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DYNAMICS OF THE CHANNEL BEDS LEVEL IN MOUNTAIN RIVERS IN THE LIGHT OF THE MINIMUM WATER STAGES ANALYSIS

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Abstract: Changing the position of the river channel bed is one of the more visible morphological processes in mountain areas. The analysis of the dynamics of the position of river channel beds (rivers: Ropa, Zdynia, Wisłok) located in the Polish Carpathians is presented. The different indicators relating to the course of long-term daily water stages (1997-2014) were used: daily, minimum monthly, average minimum monthly and average minimum annual. The analysis conducted using the above-mentioned indicators showed similar results on both direction and scale of changes of river channel beds in a multi-year period. In the alluvial Zdynia River channel deepening was a dominant process (2.2 to 2.4 cm/year). In the alluvial Ropa River channel the raising of the level channel bed was observed (0.3 to 1.3 cm/year). In the case of the Wisłok River the greatest rock bed level stability was noticed (deepening 0.3 cm/year). Two main factors determine changes in the position of the river channel beds: natural and anthropogenic.

Key words: Polish Carpathians, Low Beskid, Ropa river, Zdynia river, Wisłok river, water stages, channel bed

1. INTRODUCTION

Morphology of river channels is constantly changing in time and space, and the process is dependent on both natural and anthropogenic factors. Floods play a key role among the natural factors shaping the morphology of Mountain Rivers, especially those with extreme flows, due to high intensity rainfall (Soja & Starkel, 2007; Frandofer & Lehotský, 2011; Kijowska-Strugała, 2012; Gorczyca et al., 2014; Wiejaczkaet al., 2014). The occurrence of floods in the form of clustering (grouping of several events in a short period of time) enhances environmental effects (Starkel, 2003). According to Wohl, (2006), human effects on mountain streams may result from activities undertaken within the stream channel that directly alter channel geometry, the dynamics of water and sediment movement, contaminants in the stream, or aquatic and riparian communities. Human effects can also result from activities within the watershed that indirectly affect streams by altering the movement of water, sediment, and contaminants into the channel. Examples of human activitieswhich directly alter the morphology of river channels include: flow control, fragmentation of channels with water structures, banks stabilization and gravel exploitation (Brandt, 2000; Grams & Schmidt, 2002; Petts & Gurnell, 2005; Rinaldi et al., 2005; Gregory, 2006; Korpak, 2007). According to Krzemień, (2006), within areas of high human impact, rivers and streams adapt the structure of their channel systems to the changed conditions in the beds of valleys and on the slopes. Elosegi et al., (2010) reported that human activity leads to the transformation of the natural environment into a more homogeneous one with low diversity.

In the case of rivers in the Polish Carpathians, over the last few decades, there has been a clear deepening of river channels, ranging from approx. 0.5 to 4.0 m (Wyżga, 1991, 2007; Lach & Wyżga, 2002; Zawiejska & Wyżga, 2010). According to Wyżga, (2007), rivers draining the Polish Carpathians deeply incised over the 20th century and in many sections, the downcutting was especially rapid in the second half of the century. Incision has resulted from the increase in transport capacity of the rivers, as caused by their channelization, and the concomitant decrease in sediment supply to the channels and in-stream gravel mining. Noticeable deepening of the Carpathian Rivers can be observed downstream of dams, when sediment-free water outflowing from the reservoir consumes its energy to erode the channel bed (Malarz, 2004-2005; Wiejaczka et al., 2014). Changes in the morphometry of the Carpathian Rivers can also be observed upstream of reservoirs (Książek, 2006; Liro, 2014).

The process of deepening of river channels in recent decades is also common in the Romanian Carpathians. However, studies based on the multi-period hydrometric measurements data shows that considerable group of rivers has a tendency to aggradation or stabilization of channel bed positions (Rădoane et al., 2010; Rădoane et al., 2013).

Changing the position of the river channel bed is one of the more visible morphological processes in mountain areas. There are two approaches to monitor channel form changes. The firstis morphological mapping of channel forms on the basis of available topographic maps. This method gives only qualitative data to evaluate channel changes especially lateral erosion, vertical erosion to a lesser degree. The second, geodetic method, coupled with the first approach, gives both, qualitative and quantitative data (Dauksza, 2009).

Analysis of changes in the position of river channel beds can also be performed on the basis of the minimum water stagesin the river (Soja, 1977; Dauksza, 2009; Wiejaczka et al., 2014; Tamang & Mandal, 2015). The use of daily data on water stages in the river is not an accurate way to determine the change in the position of the channel bed but it provides reliable information about the direction of change (beddeepening or raising) and its intensity. Comparative research methods presented in the above-cited studies show that, in the absence of data from channel geodesic research, assessing changes in the position of channel bed can uselong-term series of data on water stages in the river.

