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Particle-size distribution of channel bars of the lower Vistula between Bobrowniki and Bydgoszcz-Fordon

Abstract: This study presents the diversity of sediments forming sand bars located in the Vistula channel between 695 km and 775 km of its course. The analysed section of the Vistula channel is located in the Toruń Basin. During the fieldwork carried out on 20-21 September 2011, 45 channel bars were identified and sampled. The collected samples were analysed in a laboratory. The obtained results were presented in the form of figures and graphics. The research related to the Vistula bed load performed to date was based on various research methods. The authors applied the sampling method used by Z. Babiński (1992). It was employed also by other authors (Habel, 2013). The obtained results were referred to other studies and the findings clearly indicate that such detailed research must be conducted along the whole middle section of the Lower Vistula valley.
Keywords: Toruń Basin, Vistula channel, particle diameter, water levels

1. Introduction

The Vistula River is the longest river in Poland, beginning its course in the Beskids area and flowing into the Baltic Sea. It runs through genetically diverse areas and, due to its importance, has been a frequent object of research. Authors of individual studies analysed the geology and geomorphology of the Vistula valley (Wiśniewski, 1976, 1982; Banach, 1977; Tomczak, 1982, 1987; Niewiarowski, 1987; Starkel and Wiśniewski, 1990; Andrzejewski, 1995; Starkel, 2001; Falkowski, 2007; Magnuszewski and Moran, 2015), channel forms of various sections of the Vistula (Born, 1958; Kociszewska-Musiał, 1970, 1990; Babiński, 1979, 1982, 1992; Habel, 2013, Pieron and Hojan, 2013; Pieron et al., 2013) as well ice dams and floods (Grześ, 1986, 1991; Gierszewski, 1991; Cyberski et al., 2006). In the Kujawy-Pomerania Province, detailed research in the Vistula valley was carried out by, inter alia, Z. Babiński (1979, 1982, 1984, 1992), M. Habel (2007, 2013), J. Kordowski (2007), M. Gorączko (2013, 2015) and P. Gierszewski et al. (2015). Due to the fact that the Vistula valley is used by representatives of the animal kingdom, the first scientific studies regarding transformations of the channel morphology as a result of their activity have been published (Hojan and Rurek, 2016).

One of the first researches on particle size distribution of the Lower Vistula bed load was carried out by A. Born (1958), who collected samples from shoals, midstream, and bed load. Other measurements were made by G. Kociszewska-Musiał (1970) in 1967, that is before building a dam on the Vistula in Włocławek. The author, using a sampler thrown from a boat, collected samples of the material from the river bed every 5 km along the river course. According to the author, “the inability to collect more samples along a longer river section and to compare these forms excluded the purposefulness of their in-depth examination”. Further research on channel bars and their particle size distribution was conducted by Z. Babiński (1979, 1992). The author collected samples in 1973, applying carpet method in 14 cross-sections using the Ekman Grab Sampler, while in subsequent years samples were collected from sand bar fronts located between 2 and 10 km apart. In 1988, Z. Babiński (1992) applied the method of collecting samples from sand bar fronts which was used also by B.J. Bluck (1987). Whereas D. Giriat (2003) collected 11 samples along the section between Włocławek and Grudziądz on 7 dates in the period 1999–2001. M. Habel (2013) collected 72 samples from each sand bar front that was above the water surface in June 2008. Research on other rivers was conducted by i.a. A. Kostrzewski (1970), who collected samples from a sand bar on the Bóbr River and argued that groove sampling was the best sampling method in the vertical profile of a sand bar.

However, all these studies lack the information about water levels on the sampling day and in the preceding period, which is significant for interpreting the sedimentation processes.

The purpose of this study is to analyse the distribution of sand bars along the Lower Vistula section between Bobrowniki and Fordon and to carry out a particle size analysis of sediments forming the channel bars, as well as to identify the factors that contributed to the textural variability of the examined forms.

