Geomorphometric attributes of channel heads initiated by seepage erosion in a postglacial zone (NW Poland)

Małgorzata Mazurek
Institute of Geoecology and Geoinformation
Adam Mickiewicz University in Poznań
Poland
gmazurek@amu.edu.pl

Abstract—**Channel initiation, which is a key factor in the evolution of landforms, is caused by a combination of various hydrogeomorphic processes. This study supplies quantitative data about the size of channel heads driven mostly by groundwater seepage in lowland areas. The chief aims of the present paper is to examine the geometry and morphometry of channel heads in NW Poland and identify the nature of the erosional effect of groundwater outflows. Detailed topographic studies were conducted in selected 24 channel heads (in the form of headwater alcoves) judged to be representative in hydrogeomorphological terms in the southern part of the Parsęta catchment (NW Poland). Morphometric surveying of headwater zones made it possible to identify morphological effects of groundwater seepage erosion in a postglacial landscape.**

Headwater alcoves of various forms are often distinctive features of the postglacial relief of the Parsęta catchment. Those predominating in the study area are compact landforms, semi-circular and narrowing, or paraboloidal, elongated in outline, as evidenced by the low values of the indices of form Cf and circularity Ck as well as the elongation index Cw. A small proportion of headwater alcoves located in scarps are complex, composed of several alcoves combined by a common outflow. The elongation is primarily due to backward erosion along the long axis of an alcove, but in favourable morphological conditions it may have been predetermined by the shape of the initial forms. The scarps closing alcove heads can reach heights of more than ten metres. The transition of alcove slopes into a flat bottom takes place via a clearly marked segment of a concave slope. The diversity of channel head morphology is related to the areal extent of the contributing area, structural or lithological variability which locally increases hydraulic conductivity, and the character and discharge of groundwater outflows.

I. Introduction

The channel initiation mechanisms are closely connected with the water flowpath characteristics of the slope system. In the lowland area of central Europe with its high sediment infiltration capacity, groundwater seepage erosion can be the primary mechanism that controls channel initiation (e.g. [3], [11]) and the development of a valley head (e.g. [1]). Within zones of groundwater emergence, the combined action of groundwater, water flowing at the surface and mass movement leads to the development of channel heads in form of headwater alcoves. Lack of data on the geomorphometry of channel heads makes it impossible to identify the nature of the erosional effect of groundwater outflows and their contribution to the formation of river valleys. Still, groundwater outflows are not fully appreciated as a morphogenetic factor in temperate zones [9] due to climate fluctuations and changes in land cover that result in lowering of the groundwater table, which diminishes the significance of this erosional factor and weakens the coupling between the outflows and the erosional landforms associated with them.

The objective of the present paper is to examine the geometry and morphometry of channel heads in the southern part of the Parsęta drainage basin (NW Poland) (Fig. 1A). The determination of the place and formation of the beginning of a river channel initiated by groundwater outflows is of key importance for the modelling of the stream network development. Detailed topographic studies were conducted in selected 24 channel heads (Fig. 1B) judged to be representative in hydrogeomorphological terms.

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II. Study area

The study area comprises the southern part of the Parsęta catchment, which covers an area of 617.2 km^2 and is situated in the borderland between the South Baltic Lakeland and the South Baltic Coastal Lowland. In the Parsęta basin's geological structure, a fundamental role is played by the complex of 52- to 214-m-thick Pleistocene and Holocene deposits, which comprise five and locally six levels of tills, glaciofluvial sands and gravels, river sands, and ice-dam silts and sands [11]. Channel heads develop within a variety of landforms, e.g. on scarps of morainic uplands, slopes of subglacial tunnel valleys, kettle-holes and river terraces, and slopes of kame hummocks and dead-ice moraines. The diversity of hydrogeological conditions results in various types of outflows, which largely occur in the contact zones between glaciofluvial or fluvial sand-gravel deposits, glacial sands or erosion pavement, and their underlying semi-permeable tills or poorly permeable loamy sands. As to the location of the outflows in terms of relief morphology, they can be found along the entire length of alcove slopes or can be concentrated at the base of steep slopes.

III. Methods

The small size of headwater alcoves found on the Polish Plain makes it impossible to derive their morphometric characteristics on the basis of topographic maps. Exact topographic measurements were taken using a combined method employing a GPS receiver Leica SR530 and a total station ELTA R55w. The ordinary kriging method was employed to perform interpolation in DEM grid of 0.5 m-resolution. The morphometric analysis was conducted for 24 channel heads (Fig. 1B) on the basis of a digital elevation model. The physical-geographic characteristics employed in the description of the geometry (e.g. shape index Cf, circularity index Ck, elongation index Cw, etc.), morphometry and relief of a headwater alcove are those used both in the morphometric analysis of river catchments ([2], [4], [7], [13]) and individual landforms, like gullies, landslides, glacial cirques, or atolls ([5], [6], [8]).