The main objective of this article is to analyze the dynamics of the position of river channel beds located within the same physio-geographical unit of the Carpathians (Fig. 1), basing on long-term observation series of daily water stages (1997-2014).

The paper compares the direction and scale of changes in the position of river channel beds using different indicators relating to the course of water stages. Three rivers located within the Polish Carpathians were chosen for the analysis: the Ropa River, the Zdynia River and the Wisłok River. The main selection criteria included: location within the same physio-geographical unit, long-term observation series of daily water stages, as well as different types of hydrological regime.

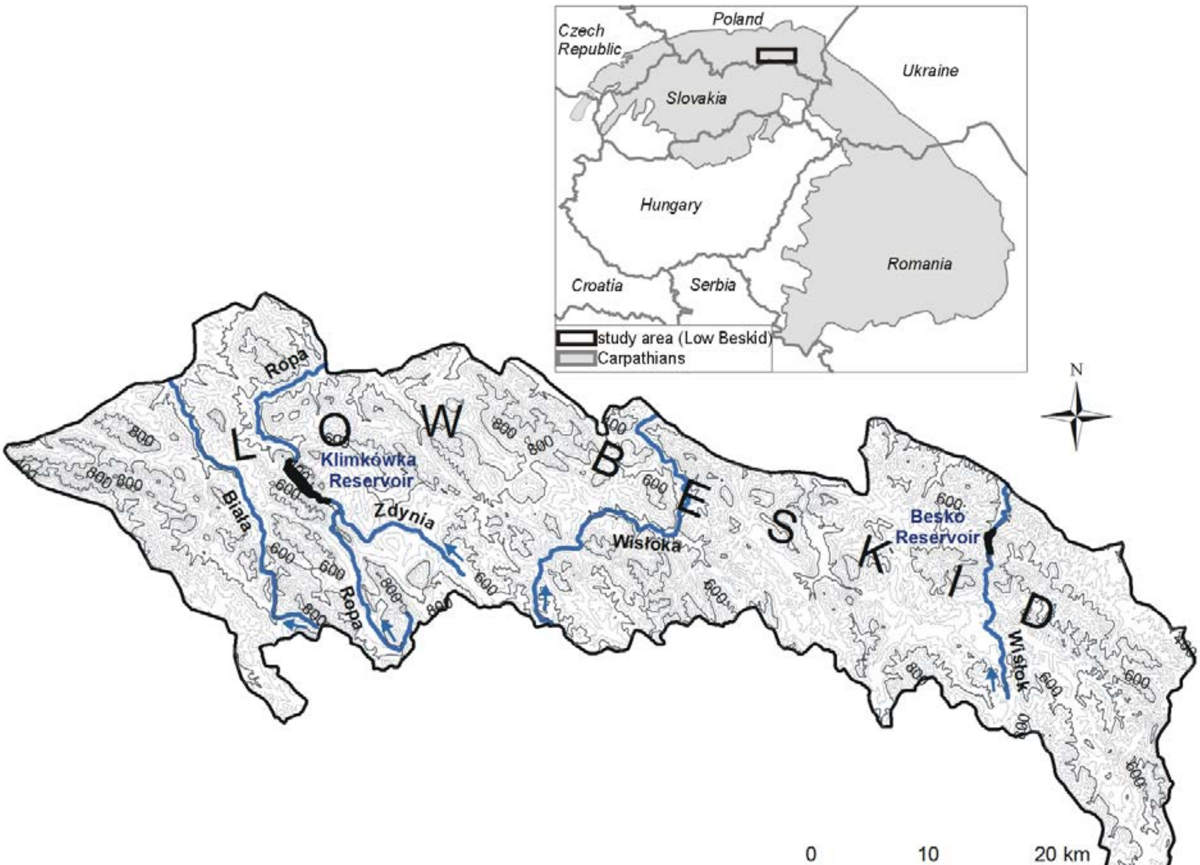

Figure1.Study area

In addition, the selected rivers supply two large retention reservoirs located within the Low Beskid - Klimkówka and Besko.

2. RESEARCH AREA AND METHODOLOGY

The rivers considered, although theydrain the area of the same physio-geographical unit, due to the extreme position within the Low Beskid (transition area between the Western and Eastern Polish Carpathians), are characterized by varying hydrological regimes. Dynowska, (1971) assumes one type of river regime system for the area of the Low Beskid - unstageled with floods: spring, summer and winter and with rain, snow and ground water supply. The author points out, however, that the Wisłok River regime is a transition regime between the rivers of the Western Carpathians (in addition to the spring raised water stages, very clear summer raised water stages), and the Eastern Carpathians (having no summer floods, the main flood is in the spring, the secondary – in the winter). Differing of the hydrological regime of the Ropa and Zdynia rivers, as outlined above, in relation to the Wisłok River, reflects the course of the average monthly flows in the hydrological years 1997-2014, presented in figure 2.