2. Research material and methods

The research on particle size distribution of channel bars in the Vistula channel was carried out along a 80 km long section, from Bobrowniki (695 km) to Bydgoszcz-Fordon (775 km) (Fig. 1). This fragment of the channel is partly altered by human activity. The former border between Prussia and Russia ran in the present Kujawy-Pomerania Province, which influenced the engineering (regulation) of the Vistula. The boundary between the section modified during the Partitions of Poland and the unmodified section is located at the 719 km of the Vistula course.

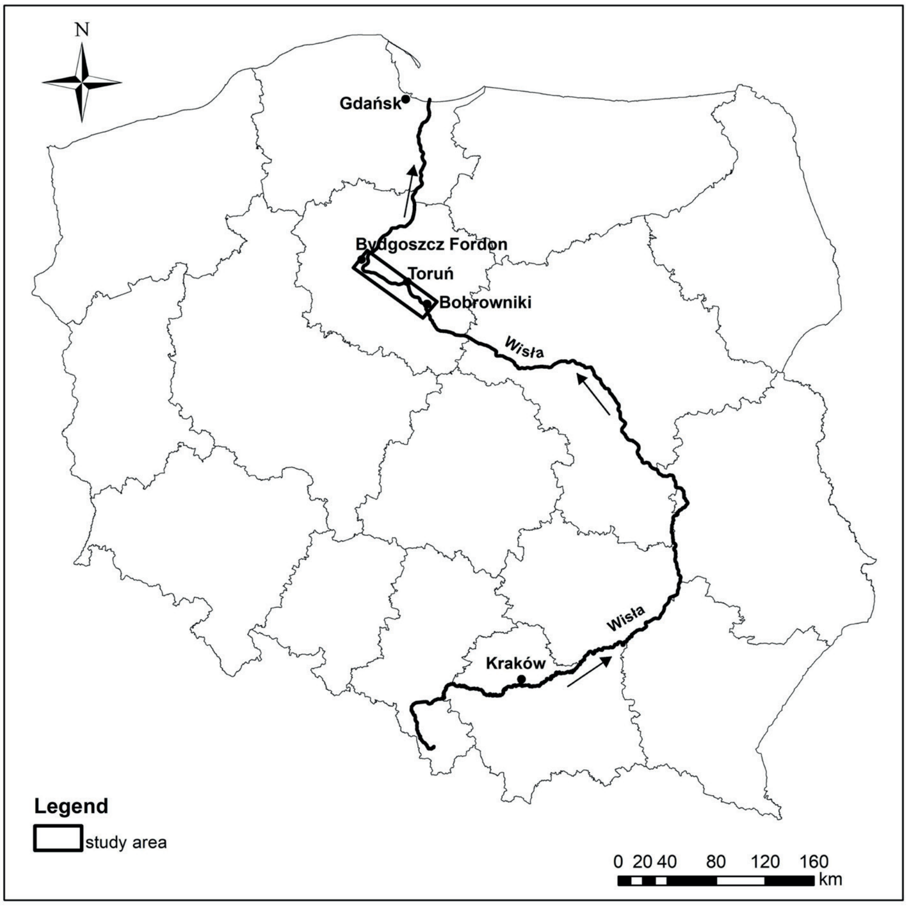

Figure 1. Location of the study area against the background of Poland territory

Two sections can be distinguished within the analysed fragment of the Vistula channel between Bobrowniki and Bydgoszcz-Fordon. The first one is a heavily transformed section between the barrage in Włocławek and the Tążyna estuary, and the other one – from the Tążyna estuary to Bydgoszcz – is a channel section engineered (regulated) in the late 19th century (Babiński, 1982, 1992, 1999). The former resembles a braided and anastomosing river with central bars, whereas the latter is characterised by alternating transverse bars intersected by point bars.

In September 2011, the renovation works were performed on the barrage in Włocławek. The flow was suspended between 6 a.m. and 9 a.m. (Komunikat…, 2011). Daily changes in water levels resulted in alternating flooding and exposure of the sand bars. As a consequence, new and clear bed forms appeared on the surface of sand bars. On 20 September, samples were collected along the section from Bobrowniki to Toruń. The water level at the staff gauge in Toruń decreased from 284 cm at 6 a.m. to 190 cm at 9 p.m. on 21 September. On 21 September, samples were collected along the section between Toruń and Bydgoszcz-Fordon. The water level in Toruń was 248 cm at 8 a.m. and gradually decreased to 199 cm at5 p.m., while increased from 198 cm at 8 a.m. to 216 cm at 5 p.m. at the staff gauge in Bydgoszcz-Fordon (Fig. 2).

