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TRANSPORT OF DISSOLVED AND SUSPENDED MATTER IN SMALL CATCHMENTS OF THE WIELICZKA FOOTHILLS NEAR ŁAZY

Abstract: This paper presents the diversity and seasonal variability of the transport of dissolved and suspended matter in selected catchments of the Wieliczka Foothills (part of the Carpathian Foothills). Based on four years of research the significant influence of the relief on the limited displacement of clastic material from summits to stream beds was observed. A domination of chemical over mechanical denudation was documented.

1. Introduction

Because of erosion processes in the Wieliczka Foothill catchments, dissolved and suspended matter is mainly exported. The loads of these materials reflect complex morphogenetic processes in the catchment and river bed. However, they do not permit identification of the part of the catchment actively involved in the supply of matter to the rivers. Identifying the sources and dynamics of the supply of dissolved and suspended matter to the river system and determining the particle size of these materials in the river beds allow the directions and rates of relief evolution to be determined (Froehlich, 1982; Krzemień, 1991; Kostrzewski et al., 1994). Most published work concerning the Carpathians and aimed at investigating the dynamics of dissolved and suspended matter transport apply to the Beskid part of the Carpathians (Figuła, 1966; Froehlich, 1982; Welc, 1985; Łajczak, 1989). The amount of research data applying to the Carpathian Foothills is, however, very moderate. In the literature, reference is mainly made to the results of the research carried out by A. Reniger (1957) and K. Figuła (1966), which, as underlined by the authors themselves, is only preliminary and based on a limited number of measurements. Attempts were thus made to investigate the chemical and mechanical denudation yield in the Carpathian Foothills based on loads in the transiting rivers. As a result of these studies, a high level of morphological activity in this region was suggested (Łajczak, 1989, 1992). For this reason systematic balance studies of the transport of dissolved and suspended matter have been undertaken in the Carpathian Foothills, close to the Research Field Centre of the Institute of Geography, Jagiellonian University in Łazy near Bochnia (Krzemień, 1996).

The aim of the studies carried out in this region since 1993 is to investigate the diversity and seasonal variability of the export of dissolved and suspended matter from foothill catchments of various sizes as well as the relationships between the types of material transported. The investigations were carried out mainly in the experimental drainage basins of the Stara Rzeka River (22.4 km^2) and Dworski stream (0.29 km^2) and partially in the Kubaleniec catchment (1.0 km^2) (Tab. 1).

Tab. 1. Concentration of dissolved and suspended particulate matter in the catchment of the Stara Rzeka River and in the tributary catchments with reference to the geological structure and land use patterns in 1993-1996.

Tab. 1. Koncentracja materiału rozpuszczonego i zawiesiny w zlewni Starej Rzeki oraz w zlewniach cząstkowych na tle budowy geologicznej i użytkowania ziemi w latach 1993-1996.

Water course	Area	Geology	Land use - Użytkowanie				TDS - Mineralizacja mg/l		TSS - Zawiesina mg/l	
Ciek	Obszar km^2	Budowa geologiczna	forests lasy	grassland łaki i pastwiska	arable land orne	others inne	high flow wezbrania	between high flows okr. miedzy-wezbraniowe	high flow wezbrania	between high flows okr. miedzy-wezbraniowe
Stara Rzeka	22.4	Flysch, sandstone and Miocene clay, loess-like surface deposits. Flisz, piaskowce i iły mioceńskie, utwory lessopodobne	41.3	13.3	38.7	6.7	103-199	308-430	1 335-13 298	1.4-21.0
Kubaleniec	1.0	Sandstone, Miocene clay, loess-like surface deposits. Piaskowce, iły mioceńskie, utwory lessopodobne	0.4	22.4	64.7	12.5	173-273	387-744	213-339	1.0-19.5
Dworski Potok	0.29		1.6	59.8	33.2	5.4	51-270	426-759	108-2 006	1.3-21.0

2. Area of the study

The area of the study covers three catchments (Fig. 1) located in the northern marginal area of the Wieliczka Foothills near Bochnia, between the rivers of Raba and Uszwica. The main river under research - Stara Rzeka - is a tributary of the Vistula river. The upper part of Stara Rzeka is situated within the Wieliczka Foothills while the lower part crosses the Sandomierz Basin. The foothill part is built of flysch rock of Silesian and sub-Silesian units and of Miocene sandstone and clay. The slopes and summit areas are covered with thick loess-like formations and the valley bottoms are lined with dusty deposits of prolluvial origin. The wide and smooth ridges are at an elevation up to 260-360 m a.s.l.

