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FLUVIAL SYSTEM IN TWO SMALL CATCHMENTS IN THE CITY OF KIELCE (POLAND)

Keywords: *urban catchments, fluvial processes, anthropogenic impact on runoff*

Introduction. Urban areas are taking up more and more space every year. This means that areas featuring impermeable surfaces, extensive sewer networks, and hydraulic structures are expanding as well. This causes an imbalance in the natural proportion between infiltration and surface runoff which further leads to an acceleration of surface runoff from such areas. Rivers are a sensitive system that reacts to natural and anthropogenic changes in catchments. Land use as well as riverbed management impacts the course of hydrological and fluvial processes (Froehlich 1975, 1982, Święca 1998). Energy and matter such as water and debris are transported away from catchment geo-ecosystems via river channels and sometimes via valley bottoms as well (Biernat, Ciupa 1992, Kostrzewski 1993, Kostrzewski, Mazurek, Zwoliński 1994). This region is relatively well known in terms of hydrological studies (Jankowski 1986, Dynowska 1988, Jankowski, Kaniecki 1996, Czaja 1999). A further consequence of an accelerated water cycle in urban areas is an increase in the frequency of elevated water energy states that initiate and magnify erosion processes, transport processes, and sediment accumulation process in river channels in the area of interest.

Riverbed systems, the way they function, and their means of sediment supply have been the subject of many publications in the field of fluvial geomorphology (Froehlich 1975, 1982, 1992, Ciupa 1991, Krzemień 1991, Kostrzewski, Mazurek, Zwoliński 1994, Święca 1998). The above publications were mainly concerned with natural and agricultural river catchments. Urban areas in Poland – ever growing in size – have not been studied to a significant extent from a fluvial geomorphological perspective. Only certain aspects of urban catchments have been studied and described in the literature (Kupczuk, Biernat, Ciupa, 1998, Ciupa, 2000, 2001, Trząski, Molenda, Kupka, 2000).

The purpose of this work is to describe selected fluvial processes in the riverbed systems of the Silnica and Sufraganiec rivers that flow across urban and suburban districts of Kielce.

Research Area and Methods. Two catchments featuring a similar surface area but different land use located adjacent to one another in the urban and suburban zones of Kielce were selected for comparative research purposes. The Silnica and the Sufraganiec are mountain-type rivers with lengths of 18.9 km and 17.8 km, respectively. The surface area of the Silnica catchment is about 50 km^2 and is about 40% urban. The Sufraganiec catchment (62 km^2) is agricultural and forested in nature with less than 7% of the surface area being urban in nature (Fig. 1).

Research work was performed at eight stationary hydrometric cross sections (5 on the Silnica and 3 on the Sufraganiec) from 1997 to 2001. Water level, water temperature, suspended sediment concentration, and dissolved matter concentration measurements were performed daily. Suspended sediment concentration was determined using the filtration method while dissolved matter concentration was determined using the conductometric method. Measurement frequency was increased