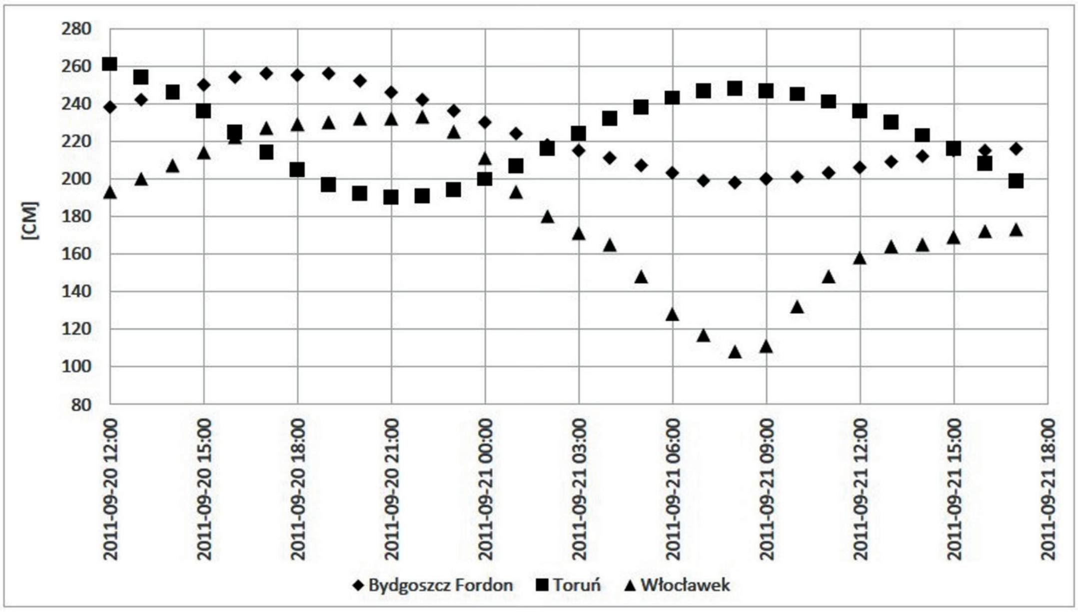

Figure 2. Water levels along the Włocławek-Bydgoszcz-Fordon section on 20/21 September 2011. Prepared by the authors based on IMGW data (www.pogodynka.pl)

During the fieldwork, the authors sailed along the Vistula River and located bars, whose upper part was above the water level on 20–21 September 2011. Samples were collected at the front of each bar and photographic documentation was prepared.

The method proposed by Z. Babiński (1992) was employed in the study of channel bar sediments, consisting in collecting samples from sandbar fronts. To this end, a plug for PVC pipes with a diameter of 50 mm was used by pushing it into the bar front. Then, a spatula was inserted under the plug so that the sand could not spill out of the plug. Samples were collected from each bar that could be approached by boat from its front. The sampling location was marked with the use of a GPS receiver by Trimble. Based on these measurements, maps with the distribution of sand bars and particle diameter (D_{50}) were prepared in ArcGis software.

The particle size distribution of the collected samples was analysed in the laboratory of the Institute of Geography, Kazimierz Wielki University in Bydgoszcz. The samples were dried at a temperature of 105°C and sieved through a sieve set using a Retsch shaker. The obtained results were analysed using the Gradistat software, which calculates particle size distribution parameters.

3. Research results

Based on the documented location of the sand bars, it was found that their distribution and gran size composition in the Lower Vistula channel is varied. The average distance between the bars along the section of 80 km was 1.8 km. The bars were distributed closer to each other along the unregulated section – average spacing of 1.31 km, and 2.16 km along the regulated section. The maximum distance between the bars was 3.96 km along the unregulated section (up to the Tążyna estuary) and 9.23 km along the unregulated section. The minimum distance between the bars was less varied, i.e. 0.22 km and 0.46 km, respectively (Fig. 3). This implies that variable water dynamics and other factors, such as geological structure, affect the formation of channel bars.

