Visualizing morphometric changes in a piping system using DEM and GIS analysis: the Bieszczady Mts., Poland

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Abstract— **This paper presents the morphometric changes in a selected piping system in the Tyskowa catchment in the Bieszczady Mts. (Eastern Carpathians) in Poland. The detailed geodesic measurements were made twice a year – in spring and in autumn – in 2013-2014. The Topcon Hiper II (base and rover) with the FC-250 field controller were used. The high resolution elevation model and additional maps were prepared using ArcGIS 10.2 software with ArcScene for 3D visualization. The positive and negative openness index were calculated in Saga GIS 2.1.4 software. The morphometric changes were calculated using Algebra map in ArcGIS 10.2. The different ways of the piping system visualization allow emphasizing the position of pipes in the slope-valley system. The concavity above the existing gully with the surface traces of pipe collapsing indicate the influence of piping in the gully formation and in its future development. The morphometric changes in the piping system enables to present erosion and accumulation zone within the piping system.**

I. Introduction

Piping is a subsurface process which leads to the formation of underground channels (pipes) by concentrated flowing water [1], [2]. From geomorphological point of view, the role of piping may be crucial, because the pipe collapse can result in the formation of discontinuous gully, and after regular gully. Therefore, the question about morphometric changes in a piping system thus dynamics of its possible development into gullies is worth of research.

Most research on piping is dedicated to the role of piping in relief development [3], particularly gully development (e.g. [4], [5]) and the factors controlling pipes development (e.g. [6], [7], [8]). The piping dynamics is considered mostly in terms of the soil erosion rates (e.g. [9], [10]).

Therefore, the aim of this study is to present the piping dynamics in different way – by visualizing the morphometric changes in a piping system using high resolution elevation model (0.25 m) and GIS analysis. The detailed objectives are: (1) to present the selected piping system in different maps to extract the information of its position in a slope-valley system; (2) to analyze the elevation data using terrain analysis indexes (positive and negative openness index); (3) to present the vertical differences in the ground level within the piping system in 2013-2014.

II. Study area

A. *Tyskowa catchment*

The analyzed piping system is located in the Tyskowa catchment in the Polish Bieszczady Mts., which are part of the Eastern Carpathians (Fig. 1). The Bieszczady Mts. are mainly formed of the Carpathian Flysch characterized by thick-bedded sandstones alternating with shales, where on the slopes developed silty-clay cover beds. It is a mid-mountain region, with altitudes ranging from 573 m to 894 m a.s.l. on the highest point. The climate is temperate with a mean annual temperature ranges from 4.0°C to 5.0°C [11] and a mean annual precipitation of 1000-1300 mm [12].

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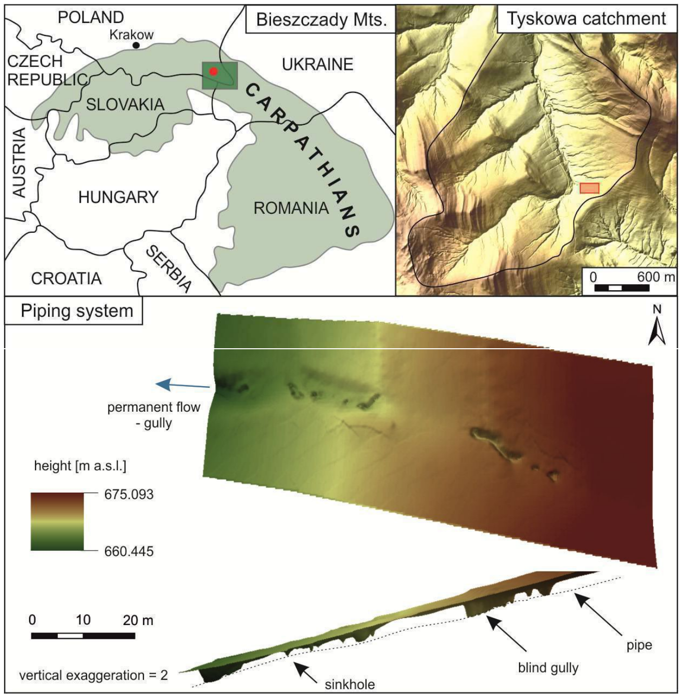

Figure 1. Location of study area with the 3D image of analyzed piping system.

B. Piping system

Piping system is a complex of piping forms, which are associated with one or more combined pipes [13], [14], [15]. The studied piping system constitutes of 4 sinkholes and 3 blind (discontinuous) gullies. It is located in the upper part of the catchment, on the slope of W aspect and average gradient of 10° to 15°. The majority of piping system is developed in grassland and the pipe outlet is in the forest in the channel head of the gully.

