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## FLOODS IN THE UPPER PART OF VISTULA AND ODRA RIVER BASINS IN THE 19<sup>TH</sup> AND 20<sup>TH</sup> CENTURIES

### POWODZIE W GÓRNEJ CZĘŚCI DORZECZY WISŁY I ODRY W XIX I XX WIEKU

**Abstract:** The discussion of floods in this paper covers the section of the Odra River basin from its source down to the mouth of the Nysa Klodzka River and the section of the Vistula River basin down to the Krakow profile. The area of the upper part of Odra River basin is 13,455 km<sup>2</sup> and the length of the river bed in this section is ca. 273.0 km. In the reach examined, the Vistula River is 184.8 km long and has a catchment area of approximately 8,101 km<sup>2</sup>. Geographical and environmental conditions in the upper part of the Vistula and Odra Rivers basins are conducive to floods both in the summer and winter seasons. The analyses conducted for the 19<sup>th</sup> and 20<sup>th</sup> centuries demonstrate that two main types of floods can be distinguished. Floods with a single flood wave peak occurred in the following years in the upper Odra River basin: 1813, 1831, 1879, 1889, 1890 and 1896, and on the Vistula River they were recorded in 1805, 1813, 1816, 1818, 1826, 1830, 1834, 1844 and 1845. In the 20<sup>th</sup> century, similar phenomena were recorded on the Odra River in 1903, 1909, 1911, 1915, 1925, 1960, 1970 and 1985, and on the Vistula River they occurred in 1903, 1908, 1925, 1931, 1934, 1939, 1948, 1951, 1970, 1972, 1991, 1996, 1997 and 1999. The second category includes floods with two, three or more flood wave peaks. These are caused by successive episodes of high rainfall separated by dry periods that last for a few days, a fortnight or even several weeks. Such floods occurred on the upper Odra River in 1847, 1854, 1880, 1888, 1892, 1897 and 1899; while on the Vistula River only two (1839 and 1843) floods featured two flood wave peaks. In the 20<sup>th</sup> century on the upper Odra River, floods of this type occurred in 1902, 1926, 1939, 1940, 1972, 1977 and 1997; on the upper Vistula River, they were recorded in 1906, 1915, 1919, 1920, 1940, 1958, 1960 and 1987.

**Keywords:** floods, Odra River, Vistula River, southern Poland

## Introduction

For many centuries, rivers have been of interest to settlers and therefore traces of human presence can be found in almost every major river valley. Villages, settlements and cities have been situated in such areas and intensive farming has taken place as valleys offer fertile soil and rivers provide the water required for domestic and agricultural purposes. Development processes in river valleys intensified, particularly in the 18<sup>th</sup> century, as industrialisation and urbanisation progressed rapidly. Many urban and industrial centres were located in river valleys and the towns that had existed there for hundreds of years

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expanded. As a result such valleys started to function as axes of national economies. While taking advantage of the benefits provided by rivers and their valleys both in the past and in the present, humans have always been aware of the great dangers associated with flowing water [1]. Since the times of early settlements built on river banks, hydraulic engineering structures have been constructed to act as protection from the devastating effects of floods [2, 3]. As a result of intensive development within river valleys, the value of assets accumulated in those areas has grown significantly. As a result, the potential losses caused by floods are becoming ever higher. This leads to a push towards providing more effective protection to the property and life of valley inhabitants by hydraulic engineering measures, increasing in turn the value of the property accumulated in such areas and thus also the potential losses from flooding [4, 5]. Such self-perpetuating processes can now be observed in many highly developed regions of the world.



Fig. 1. The study area extended from the catchment of the Odra River to the Ujscie Nysy profile and the catchment of the Vistula River to the Krakow profile

The discussion of floods in this paper covers the section of the Odra River basin from its source down to the mouth of the Nysa Klodzka River and the section of the Vistula River basin down to the Krakow profile (Fig. 1). The area of the upper part of the Odra River basin is 13,455 km<sup>2</sup> and the length of the river bed in this section is ca. 273.0 km. In the reach examined, the Vistula River is 184.8 km long and has a catchment area of approximately 8,101 km<sup>2</sup> [6].