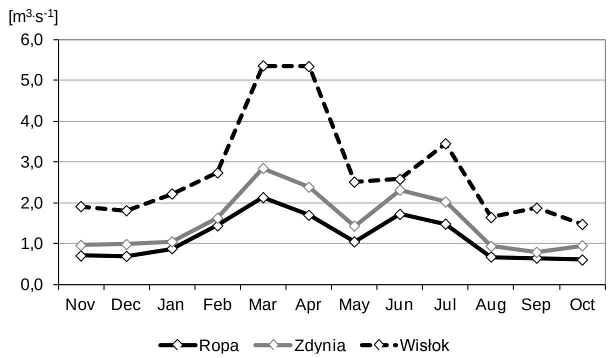

Figure 2. Average monthly flows in the hydrological years of 1997-2014 on the Ropa, Zdynia and Wisłok rivers

The analyzed rivers are located within the Magura (the Ropa and Zdynia rivers) and Silesia (the Wisłok River) Nappes. The catchment of the Zdynia River and the upper catchment of the Ropa River build tertiary inoceramus forms, relatively resistant to weathering (shale and sandstone) and Magura shale, sandstone and marl, forming the highest ridges. Valleys were carved in less resistant shale and Sub-magura, Beloveza, Hieroglyphic sandstones, agglomerates and variegated shale (Geological Map 1:50000). The upper part of the Wisłok river catchment is formed by inoceramus shale and sandstones as well as Hieroglyphic and Menilite shale and sandstones with patches of tertiary Krosno sandstones and shale (Jankowski, 2005).

The width of the channels on the relevant sections of the rivers is about 13 m on the Ropa, 12 m - Zdynia, 8 m and 25 m – Wisłok (Fig. 3). Banks of the Ropa and Zdynia channels at the location of watergauging stations are reinforced and regulated (Fig. 3). Channels of the Ropa and Zdynia rivers, at the location of water gauging stations, are alluvial, while the bed of the Wisłok River includes rock outcrops. The Ropa and Wisłok rivers have a similar diveristy of natural hydromorphological elements but the Ropa channel is much more modified by human activity than the Wisłok River (Wiejaczka & Kijowska-Strugała, 2014).

The analysis is based on data on daily water stages from hydrological years (November-October) from 1997 to 2014 (6:00 UTC) observed at cross-sections in watergauging stations located approx. 1-2 km upstream of the reservoirs. Watergauging cross-sections, included in the hydrological warp of the reservoirs, close catchments with surfaces of 68 km^2 – the Ropa river, 101 km^2 – the Zdynia river and 207 km^2 – the Wisłok river. The data was provided by the Regional Water Management Board in Cracow. Characteristics of the dynamics of the position of the river channel beds were based on the analysis of water stages at various time intervals during the years 1997-2014. Location change of the river channel beds was presented on basis of the following indicators: daily water stages, minimum monthly water stages, average minimum monthly water stages, average annual minimum water stages. Data used for analysis were not corrected due to the presence office cover on rivers (usually between December-February) due to the lack of information about its thickness.

3. RESULTS AND DISCUSSION

3.1. Dynamics of river channel beds in the light of the analysis of daily water stages in the years 1997-2014

Location change of the river channel beds can be observed by analyzing the course of daily water stages in a multi-year period. In the first part of the multi-year period (1997-2005), daily water stages on the Ropa River were in the range of 130-345 cm, 386-597 cm on the Zdynia River, and 92-227 cm on the Wisłok River (Fig. 4). In the next period (2006-2014), the range of daily extreme stages was: 136-430 cm, 374-670 cm, 91-224 cm, respectively. In the compared periods, different ranges of daily fluctuations in water stages in rivers can be seen.