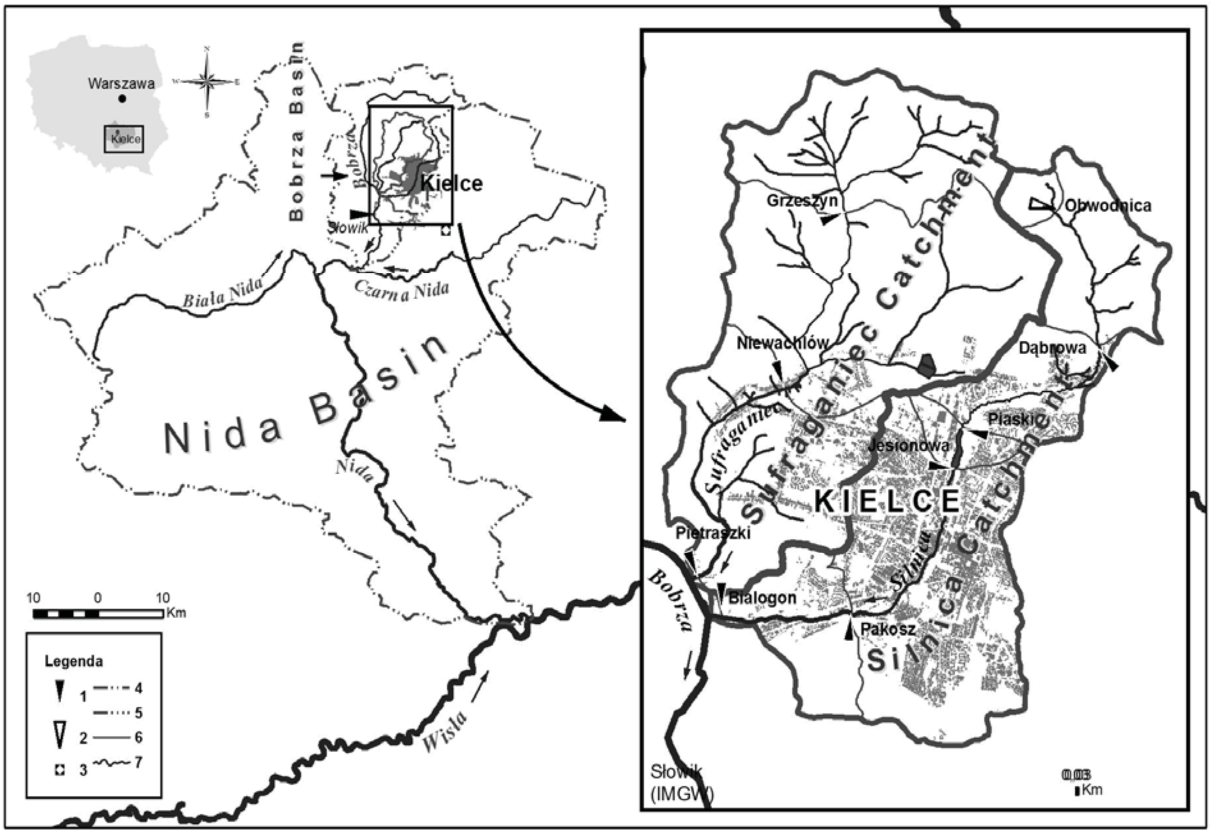

Fig. 1. **Location of the Sufraganiec and Silnica river basins.**
Legend: 1. water level indicator, 2. seasonal water-level indicator, 3. Kielce-Suków weather station (RSH-M IMGW), 4. second-order drainage divide, 5. third-order drainage divide, 6. fourth-order drainage divide, 7. streams.

during selected flood events from several times a day to more than a dozen times a day. Limnigraphic measurements were performed at six hydrometric cross sections during the summer season (April to October) while pluviographic measurements were performed at four cross sections during the same time period.

On average, once every 2 or 3 weeks, the following measurements were performed at 9 research cross sections: intensity of discharge, suspended sediment concentration, specific conductance of water, hydrogen ion concentration (pH), and oxygen content. One of the 9 cross sections was not observed continuously – the cross section closing off the upstream part of the Silnica catchment. The chemical composition of water was analyzed for the following: chloride, sulfate, ammonia nitrogen, nitrate, nitrite, elemental nitrogen, phosphate, elemental phosphorus, water hardness, elemental iron, and COD (chemical oxygen demand). The presence of the following heavy metals was also detected in 12 sampling series: chromium, zinc, aluminum, cadmium, copper, nickel, lead, and mercury.

The research process also involved the mapping of riverbeds based on topographic maps (scale: 1:10 000). The riverbeds of interest were mapped three times. The mapping was done with the following terrain information categories in mind: riverbed, riverbanks, flood plain, hydraulic structures. The mapping fieldwork was based on established riverbed mapping methods (Florek 1978, Zwoliński 1988) as well as riverbed classification methods (Krzemień 1999) with minor adjustments being made for urban areas. Next, in order to determine Manning's coefficient of roughness for different parts of each valley, land use analysis was performed in the near riverbank zone.

Research Results. Research results indicate fundamental differences in the way the fluvial system functions in catchments with different land use and degree of human pressure. These differences apply to both the dynamics and the intensity of hydrological and fluvial processes. Flood wave heights are relatively small in partial catchments largely unaffected by human pressure. River reaction times and longer and discharge variability is negligible in such catchments. A very different type of situation exists in the middle and downstream sections of the Silnica River – in urban areas. This part of the catchment is characterized by the impermeable surfaces of roads, parking lots, and roofs that render rainwater infiltration impossible. Even small amounts of rainfall, 2-3 mm per 15 min, can cause river water levels to rise 15-20 cm. Flood wave concentration times are generally considerably under one hour – flood waves 1.5 to 2.5 m in height. However, once a flood wave passes, water levels return to their original state within 5-20 hours. This underscores the importance of the river's surface water supply over its groundwater supply. Every rainfall event is immediately reflected in a rise in river water level. This leads to highly irregular river flow and highly variable river flow speeds as well as an increased frequency of the former and the latter. As a result, certain riverbank sections experience a magnified impact of water flow energy. This further leads to increased riverbed process dynamics – especially fluvial transport dynamics. The variability of discharge and the nature of eroded material supply sources is reflected in the dynamics and magnitude of fluvial transport loads as well as in the shaping of the geometry of un-reinforced riverbank sections. This is especially true of the Silnica River which experiences far more water flow energy variability than does the Sufraganiec River.