III. Materials and Methods

The elevation data were collected in the field using the Topcon Hiper II (base and rover) with the FC-250 field controller. The detailed geodesic measurements were made twice a year – in spring (early April, after snow melting) and in autumn (late October – early November, after summer rainfalls, before snowfalls) in 2013-2014. The individual surface piping forms were additionally measured with a measuring tape.

The digital elevation model (DEM) and additional maps of 0.25 m resolution were prepared using ArcGIS 10.2 software with ArcScene for 3D visualization. The positive and negative openness index were calculated in Saga GIS 2.1.4 software. The morphometric changes were calculated using Algebra map in ArcGIS 10.2. According to the observer error (estimating 0.05 m), the root mean squared error (RMSE) was calculated (RMSE = 0.07 m).

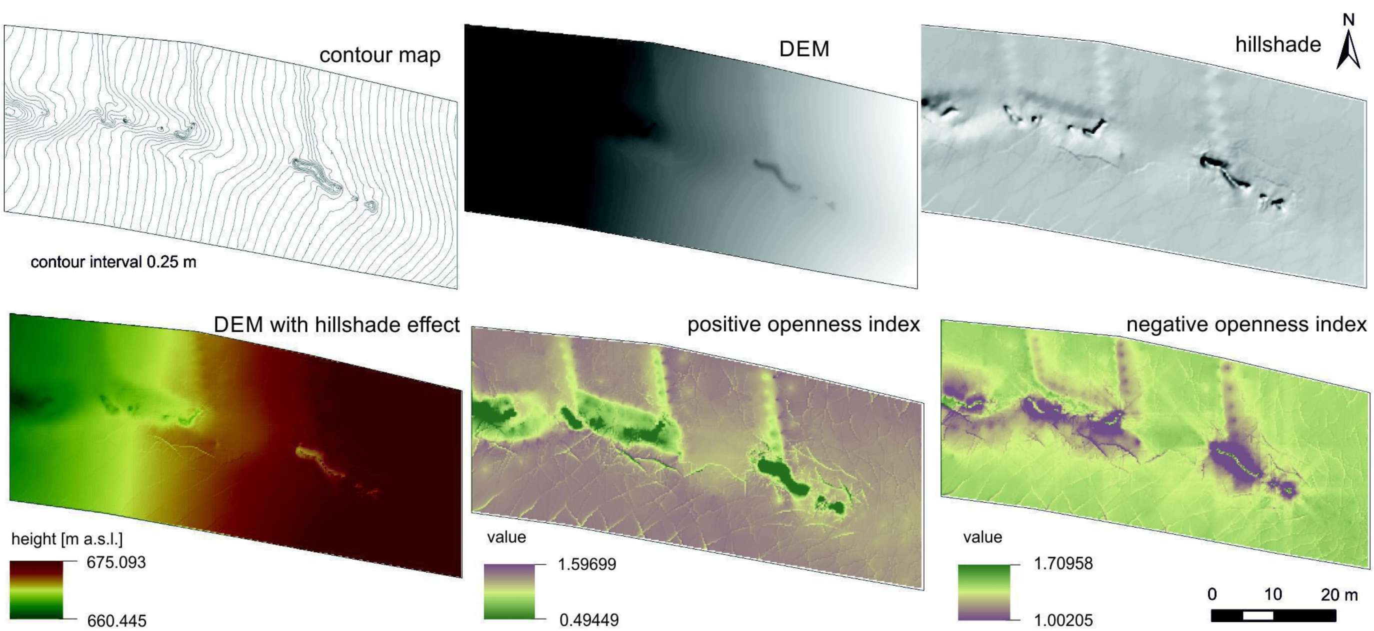

Figure 2. The different way of visualizing elevation data of the piping system.

IV. Results

The depth of sinkholes in the study area ranges from 0.50 to 1.00 m, which is also the depth at which pipes developed, since the bottom of a sinkhole is the bottom of a pipe. The blind (discontinuous) gully reaches maximum 1.50 m of the depth, 11.25 m long and 1.50 m wide in the maximum point.

The piping system can be visualized by distinguishing the surface traces of collapsed pipes (sinkholes, blind gully etc.). It can be done by creating the contour map with appropriate contour interval (Fig. 2). To extract the concavity of these piping forms in DEM is helpful to use a hillshade effect or 3D images (Fig. 1, 2). The positive and negative openness index marks the places of concavities, but also emphasizes abandoned agricultural terraces (perpendicular to the system). The negative openness index reflects also the flat bottom of the blind (discontinuous) gullies (Fig. 2).

