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DIFFERENTIAL DIGITAL TERRAIN MODEL APPLIED TO EVALUATE CHANGES IN THE RELIEF FEATURES

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ABSTRACT - Under this research study, on the example of a village of Kasinka Mała, a possibility of applying a Digital Terrain Model (DTM) to evaluate changes in the cultural landscape was assessed.

Key words: cultural landscape, Digital Terrain Model.

INTRODUCTION

A contemporary interpretation of Landscape refers to a spatial and material dimension of the Earth's reality, and, so, the landscape covers a complex system consisting of the following forms: relief features, flora (vegetation) and waters (Zonneveld, 1990).

Cultural landscape, also called anthropogenic landscape, is associated with human activities in the domain of culture. It is an area of intense human activities, causing essential changes in the system of natural environmental conditions and introducing spatial (3D) elements created and produced by man (Ambosiewicz, Mackiewicz, 1998; Banaszak and Kasprzyk, 1993; Mazur, 1998; Meeus 1990, 1995; Szczęsny, 1982).

One of the highly complicated tasks in the field of natural science is to study landscape, specifically, to assess landscape, and to forecast all the required changes and modes/states of preservation. Until now, investigations on the landscape were based on rather intuitive methods characterized by a certain degree of subjectivity. Owing to the complexity of issues, in particular to the complexity of spatial parameters describing the landscape, it is necessary to support the assessment of landscape by applying various scientific branches. Owing to this fact, quite a lot of outcomes of scientific research aiming at evaluating the landscape are often very biased, one-sided, or even divergent.

A Digital Terrain Model (DTM) is one of the products of the modern digital photogrammetry and can be applied to evaluate changes in the anthropogenic landscape.

METHODS TO OBTAIN A DIGITAL TERRAIN MODEL

When digitally approaching a topographic surface, the first essential problem encountered is connected with choosing a field measurement method and with creating an input basis for further calculations. In geodetic-cartographic works, there are three approach procedures usually utilized to choose source data. All of them are associated with a terrain modelling process and with its application (Piasek, 1993).

The first approach procedure covers a method of direct measurements taken by electronic devices (the testing/measuring stands/stations are either automatic or semi-automatic) within a limited

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range of the terrain surface. Using this approach, highly accurate measurements are obtained; they can be applied to designing earth structures, computing total cubic contents (cubatures) of earth masses etc.

The second approach is associated with photogrammetric measurements, which are processed by a stereo plotting machine; the processed images usually have accuracy dependent on the differentiation in the heights (elevation) of the terrain measured. Most frequently, this approach is applied to large ranges of surfaces. A typical example of the second approach application comprises dam designs, water reservoirs designs, and designs of roads and highways/motorways (Piasek, 2000).

The third approach is based on the digitalization of existing maps. Data can be processed manually, automatically or semi-automatically. This option is characterized by a poor accuracy subject to the scale of maps being processed; it is applied, among other things, to reproduce the configuration of the studied terrain and its relief features (Petrie, 1987a, 1987b).

A DIGITAL FORM OF THE TERRAIN MODEL

A Digital Terrain Model can be represented in the form of:

- TIN – a network of irregular triangles;
- GRID – with randomly assumed sizes of a mesh and sides parallel to a local or national coordinate system,
- Contour Model

TIN – (eng. *Triangular Irregular Network*) numerous irregular nettings form a network of irregular triangles with vertices lying on measurement points; the triangles create surfaces, which are most congruent with the terrain. This DT Model depends on the method of setting measurement points; morphological forms of the terrain are easy to be maintained and to be described within the same structure since the shape and the size of triangles are adjusted to terrain forms. A weak point of the TIN structure is the necessity of having larger sets files to archive data. No TIN structure is provided/ generated when automatically generating a DTM.
The Digital Terrain Model shaped as a network of triangles is recommended for applications to terrains characterized by an intricate configuration and relief features, with lots of anthropogenic elements.
GRID – is a regular network composed of nettings made up of quadrates, rectangles or triangles; in the knots of the netting, there are points of a definite terrain height. The GRID is regarded as a ‘secondary’ network with meshes that are freely/randomly dimensioned and their sides are parallel to the coordination system assumed. This DTM appears more useful when generating digital orthophotomaps.
Contour Model – comprises isolines describing terrain surfaces; the basic element of this DTM is a sequence of coordinate pairs of a point of ‘Z’, which is its given height. This type of representation of the terrain configuration and relief features is typical when using cartographic methods.