Fig. 1. Location of the study area.

Rys. 1. Położenie obszaru badań.

The Stara Rzeka valley floor is flat and 100-250 meters wide. It is dissected by a three-to-five-metre-deep and meandering channel of twenty to thirty metres in width. The valley floor includes a river channel of about four metres in width. The banks of the channel are undercut over a considerable length.

The Dworski stream valley floor is flat, filled with silty alluvia and has a width of thirty to a hundred metres. The bed of the stream cuts a channel 0.5-1.5 meters deep. The stream bed is mostly covered with higrophilic vegetation.

The bottom of the valley of Kubaleniec is also flat, wide and damp at some spots. It is filled with dusty and sandy deposits with clay insertions. The bed of the stream is meandering and reaches a maximum width of two metres. It cuts the valley bottom down to a depth of three metres at its lower course section.

During the period of investigation (1993-1996) the total annual precipitation ranged between 540.4 mm in 1993 and 773.8 mm in 1996. As compared to the average values from the decade 1987-1996 (624.0 mm), the years 1993 and 1995 were ‘drier’ and 1994 and 1996 were significantly ‘wetter’ (Tab. 2).

The average annual discharges of the Stara Rzeka River ranged from 0.072 m^{-3} s^{-1} to 0.167 m^{-3} s^{-1} (Tab. 3). As compared to the average discharges for the decade 1987-1996 (0.131 m^{-3} s^{-1}), the averages in the period of study were lower in 1993, 1994 and 1995 and higher in 1996. The average annual discharges in the Dworski stream ranged from 1.16 l s^{-1} to 2.79 l s^{-1} (Tab. 4). As compared to the averages in 1987-1996 (1.38 l s^{-1}) the discharges were lower in 1993, close to average in 1994 and higher in 1995 and 1996.

In the Stara Rzeka drainage basin, forests cover 41.3% of the area, grasslands account for 13.3% and arable land covers 38.7%. Until 1994 forests occupied 1.6% of the Dworski stream catchment, grasslands - 59.8% and arable land - 33.2% (see Tab. 1). In the spring of 1995, part of the grassland area was ploughed thus increasing the area of arable land.

Tab. 2. Total monthly and annual precipitation (in mm) recorded by the meteorological station in Łazy during the hydrological years 1993-1996.

Tab. 2. Sumy opadów miesięcznych i rocznych (w mm) na stacji meteorologicznej w Łazach w latach hydrologicznych 1993-1996.

Hydrological year Rok hydrologiczny	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	Annual total Suma roczna
1993	31.8	40.0	24.2	20.0	48.4	26.0	45.7	80.7	87.3	61.8	37.5	37.0	540.4
1994	29.7	18.4	42.4	8.2	61.2	119.0	82.9	80.7	43.2	80.9	78.4	77.0	722.0
1995	20.8	27.8	14.7	35.5	46.6	73.1	124.0	87.6	35.9	52.8	67.8	13.1	599.7
1996	28.0	39.5	27.8	11.0	34.4	45.5	94.5	121.1	80.8	154.8	107.2	29.2	773.8

Tab. 3. Average monthly and annual flows ($m^3 s^{-1}$) of the Stara Rzeka River during the hydrological years 1993-1996.

Tab. 3. Średnie miesięczne i roczne przepływy ($m^3 s^{-1}$) Starej Rzeki w latach hydrologicznych 1993-1996.