## Methods

This analysis necessitated detailed indoor studies. The reconstruction of meteorological and hydrological conditions in the period up until the mid-19<sup>th</sup> century is difficult and imprecise. The relevant information is contained in numerous, often handwritten historical sources that include calendars and diaries as well as chronicles maintained by families, parishes, monasteries and cities. A significant advantage of such sources of information is that they were written by people who were very knowledgeable about the places they described, while their main shortcomings include heterogeneity and considerable subjectivity in the description of events. Such sources are usually dispersed, hence searching for them and verifying their contents is a very time-consuming task that requires a lot of historical and geographical knowledge. In modern times, studies of the causes of floods and the variation in their occurrence have been primarily based on detailed meteorological and hydrological data as well as on the modelling of water runoff and physiographic conditions in the catchment.

## Results and discussion

Owing to the variation in the associated climate and hydrological conditions and in the seasons of the year during which floods occur, these have been divided into certain categories. Floods are most frequently classified by their origins, which allows summer and winter floods to be distinguished [7, 8].

In the area in question, floods caused by rainfall occur in the summer half-year. These include freshet floods caused by torrential rain that are local in character and may occur in mountainous areas as well as in uplands or lowlands. Another type is the freshet flood caused by rainfall from weather fronts. These may occur throughout the area examined. A peculiar phenomenon related to weather fronts is extensive flooding caused by continuous heavy rain that lasts for several days or even a fortnight. Such floods occur mainly in June, July or August. In the winter half-year, two types of floods are possible. Firstly, thaw freshets result from the sudden melting of the snow cover. These have a considerable extent and occur in the early spring (March, April) in the Odra and Vistula River valleys. Such floods may occur along the entire length of the valley but present the greatest threat in its lower and middle reaches. The second category of flooding is that caused by frazil and ice jams. The former occur when frazil ice, *ie* ice crystals that form clumps and patches, emerges in chilled water masses. In places where the river channel becomes shallower or narrower, patches of frazil ice are lifted above the water and form jams that may cause water stages to rise considerably. The latter occur in late winter when ice cover starts to break and the shape of the channel (mainly width and depth) prevents the floes from flowing smoothly down the river, leading to the formation of ice jams.

### Floods in the upper part of Vistula River basin

As concerns the floods that occurred in the 19<sup>th</sup> century in the upper reaches of the Vistula River, we have fairly detailed descriptions of their occurrence and course, particularly in the Krakow area. This information, however, usually refers to the loss of life and property caused by the swollen rivers while data on water stages and flow rates for individual profiles are lacking. In the case of catastrophic floods, like those of August 1813, only certain estimates are provided which were calculated on the basis of high water marks that indicate the highest stage reached by the river. The records and notes at our disposal concern 16 floods that occurred on the upper Vistula River in the 19<sup>th</sup> century. There is significant variation in the frequency of their occurrence. In the first half of the period until 1845, 11 floods were recorded in the upper part of Vistula River basin. Only two of these (in 1839 and 1843) featured two flood waves, while the remaining ones are classified as events with a single flood wave peak. In the century in question, such floods occurred in 1805, 1813, 1816, 1818, 1826, 1830, 1834, 1844 and 1845. During that period, summer floods dominated (nine events), while two floods (in 1834 and 1843) occurred in winter. At the beginning of the 19<sup>th</sup> century, many prolonged dry and cool periods were recorded. While the first records of floods in the area in question date from 1805, they only concern local inundations that affected the vicinity of Babice and Oswiecim on the banks of the Vistula River. At that time, increased water supply came mainly from the Silesian Upland, which is drained by the Przemsza River. It was only in 1813 that one of the greatest floods of the 19<sup>th</sup> century occurred on the upper Vistula River (simultaneously with one on the Odra River). In that year, heavy rainfall had already started in July, significantly reducing the water retention capacity of the catchment. The highest water stages on the river were recorded on 26 August. This flood wave peak was caused by heavy rainfall that affected the Silesian Upland and the section of the upper part of Vistula River basin situated in the Beskid Mountains. In Krakow, there are numerous high water marks on buildings that show the extent to which the city was flooded [9].