ACCURACY OF THE DIGITAL TERRAIN MODEL

The accuracy of DTM is characterized by a mean height error obtained by the interpolation of a resulting DTM as presented by the Equation 2. The accuracy of DTM depends on the following factors:

- errors in source data;
- size of the netting mesh;
- character of the relief features;
- methods of interpolation.

The above factors are compiled in an empirical equation by Ackermann; in the equation, its second term includes errors connected with the interpolation of height in the resulting (secondary) network knots (Technical Guidelines K-2.8):

$$m^2_{DTM} = m^2_z + (\alpha\, d)^2 \qquad (1)$$

where:

m_{DTM} – mean error of the height being interpolated;
m_z – mean error of the measurement data;
α – coefficient describing the character of relief features;
d – mean distance between individual measurement points.

Value of **α** *coefficient:*

α = 0.004 – 0.007 – relating to flat terrains;
α = 0.01 – 0.02 – relating to terrains with moderate relief features;
α = 0.02 – 0.04 – relating to terrains with steep and irregular surfaces.

Mean error of the height determined is:

$m_z = \pm (m^2_{DTM} - (\alpha\, d)^2)^{½}$; the height value should not exceed 1/3 of the contour distance (interval) as assumed for a given topographic map with a given scale.

Prof. Torlegard provides equations describing the accuracy of a resulting DTM obtained from a measurement made on the basis of aerial photographs; the equations depend of the type of a particular terrain:

M_Z = 0.2 ÷ 0.4 ‰ · H – with regard to a flat terrain;
M_Z = 1.0 ÷ 2.0 ‰ · H – with regard to mountainous terrains;
$M_{Z\,max} = 2 \div 3 \times M_Z$

As for the 1:26 000 aerial photographs, it is possible to receive a maximum accuracy level of $M_Z = \pm 0.8$ m, and as for the 1:5 000 aerial photographs, their accuracy is: $M_Z = \pm 0.25$ m.

The accuracy of DTM, obtained using an automatic method of measuring a point height (serial correlation), is comparable or higher than the accuracy of DTM obtained using an analytical plotting instrument for photographs scanned using 15 µm pixels :

- as for the flat and undulating terrains, the mean error is: $m_{DTM} \leq 0.10$‰ ·H
- as for the mountainous terrain, the mean error is: $m_{DTM} \leq 0.25$‰ ·H

However, in the case of photographs scanned using 30 µm pixels:

- as for the flat and undulating terrains, the mean error is: $m_{DTM} \leq 0.10$‰ ·H
- as for the mountainous terrain, the mean error is: $m_{DTM} \leq 0.20 - 0.35$‰ ·H

(Dorozhynskyy, 2002)

The measurement of such form lines of the terrains, such as lines of discontinuity, skeleton lines, surface area of exclusions, is performed by using the manual digitalization of such objects on a stereoscopic model. Next, this measurement is applied to the process of generating an ultimate/resulting DTM.

The above-cited mean error of the height value, obtained by interpolating the resulting DTM, allows for the determination of its accuracy. The mentioned error covers the following factors:

measurement errors, accuracy of input data, dimension of the netting mesh and a factor describing the character of a given terrain.

It is worth emphasizing that while developing DTM, a technologically important element to be considered and included is the determination of the interrelations existing among the density and accuracy of surface measurements, the complexity of terrain forms and the density of the secondary DTM network being generated.