The course of maximum water stages in rivers is largely dependent on the size of water flow, while

Figure 3. Location of watergauging within the Ropa, Zdynia and Wisłok river channels

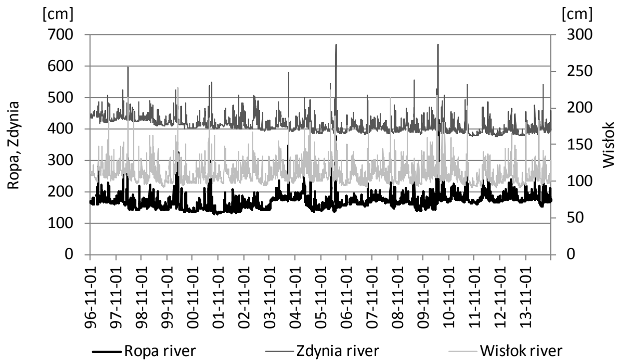

Figure 4. Daily water stages (6:00 UTC) on the Ropa, Zdynia and Wisłok rivers in the period of 1997-2014

minimum stages are additionally shaped by the changing position of channel beds. In the case of the Ropa river, the periods under consideration showed an increase in extremely low daily stages (by 6 cm), decrease in the Zdynia River (by 12 cm), while stages in the Wisłok River are at a similar stage.

Analysis of trends in daily water stages throughout the multi-year period of 1997-2014 shows an increasing trend of water stages in the Ropa river, amounting to 1.1 cm/year (Table 1) and a decreasing trend in the Zdynia River, 2.2 cm/year. For the Wisłok River, the trend of daily water stages showed a very insignificant bedlowering (0.3 cm/year).

3.2. Dynamics of river channel beds in the light of the analysis of the minimum monthly water stages

Changes in the channel position of the rivers also reflect the minimum monthly water stages in the period 1997-2014 (Fig. 5). On the Ropa river, the lowest monthly water stages in 1997-2005 ranged between 130 cm (September 2001) and 192 cm (February 2005), and in the years 2006-2014, between 136 cm (May 2006) and 181 cm (March 2012). In summer half year 1997 (May - October), the minimum monthly water stage of 161 cm was recorded in October, and the corresponding flow amounted to 0.18 m^3/s. In 2005, in the middle of the multi-year period, the lowest monthly stage of water 137 cm (0.06m^3/s) was recorded in July. In June 2014, the lowest monthly stage of water at a flow rate of 0.28 m^3/s, similar to that recorded in 1997, amounted to 151 cm. Noteworthy is a very large change in the lowest water stage of the Ropa River in June 2010, 33 cm in relation to May.

Such a significant increase in the minimum water stages was the result of intensive accumulation of debris on the section where the watergauging patch was placed, following an extremely high flood in early June. The role of floods in the formation of the channel bed of the Ropa River is very clear.

Table 1. Average rate of the Ropa, Zdynia and Wisłok rivers deepening or raising

Indicators	Ropa river	Zdynia river	Wisłok river
Daily water stages	Linear trend		
	y=0,003x+33,63	y=-0,006x+659,5	y=-0,0007x+135,12
	cm/rok		
	1,1	-2,2	-0,3
Minimal water stages	Linear trend		
	y=0,0253x+150,9	y=-0,2059x+421,55	y=-0,0213x+102,64
	cm/rok		
	0,3	-2,4	-0,3
Average minimum annual water stages	Linear trend		
	y=1,3102x+144,11	y=-2,4257x+422,19	y=-0,237x+102,5
	cm/rok		
	1,3	-2,4	-0,2