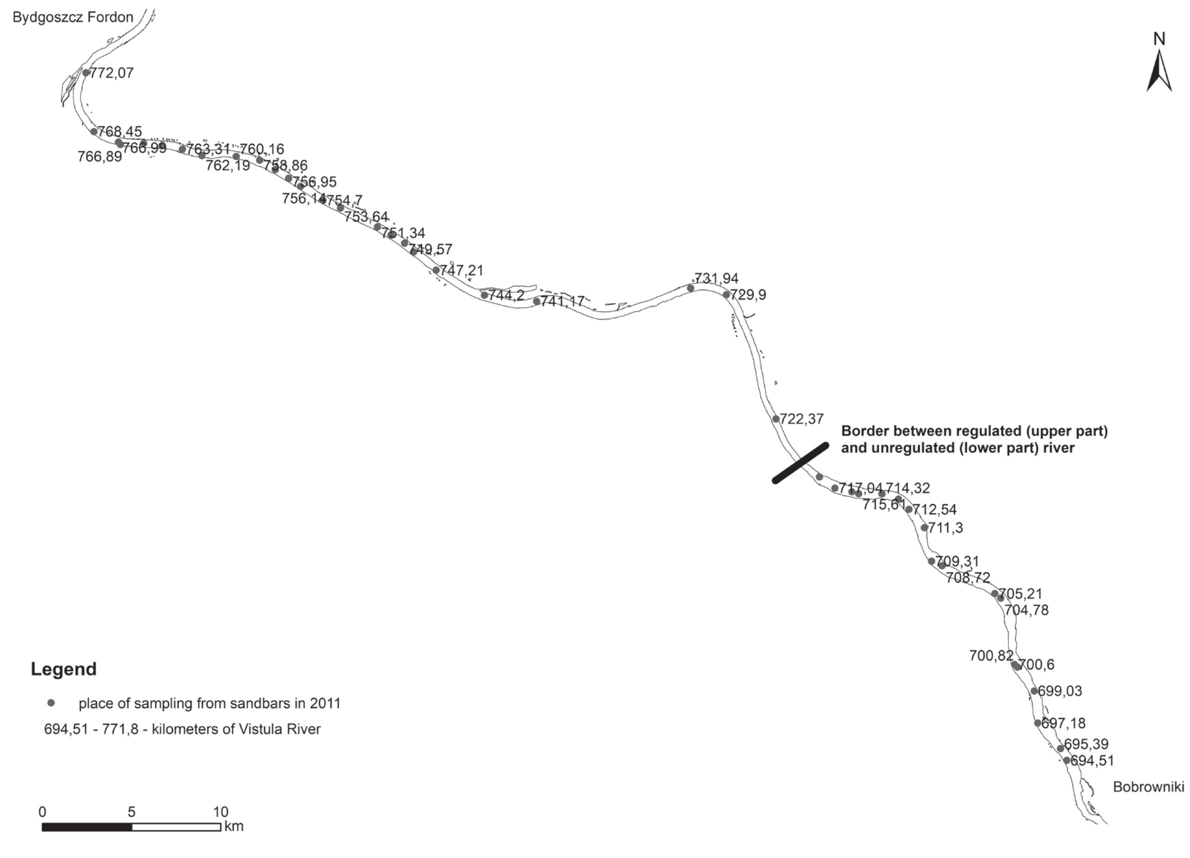

Figure 3. Distribution of channel bars along the analysed section

Based on the conducted research, it was determined that the D_{50} particle diameter ranged from 0.319 mm to 0.920 mm, 0.436 mm on average, along the section from Bobrowniki to the beginning of the regulated channel (up to the Tążyna estuary) (Fig. 4). For this section, coarser particles were found between Bobrowniki and Nieszawa. Bars containing finer particles were present at the end of the unregulated section. The particle size distribution analysis showed that the bars were built of medium-grained sand with the exception of bar no. 18, which contained coarse-grained sand (Fig. 4). The sorting up to Nieszawa was moderately good and good, and also good in the case of finer particles upstream of the Tążyna estuary.