In the case, a DTM is generated for an orthophotomap by using a photogrammetric method, the size of a netting mesh (it is the so called ‘secondary network’) is as follows:

secondary netting mesh of a given DTM $\leq$ 20 · m_{DTM} as for a flat terrain;
secondary netting mesh of a given DTM $\leq$ 10 · m_{DTM} as for an undulating terrain.

APPLICATIONS OF DTM

The Digital Terrain Model has been more and more frequently practically applied in cartometrical surveys and studies. It is used:

- to automatically generate contour lines of shaded relief to develop: maps of terrain roughness, slope maps, maps of slope insolation, longitudinal (long) and transversal (cross) profiles, perspective views of terrains;
- to generate digital orhtophotomaps and stereoorthophotomaps. DTM is indispensably necessary in a process of digital generation of orthophotomaps for the purpose of eliminating image distortions caused by the terrain variation in level;
- to support such computer systems as GIS/LIS, where DTM is a separate thematic stratum;
- to assess the output volume in opencast mines and to determine the tempo of progression of erosion processes;
- to determine limits of inundation lines while performing simulations of a flood-wave height;
- to design communication roads, for example highways/motorways, with an option to quickly switch among various route run alternatives (how those roads may run), to draw up cost analyses, earthwork timetable (construction plan) and to determine the degree of incorporating the road into landscape and the visibility degree along the entire route.

Presently, DTM is applied to investigate phenomena occurring on terrain surfaces, as well as to spatial planning and engineering designing. In many publications, DTM is highlighted as being very necessary and useful; many authors also describe its multiple applications in many branches of the national economy (Baranowski, 1998, Adamczewski, 1998, Kurczyński, Preuss, 1998, Miłek, 1999).

A DTM generated can be visualized in different ways depending on its eventual applications.

THE AREA UNDER INVESTIGATIONS

The researches on the assessment of changes in the landscape of submontane terrains were performed in the village of Kasinka Mała, in the gmina (commune) of Mszana Dolna.

A town of Mszana Dolna is located in the inner-mountain depression within the Beskid Wyspowy Range. The area of Mszana Dolna covers the bottom of this mountain depression and the slopes of hills/summits surrounding the depression. The intermontane valley, where Mszana Dolna is situated, is of erosional origin. It was cut out in multi-coloured slates from the Eocene era by two main rivers Raba and Mszana, by their tributaries Porębianka and Słomka, which converge in this valley, and by many smaller brooks and streams. The bottom of this valley is lined with layers made up of gravels, sands, and flysch silt. The thickness of those layers is 5 m.

A key factor deciding on specific landscape values and scenic-aesthetic advantages of this town is the variety of relief features and the terrain configuration diversity. The following places should be cited as very noticeable in this district: - southern slopes of the summit of Lubogoszcz; -

almost the entire ridge of the Adamczykowa Mount – Gronoszowa, between the valley of the River Raba and the village of Poręba; - a considerable part of the hill slopes within the Zarabie region; and, finally: - a significant part of hill slopes with northern exposure and descent into the valley of the river Słomka.

In each of the places named above, each single, not built-up plot is qualified as a very attractive and scenic location and each single field-path or green lane is regarded a very enthralling scenic route. Owing to the landscape and aesthetic values of this area, it is highly recommended to maintain the agricultural and forest character of the slopes surrounding the valley of the town of Mszana Dolna. This particular type of space use is the only warranty that all its environmental, cultural and recreational values can be maintained and preserved.

The village of Kasinka Mała (fig.1) is situated near the main road from the town of Mszana Dolna to Cracow [in Polish: Kraków] in the Province of Małopolska, in the powiat of Limanowa, and in the gmina of Mszana Dolna; it is the western edge of the Beskid Wyspowy Range. The altitude of the location of Kasinka Małą ranges between 370 and 440 m above sea level. Kasinka Mała lies where the mouth of the river Kasinka flows into the river Raba (right-hand tributary of the Vistula river). The Kasinka Mała village borders on the following localities: Mszana Dolna, Lubień, Kasina Wielka and Węglówka.