IV. Results

The field investigations and Geographic Information Systems analysis carried out so far have supplied quantitative data about the size of headwater alcoves developing in lowland areas in loose postglacial deposits. They are compact landforms, poorly branched, semi-circular or elongated in outline. The headwater alcoves within which tachymetric measurements were taken have small bottom areas averaging 516 m^2 (70-4626 m^2). The maximum length of an alcove bottom range from 13.5 m to 112.3 m, with an average of 35 m. The maximum width of the alcove bottom perpendicular to the length varies between 4.6 m and 63.5 m, with an average of 18.3 m. The maximum length/maximum width ratios remain greater than 1 and average 2.3, which shows that at the sites under study alcove bottoms are generally elongated (the elongation index Cw=0.61 on average) and narrow. However, the elongation cannot be treated only as a result of the seepage erosion of their heads as the predominant process. In the three forms under study, the high L/W figures, reflect the elongation of older forms variously modified by seepage erosion. The lowest indices of form Cf and circularity Ck are displayed by channel heads developing within older, inherited landforms: gullies and denudation-erosional valleys.

The scarps closing alcove heads can reach heights of more than ten metres. The height of the slope Hs closing the channel head is defined as the difference in the altitude of the first break of slope and the flattening at its foot passing into the bottom. The height of the steps and headwalls closing Hs measures from 0.7 m to 10.0 m. The mean gradients of concave and concave-convex slopes assume from 12 to 38°, their range being smaller within alcove bottoms, from 3 to 16°. The transition of alcove slopes into a flat bottom takes place via a clearly marked segment of a concave slope (Fig. 1C). The formation of the footslope is an effect of the direct impact of headwater erosion on the alcove slopes. The transition of the slopes into a headwater zone bottom with a considerably smaller gradient is effected through a short length of a concave foot slope. The ratio of the gradient of the bottom Sb to that of the head wall Ss [8] reflects the nature of contact of the slope system with the channel system. The ratio varies from 0.03 to 0.42, which indicates that the beginning of a channel is marked with an abrupt change of slope, thus making it fairly easy to identify a bottom with a much gentler gradient.

Digital elevation models (DEMs) with a horizontal resolution of 0.5 m and the morphometric parameters of headwater alcoves they yielded, as well as an analysis of their topographic and hydrogeological location and the nature of groundwater outflows, provided a basis for distinguishing three morphological types of headwater alcoves in the southern part of the Parsęta catchment [11]:

1. The most numerous group embraces basin-like alcoves. This type (I) includes landforms with bottoms elliptic in plan, small and compact, displaying the widest differences in extreme heights.
2. The next type (II) of bowl-like headwater alcoves covers extensive alcoves or their complexes, with maximum length and width figures as well as broad bottoms with low slopes (Fig. 1C).
3. Type III includes spindle-like alcoves, small, elongated and narrow. Here belong largely alcoves located in older denudational depressions and erosional-denudational dissections and small valleys whose bottoms and slopes are

now being modified by headwater processes. They display wide differences in height and considerable slope gradients. The channel head is closed by a low step resulting from the dissection of the bottom of the initial forms due to erosion by groundwater outflows. The morphometry of the group of elongated and narrow alcoves in the southern part of the Parsęta catchment is similar to the landforms in the Łódź Hills (Central Poland), which were examined by [12]. Their common morphological features result, among other things, from the similarity in the geological structure (glacial sands and tills, fluvioglacial sands) and hence from the groundwater flow conditions and outflow type.

There are a few alcoves that do not fall into any of the three morphological types distinguished: poorly developed, in the initial stage of formation, of slight depth, and with no clearly marked bottom. This type is characteristic of young alcoves with low-discharge outflows in their area.

V. CONCLUSION

Channel heads determined by groundwater outflows that assume the form of an alcove or a set of alcoves develop within hollows of varying genesis or dissect slopes to form their own headwater depressions (i.e. valley heads). The variability of parameters describing channel heads reflects the original relief, which can be regarded as a factor partially accounting for the shape of the channel heads and a factor conducive to the location of groundwater outflows and seepage erosion. The lithology and stratigraphy of Pleistocene and Holocene deposits in the study area control the shape, orientation and size of the alcoves ([10] and [11]).

