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Channel morphology changes and their relationship to valley bottom geology and human interventions; a case study from the Vistula Valley in Warsaw, Poland

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ABSTRACT

The aim of the study was to determine the role of the geological setting of channel zone in the morphological variability of a river reach situated between engineered and seminatural channel sections. Investigations were carried out in the Vistula River channel in Warsaw. The study included the drilling of 60 geological boreholes in the river channel and the registering of sedimentary structures of modern river-channel sediments. The morphology of the channel was defined based on a series of bathymetric measurements of different river levels. To identify the reasons for the variation in the channel-bed morphology, numerical modelling of river flow was performed. Calculations were made using the FLUENT CFD (Computational Fluid Dynamics) model. The stabilization of bottom erosion along the engineered reach of the river was found to be associated with a shallow depth to the top of the basement of modern alluvial sediments, composed of erosion-resistant glacial deposits. The suballuvial basement in this part of the river channel also serves as a local base level in relation to the river reach upstream.

1. Introduction

1.1. Background

The main objective of the geological study carried out for the projects of development of river valleys is the identification of not only the current state of the fluvial environment but also the nature and directions of its evolution (Falkowski, 1971). Such attitude on the one hand allows for the selection of optimal ways of restricting changes harmful to the environment (Brookes, 1992), and on the other hand, it enables prediction of interactions between the fluvial environment and the specific mode of river valley development (Gregory et al., 2008). Apart from processes resulting from the attaining of geomorphological maturity by the river valley (Davis, 1899), the mechanism of fluvial environment evolution relies on the matching of the erosional and depositional processes to the changes in the hydrological regime (Vanderberghe, 2002; Gregory et al., 2008) and to the changes in the water runoff conditions (Phillips, 2013). These changes can result from climate evolution (Knox, 2000; Starkel, 2002; Mouri et al., 2012) and from human impact, which can consist of, for instance, specific land use in the drainage basin area (Falkowski, 1971, 1983; Starkel, 1983; Keesstra et al., 2005; Abate et al., 2015; Clerici et al., 2015; Magliulo et al., 2016), engineering of river channels (Łajczak, 1995; Biedenharn et al., 2000; Gregory, 2006; Hooke, 2006; Gendaszek et al., 2012) or channel zone (Hesselink et al., 2003), its restructuring (Miller and Kochel, 2010), construction of dams (Brandt, 2000; Rollet et al., 2014), as well as intense bedload extraction (Gaillot and Piègay, 1999; Martìn-Vide et al., 2010; Lièbault et al., 2013; Moretto et al., 2014).

Changes in the river valley environment and within river channels themselves can proceed differently in the individual sections of the river valley (Simons and Darby, 2002; Piègay et al., 2005; Migiros et al., 2011; Heitmuller et al., 2015; Keller et al., 2015). The major feature of river valley, which indicates the susceptibility of individual river courses to the changes under certain development conditions, is the shape of the landform itself (Sidorchuk, 2003; Miller and Kochel, 2010).

The presence of river reaches with diverse morphology along valley courses (Fryis and Brierley, 2013), particularly of lowland rivers, can be caused by valley polygenesis (Falkowski, 1997) and/or different susceptibilities to erosion of bedrock/deposits that form the base of the valley (Pożaryski and Kalicki, 1995; Heitmuller et al., 2015; Keller et al., 2015). Resistant deposits that appear within the range of river downcutting constitute a restriction for the formation and development of valleys/floodplains (Piègay et al., 2005; Fryis and Brierley, 2010). Such factors restraining the ease of fluvial processes can emerge within the reach of river erosion as a result of either tectonic activity of the river valley basement (Ouchi, 1985; Spitz and Schumm, 1997; Holbrook and Schumm,

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1999), lowering of the recipient water level (Blum and Tornquist, 2000), or as the result of an increase in depth of flood-flow downcutting (compare Leopold et al., 1964) that accompanies the changes in hydrological regime (Falkowski, 2007a; Falkowska and Falkowski, 2015).

Geological setting of individual sections of the valley affects the dynamics of erosion and deposition (Fryis and Brierley, 2010). Such diversity first manifests itself in the width of the valley bottom. Narrow reaches, sometimes referred to as gorges and characterised by higher flow dynamics, alternate with basin-like reaches with a lower profile and lower flow energy (compare Bizzi and Lerner, 2015).

Differentiation of river valley morphology was a significant reason for settlement decisions. In the narrow reaches of river valleys in the Polish Lowlands, the channel bottom, restricted by geology, exhibited morphological stability (Falkowski, 2007a) that was convenient for channel crossing (along trade or military routes; Gieysztor, 1982; Carter, 1994). The presence of fords favoured primary colonization. Further urbanization caused gradual channel engineering. Channel engineering works, such as straightening, narrowing and bank revetment, are commonly considered the main reasons for the increase in river incision (Chin, 2006). Concurrently, a very important feature of the fluvial environment considered responsible for river incision is alluvia underfit (Phillips, 2013). This could be caused by bedload extraction (e.g., Lièbault et al., 2013; Moretto et al., 2014) as well as restriction in bedload input from the catchment area (compare Rollet et al., 2014). Changes in bedload balance are commonly considered as a threat not only to urban infrastructure but also to valley environment (stability of valuable natural habitats as was stated, e.g., by Simons and Darby, 2002).