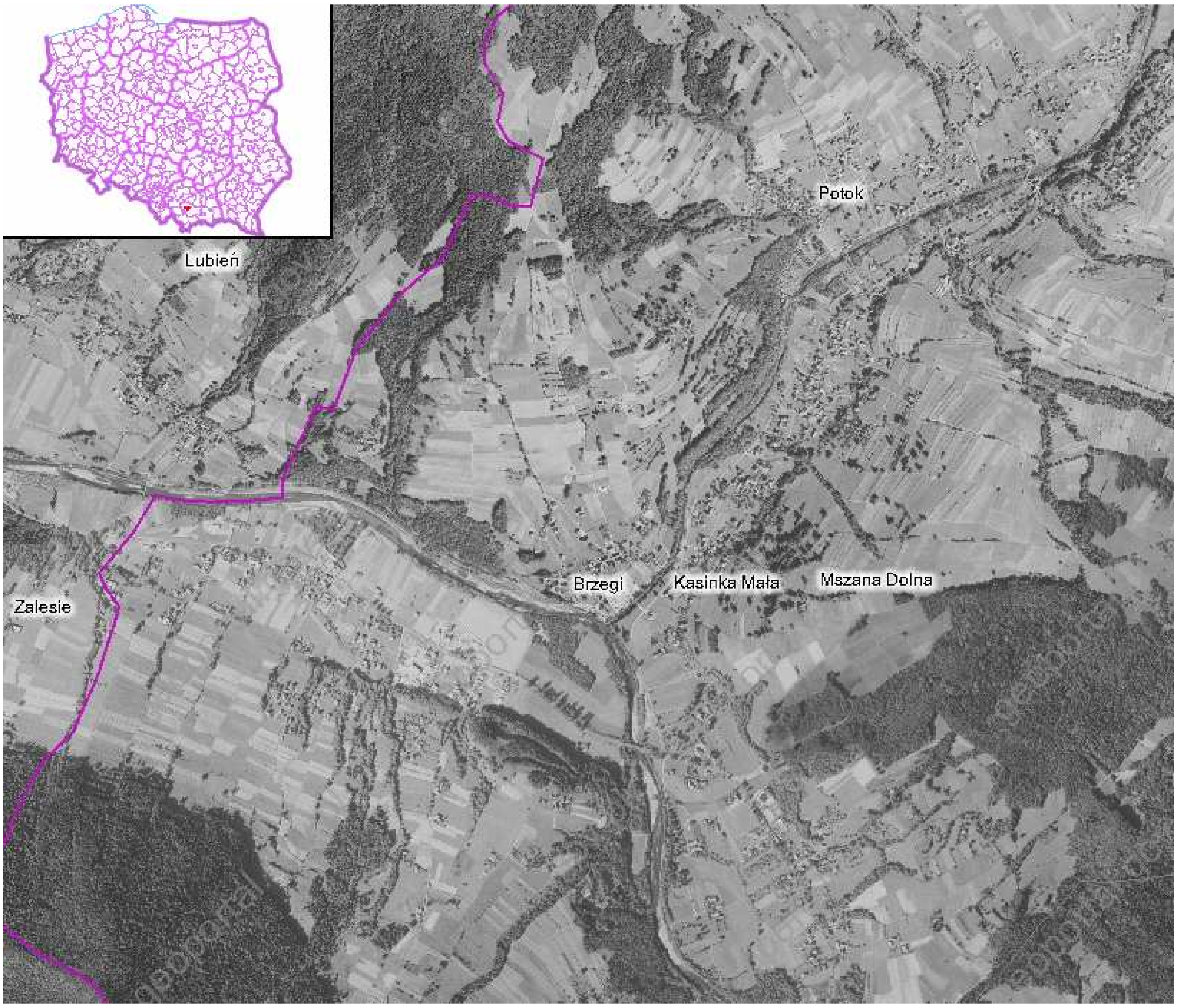


Figure 1. *The Area under investigation– Kasinka Mała.*
Source: WWW site in Internet: 'Geoportal'