The visualization of morphometric changes in the piping system allows to distinguish areas where prevails erosion and accumulation within the collapsed pipe(s). In the upper part of the piping system dominates accumulation, because of the blind gully and sinkhole walls failure. In the lower part, the erosion area in the pipe inlet is noticed. This may indicate the linkage of side pipe to the principal pipe (E-W direction). It requires further research, for instance geophysical investigations which can present the subsurface network of pipes.(Fig. 3).

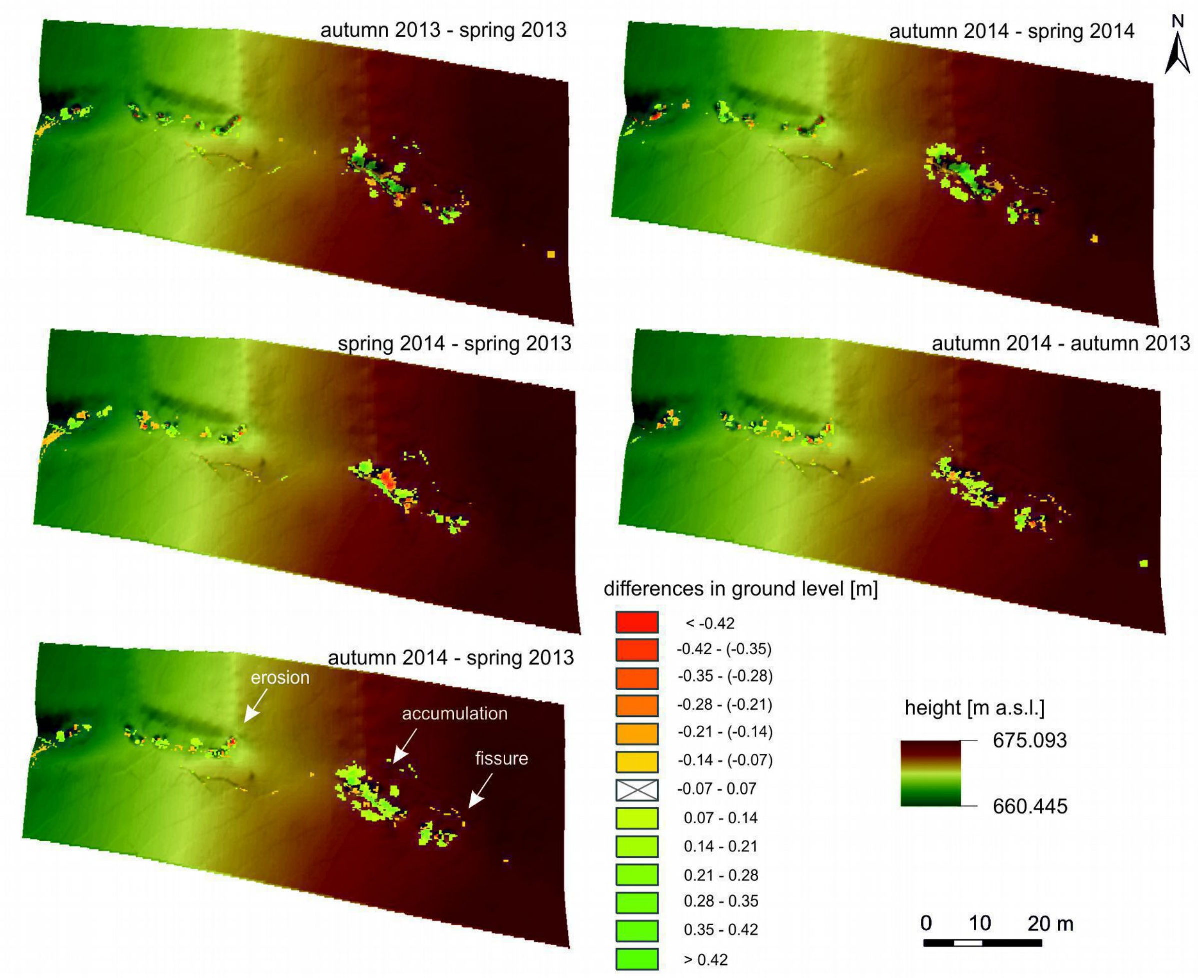

Figure 3. The morphometric changes in the piping system in 2013-2014.