Hydrological year Rok hydrologiczny	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	Mean Średnia
1993	0.091	0.142	0.127	0.051	0.024	0.507	0.507	0.009	0.015	0.004	0.009	0.012	0114
1994	0.025	0.017	0.059	0.047	0.142	0.712	0.712	0.216	0.004	0.005	0.01	0.033	0.116
1995	0.03	0.061	0.06	0.085	0.146	0.214	0.214	0.11	0.018	0.001	0.005	0.005	0.072
1996	0.02	0.07	0.06	0.02	0.25	0.27	0.27	0.16	0.04	0.27	0.56	0.140	0.167

Tab. 4. Average monthly and annual flows ($l s^{-1}$) of the Dworski Potok Stream during the hydrological years 1993-1996.

Tab. 4. Średnie miesięczne i roczne przepływy ($l s^{-1}$) Dworskiego Potoku w latach hydrologicznych 1993-1996.

Hydrological year Rok hydrologiczny	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	Mean Średnia
1993	1.03	1.51	1.57	1.00	2.96	4.49	0.37	0.18	0.19	0.01	0.14	0.42	1.16
1994	0.55	0.71	1.15	1.15	1.98	7.44	1.44	1.48	0.05	0	0.16	0.93	1.45
1995	1.01	1.44	1.46	1.69	2.23	2.44	2.82	1.47	0.54	0	0.05	0.06	1.32
1996	0.59	0.88	1.46	0.71	3.66	3.24	1.15	10.04	0.58	2.89	6.08	2.18	2.79

3. Methodology

The investigated catchments of the Stara Rzeka River, Dworski and Kubaleniec streams were controlled by hydrometric profiles with flumes and limnigraphs (see Fig. 1). The water levels were measured and one-liter water samples are taken to determine conductivity, TDS (total dissolved solids) and TSS (total suspended solids). Conductivity was measured daily. Concentration of dissolved and suspended matter was measured every three days. During high flow periods the frequency of measurements was increased (one-hour, half an hour or even fifteen minutes intervals). Conductivity was measured using a computer-controlled conductometer CC-315 with a reference temperature of 25°C. The concentrations of dissolved solids were determined by evaporating the water and drying the samples at 180°C. The determination of daily contents of dissolved matter was based on the relationship between this parameter and the conductivity (Krzemień, 1995). The concentration of suspended solids was determined by centrifugation in an MPW 6 centrifuge and by evaporating the remaining water at 105°C. All the analyses were performed by B. Jaszczyńska, M. Cisowska and A. Tutaj at the hydrochemical laboratory of the Research Field Centre.

The dissolved matter loads were calculated by multiplying the concentration of the material by the water run-off for particular days, months and years. The suspended solid loads were determined separately for the periods of high flows and the periods between them. They were expressed as a product of the concentration of suspended solids, the water discharge and the time interval between measurements.

4. Transport of dissolved matter

4.1. Spatial diversity and variability in the concentration of dissolved matter over the year

The water samples from the Stara Rzeka catchment are characterized by a wide range of dissolved matter concentrations - from 103 to 759 mg l^{-1} depending on their origin, circulation time and course (see Tab. 1). They are very similar to the values obtained in other mountain rivers similar in size (Chełmicki et al. 1992). The water in the Stara Rzeka River is less mineralized (up to 335 mg l^{-1}). The highest concentrations of dissolved matter were found in the water of the Dworski stream (up to 759 mg l^{-1}). This is mainly connected with particular geological formations. The upper section of the Stara Rzeka river together with Leśny stream carries water mainly from the head area of the flysch step. In this area the streams are supplied with water of lower mineralization. In the lower section of the catchment, the Stara Rzeka River is supplied by water from the tributaries of Dworski and Kubaleniec streams, which carry water from an area of sandstone and Miocene clay, covered with thick loess-like superficial deposits.

4.2. Variability in dissolved matter transport during high flows

During the high flow periods there is a very discernible decrease in the concentration of dissolved matter. The largest decrease in concentration takes place in small catchments such as the Dworski and Kubaleniec streams. The lowest concentrations were noted in the Dworski stream during a major flow event on June 10, 1996. The degree of variability in mineralization of the Stara Rzeka is significantly lower than in the case of Dworski stream, which is linked with the different functioning patterns of various types of water courses (see Tab. 1). During precipitation events, as well as thaw and snowmelt periods, the level and rate of mineralization changes depending on the mechanism and intensity of surface runoff (Chełmicki et al., 1992). During high flow periods, changes in concentration are the most significant, and particular high flow events are characterized by individual time-distributions of the mineral content (Froehlich, 1982).