In the 20<sup>th</sup> century, there were 23 catastrophic floods on the upper Vistula River. During that period, water stages rose much more frequently in the area covered by this study. On average, one flood was recorded every four years. Obviously, there were certain exceptions to this rule where the river basin was affected by floods year after year as well as prolonged periods without major floods. In 15 cases, such floods only featured a single distinct flood wave peak which was caused by continuous or torrential rain. Such cases occurred in 1903, 1908, 1925, 1931, 1934, 1939, 1948, 1951, 1970, 1972, 1991, 1996, 1997 and 1999. This group also includes the 1912 flood, which was caused by the water flow being blocked as a result of spring ice jams. The remaining floods featured two, three or even four flood wave peaks, which were separated by periods of several days or weeks. Such floods occurred in 1906, 1915, 1919, 1920, 1940, 1958, 1960 and 1987. The greatest floods of the 20<sup>th</sup> century in the upper part of Vistula River basin were those that occurred at the beginning and end of that period. In 1903 there was a catastrophic flood which was caused by July rains in the Beskid Mountains section of the river basin. High water stages on the Mala Wisla River were compounded by the inflow of flood waters from the Sola and Skawa Rivers that originate in the Beskid Mountains. In Krakow, the highest water stage was recorded on 12 July at 5.30 pm and the speed at which the flood wave moved was around 2.3 km/h. The water stages recorded in Krakow during that flood on the Vistula

River were only exceeded during the memorable flood of 1997, which has been described in a fairly detailed manner in the literature [10, 11].

### **Floods in the upper part of Odra River basin**

In the 19<sup>th</sup> century, several floods with a single flood wave peak caused by continuous or torrential rain (a single rain episode) occurred within the upper Odra River valley. In the century in question, such floods occurred in 1813, 1831, 1879, 1889, 1890 and 1896. However, during the 19<sup>th</sup> century, floods with two, three or even five flood wave peaks were much more common. Such extreme events were recorded in 1821, 1826, 1847, 1854, 1883 and 1897. They were caused by several episodes of very heavy rainfall separated by dry spells that spanned from a few to around a dozen days. Such periods of rain with dry spells commonly lasted from 4 to 8 weeks. Apart from those already mentioned, large floods of this type also occurred in 1880, 1883, 1888, 1891, 1892, 1897 and 1899 [9].

In the 19<sup>th</sup> century, three distinctive periods can be distinguished with respect to floods. The first one covers the years from 1813 to 1855. It is very difficult to analyse this period in detail since we do not have any instrumental measurements of precipitation or descriptions of prevailing weather conditions at our disposal. Only water stages were observed in a reasonably meticulous manner, although usually only during floods. Such observations were conducted at several sections along the Odra River within major cities and also at existing locks. The extant meteorological observations concern rainfall measurements at several gauging stations situated in the lowlands and in river valleys, usually within major cities or on their outskirts. Such stations operated mainly in the South-Eastern Sudetes and Western Carpathians as well as in the Sudetic Foreland and on the Silesian Upland. The second period covers the years from 1856 to 1878. No catastrophic floods occurred on the upper Odra River at that time. The third period covers the last 22 years of the 19<sup>th</sup> century. During this time, one catastrophic flood, 8 major ones and as many as 12 large floods were recorded on the upper Odra River. Those floods were generated in the South-Eastern Sudetes and in the Western Carpathians. Only the 1880 flood was the result of continuous rainfall, which affected the entire upper section of the river basin [9].

