the north-west/south-east fault. This long and multiple descent resulted in the formation and development of the river Sava valley after the end of the last great ice age at the end of Pleistocene. The wide initial depression enabled the river’s intense activity and this was conducive to the development of very deep and varied layers of the Quaternary age.

3. 2. Geomorphological characteristics

The examined area has significantly plain morphology. The current topography is the result of various geomorphological processes of which fluvial and anthrophogenic processes are the most important. The main event in the origin of the topography of the examined area is the morphostructure of the Sava rift. It represents the "initial topography" which was the origin of the river Sava. This lead to the fluvial processes and other geomorphological processes.

The fluvial geomorphological process plays a dominant role in the contemporary formation of the examined area. The development of the fluvial type of relief is determined, above all, by the valleys of the rivers Sava and Una. These rivers have very low and widely developed valley sides which may be at the level of their riverbeds. The bottom of their riverbeds represents the space at which intense accumulation of various material occurs.

From among the geomorphological forms, flood plains and alluvial plains of the rivers Sava and Una, meanders and riverbeds can be extracted. The origin of flood plains is related to the periods of floods. They have no clearly defined border and they are connected with the morphology of the surrounding area. Generally speaking, differing from sediments of alluvial plains, they are consist of coarse grained material. On the existing flood plains there are contemporary meanders of the river Sava (Klenov bok) and many other meanders of the river Una. Their origin is related to the existence of wide and narrow bottoms of river valleys. Because of these bottoms there are appearances of swerves of the river's flute and intense migration of riverbeds. The wide alluvial plains of the rivers Sava and Una are, in fact, dominant accumulation forms of contemporary bottoms of river valleys. Alluvions are tens of kilometres long, a hectometre wide and tens of metres thick.



Picture 3. Geological map of the examined area
(General Geological Map 1:100000, sheet Kostajnica)

On the examined area there are also geomorphological forms of swamp type of relief, originated on occasionally flooded area. These forms are connected with the activity of fluvial process. The migration of river courses causes the formation of meanders, after the alignment of the river courses those meanders convert into oxbow lakes. In them, swamp sedimentation of the finest material occurs with important participation of organogenic vegetal components. Backwaters of the river Una and occasionally swamp parts of the terrain, remained on the bottom of river valleys especially expressed in the central part of the examined area, also belong to the forms of swamp relief.

At the southern edge of the terrain, there is a hilly hinterland that is part of the northern slopes of the Prosara mountain (365m). On its slopes there are geomorphological forms belonging to the slope type of relief, notably small coombs. They are erozoic forms of Mesozoic, cut into friable metamorphic rocks. They are a hectometre long, but the width and depth do not exceed a few metres. Material drifted by occasional flows, is deposited on the bottom of slopes forming lobes tens of metres long, tens of metres wide and metres deep.

Man certainly plays a great part in the morphological formation of the examined area. Intense human activity exists, consisting of agricultural activities, construction of communications and urbanisation. Human activity has produced geomorphological forms such as artificial channels and orderly coombs built for irrigation, as well as slashes built for infrastructure and other objects. But the most important forms made by human activity are certainly embankments situated along the banks of the rivers Sava and Una, built to protect settlements and cultivated areas from floods.

By multi-temporal analysis of available air images it can be confirmed that extension of the area of embankment is possible, especially on the larger area of Donja Gradina. An obvious result of man's activity are the weakly expressed positive forms in relief in the area of Donja Gradina by the right bank of the river Sava (artificial mounds ?) with various dimensions.

4. Research and air images to date

In the period after the Second World War there have been many anthropological studies and within them trial excavations of whole graves.

In 1945, the first panoramic image was taken. But only one part is saved: that which the authors Kosta Halvaty and Gustav Gavrin included in the documentary "Jasenovac" as an introductory sequence, and which is kept in the Yugoslav Film Library (Jugosleovenska Kinoteka) under the ordinal number 3083.

In 1946, the Yugoslav Military Air-Force carried out air image acquisition of the course of the river Sava and this covered the area from Krapje to Stara Gradiska. The image acquisition was carried out by a reconnaissance camera with changeable overlap and sidelap. Today the photographic negatives are kept in the archives of the Military Geographical Institute (VGI) in Belgrade.

In 1957, the first photogammetric panchromatic image acquisition of the larger area of Jasenovac, was carried out by the Institute for Photogammetry in Belgrade (*Zavod za fotogrametriju*). Until the beginning of the war in the region of the former Yugoslavia, photographic material was kept in the Institute for Urban Planning of Bosnia and Herzegovina in Sarajevo (Urbanisticki zavod BiH).