SOURCE MATERIALS, METHOD OF ACQUIRING DATA

The investigations on the possibility of applying photogrammetric methods to the assessment of changes in the landscape of submontane terrains were performed in the village of Kasinka Mała.

This particular investigation object has been selected as an example of a typical submontane area where changes in the landscape had occurred. For the research purposes, two types of photographs were used: - colour aerial photographs at a scale of 1:26 000, taken in a period from 1995 to 1997 under the PHARE programme; - archive panchromatic photographs at scales of 1:19 000 and 1:20 000, taken during the 1960s and 1970s. This set of photographs constitutes a valuable material and allows for the determination of both the changes occurring in the environment and the tempo of their progressing.

DEVELOPING DTM AND ASSESSING ITS ACCURACY

Most frequently, the planimetric and contour (topographic) map is a model of terrain relief forms. A very important element of such map is that contour lines are very well drawn. When a contour drawing is replaced by a digital terrain surface model, then, new possibilities appear in the domain of landscape (Nita, 2001b). With DTMs, a procedure of obtaining essential parameters that characterize basic land features/forms becomes much more feasible and more precise. In addition, with DTMs, we can simply and quickly assess slope and terrace surfaces, determine and report averaged or real angles of slopes and insolation or show exposures/aspects of some selected surfaces. Relief features, landforms or their fragments can be compiled in thematic modules and we can put on those thematic modules and assess all kinds of changes as suggested for a given landscape to achieve a full visualization thereof from any perspective. Additionally, aerial photographs can be successfully placed on such modules (Chybiorz, Nita, 1999).

For the purpose of the present research study, a Digital Terrain Model was manually produced at a 'Dephos' photogrammetric station by importing a project from the ImageStation. Height Data for this DTM were taken from photogrammetric data set (stereo-pairs of aerial photographs).

A grid with a 30 x 30 m mesh was established, the model was complemented by discontinuity lines (stream lines, crest lines) and the grid was filled in the places with breaks in the terrain relief.

Discontinuity lines add vividness to the resulting DTM and improve its three-dimensionality, especially in the areas showing a diversified relief. In the next stage of investigations, DTM will be used as a method of representing the terrain relief or as a basis for various analyses to be performed. Profiles, a contour map or a 3D terrain model, known as block-diagram, can be developed quickly and easily from any DTM. The Digital Terrain Model was produced for each single stereogram and visualized in the 'Surfer' software. In the further phase of the study project, the Digital Terrain Model will be applied to produce a differential model.

The determination accuracy of the height of a given point from DTM was computed on the basis of the following formula developed by Prof. Akcermann:

$$m^2_{DTM} = m^2_z + (\alpha\, d)^2$$

where:

m_z – for undulating terrains H/10 000

H = 2000 m

$\alpha = 0.010 – 0.020$ – for undulating terrains

d = 30m

$$m^2_{DTM} = (2000\text{m}/10\,000)^2 + (0.015 \cdot 30\text{ m})^2 =$$

$$= (0.2)^2 + (1.5)^2 = 0.04 + 2.25 = 2.29\text{m}\sqrt{2.29}\text{ m} = 1.5\text{ m}$$

The determination accuracy of the height of a given point from DTM is: 2· m_{DTM} = 2· 1.5m = 3.0 m.