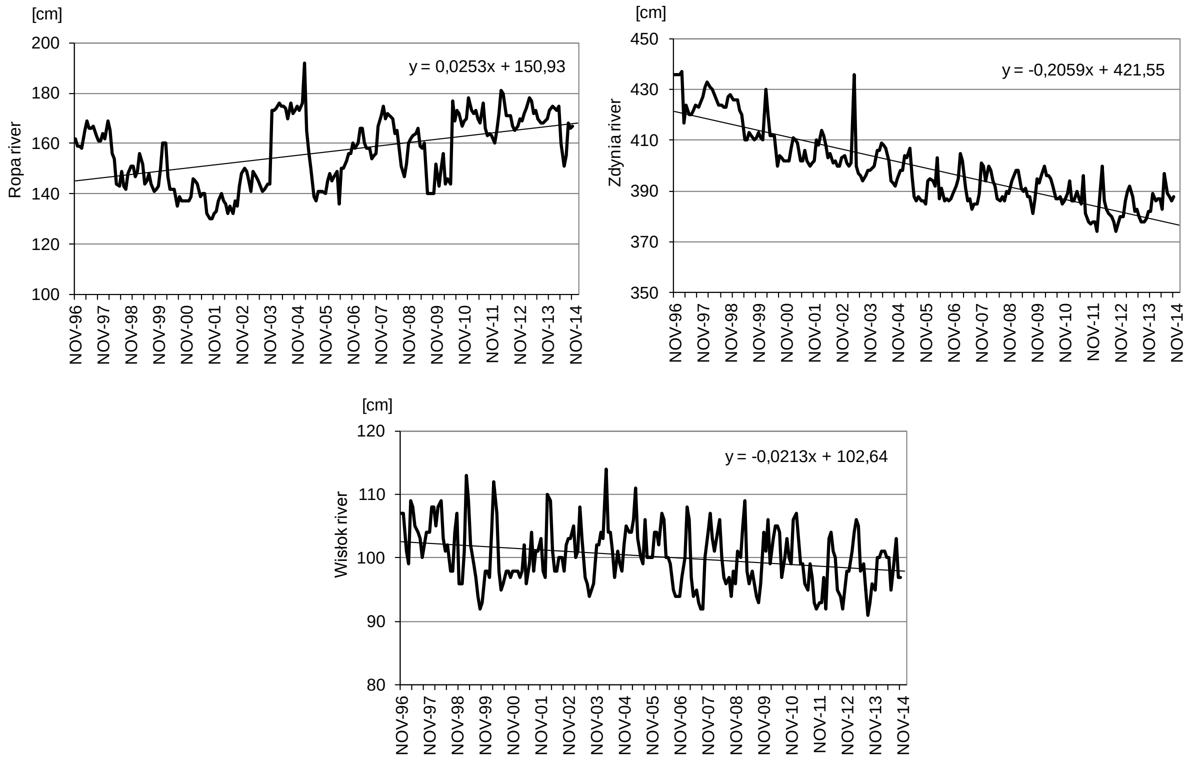

Figure 5. Minimum monthly water stages on the rivers: Ropa, Zdynia and Wisłok in the period of 1997-2014

Average annual rate of increase of the minimum monthly Ropa stages in the multi-year period of 1997-2014 in the light of the data presented in figure 5 is 0.3 cm/year (Table 1).

Comparison of the lowest monthly water stages for the years 1997-2014 on the Zdynia River confirms the trend of channel deepening (Fig. 5). The lowest monthly stage of water in 1997-2005 ranged between 386 cm (July 2005) and 437 cm (February1997), while in the period of 2006-2014, between 374 cm (January 2012) and 405 cm (February 2007). In the summer half year of 1997, the lowest monthly water stage on the Zdynia river 420 cm was recorded in May, at a flow rate of 0.12m^3/s. In 2005, in the middle of the multi-year period, the lowest water stage on the Zdynia River was 386 cm in July, at a flow rate of 0.16 m^3/s, and in 383 cm May 2014 (0.26m^3/s). Theexamples show that minimum monthly water stages, decreasing in the multi-year period, correspond to higher and higher flows, which obviously evidences river channel deepening. The average rate of the monthly lowest stages decreasing in the multi-year period on the Zdynia River is 2.4 cm/year (Table1).

For the Wisłok river, the lowest monthly stage of water in 1997-2005 ranged from 92 cm (September 1999) to 124 cm (March 2004), while in the period of 2006-2014, from 91 cm (August 2013) to 109 cm

(March 2009). In summer half year of 1997 (August) lowest monthly water stage was 100 cm and in 2005 (July) 99 cm. The corresponding flow rate amounted to, respectively, 0.5 m^3/s and 0.4 m^3/s. In 2014, the lowest monthly water stage decreased to 95 cm (0.3m^3/sin June). The course of the lowest monthly water stagesshows a very weak trend towards channel lowering, equal to 0.3 cm/year (Table1). It can be concluded that the stage of the Wisłok river channel bed in the multi-year period was relatively stable.

3.3. Dynamics of river channel beds in the light of the analysis of the average monthly minimum water stages

The trends outlined above within changes in the channel bed position of the rivers can also be observed when comparing the average minimum monthly water stages between the two periods 1997-2005 and 2006-2014 (Table 2). In the Ropa River, these values, in the first period, fluctuated during the year between 145 cm (September) and 159 cm (February). In the next period, the range increased because the lowest average monthly water stage was at the level of 159 cm (May), while the highest at 166 cm (February, March). Average monthly minimum water stages hadraised by an average of 11 cm, which proves that the bed of the Ropa river channel was raised over the entire multi-year period of 1997-2014.