Along the regulated section, the D_{50} particle diameter ranged from 0.317 mm to 0.701 mm, with the average value of 0.439 mm (Fig. 4). The bars contained moderately well and well sorted medium-grained sand.

The variability of the accumulated sediment fractions results from the deep erosion rate upstream of the bars from which the samples were collected. Changes in the Vistula channel flow rate depend on, apart from natural flows, emergency water discharges from the Włocławek Reservoir, which indirectly influence the relocation and formation of bars.

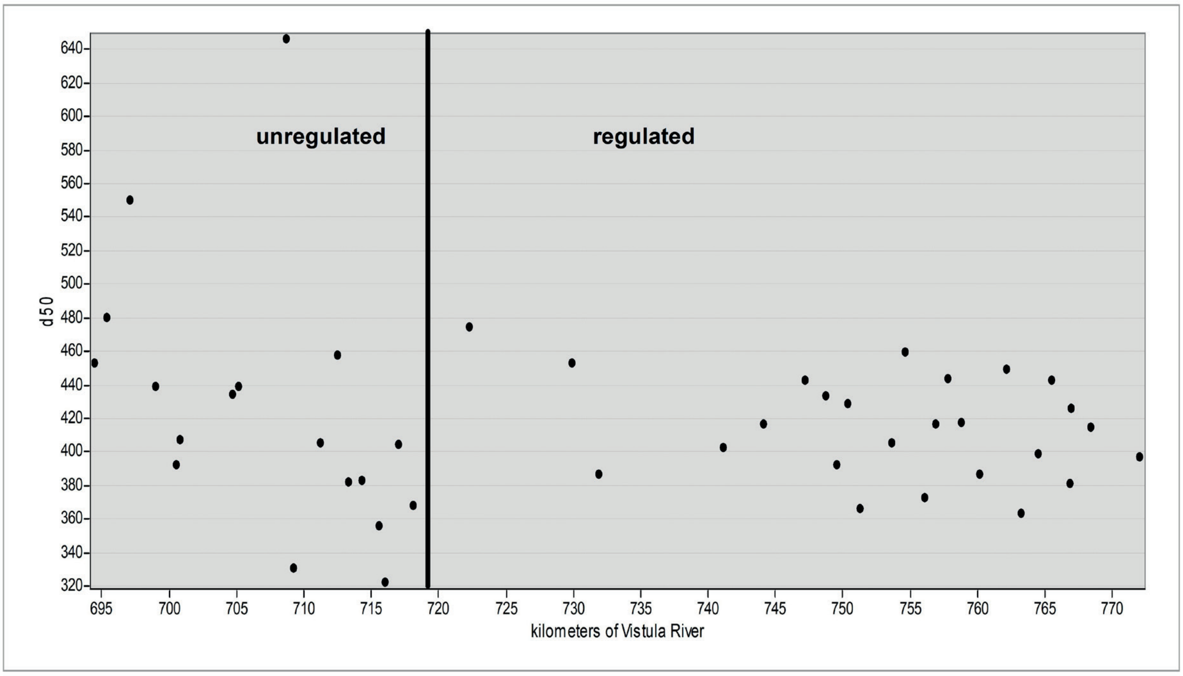

Figure 4. Average particle diameter along the section from Bobrowniki to Bydgoszcz-Fordon

4. Discussion and conclusions

The occurrence of channel bars is closely related to water flow rates and water levels (Babiński, 1992). The first bars appear on the surface within the transition zone between medium water levels (MW) and medium low water levels (LMW) and the flow rate of ca. 700 m^3s^{-1}.Their size and number increase along with further lowering of water levels. Therefore, it is important to measure the bar front height in relation to the water table (using GPS or simple measurement instruments) during the sampling process, because bars are formed in various conditions of flow dynamics (depending on the bar height). Sampling should be performed within a short time after the appearance of bars as their surface and fronts are subject to transformations as a result of rainfall and wind.