In 1976, infrared imaging of the area of Donja Gradina and Jasenovac was carried out by the Geodetic Institute of Slovenia in Ljubljana (*Geodetski zavod Slovenije*). Until the beginning of the war in the region of the former Yugoslavia, this material was kept in the Institute for Urban Planning of Bosnia and Herzegovina.

Between 1960 and 1990, image acquisition of the area which had once included a system of ustasha genocide camps was carried out by VGI, with the intention of complementing the content of topographic maps of 1:25000 scale.

In 1983 photogammetric colour image acquisition of the area of 206km^2 including the intake of the river Sava upstream from Krapje to Stara Gradiska, was carried out by VGI, and it was organised by the Memorial Complex Jasenovac and Ina - Project from Zagreb. Photographic negatives are kept in the archives of VGI.

Through analysis and interpretation of the infrared images from 1976 and through comparison with the locations of mass graves that had already been discovered, the locations of existing, new, and until then undiscovered graves, could be established with varying degrees of probability. The places with a higher probability of graves existing covered 13425km^2 and the places with a lower probability of graves existing covered 2734km^2 (Bulajic, 1999).

After colour photogammetric image acquisition in 1983, at a meeting held on April 21st 1984, Mr Olujic introduced his study and gave results of his searches based on image interpretation. He used colour images from 1983, panchromatic images from 1957 and infrared images from 1976.

Here is a quotation from his study: " The possibility of the registration of mass graves of concentration camp victims, are supposed on the fact that those graves are mostly dug a few tenths of metre square underground and that they have regular geometric contours, differing to natural depression. Besides, it could reasonably be supposed that the locations of graves are the places which were dig up, filled with new corpses and again covered with a thin layer of earth. This allows the supposition that those places have a different rigidity than the surrounding area, different degree of humidity and different species and

intensity of vegetation. Besides, it was expected that the covering layer the graves would subside a lot due to the putrefaction of corpses, this should delineate in air images as depressions of regular contours...
... On April 6th, 1984, six locations marked on a photo sketch, were checked. These locations are situated in the region of the former camp and in its neighbourhood. The examination was done by iron bars of 150 cm and after that there was excavation. The pits (tested in order to show the presence of ostheological remains) withd dimensions of 40×40 cm and up to a hundred centimetres in depth, were dug up.
The result of examination was the following: human bones and skulls and many different objects such as spoons, toothbrushes, wallets, women's necklaces (scattered), women's shoes, were found at four locations. All those objects were found at a depth of 80 to 100 cm. At one of these locations remains of lime were found.
At the location situated near the indicated graveyard in the former concentration camp, cow bones were found. According to the report of R. Trivuncic, at the time of camp's existance there were kitchesn and butcher shop at that place, so animal bones were being thrown in the grave.
At two locations, outside the former camp, by terrain examination, remains indicating the existance of graves, weren't found." (Olujic, 1984).

5. Input data

With its rich resource of various images from different periods, the archives of VGI enables the research to take place. The images shown in Table 1 were taken from the archives of VGI.

Table 1. Air-images, from the archives of VGI, used in the study

Year of image acquiring		Image scale	Ordinal number in the archives	Number of flight line	Direction of flight W - west E - east SE - south-east NW - north-west	Number of image
black-white	colour					
1946		7500	284	475/19	NW-SE	702
1961		32 500	1573 1572 1571	10 11 12	W-E E-W E-W	0107, 0109, 0111 0154, 0153, 0151 0073, 0072, 0070
1975		26 000	4301 4302	700 701	W-E E-W	1956, 1958, 1960 2008, 2006, 2004
1977		26 000	4719	104	E-W	2468, 2466, 2464
	1983	9 000	5334/1 5334/1 5334/1	498 499 500	SE-NW SE-NW NW-SE	9644, 9643, 9642 9695, 9694, 9693 9616, 9617, 9618

The images have been chosen to cover different time intervals in order to facilitate multi-temporal analysis of changes to the terrain. Colour images from 1983 were taken in order to try to classify and extract areas of water, vegetation and the possible locations of mass graves, with the help of digital processing.

Bearing in mind the image acquisition of 1946, which included the areas of the Jasenovac camp and Donja Gradina, film negatives were searched within the archives of VGI. Image acquisition was carried out on October 3rd 1946, eighteen months after the release of the prisoners from the Jasenovac camp on April 22nd 1945. It would be expected that the evidence of crimes carried out in Donja Gradina would be fresh and objects destroyed within the camp and Jasenovac village would still be present. Image acquisition was carried out by focal lens camera f=200.69mm from a height of 1500m and with a scale of approximately 1:7500.