Changes in the dynamics of the channel and overbank processes induced by engineering works could reach upstream and downstream beyond the ford zone (primary urban zone). An example of such changes is the channel of the Vistula River in Warsaw (Fig. 1).

1.2. Study site

The floodplain of the Vistula in Warsaw, which has a width of several kilometres upstream and downstream from the city, narrows to about 400 m in the city reach to form the so-called 'Warsaw corset' (Różycki, 1972; Falkowski, 1990) (Fig. 1). Here, the basement of the contemporary alluvia forms a morphological protrusion composed of glaciotectonically disturbed and uplifted Neogene lacustrine clays and Pleistocene glacial deposits. Their surface is covered by a residual lag (composed of glacial gravels and pebbles). The top surface of the suballuvial basement, which has a very complicated morphology in the city, descends upstream and downstream of the 'Warsaw corset' zone (Falkowski, 1990).

Because of the further development of Warsaw and the accompanying channel engineering, the border zone of concentrated flow (narrowed channel) has been stretched out about 10 km upstream from the boundaries of the 'corset' (Popek et al., 2009). Changes in flow dynamics gradually approached the seminatural zone (insignificantly constrained by hydraulic structures). An indicator of difference of channel processes between constrained and unconstrained channel stretches is the bedload balance.

The problem of bedload balance is of crucial importance for Warsaw Vistula channel management. Research conducted in the years 1981–

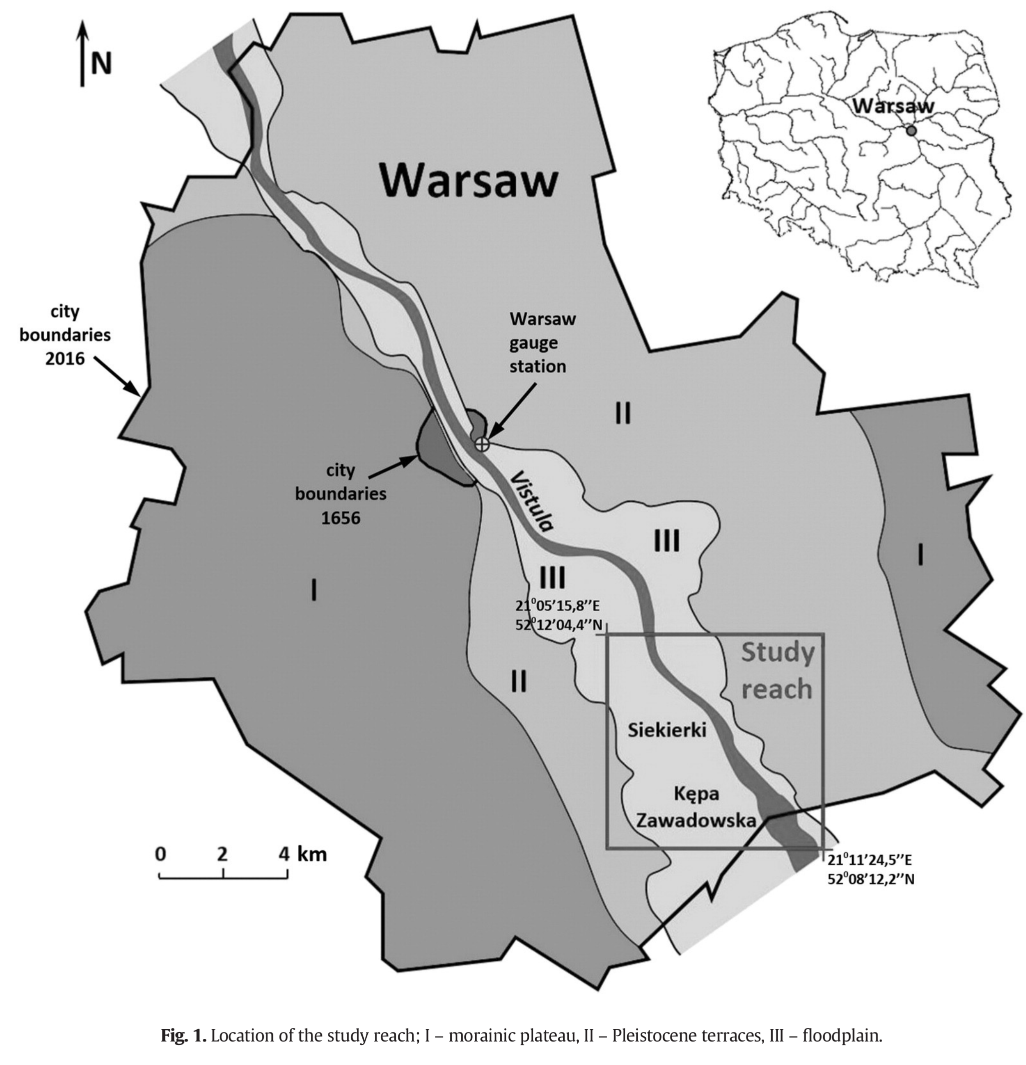

Fig. 1. Location of the study reach; I – morainic plateau, II – Pleistocene terraces, III – floodplain.