Table 2. Average minimum monthly water stages on the Ropa, Zdynia and Wisłok rivers in the periods of 1997-2005 and 2006-2014

Period	Ropa river		Zdynia river		Wisłok river	
	1997-2005	2006-2014	1997-2005	2006-2014	1997-2005	2006-2014
November	151	162	414	384	103	98
December	154	162	413	389	102	100
January	157	165	413	391	101	102
February	159	166	418	394	103	101
March	154	166	413	395	108	104
April	153	165	417	392	107	103
May	149	159	409	387	101	99
June	148	164	407	388	99	99
July	147	160	406	386	99	96
August	146	160	405	384	99	95
September	145	159	404	382	98	94
October	147	161	405	384	99	96
Average	151	162	410	388	102	99
Standard deviation	4,4	2,6	4,8	3,9	2,9	3,1
Coefficient of variation (%)	2,9	1,6	1,2	1	2,9	3,1

In the Zdynia and Wisłok rivers, a reverse process was observed. In the period of 1997-2005, the average minimum monthly water stages on the Zdynia River were in the range of 404 cm (September) and 418 cm (February), and on the Wisłok river - in the average range of 98 cm (September) to 108 cm (March), (Table 2). In the next period, the average minimum water stages dropped by 19-29 cm on the Zdynia River and by 1-5 cm in the case of the Wisłok River. The largest differences in the annual cycle were seen between the compared multi-year periods in the autumn and winter on the Zdynia River and in the autumn on the Wisłok River. Average minimum monthly water stages dropped on average by 22 cm on the Zdynia River, which indicates a significant deepening of the river channel in the multi-year period. On the Wisłok River, decrease in the average minimum water stages amounted to only 3 cm.

3.4. Dynamics of river channel bedsin the light of the analysis of the average minimum annual water stages

In 1997-2002, in the course of the average minimum annual water stages on the Ropa River, a decrease in the value was seen, from 163 cm to 136 cm (Fig. 6), which demonstrates the progressive removing of the material from the bed of the river channel, and thus deepening. Since 2003, we can distinguish one-, two-year cycles of increases and decreases in average annual minimum water stages between successive years on the Ropa River, in the range of 1-26 cm. It should be noted that the increase in the average minimum annual water stage on the Ropa River channel, as noticeable in 2004, was due to the control works within the channel, resulting in the anthropogenic raising of the bed of the river by approx. 30 cm. Assuming that the trend of changing average annual low water stages observed in the years 1997-2014 is a reflection of the Ropa River channel bed changes, it can be assumed that the average rate of the channel raising was 1.3 cm/year (Fig. 6, Table 1).

The course of the average annual minimum water stages on the Zdynia River indicates the presence of few periods with different rates of channel deepening (Fig. 6). In 1997-2001, the average annual minimum water stages decreased from 427 cm to 404 cm, an intense channel deepening by approx. 23 cm can be assumed. In subsequent years (2001-2004), values of the analyzed variable remained at a similar stage (405-401 cm), indicating no change of the position of the Zdynia river channel bed in close proximity to a watergauging station. Floods in this period did not have enough energy to lead to changes in the morphology of the channel.