Stereogram 1169 ÷ 1170 (in the year 1963)

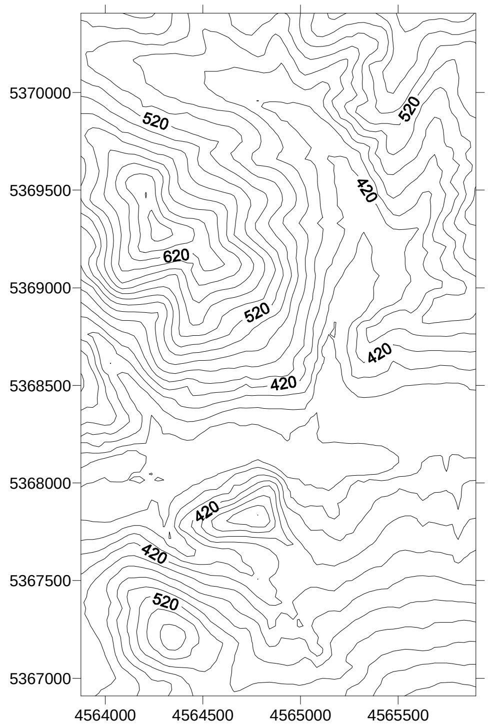
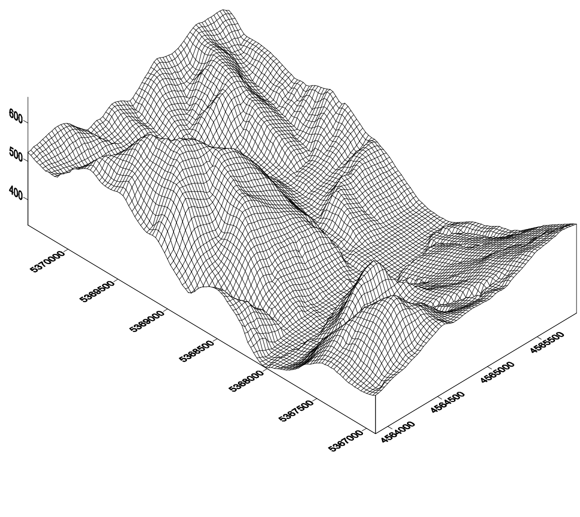
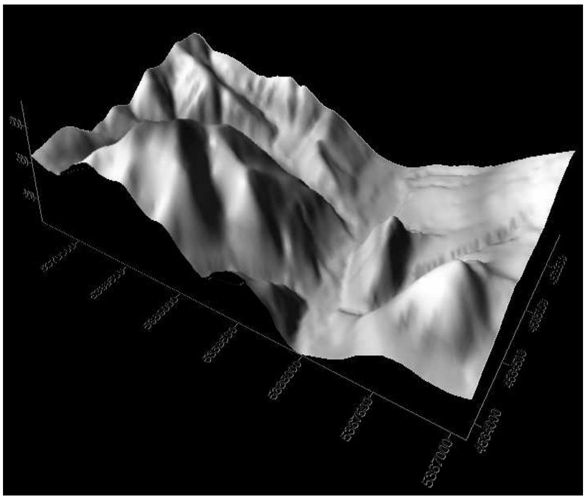


Figure 2. *Arrangement of the contours of the terrain investigated; contours were generated using DTM for a stereogram No. 1169 ÷1170 (in the year 1 963).*





Figures 2a and 2b. *Digital Terrain Model constructed on the basis of a model made up of archive black & white photographs for a stereogram No. 1169 ÷1170 (in the year 1963).*

Stereogram 1240 ÷ 1241 (in the year 1977)