The formation of channel heads is an effect of co-operation and interaction of such influences as seepage erosion, slope processes, and fluvial accumulation and erosion. Depending on headward erosion, gravitational mass movements, and the possibility of deposits being removed by water, the alcoves grow in width and depth. Such a pattern of processes leads to the formation of steeply inclined alcove slopes with a distinct concave section at the foot that passes into a flat bottom. The rate of alcove development is fast if groundwater outflows are able to remove all the gathering colluvial material and other debris from the foot of the slopes. Values of the morphometric parameters and indicators show an increase in height differences and elongation of the alcoves, which may be associated with the rejuvenation of the relief of scarps and slopes in postglacial areas. The characteristics of channel heads as described in physical-geographic terms as well as deposits found in them (peats, calcareous sinter) can be helpful in, e.g., reconstructing of changes in the groundwater table, interpretating of stages in their development.

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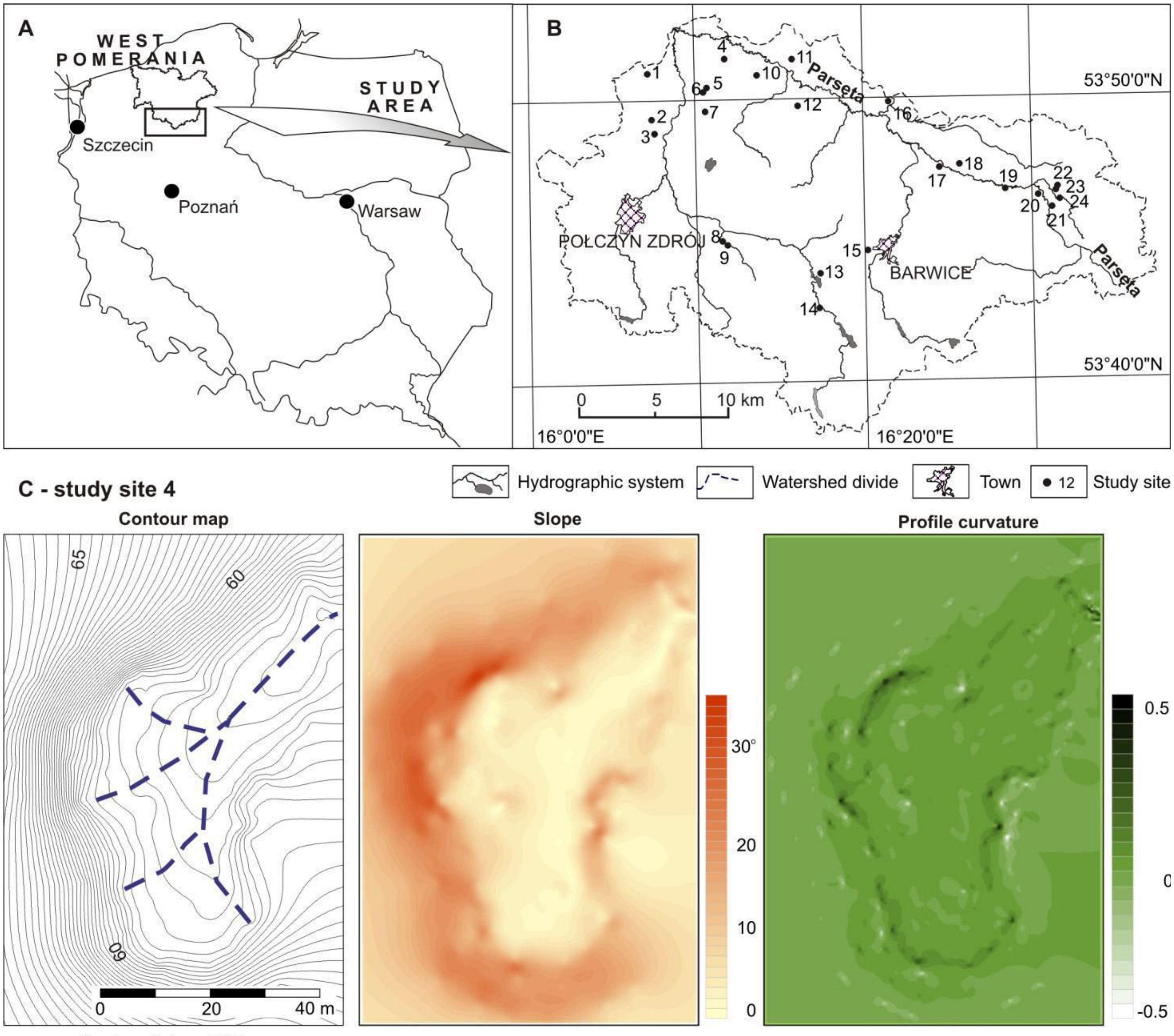

Figure 1. Location of: A. study area, B. study sites in the southern part of the Parsęta catchment; C. study site 4: contour map with hydrographic elements, slope and profile curvature