According to the existing evidence, the negatives including the aforementioned areas, should have been in the cases 281, 282, 283 and 284. Unfortunately, after a detailed search, the cases containing negatives which included the areas of Jasenovac and a large part of Donja Gradina, were not found.

Negative case 283 (688, 690, 692, 694, 696 and 698) and case 284 (702, 704 and 706) were scanned and so protected from further ageing and possible loss. Even after the completion of this study, the location of cases 281 and 282 has not yet been discovered.

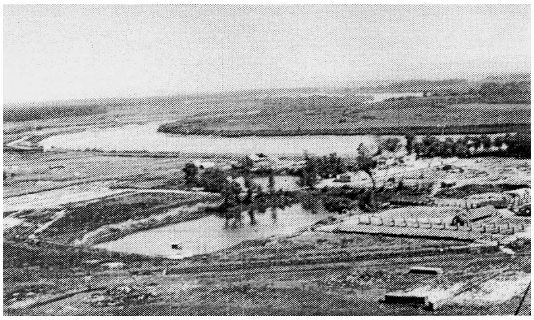
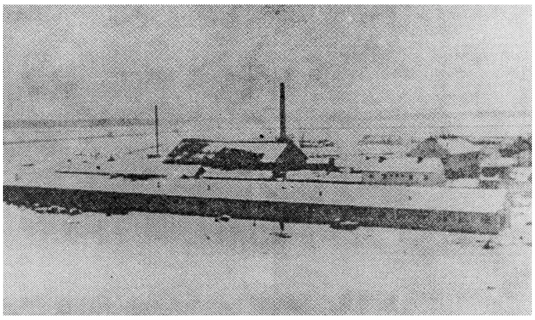
In order to enrich the potential of input data, the Yugoslav Film Library (Jugoslovanska Kinoteka) was contacted. This was also done with the aim of using the introductory sequence of the documentary made by Kosta Halvaty and Gustav Gavrin in 1945, in which the Jasenovac camp and the northern edge of Donja Gradina are covered by an oblique, panoramic air image (Picture 4).

By reviewing the material from the Yugoslav Film Library, it was discovered that the area of Donja Gradina was not included in the introductory sequence of the documentary. It is therefore not useful for collation of data which included the location of mass graves and the analysis of relief changes occurring under the influence of exogenous processes and by human activity. Additionally it was confirmed that besides the introductory sequence of the "Jasenovac" documentary, the Yugoslav Film Library has no separate aerial photography.

Along with panchromatic colour images, it is also necessary to acquire images which include infrared and microwave spectral areas.

As geodetic bases, the following sheets of 1: 25000 topographic map (TK25) are taken:
- Bosanska Dubica 2-3 (372-2-3),
- Bosanska Dubica 2-4 (372-2-4),
- Bosanska Dubica 4-1 (372-4-1),
- Bosanska Dubica 4-2 (372-4-2) and

Coordinates of the State Trigonometric Network (Drzavna trigonometrijska mreza, DTM*)*.

Picture 4. Panoramic air image of the Jasenovac camp, cadres from the "Jasenovac" documentary "Jasenovac" (the Yugoslav Film Library, No. 3083) (Bulajic, 1999)

6. Display, analysis and interpretation of images

The application of remote sensing methods includes analysis and interpretation of collected material and the formation of new bases. Stereoscopic analysis of the searched area was done with the help of multi-parametral analysis in order to extract areas with differing characteristics.