In the early 20<sup>th</sup> century, a dense network of meteorological stations and posts already operated in the upper part of Odra River basin and there were numerous gauging stations on the Odra River and along its tributaries. River flow rates were also systematically measured at control sections during low, medium and high water stages. Flow rates during major floods were estimated as well. In a similar manner to the 19<sup>th</sup> century, both floods featuring a single flood wave peak and those that included two, three or even four such peaks occurred in the 20<sup>th</sup> century. The frequency of flooding also varied significantly, with such events occurring both in individual years and in two-, three-, four- or even five-year sequences.

The first period covers the years from 1901 to 1940 when 30 significant events occurred, of which 9 were catastrophic and 21 were major floods. Given the fact that the final two decades of the 19<sup>th</sup> century were also a period when floods were relatively common, it can be assumed that from 1879 until 1940, very wet weather conditions prevailed in the upper part of Odra River basin that were conducive to flooding. In that period, 41 events occurred, of which 10 were catastrophic and 31 were major floods. The years from 1941 to 1957 can be considered a dry period with only one major winter flood (in March 1947) and one catastrophic flood (in July 1949). It should be noted, however, that

the water stages, and thus also the flood wave peaks, observed in Raciborz after 1942 cannot be compared to earlier observations. This is because at that time a new channel was constructed for the Odra River (the so-called Flood Channel), which diverted excess water during high water stages. The new measurement section was situated at Miedonia below Raciborz where channel parameters, the width of the inter-levee area and the hydraulic gradients were different.

From 1958 to 1985, a series of catastrophic and major floods occurred in the upper part of Odra River basin (in 1958, 1960, 1962, 1965, 1966, 1968, 1970, 1972, 1977 and 1985). Afterwards, an eleven-year period of “hydrological calm” within the basin followed. This ended in 1997 when the largest catastrophic flood ever observed in the upper part of Odra River basin occurred. The two flood wave peaks in July 1997 exceeded the highest water stages recorded so far by several dozen to more than 100 cm. The analysis also demonstrates that in the second half of the 20<sup>th</sup> century, there were fewer large floods but the magnitude and extent of such events increased. Of particular note were the floods that occurred in 1960, 1972, 1977 and 1985 and also the catastrophic flood of 1997 [9, 10].

## Conclusions

It is possible to assess the number, course and nature of floods in the area studied over the past two centuries because numerous records exist of natural disasters in that area. Of those disasters, large portions were floods. A factor that significantly limits the usefulness of such historical sources is their huge number and considerable dispersion. Until the 19<sup>th</sup> century they were mainly manuscripts written in Latin and in the German Gothic script. Searching for such sources and verifying their contents requires large, interdisciplinary teams because it is a very time-consuming task that requires the knowledge of already “dead” languages alongside historical and geographical knowledge. A significant element of the historical records concerning the floods that affected the area in question have been studied and presented in numerous publications [2-4, 7-12]. In the 19<sup>th</sup> century, rainfall and river water stages used to be observed visually until the 1870s when systematic instrumental measurements began at rain and gauging stations.

Geographical and environmental conditions in the upper part of the Vistula and Odra Rivers basins are conducive to floods both in the summer and winter seasons [13]. The analyses conducted for the 19<sup>th</sup> and 20<sup>th</sup> centuries demonstrate that two main types of floods can be distinguished. Floods with a single flood wave peak occurred in the following years in the upper part of Odra River basin: 1813, 1831, 1879, 1889, 1890 and 1896, and on the Vistula River they were recorded in 1805, 1813, 1816, 1818, 1826, 1830, 1834, 1844 and 1845. In the 20<sup>th</sup> century, similar phenomena were recorded on the Odra River in 1903, 1909, 1911, 1915, 1925, 1960, 1970 and 1985, and on the Vistula River they occurred in 1903, 1908, 1925, 1931, 1934, 1939, 1948, 1951, 1970, 1972, 1991, 1996, 1997 and 1999. The second category includes floods with two, three or more flood wave peaks. These are caused by successive episodes of high rainfall separated by dry periods that last for a few days, a fortnight or even several weeks. Such floods occurred on the upper Odra River in 1847, 1854, 1880, 1888, 1892, 1897 and 1899; while on the Vistula River only two (1839 and 1843) floods featured two flood wave peaks. In the 20<sup>th</sup> century on the upper Odra River, floods of this type occurred in 1902, 1926, 1939, 1940, 1972, 1977 and 1997; on the

