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Changes of selected topographic parameters of Krakow Old Town (Poland) during the last millennium as a result of the deposition of cultural sediments

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Abstract—**Investigations of changes in land topography over the last millennium were carried out within the boundaries of Krakow Old Town and were estimated from archaeological and geoengineering data. With the application of DEM, four topographic parameters were calculated (altitude, local relative height, slope and aspect) in two time situations: the present-day and before the rapid development of the town. Based on the parameters, changes in the land morphometry of the study area were analysed in detail and were compared with the thickness of cultural deposits (varying from 1 m to 15 m). There is a dominating trend of land flattening in the study area.**

I. Introduction

The central parts of towns with a long history distinguish themselves when compared to younger peripheral urban areas in terms of their considerably transformed topography. This is mainly due to the large-scale deposition of cultural sediments, sometimes with a contribution from sedimentation influenced by natural processes [1, 2]. Such changes lead to the building up of the area concerned and usually to its flattening [3]. Simultaneously, processes of land lowering occur on a local scale due to earthworks, mining works or river-control works [4]. Unlike the present situation, the estimation of the morphometry of the former relief of towns (i.e. before the beginning of rapid changes in the topography of urbanised areas) requires knowledge of the spatial differentiation of the thickness of the layer of cultural deposits and the thickness of the loss of the bedrock layer and/or unconsolidated sediments. Vertical changes in the topography of urban areas may be estimated based on archaeological or geoengineering investigations, and, in shorter time intervals, based on comparative analysis of maps [1, 3, 5, 6]. With the application of DEM generated on the basis of LiDAR data, different topographic parameters may be calculated such as altitude, local relative height, slope and aspect. Based on the reconstructed topographic surface before the accumulation of cultural deposits, and on the investigation results which meet strict archaeological and/or geoengineering criteria, it is possible to prepare a DEM and calculate the above-mentioned parameters which describe the former topography. A comparison of the results obtained makes it possible to evaluate changes in the topography of urban areas, which have mainly occurred due to the deposition of cultural sediments.

Studies discussing changes in urban geomorphometry, e.g. [6-10], focus on spatial variability in the thickness of the layers of cultural sediments. They give little attention to how other features of urban topography resulting from this process have changed from their pre-urban status. This study, on the other hand, takes into account changes in slope and aspect within the city's historic centre.

The analysis was carried out within the boundaries of Krakow Old Town, Poland. Based on topographic parameters, the changes in land topography of this area were compared with the thickness of the cultural layer which occurred during the last millennium.

II. Data Used and Methods

The original topography of the area studied was reconstructed based on published contour-line maps of different scales. These maps were prepared from the results of archaeological investigations. The roof of the in situ fossil soil overbuilt by cultural deposits is assumed to be the former level

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of the ground surface. Another source of information in the assessment of the original topography of the study area is found in published maps that are based on the results of geoengineering investigations. The maps also show the altitude of the deposits [m a.s.l.] lying under the cultural layer. From the above-mentioned data, a DEM was generated which showed the topography of the study area as it was about 1000 years ago. Using LiDAR data, a DEM was prepared which showed the present topography of the area studied.

To show the present and the former topography of the area studied, the following parameters were calculated: altitude, local relative height, slope, aspect. QGIS, SAGA GIS and GRASS GIS were used for spatial analyses. The values of the parameters were shown graphically for the whole study area which made it possible to evaluate the changes in topography between the initial and modern situations of any part of the area. The location of the parts of the study area analysed is facilitated by a square grid with sides of 150 m placed on the background of the borders of the individual landforms analysed. Based on the altitude [m a.s.l.] calculated as a mean value for each square of the grid at both moments in time analysed, the changes in each square of the grid were determined at a local scale Δh [m]. Changes in the slopes of the study area were estimated based on a comparison of the percentage [%] of parts of the area studied showing selected slopes [°] in both time periods analysed. In a similar way, changes in aspect in the study area were also estimated.

The thickness of the layer of cultural deposits was estimated from the topographic surfaces generated – both initial and modern. The differentiation of deposit thickness was shown as a contour line map which contained the boundaries of the landforms analysed.