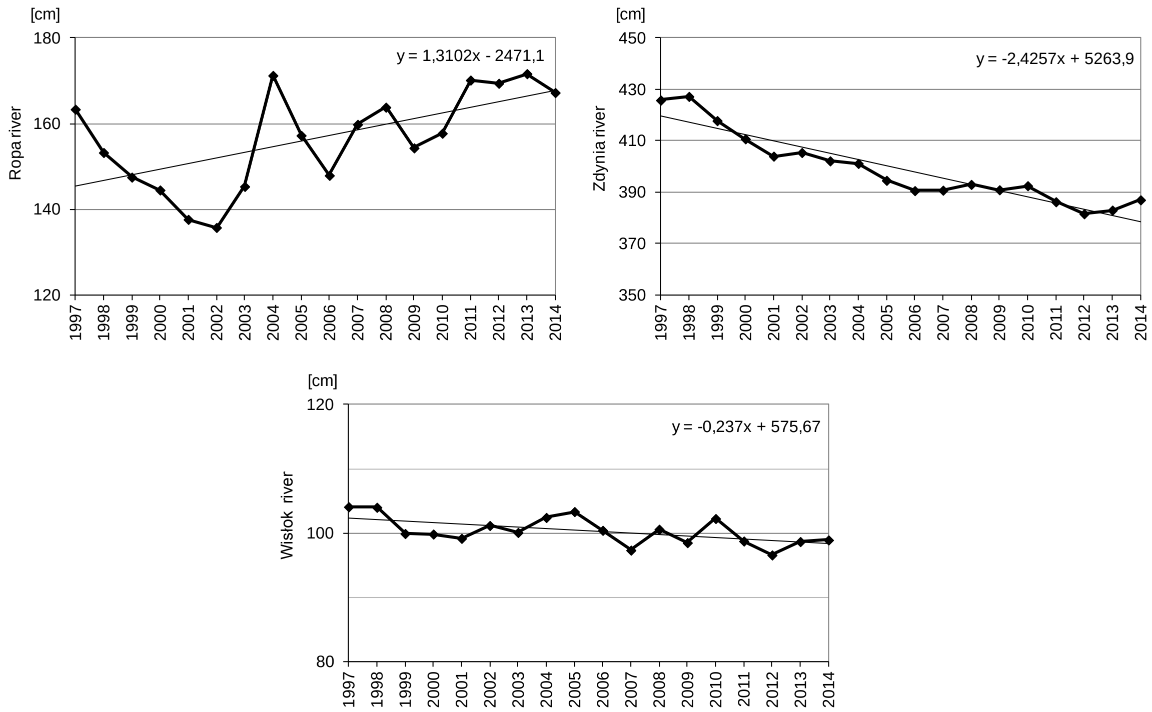

Figure 6. Average minimum annual water stages on the rivers: Ropa, Zdynia and Wisłok in the period of 1997-2014

In 2004-2006, a clear decrease in average annual low water stages was recorded (and thus the stage of the channel bed) from 401 cm to 391 cm. After 2006, the stages remained at a similar stage, while in the years 2010-2012, their decrease was recorded from 393 cm to 382 cm. In subsequent years (2013-2014) average annual minimum water stages increased to 387 cm, (Fig. 6). Within the multi-year period, the Zdynia river channel deepening dominated, amounting to, by the trend line, 2.4 cm/year.

On the Wisłok River, a very low dynamics of average annual minimum water stages was observed. Throughout the multi-year period of 1997-2014, fluctuation range of values was in the narrow range of 97-104 cm. The trend line presented in figure 4 shows a very weak channel bed trend towards lowering, equal to 0.3 cm/year. This demonstrates the lack of significant changes in the position of the Wisłok river channel bed over several years.

4. CONCLUSIONS

Analysis of water stages in the years 1997-2014 on the rivers: Ropa, Zdynia and Wisłok, located within the Polish Carpathians, revealed a variable dynamics of changes in the position of the channel beds of the rivers. The results obtained allowed to formulate the following conclusions relating to the objectives determined in the paper:

1) Indicators proposed in the article, i.e. daily, monthly minimum, average monthly minimum and average minimum annual water stages can be used to assess the dynamics of river channel beds. The analysis conducted using the above-mentioned indicators showed similar results on both direction and scale of changes of river channel beds in a multi-year period.

2) Deepening was a dominant process in the alluvial Zdynia river channel in the multi-year period,it was due to erosion of the bed. The rate of the channel deepening ranged from 2.2 to 2.4 cm/year, depending on the indicator selected for analysis. On the other hand, a reverse trend was observed in the alluvial Ropa river channel, i.e. raising the stage of the channel bed. The average rate of channel bedraising in the case of the Ropa River ranged from 0.3 to 1.3 cm/year. Inthe case of the Wisłok River, over the entire multi-year period, the greatestrock bedlevelstability was observed, as compared to other rivers. Average rate of deepening, according to various indicators,was 0.3 cm/year.

3) Two main factors determine changes in the position of the river channel beds: natural (floods, tributaries, type of the channel bedsubstrate) and anthropogenic (control works in the channel, reservoir backwater). In the case of the Ropa River, raising the channel bed observed, was due to the following factors: loss of transport strength of rivers during large floods caused by backwater of the Klimkówka reservoir, blocking the flow of the Ropa river, due to its tributary – the Zdynia River (having higher flows than the Ropa river) and control work within its channel. Floods on the Zdynia River are a major cause of channel deepening. No major changes on the Wisłok river results from its rock channel bed.

REFERENCES

Brandt, S. A., 2000. *Classification of geomorphological effects downstream of dams.* Catena, 40(4), 375-401.

Dauksza, L., 2009. *The Ropa River channel changes during 20th century at Szymbark (polish Flysch Carpathians)* Studia Geomorphologica Carpatho–Balcanica, 43, 115-126.

Dynowska, I., 1971. *Typy reżimów rzecznych w Polsce,* Zesz. Nauk. UJ, Prace Geogr., 50, 1-150.

Elosegi, A., Díez, J. & Mutz, M., 2010. *Effects of hydromorphological integrity on biodiversity and functioning of river ecosystems*. Hydrobiologia, 657, 1, 199-215.

Frandofer, M. & Lehotský, M., 2011. *Channel adjustment of a mixed bedrock-alluvial river in response to recent extreme flood events (the upper topľa river).* Geomorphologia Slovaca et Bohemica, 11, 2, 59-71.

Grams, P. E. & Schmidt, J. C., 2002. *Streamflow regulation and multi-stage flood plain formation: channel narrowing on the aggrading Green River in the eastern Uinta Mountains.* Colorado and Utah. Geomorphology, *44,* 3, 337-360.