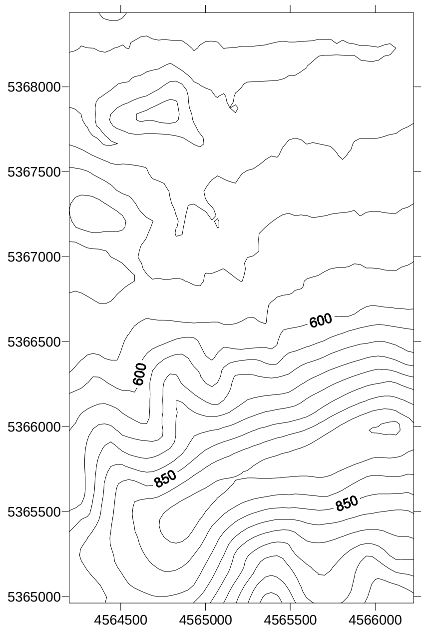
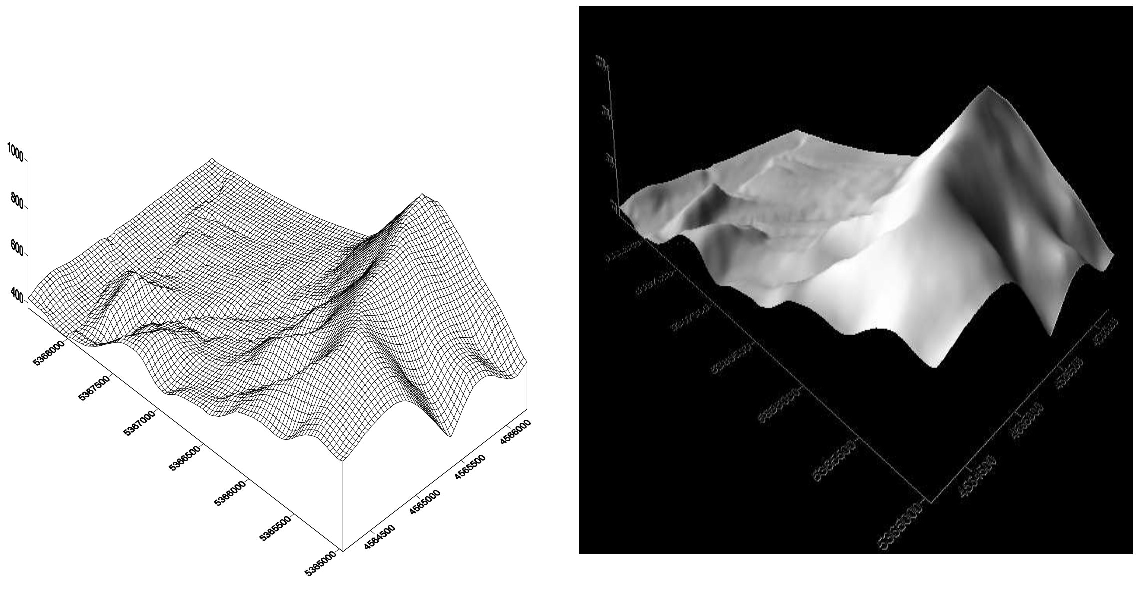


Figure 3. *Arrangement of the contours of the terrain investigated; contours were generated using DTM for a stereogram No. 1240÷1241 (in the year 1977).*



Figures 3a and 3b. *Digital Terrain Model constructed on the basis of a model made up of archive black & white photographs for a stereogram No. 1240÷1241 (in the year 1977).*

Stereogram 7017 ÷ 7018 (in the year 1997)