4.3. Dissolved matter runoff from the watershed

Throughout the period of study the transport of dissolved matter from the Stara Rzeka and Dworski catchments was, to a large degree, related to the runoff regime in streams (Tab. 3 and 4, Fig. 2 and 3). Usually the most intense runoff of this type of material from particular catchments occurs during the winter season and is linked with snowmelt- and precipitation-caused high flows. Only during very humid years, the runoff of this material may slightly dominate during the summer season (Fig. 4). The contribution of the winter season to the transport of dissolved material from the drainage area of the Stara Rzeka ranges between 40.5% and 92.5%, and in the Dworski stream catchment it varies between 49.8% and 87.6%. The highest monthly loads were carried from both catchments mainly in March and April. Only in 1996 did the maximum load occur in both catchments in September. The lowest loads in both catchments generally occurred during the summer low discharge periods in July or August (see Fig. 2 and 3).

During the period investigated (1993-1996), the annual loads of dissolved matter flowing out from the drainage basin of Stara Rzeka River ranged from 657.9 to 1,327.2 tons. During the same period, waters of the Dworski catchment carried between 13.7 and 21.4 tons of matter.

The rate of chemical denudation in the Stara Rzeka catchment ranged from 29.4 tons km^{-2} per annum in 1995 to 59.3 tons km^{-2} per annum in 1996. In the Dworski stream this parameter varied between 47.2 tons km^{-2} per annum in 1995 to 73.8 tons km^{-2} per annum in 1996.

5. Transport of suspended matter

5.1. Annual variability of suspended matter concentration

The concentrations of suspended matter recorded to date in the Stara Rzeka drainage area do not differ from the values observed in other foothill catchments (see

Fig. 2. Monthly loads (in tons) of dissolved matter exported from the Stara Rzeka catchment in 1993-1996.

Rys. 2. Miesięczne ładunki wyniesionego ładunku rozpuszczonego ze zlewni Starej Rzeki w latach 1993-1996 (w tonach).

Fig. 3. Monthly loads (in tons) of dissolved matter exported from the Dworski Potok catchment in 1993-1996.

Rys. 3. Miesięczne ładunki wyniesionego ładunku rozpuszczonego ze zlewni Dworskiego Potoku w latach 1993-1996 (w tonach).

Fig. 4. Percentage share of the six month seasons: winter (a) and summer (b) in the export of dissolved matter from the Stara Rzeka and Dworski Potok catchments in 1993-1996.

Rys. 4. Procentowy udział wyniesionego materiału rozpuszczonego ze zlewni Starej Rzeki i Dworskiego Potoku w półroczach: zimowym (a) i letnim (b) w latach 1993-1996.

Tab. 1, after Krzemień, Święchowicz, 1992). In the literature addressing the issue of the foothill catchments the maximum quoted suspended matter concentrations ranged between 1000 and 7040 mg l^{-1}. The maximum concentration (13,298 mg l^{-1}) was recorded on June 10, 1996.. These values are definitely lower than those recorded in the Beskid catchments (Froehlich, 1982). The highest suspended matter concentration recorded in Stara Rzeka reaches only 50% of the values recorded in the rivers of the Beskid Mountains.

During the study period, the maximum concentrations of suspended matter during the snowmelt-related and summer high flows ranged from 1335 to 13,298 mg l^{-1} in Stara Rzeka and from 108 to 2006 mg l^{-1} in Dworski stream. Relatively low maximum values of suspended matter concentration (213-339 mg l^{-1}) have been recorded for Kubaleniec stream, which cuts through the broad meadows covering the bottom of the valley (see Tab. 1). During the intervals between high flow events, small amounts of suspended matter are exported from the catchment. The concentration of suspended matter at this time reached about 19-21 mg l^{-1}. The suspended matter content often varies in an annual and daily cycles. These periodical changes in transport rate result not only from events occurring over the entire area of the catchment but also, to a major extent, from the hydrodynamic and hydraulic conditions of the stream bed (Kostrzewski, Zwoliński, 1992).