III. Results and conclusions

In the boundaries of Krakow Old Town (9 km^2), four types of landform occur: (1) the Holocene plain of the Vistula river which occupies most of the study area, (2) the channels of the Vistula river and its tributaries, (3) a fragment of the Pleistocene terrace which rises 7-10 m above the Holocene plain, (4) isolated limestone hills of steep, locally rocky slopes elevated up to 40 m above the Holocene plain. A fragment of the Pleistocene terrace is connected as a spur with the centrally located Wawel Hill. In the past, the Vistula channel was meandering and adjacent to wetlands (including oxbow lakes and peripheral depressions – backswamps filled with peat). The latter landforms occurred in a large area around Wawel Hill and at the foot of the spur escarpment of the Pleistocene terrace [11]. The original topography of the study area (before the beginning of settlement in Krakow) was dominated by areas at an altitude of 195-200 m a.s.l. Convex landforms (limestone hills, sandbars in the area of the Vistula floodplain) showed clear limits which separated them from the concave landforms. Local height differences at the hill margins often exceeded 10 m reaching even 40 m. In the case of sandbars within the Vistula floodplain, these locally exceeded 5 m [Fig. 1]. The mean depth of the Vistula channel was 2 m (maximum 4 m) and it was accompanied by a low levee. Most of the study area showed a slope <=2° (Vistula floodplain, hilltop of the Middle Pleistocene terrace, fragments of the hilltops of limestone hills). Larger inclinations (2-5°) occurred in the case of sandbar slopes, long sections of the escarpment of the Middle Pleistocene terrace and at the foot of the limestone hills. A slope in the range 5-10° occurred within the escarpment of the Middle Pleistocene terrace directly above the Vistula backswamps and slopes of the limestone hills. The highest limestone hills (especially their slopes adjacent to the Vistula), showed even steeper slopes (10-20°, locally >20°). A vast area of the inclination <=2° was classified as without aspect. The fragments of land with N, E, S and W aspects had similar total areas at that point in time.

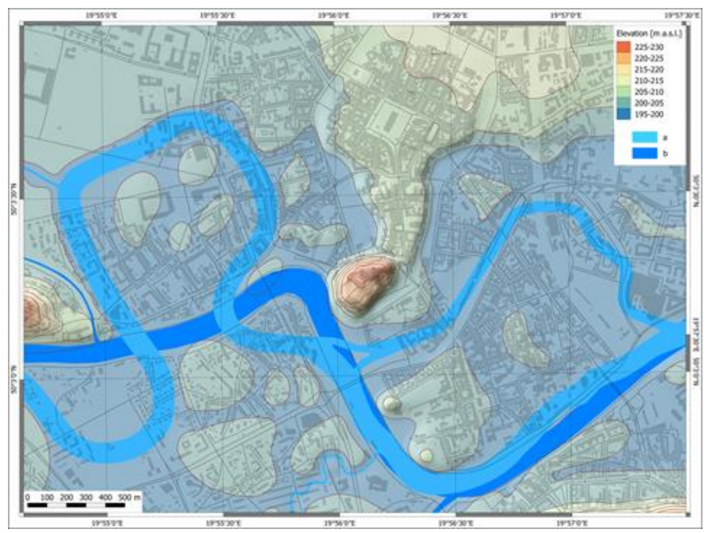

Figure 1. Hypsometry of the study area ca. 1000 AD. River channels: a – ca. 1000 AD, b – today.

The layer of cultural deposits accumulated during the last millennium covered almost the whole of the study area, except for local quarries within the slopes of the limestone hills, and the Vistula channel, which was deepened by about 4 m due to river-control works [12]. The mean thickness of this layer is 3.4 m, but it shows considerable spatial variation from 1-2 m in most of the area studied to 5-8 m within the palaeochannels and in the area of the former backswamps, and even to 15 m on the slopes of Wawel Hill where the Royal Castle and Cathedral are located [Fig. 2, Photo. 1].