upper Vistula River, they were recorded in 1906, 1915, 1919, 1920, 1940, 1958, 1960 and 1987.

In the 19<sup>th</sup> and 20<sup>th</sup> centuries, there were only a few cases when floods simultaneously affected the basins of the Vistula and Odra Rivers. This usually happened during catastrophic floods, which included, *ia*, those of 1813, 1903, 1915, 1925, 1939, 1940, 1960, 1970, 1972 and 1997.

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## POWODZIE W GÓRNEJ CZĘŚCI DORZECZY WISŁY I ODRY W XIX I XX WIEKU

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**Abstrakt:** Celem badań jest analiza powodzi w XIX i XX w. w górnej części dorzecza Odry (tj. po ujściu Nysy Kłodzkiej) oraz w górnej części dorzecza Wisły (tj. po profil w Krakowie). Powierzchnia badanej części dorzecza Odry wynosi 13 455 km<sup>2</sup>, a długość koryta rzeki około 273,0 km. Wisła na opisywanym odcinku ma długość 184,8 km, a powierzchnia zlewni wynosi około 8101 km<sup>2</sup>. Warunki środowiska geograficznego dorzecza górnej Wisły i Odry powodują powstawanie powodzi zarówno w półroczu letnim, jak i zimowym. Z przeprowadzonych analiz dla okresu XIX i XX wieku wynika, że w przebiegu powodzi można wyróżnić dwa ich zasadnicze typy. Wezbrania o jednej kulminacji w XIX wieku w górnej części dorzecza Odry wystąpiły w latach: 1813, 1831, 1879, 1889, 1890 i 1896, a w górnej części dorzecza Wisły w latach: 1805, 1813, 1816, 1818, 1826, 1830, 1834,

1844 i 1845. W XX wieku podobne zjawiska notowano na Odrze w latach: 1903, 1909, 1911, 1915, 1925, 1960, 1970 i 1985, a na Wiśle w latach: 1903, 1908, 1925, 1931, 1934, 1939, 1948, 1951, 1970, 1972, 1991, 1996, 1997 i 1999. Do drugiego typu powodzi zaliczono te o dwóch, trzech i większej liczbie kulminacji. Ich przyczyną były fale następujących po sobie dużych opadów deszczu, przedzielone kilku-, kilkunastodniowymi, a nawet kilkutygodniowymi okresami bezopadowymi. Tego typu powodzie wystąpiły na górnej Odrze w latach: 1847, 1854, 1880, 1888, 1892, 1897 i 1899, a na Wiśle jedynie dwie powodzie z 1839 i 1843 roku odznaczały się dwiema kulminacjami. W XX wieku na górnej Odrze powodzie o tego typu parametrach miały miejsce w latach: 1902, 1926, 1939, 1940, 1972, 1977 i 1997, a na górnej Wiśle były to: 1906, 1915, 1919, 1920, 1940, 1958, 1960 oraz 1987. Na przestrzeni XIX i XX wieku wystąpiło tylko kilka przypadków, gdy powodzie miały miejsce zarówno w górnej części dorzecza Wisły, jak i w górnej części dorzecza Odry. Taka sytuacja zazwyczaj miała miejsce w przypadku katastrofalnych wezbrań, do których zalicza się m.in. te z lat: 1813, 1903, 1915, 1925, 1939, 1940, 1960, 1970, 1972 i 1997.

**Słowa kluczowe:** powódzie, Odra, Wisła, południowa Polska