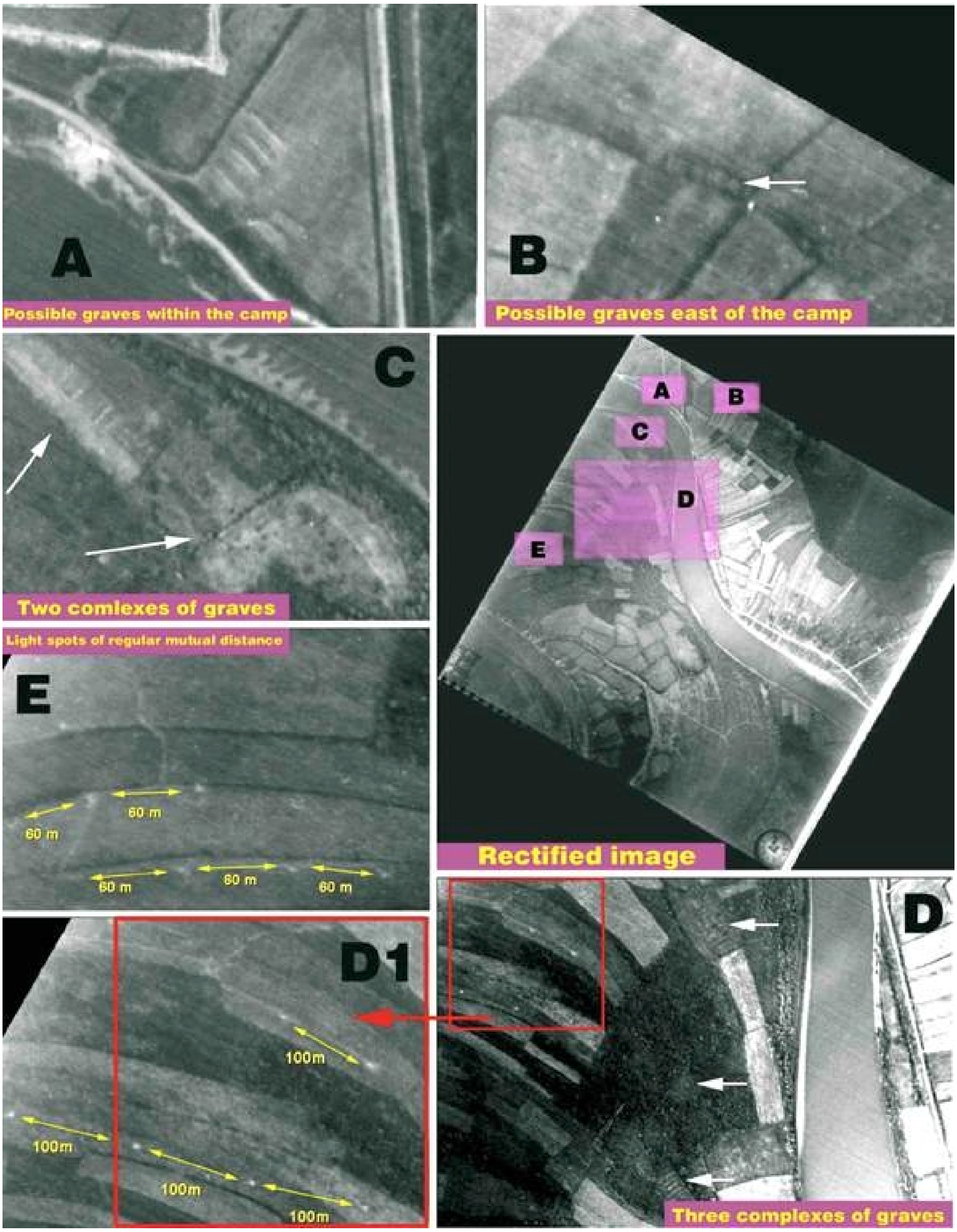
A special place in the study was given to image processing, an integral part of remote sensing. The application of computer science includes the following:

- preprocessing - preliminary material review, with the aim of indicating possible defects and removing deformations that appeared during the conversion of air images and topographic maps into digital format;
- georeferencing needed for the introduction of bases into selected cartographic projection - state co-ordinate system;
- making mosaics for review and efficient manipulation of the examined area;
- image enhancement using a large number of procedures;
- classification of image content in order to extract the area of definite content;
- orthorectification of air images and their usage as a high accuracy control bases for entering data and updating topographic maps;
- establishing the link between different data sets in order to qualitatively collect new data by performing analyses and visualisations of the examined area;

- multi-temporal analysis with the aim of registering and reconstructing morphological changes, changes to vegetation and other changes of terrain;
- making high resolution DEM as a primary base necessary for comprehensive analysis, aerial photgraph interpretation and data collection.

Application of the procedures of remote sensing, though limited by the quality and kind of accessible searching material, gives a great amount of a high-quality data for discovering mass graves and also making geotopographic bases for further specific historical research.

Aerial photograph number 702, taken in 1946, is very precious. The image is still applicable, despite the fact that it is 54 years old. Three obvious areas of mass graves were identified, as were further locations where their existence is possible. In addition, light spots with a regular mutual distance of 60m and 100m were noticed. These spots are assumed to be the places where corpses were burned during the destruction of criminal evidence at the end of the Second World War (Picture 5).