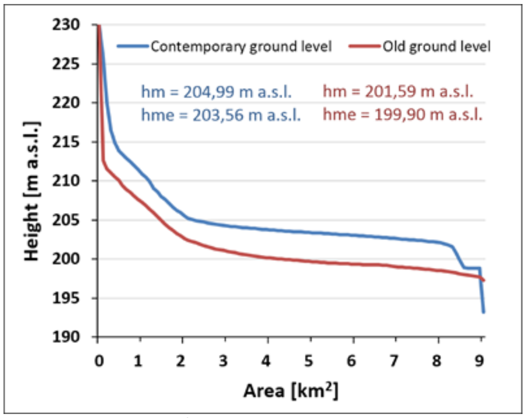

Figure 2. Hypsometric curves of the study area: today (top) and ca. 1000 AD (bottom).

Photo 1. Cultural deposits exposed in the Underground Museum of the Old Town in Krakow (Phot. R. Zarychta).

At present, almost the whole area of the Vistula floodplain is located at an altitude 200-205 ma a.s.l., therefore concave landforms such as palaeochannels, oxbow lakes and backswamps, as well as low convex landforms (sandbars and the lowest limestone hill) became hidden under deposits (partly fluvial ones) [Fig. 3]. At a height exceeding 205 m a.s.l., there is the foot of the escarpments of the Middle Pleistocene terrace, whereas the foot of the highest limestone hills reaches 210 m a.s.l. Some anthropogenic landforms, such as railway embankments, flood control embankments next to the Vistula channel, bridge abutments, and observation hillocks, developed within the Vistula floodplain and these usually exceed 5 m (up to 205 m a.s.l. or higher). During construction works, several metre-deep concave landforms were produced, later occupied by buildings. Local depressions commonly occur within the Vistula floodplain in the area covered by buildings from the 19th century and the beginning of the 20th century. These include back-yards located 1-2 m lower than the neighbouring streets. On the Vistula floodplain and on the Middle Pleistocene terrace, up to 3 m deep local depressions representing the former topography occur around old churches and synagogues [Photo. 2]. At present the hilltop of the spur of the Middle Pleistocene terrace is located above the altitude of 210 m a.s.l. The W-E profile of this landform no longer shows a table-like shape, as its escarpment and foot were overbuilt by cultural deposits, (its southern part providing an exception). The height of limestone hills has not changed, however cultural deposits were accumulated at their foot and on their slopes (e.g. SE slope of Wawel Hill) which resulted in a decrease in local height differences around these hills. Despite the changes in modern relief discussed, the slopes within most of the study area are still <=2°. Within the Vistula floodplain, there are small areas showing slopes of up to 20° or more (convex and concave anthropogenic landforms – especially linear ones). Slopes of the highest limestone hills still reach the value of 20°, and its N and W slopes exceed 20°. At present, areas of zero-aspect still predominate (slope <=2°). Lower located areas contain numerous anthropogenic forms of varying aspect.

Figure 3. Hypsometry of the study area today. River channels: a – ca. 1000 AD, b – today.

Photo 2. Narrow depression around the walls of an old church representing the former ground level (Phot. R. Zarychta).

The overlaying of the area of Krakow Old Town by anthropogenic deposits (more often in the case of concave landforms than convex ones), and also the development of high convex anthropogenic landforms, caused an uneven increase in altitude values (1-15 m) and an increase in the variation of local height differences. This resulted in an increase in slope and differentiation into greater variety at a local scale. In the study area, the area with a slope <=2° decreased by 6%, whereas the areas with slope 5-10° and >20° doubled. Areas without an aspect decreased, whereas the areas with S, W and E aspects increased [Fig. 4]. In the whole study area, a trend to area flattening occurred as a result of the deposition of anthropogenic sediments, however at a local scale, there was a trend to an increase in undulation that is visible.

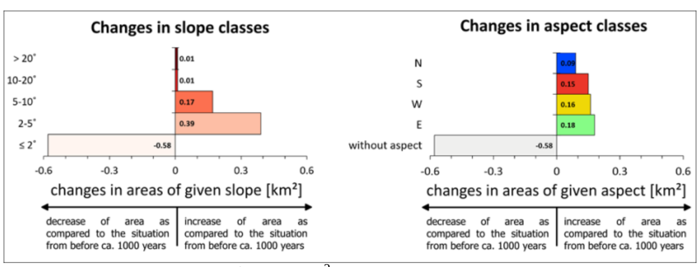

Figure 4. Change in size of area [km^2] within the Krakow historic city centre by slope range [°] and aspect during the last millennium.

Source of Figs. 1-4: [13].

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