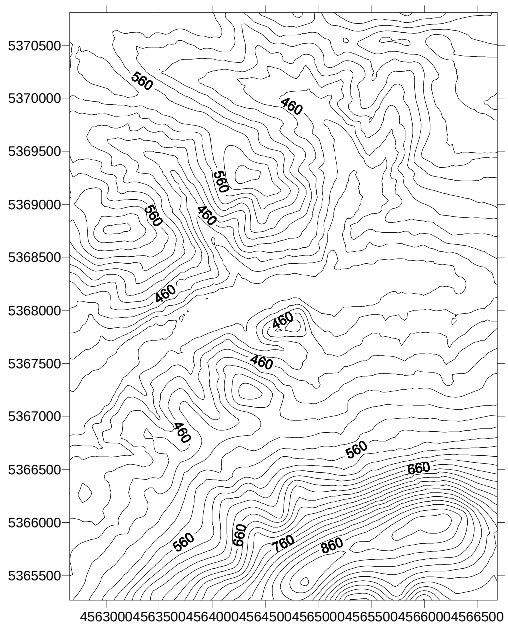
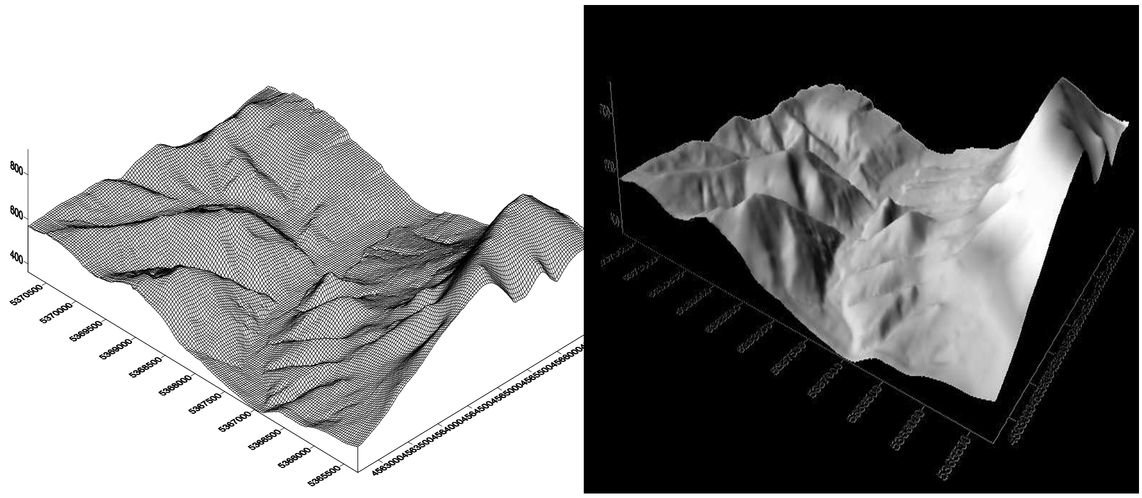


Figure 4. *Arrangement of the contours of the terrain investigated; contours were generated using DTM for a stereogram No. 7017 ÷7018 (in the year 1 997).*



Figures 4a and 4b. *Digital Terrain Model constructed on the basis of a model made up of archive black & white photographs for a stereogram No. 7017 ÷7018 (in the year 1997).*

Based on the above Digital Terrain Models, differential digital terrain models were constructed at a 'Dephos' digital photogrammetric station.

The determination accuracy of the height of a given point from DTM is about 3.0 m and no essential changes in the relief features of the terrain investigated are found; thus, the DTM constructed, the subsequently made differential DTM cannot reflect any changes in the relief.

The application of the differential DTM can be recommended in the case when real changes in the relief significantly exceed the accuracy of DTM.

CONCLUSIONS

On the basis of the results obtained from the analysis accomplished under this research study, it was confirmed that for the purpose of picking out changes occurring in the landscape, the application of the differential DTM (provided the changes in the relief significantly exceed the accuracy of DTM) is very useful and helpful.

This research study was based on the aerial photographs and the existing traditional cartographic materials or digital maps, it was also supported by other research dealing with interrelations among the data referring to the terrain studied, which characterized the afforestation level of this terrain and the satellite images, which underwent a controlled classification.

Owing to this fact, it was possible to quickly ‘attach’ and use individual, author’s own research materials and information on objects from various databases and to enrich the contents of maps.

Recently, more and more cartographic materials appear in the form of digital maps. Those materials can be then applied to research studies of this description. Digital maps offer new, unlimited possibilities to accomplish analysis and thematic studies relating to landscape.

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