Picture 5. Panchromatic aerial photograph of the north-eastern part of Donja Gradina and the south-eastern part of the camp brick-plant from 1946, and the results of its analysis and interpretation; A, B, C and D - possible grave fields marked by arrows; E and D1 - light spots with a regular mutual distance of 60m and 100m that are assumed to be the places where corpses were burnt.

Mosaics of black-white images from 1961 and 1975/77 enable data collection at the level of specification for TK25. Some limitations exist in the identification of dotty objects and areas with swamps due to the shortage of stereoscopic effects and insufficient spatial resolution of scanning. In the image from 1961, the area of the camp brick-plant was partially flattened, its fence and other structures were ruined and its building material had been removed. The remains of the structures' foundations still be seen. The Macabre Lake (Sablasno jezero) was divided into two large and two small ones. But in a mosaic of the air image from 1975/77, the area of the camp is flattened and the grounds of the structure is entirely unnoticeable. The largest lake is connected with the small south-western lake and so two big and one small lake were originated. The complex of structures within the museum, embankment, conic crypt and drainage pattern were built (Picture 6).

Picture 6. The area of brick-plant camp: 1961 -above and 1975 -bellow

By comparing the positions of the riverbeds of the Una and the Sava from 1961 until 1975, great changes were noticed, caused by meandering and human activity. By detailed multi-temporal analysis of accessible aerial photgraphs, it can be confirmed that accumulation of river deposit is prevailing over erosion.

At the same time there was no erosion of the banks of Donja Gradina, which could be expressed by the drastic removal of human ash.

Picture 7. Data based on mosaics images from 1961 and 1975/77 and collected by manual screen vectorization

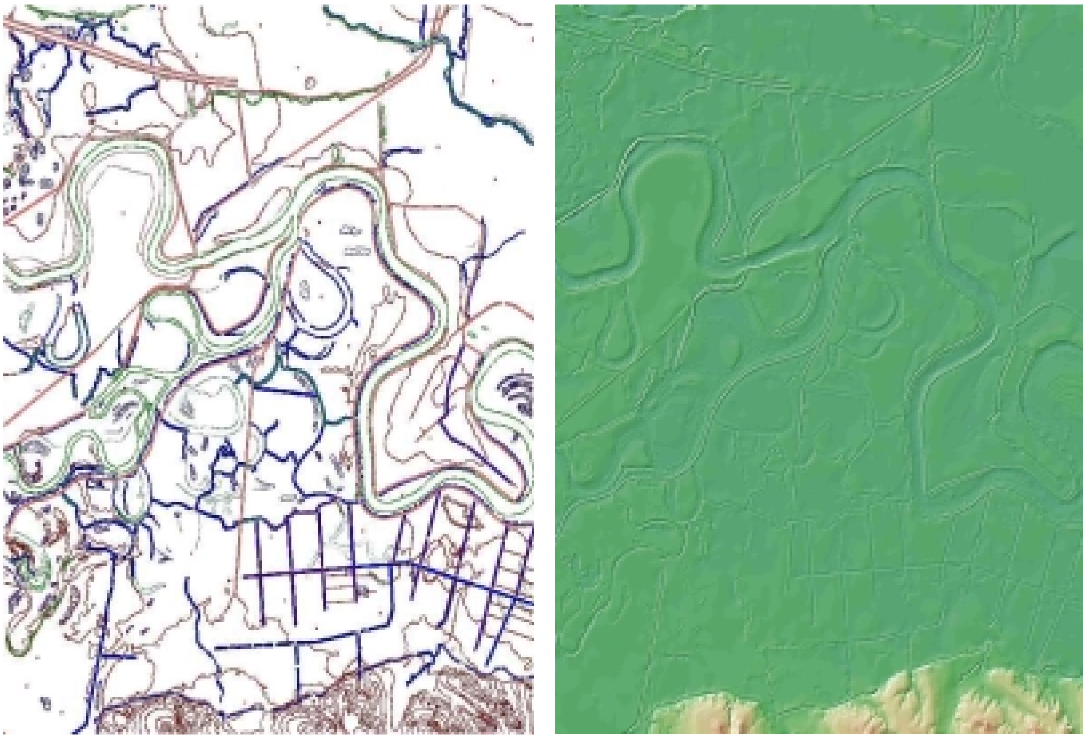
7. Digital elevation model (DEM)

DEM is a particular presentation in which cells of raster image, grid, contain data about height of the terrain. One of the most common definitions introduced by Borrough in 1968 (Pavlovic and others, 1999): DEM is a matrix with data about height, formed on a regular net representing continuous changes of relief in a space.