V. CONCLUSIONS

In recent years piping is increasingly considering as one of the geomorphological processes that impacts the relief. This paper presents the different ways of visualizing piping system to emphasize its position in a slope-valley system. On the one hand, the noticeable concavity above the existing gully with the surface traces of pipe collapsing indicate the influence of piping in the gully formation and in its future development. On the other hand, the dominance of accumulation zones underlines that these piping forms are ephemeral and after collapsing they will be filled in. However, the seasonal variation shows that the erosion occurs mainly in winter time (snow melting) – according to comparison of spring measurements, and accumulation prevails in summer time (summer rainfalls are not enough to create morphological effective flow in the piping system). It can be also a result of the vegetation cover, which is quite dense even in the end of autumn, so the field measurements can be disturbed.

Moreover, the openness and closeness indexes are appropriate and useful to visualize and identify the places where piping occurs.

This paper presents the preliminary results and conclusions, which need to be continued and expanded.

ACKNOWLEDGMENT

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REFERENCES

[1] Jones, J.A.A., 1994. “Soil piping and its hydrogeomorphic function”. Cuaternario y Geomorfología 8 (3-4), 77–102.

[2] Jones, J.A.A., 2004. “Pipe and piping”, In Encyclopaedia of Geomorphology, Edited by: Goudie, A.S., Routledge, 784–788.

[3] Bryan, R.B., Jones, J.A.A., 1997. “The significance of soil piping processes: inventory and prospect”. Geomorphology 20, 209–218.

[4] Frankl, A., Poesen, J., Deckers, J., Haile, M., Nyssen, J., 2012.” Gully head retreat rates in the semi-arid highlands of Northern Ethiopia”. Geomorphology 173–174, 185–195.

[5] Faulkner, H., 2013. “Badlands in marl lithologies: A field guide to soil dispersion, subsurface erosion and piping-origin gullies”. Catena 106, 42–53.

[6] Gutiérrez, M., Sancho, C., Benito, G., Sirvent, J., Desir, G., 1997. “Quantitative study of piping processes in badland areas of the Ebro Basin, NE Spain”. Geomorphology 20, 237–253.

[7] Botschek, J., Krause, S., Abel, T., Skowronek, A., 2002. “Piping and erodibility of loessic soils in Bergisches Land, Nordrhein-Westfalen”. Journal of Plant Nutrition and Soil Science-Zeitschrift für Pflanzenernahrung und Bodenkunde 165, 241–246.

[8] Verachtert, E., Maetens, W., Van Den Eeckhaut, M., Poesen, J., Deckers, J., 2011. “Soil loss rates due to piping erosion”. Earth Surface Processes and Landforms 36, 1715–1725.

[9] Rodzik, J., Furtak, T., Zgłobicki, W., 2009. „The impact of snowmelt and heavy rainfall runoff on erosion rates in a gully system, Lublin Upland, Poland”. Earth Surface Processes and Landforms, 34, 1938–1950.

[10] Verachtert, E., Van Den Eeckhaut, M., Poesen, J., Govers, G., Deckers, J., 2011. “Prediction of spatial patterns of collapsed pipes in loess-derived soils in a temperate humid climate using logistic regression”. Geomorphology 130, 185–196.

[11] Michna, E., Paczos, S., 1972. „Zarys klimatu Bieszczadów Zachodnich” (The outline of climate of Western Bieszczady Mts.). Lubelskie Towarzystwo Naukowe, Zakład Narodowy im. Ossolińskich, Wydawnictwo PAN, 72 p. [in Polish].

[12] Nowosad, M., 1995. “Zarys klimatu Bieszczadzkiego Parku Narodowego i jego otuliny w świetle dotychczasowych badań” (The outline of climate of Bieszczady National Park and its buffer zone shown by the previous studies)”. Roczniki Bieszczadzkie 4, 163–183 [in Polish].

[13] Czeppe, Z., 1960. “Zjawiska sufozyjne w glinach zboczowych górnej części dorzecza Sanu” (Suffosional phenomena in slope loams of the Upper San drainage basin). Biuletyn Instytutu Geologicznego, Z badań czwartorzędu 9, 297–324 [in Polish].

[14] Beckedahl, H.R., 1996. “Subsurface soil erosion phenomena in Transkei and Southern Kwazulu – Natal, South Africa”. PhD thesis, University of Natal, Pietermaritzburg (manuscript), 224 p.

[15] Bernatek, A., 2015. “The influence of piping on mid-mountain relief: a case study from the Polish Bieszczady Mts. (Eastern Carpathians)”. Carpathian Journal of Earth and Environmental Sciences (In Press).