The upstream section of the Silnica River runs through a forested area featuring wetlands. This area is characterized by natural river processes and landforms. The river flows through a suburban zone starting from just below its upstream section as far as the Kielce Reservoir. Its channel here is natural in some places and engineered in others. The river's channel is up to 1.5 m deep in the engineered sections and its banks are reinforced with concrete slabs. The local flood plain has been artificially elevated and built over in many places by local residents. This has reduced the area of the natural flood plain resulting in elevated water levels in the river. This area, however, is still dominated by natural river sections featuring sandy gravel bottoms. In the Pasmo Szydlowkowskie Gorge, eroded materials are still being delivered to the river channel directly from the slopes. The Silnica flows into the Kielce Reservoir (Volume = 170 000 m^3) where it creates a delta which has grown to about 100 m over the 30 years that the reservoir has been in operation. The rate of its growth is determined by the height of the plant cover. Traction load from the river is deposited in full into the reservoir while suspended sediment is taken in to some extent. The character of the Silnica River changes entirely downstream from the Kielce Reservoir where the river flows through central Kielce. This section of the river channel has been engineered, straightened, and deepened. The riverbanks here are high thanks to artificial embankments (1.4 to 3.5 m). The surface area of cross sections is several times greater than it would be under natural conditions. Disproportionately wide channels, characterized by almost uniform geometry, result in extremely low water levels during low-flow periods. Given the relatively small amount of shade available, water temperatures in this section of the channel are 12-15 ^{o}C higher on sunny days than they would be in a comparable natural channel section. Weirs and concrete embankments make erosion processes virtually impossible in this section of the Silnica River. The engineered nature of the channel as well as the large drops in the river's longitudinal grade do not favor sediment accumulation processes. The Silnica's 4 km channel section downstream from the reservoir functions solely as a water transportation pathway. The high manmade embankments generally prevent flooding from occurring. This section is characterized by numerous bridges, footbridges, weirs, gravity dams, stormwater system outlets, stormwater gutters, etc. Downstream from central Kielce, the Silnica River still flows through an engineered channel but the embankments tend to be made of stone or turf. A much gentler longitudinal grade as well as a large amount of clastic material originating in Kielce being transported by the river result in significant mid-channel and near-channel accumulation of sediment. This material comes mainly from street and sidewalk runoff that contains sand, especially during the winter season. The result of excess material flowing down the river is the formation of numerous mid-channel shoals. Plant cover dominates the shoals during the summer season and captures additional suspended sediment as well as traction load moving down the river during numerous floods and elevated water levels. In the disproportionately wide river channel, shoals create intra-channel pseudo-flood plains 1-3 m in width and 0.2-0.5 m in height. These sandy "flood plains" become higher with every consecutive elevated water level. The growth of such shoals reduces the size of the channel's cross section – which makes flow difficult – resulting in elevated water levels. The shoals have been removed from time to time (e.g. in 1998), however, they begin to grow again in as little as a year's time within the same section of the river channel.

The location of a body of water upstream from a central city district easily leads to the conclusion that the transported bed load and suspended sediment must, for the most part, come from that central city district. This is true when the body of water receives the entire traction load and a substantial part of the suspended sediment coming from sources upstream. Cities "produce" disproportional amounts of soluble matter, suspended sediment, and bed load. A dense network of roads and stormwater canals (covered and uncovered) creates a system that efficiently delivers water, suspended sediment, and dissolved matter to river channels. The physical nature of municipal infrastructure decidedly favors the expansion of a river's sediment supply zone – up to 65%-80% of the entire catchment area. The material in question may be transported from distant areas as far as the drainage divide. Impermeable surfaces tend to "produce" surface runoff and runoff consisting of small particles collected during rain-free periods. In a fully natural environment or one resembling a natural environment, the main sources of eroded material are the river channel itself and the narrow riverbank zone. In agricultural-forested catchments, the source zone is larger and constitutes several percent of the overall catchment area.

The mouth section of the Silnica River, free of artificial embankments, is characterized by very intense lateral and bottom erosion processes. This leads to increased geometric parameters of the channel which is a response to the frequent occurrence of maximum discharge.

The Sufraganiec River is a mountain-type stream in its headwater section. The river's channel features small cascades and sill falls and its cross sections tend to vary widely in length. Gravel and small stones cover the bottom of the headwater section and the riverbanks are 0.2 to 0.8 m high. Several paleo-meanders can be observed on the flood plain. The middle section of the Sufraganiec is characterized by natural erosion and accumulation processes. The only structures in this section are bridges and footbridges. The downstream section, on the other hand, has been engineered. The nature of the engineering is different from that along the Silnica River. In the case of the Sufraganiec River, the riverbanks are 1.2 m to 2.5 m high along the downstream section and have been reinforced using fascine and turf. This section of the river serves merely as a water transportation pathway with only limited natural processes taking place. No substantial accumulation of transported material leading to the formation of shoals is observed in this section of the Sufraganiec River in contrast to the kinds of mid-channel shoals that can be seen along the Silnica River.