Gorczyca E., Krzemień K., Wrońska-Wałach D. & Boniecki M., 2014. *Significance of extreme hydro-geomophological events in the transformation of mountain valleys (Northern Slopes of the Western Tatra Range, Carpathian Mountains, Poland).* Catena, 121, 127-141.

Gregory, K. J., 2006. *The human role in changing river channels.* Geomorphology, 79, 3, 172-191.

Jankowski, L., 2005. *Mapa geologiczna utworów podczwartorzędowych w rejonie Krosna*. Centr. Arch. Geol. Państw. Inst. Geol., Oddz. Karpacki. Kraków.

Kijowska-Strugała, M., 2012. *Impact of downpours on fluvial processes in the Polish Carpathians as exemplified by Bystrzanka stream.* Studia Geomorphologica Carpatho-Balcanica, 46, 25-40.

Korpak, J., 2007. *The influence of river training on mountain channel changes (Polish Carpathian Mountains)*. Geomorphology, 92, 3, 166-181.

Krzemień, K., 2006. *Badania struktury i dynamiki koryt rzek karpackich.* Infrastruktura i ekologia terenów wiejskich, 4, 1.

Książek, L., 2006. *Morfologia koryta rzeki Skawy w zasięgu cofki zbiornika Świnna Poręba (The morphology of the Skawa River bed within back-water reach of Świnna Poręba Reservoir).* Infrastruktura i Ekologia Terenów Wiejskich, 4, 1, 249–267.

Lach, J. & Wyżga, B., 2002. *Channel incision and flow increase of the upper Wisłoka River, southern Poland, subsequent to the reafforestation of its catchment.* Earth Surface Processes and Landforms, 27, 4, 445-462.

Liro, M., 2014. *Conceptual Model For Assessing The Channel Changes Upstream From Dam Reservoir.* Quaestiones Geographicae, 33, 1, 61-74

Malarz, R., 2004-2005. *Geomorfologiczne skutki działania zapór wodnych w okresach powodziowych w dolinie Soły.* Folia Geographica ser. Geographica-Physica, 35-36, 53-64.

Petts, G. E. & Gurnell, A. M., 2005. *Dams and geomorphology: research progress and future directions.* Geomorphology, 71, 1, 27-47.

Rădoane, M., Pandi, G. &, Rădoane, N., 2010. *Contemporary bed elevation changes from the Eastern Carpathians*. Carpathian Journal of Earth and Environmental Sciences, 5, 2, 49-60.

Rădoane, M., Obreja, F., Cristea, I. & Mihailă, D., 2013. *Changes in the channel-bed level of the eastern Carpathian rivers: Climatic vs. human control over the last 50 years*. Geomorphology, 193, 91–111.

Rinaldi, M., Wyżga, B. & Surinan, N., 2005. *Sediment mining in alluvial channels: physical effects and management perspectives.* River Res. Appl., 21, 805–828.

Soja, R., 1977. *Deepening of channel in the light of the cross profile analysis (Carpathian river as example).* Studia Geomorphologica Carpatho–Balcanica, 11, 128–138.

Soja, R. & Starkel, L., 2007. *Extreme rainfalls in Eastern Himalaya and southern slope of Meghalaya Plateau and their geomorphologic impacts.* Geomorphology, 84, 3, 170-180.

Starkel, L., 2003. *Extreme meteorological events and their role in environmental changes, the economy and history.* Paper in Global Change, 10, 7-13.

Tamang, L. & Mandal, D. K., 2015. *Bed material extraction and its effects on the forms and processes of the lower Balason River in the Darjeeling Himalayas*, India, Geographia Polonica, 88, 1-3.

Wiejaczka, Ł., Kiszka K. & Bochenek W., 2014. *Changes of the morphology of the Ropa River – upstream and downstream of the Klimkowka water reservoir.* Studia Geomorphologica Carpatho–Balcanica, 48.

Wiejaczka Ł. & Kijowska-Strugała M., 2014, *Assessment of the hydromorphological state of Carpathian rivers above and below reservoirs,* Water and Environment Journal, DOI:10.1111/wej.12082

Wohl, E., 2006. *Human impacts to mountain streams.* Geomorphology, 79, 3, 217-248.

Wyżga, B., 1991. *Present-day downcutting of the Raba River channel (Western Carpathians, Poland) and its environmental effects.* Catena, 18, 6, 551-566.

Wyżga, B. 2007. 20 *A review on channel incision in the Polish Carpathian rivers during the 20th century.* Developments in Earth Surface Processes, 11, 525-553.

Zawiejska, J. & Wyżga, B., 2010. *Twentieth-century channel change on the Dunajec River, southern Poland: Patterns, causes and controls.* Geomorphology, 117, 3, 234-246.

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