In the sphere of concrete research, DEM is important for:

- the setting of X, Y and Z coordinates;
- the extraction of contour lines and the setting of Z values;
- the computation of slope degree, confirmation of changes of terrain surface resulting from human activity and from endogenous and exogenous forces;
- the precise correction and processing of an image; and
- the measurement of distances and areas.

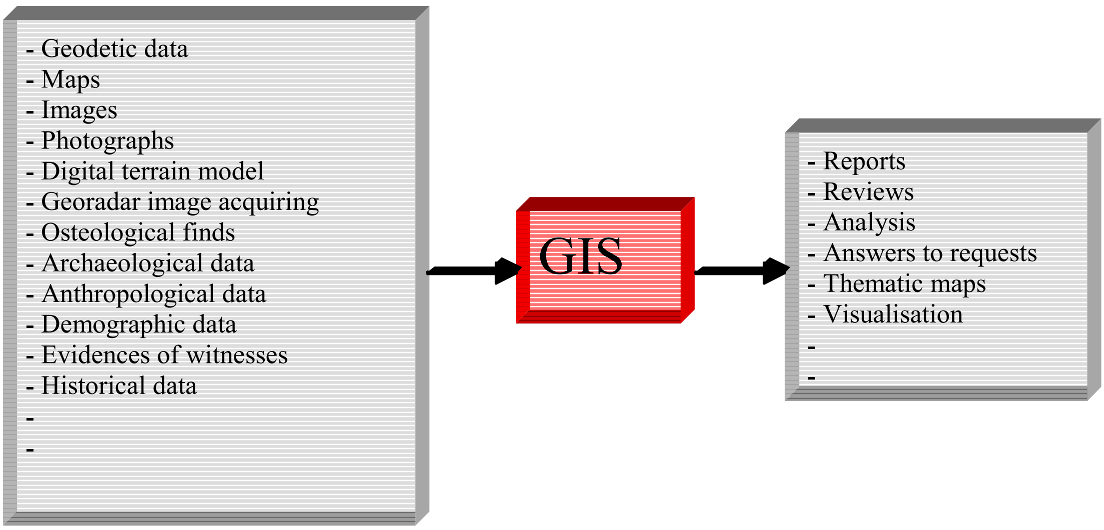
The data from which the DEM is generated are collected by manual head up vectorization. Regarding flat terrain, along with contour lines and Z points, edges of mounds, depressions, embankments, water channels and lines of slashes and plain's water courses are vectorized, by which precision of displays and visual presentation of given DEM is increased. All vectors have heights assigned, either given directly or by interpolation from TK25 (Picture 8).



Picture 8. Left - Data from which the DEM is generated; Right - DEM presentated by hipsoscale

8. Geographical information system (GIS)

Comprehensive spatial and multi-temporal analysis after more than 50 years includes an enormous quantity of data, which needs to be collected and processed. The most efficient way is by using GIS technology which combines various spatial and alphanumeric data, its archiving, analysis, interpretation and display (Scheme 2).



Scheme 2. Input and output GIS data

Generating a GIS system of utasha genocide camps, can be done using the following phases:
- Generating GIS (identification of all processes and user's needs in order to find an optimal solution),
- data collection and conversion to digital form; creation of graphic and alphanumeric databases (this phase usually requires the greatest resources),
- integration of the various data into one system,
- making applications which facilitate the making of reports, reviews, thematic maps, analysis, data updates etc. and
- users' training

It is very important to emphasise that existing databases (ex. database with the victims of the Second World War) could be quickly integrated into the GIS of utasha genocide camps. By doing this, the GIS as a whole could be formed, grown and developed. Historical science could reconstruct the events which took place in 1941 and 1945, precise confirmation of the numbers of victims, their identity, their ransacked real estate and property etc., could be simplified and accelerated.

Conclusion

- In order to get high quality output data, adequate input data are required, comprising the following: panchromatic, multispectral and radar images of high spatial resolution.
- Missing photo negatives of air image acquisition from 1946 and which cover the areas of Donja Gradina and Jasenovac camp, have to be found.
- Given data should be verified at terrain by georadar image acquisition, the results would represent the base for archaeological and anthropological research.
- All data collected by remote sensing, georadar image acquisition, archaeological and anthropological research should be linked with evidence of witnesses, osteological finds, demographic and historical data etc. into a system by the principles of GIS.

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