The fluvial system of the Silnica River basin has been altered by the laying of impermeable surfaces, the expansion of the drainage network (stormwater pipes, streets), the construction of hydraulic structures, and the appearance of new sediment supply sources and the disappearance of others. This results in the acceleration of surface runoff and the intensification of the energy that initiates fluvial processes as well as to the expansion of sediment supply zones. This leads to changes in the water cycle, sediment transport, and location and size of sediment supply zones. This is especially true of the Silnica River and has an appreciable impact on fluvial transport processes. The type of variability found in the longitudinal cross section of the Silnica River cannot be found in rivers flowing across natural environments or ones resembling natural environments. Dissolved matter concentrations can vary up to fivefold along the river's longitudinal cross section. In some cases, the solute concentration in one place can be 10 or 20 or 30 times greater than in another. This is especially true in the winter when roads are covered with sand and salt. During the winter season, the solute concentration in one place can be 100 or 200 or 300 times greater than in another. Different types of fluvial transport mechanisms function differently in dissimilar types of river sections. The Kielce Reservoir plays an important role in such processes along the longitudinal cross section of the Silnica River. The reservoir retains about 25% of the transported suspended sediment and about 20% of the dissolved matter. The fluvial transport mechanism has been observed to be different for such river sections. Laser analysis of the mechanical content of suspended sediment at selected hydrometric cross sections has shown appreciable differences in terms of texture (average grain diameter, geometry, distribution) during different stages of flood events.

The thermal regime of the rivers subject to this research has been altered both in spatial and temporal terms. Average monthly water temperature differences are around 3^oC in urban areas. 24-hour differences can reach up to 15 ^oC.

Conclusions. Urban areas alter the natural water runoff and sediment supply system via the presence of impermeable surfaces and drainage networks that accelerate water runoff and material transport processes.

In an urban fluvial system, the reaction to precipitation is very fast and releases a great amount of energy within a short period of time which enables the transfer of material loads and changes in river channel geometry.

From a hydrological and geo-morphological point of view, urban areas supplying runoff and sediment to river channels are much more efficient than corresponding natural environments.

Urban zones are characterized by extensive sediment supply areas which is reflected in the rate of sedimentation of channel and near-channel facies.

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Fluvial system in two small catchments in the city of Kielce (Poland)

Ciupa Tadeusz

Two rivers were selected for comparative research purposes whose catchments are located adjacent to one another in the urban and suburban zones of the city of Kielce in Poland. The two catchments have a similar surface area but different land use. The Silnica catchment is mostly urban while the Sufraganiec catchment is mostly agricultural and forested in nature. Research has shown that the fluvial systems in the two catchments function in fundamentally different ways. These differences are related to surface runoff dynamics as well as the intensity and the effects of fluvial processes. The urban catchment is characterized by a large surface area feeding eroded material to the river channel as well as by an unnatural acceleration of the matter and energy cycle. These characteristics are found to a much lesser extent in the Sufraganiec agricultural-forested catchment.

Keywords: *urban catchments, fluvial processes, anthropogenic impact on runoff.*

Річкова система двох малих водозбірних басейнів на території міста Кєльце (Польща)

Цюпа Тадеуш

В статті проводиться порівняльний аналіз 2-х басейнових систем в межах м. Кєльце (Польща) – р. Сільніца та р. Суффагенець. Басейн першої має переважно міський характер забудови, а другої розташований переважно на території сільськогосподарського освоєння з великою часткою лісів. Дослідження показало, що ці річкові системи функціонують у кардинально різний спосіб. Показані відмінності у типі живлення, характері та режимі стоку, тощо.

Ключові слова: *міський водозбір, руслові процеси, антропогенний вплив на стік.*

Речная система двух малых водосборных бассейнов на территории города Кельце (Польша)

Цюпа Тадеуш

В статье проводится сравнительный анализ 2-х бассейновых систем в пределах г. Кельце (Польша) - р. Сильница и р. Суффагенец. Бассейн первой имеет преимущественно городской характер застройки, а второй расположен преимущественно на территории сельскохозяйственного освоения с большой долей лесов. Исследование показало, что эти речные системы функционируют кардинально разными способами. Показаны различия в типе питания, характере и режиме стока и т.д.

Ключевые слова: городской водосбор, русловые процессы, антропогенное воздействие на сток.

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