Distances between the bars along the unregulated and regulated sections are highly varied. What is particularly noticeable is a large distance between bars no. 29 and 30 (at 722.37 and 729.9 km of the Vistula course, respectively) and between bars no. 31 and 32 (at 731.94 and 741.17 km of the Vistula course, respectively). The distance between these bars was 7.53 km and 9.23 km, respectively. This can be partly explained by the erosion zone encroaching onto the area of Toruń. However, it is more likely that the water level increased during the measurements and lower bars were flooded (Fig. 3), hence such a long distance between bars no. 31 and 32. The average distance between bars no. 34 (747.21 km) and 53 (768.45 km) is 1.18 km along the regulated section. This "accumulation" of bars could be connected with the presence of uneroded sediments in the bed. They are mentioned by R. Ingarden (1922), who specified their location at 747 km, 750 km, 755 km, 757 km, 760 km, 764-766 km and 771 km of the Vistula course. Erosional escarpments can locally reduce the riverbed gradient and the flow rate, which facilitates the bed load sedimentation.

Different research and sampling methods make the comparison of the results obtained in 2011 with the results obtained by other authors in previous years problematic. Nonetheless, the results obtained earlier were collated with those obtained in 2011. The average value of the D_{50} particle diameter decreased by 0.07 mm along the unregulated section (Table 1) and by 0.08 mm along the regulated section (Table 2). The D_{50} particle diameter was the same, that is 0.44 mm, along both sections in 2011.

As mentioned above, the results should be regarded as indicative only due to the methodological differences in sampling. An exception are measurements from 2008 and 2011, which were performed by the same methods. The increase in the maximum particle diameter relative to the results obtained by M. Habel (2013) was noticed along both the unregulated and regulated sections in 2011 (Tables 1 and 2). This increase could arise from the relocation of the erosion zone, as a result of the operation of the dam in Włocławek, beyond the boundary between the unregulated and regulated sections (Habel, 2013) and the related eluviation of fine sediment.

Table 1. Comparison of the D_{50} particle diameter based on literature – the unregulated section

Unregulated section				
Author	Year	Max [mm]	Min. [mm]	Average [mm]
Babiński Z.	1988	0.63	0.39	0.51
Giriat D.	1999	0.58	0.41	0.48
	2000	0.54	0.39	0.45
	2001	1.01	0.33	0.45
Habel M.	2013	0.55	0.33	0.40
our research	2011	0.92	0.32	0.44

Table 2. Comparison of the D_{50} particle diameter based on literature – the regulated section

Regulated section				
Author	Year	Max [mm]	Min. [mm]	Average [mm]
Babiński Z.	1988	0.95	0.25	0.52
Giriat D.	1999	0.79	0.41	0.52
	2000	0.55	0.37	0.47
	2001	0.54	0.38	0.46
Habel M.	2013	0.62	0.40	0.47
our research	2011	0.70	0.32	0.44

For the minimum values, an insignificant decrease in the particle diameter was recorded along the unregulated section and an insignificant increase along the regulated section. Along both sections, the presence of finer medium-grained sand and admixtures of fine-grained sand could be associated with lateral erosion of the banks. It occurs in association with bars which occupy a larger part of the channel. The water current is divided into two and flows along the bar on both sides, causing lateral erosion.

Apart from the activity of the erosion zone, the presence of coarse-grained sand in the bars can also be associated with lateral erosion since groins were washed away and cut off from the bank in a few places along the regulated section. In such a case, the material used for groin construction is included in the bed load transport.

It follows from the above analysis of the research results that the particle size distribution of sediments forming channel bars shows a slightly decreasing trend for 23 years. For the unregulated section, the particle diameter has decreased during this period from the value of 0.51 mm in 1988 to 0.40 mm in 2008. The fact that sand particles become smaller at the boundary between the unregulated and regulated section results from differences in flow dynamics. Before the narrowing of the Vistula channel at the Tążyna estuary, water damming and accumulation of fine material intensifies. Along the regulated section, on the other hand, the accumulation may be facilitated by the presence of uneroded sediment (erosional escarpments) in the river bed.

No significant decrease in the particle diameter was observed along with the distance from Bobrowniki to Bydgoszcz-Fordon.

The obtained results show that further extended research is required, allowing for i.a. tributaries, the lateral erosion zone, and the change of the water table gradient.

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