5.2. Variability in suspended matter concentration during high flow events

The culmination of suspended matter concentration in the Stara Rzeka River always occurs before the maximum discharge, after 36-98% of the water level peak is reached (Krzemień, Święchowicz, 1992). This indicates a quick supply of fine material from the river bed and its nearest surroundings. A different situation occurs in Dworski and Kubaleniec streams, where the maximum concentration of suspended solids may occur before the flow culmination, at about 81-98% of its height (Figs 5 and 6). Such a situation is linked with a more complex supply of fine material to the stream bed, similar to other Carpathian (Beskid Mts) rivers (Froehlich, 1975). The characteristic feature of all investigated streams is that during subsequent high discharge events the reserves of fine material are quickly exhausted and despite the discharge rates the concentration of suspended matter decreases quickly. This process is particularly discernible in the Dworski stream (see Fig. 6). During high flow events of different scales, the concentration of suspended matter was usually higher in the stream than in its tributaries. For example during high flow events caused by continuous rains (2-5 mm h^{-1}) the concentration reached 500-1127 mg l^{-1} in the Stara Rzeka River and 50-150 mg l^{-1} in the Dworski stream.

5.3. Export of suspended matter from the catchment

In particular years, the monthly loads of suspended matter exported from the catchments of the Stara Rzeka River and Dworski stream indicated a discernible culmination during the spring season (April - June) (Figs 7 and 8). The highest loads of suspended matter occurred during months when high discharge events took place. This happened both during dry and wet years. During such months, 34 to 95% of the annual load of suspended matter from the Stara Rzeka River catchment and 31 to 73% of the annual load of suspended matter from Dworski stream is exported. During a single high flow event as much as 40% of the annual load can be exported (as compared to a 'wet' hydrological year) and twice as much as during a 'dry' hydrological year. This applies to both the Stara Rzeka River and Dworski stream catchments. During the hydrological years of 1993 and 1994 most of suspended particulate matter was exported from the two catchments during the winter season, especially during the snowmelt-related high flow events. The share of this six-month period reached 73.8-99.6% in the Stara Rzeka river and 85.6-93.0% in the Dworski stream. In the hydrological years 1995 and 1996 the majority of suspended matter was exported during the summer season (in both catchments and in similar percentages) (Fig. 9). The lowest monthly loads of suspended particulate matter were exported during summer or autumn low-flow periods, mainly in August and October (see Figs 7 and 8).

In the course of a year 213.8 tonnes in 1995 and 1,338.8 tonnes in 1996 of suspended matter were exported from the Stara Rzeka River catchment. The export

Fig. 5. Water discharge (Q) and concentration of suspended particulate matter (TSS) in Kubaleniec stream during the high flow of May 18-20 1994.

Rys. 5. Przepływ wody (Q) i koncentracja zawiesiny (TSS) w Kubaleńcu podczas wezbrania 18-20 maja 1994 r.

rate in the Dworski stream catchment ranged from 1.44 tonnes in 1993 to 12.48 tonnes in 1996.

Based on the studies carried out to date it can be stated that most of the suspended matter exported comes from the stream beds and their immediate surroundings. The concentration of suspended matter in surface runoff water on non-vegetated slopes reached a maximum of 176-264 mg l^{-1} and on grass-covered slopes - 34-63 mg l^{-1} (Krzemień, Święchowicz, 1992). The material washed out from ploughed slopes is accumulated on the flat, grass-covered valley bottoms (Phots 1 and 2). This process is particularly marked during high precipitation events and snowmelt periods. During major high-flow events in the tributaries of the Stara Rzeka river, the maximum

Fig. 6. Water discharge (Q) and concentration of suspended particulate matter (TSS) in the Dworski Potok stream during the high flow event on May 1-4, 1989.

Rys. 6. Przepływ wody (Q) i koncentracja zawiesiny (TSS) w Dworskim Potoku podczas wezbrania 1-4 maja 1989 r.

observed concentration of suspended particulate matter was 2006 mg l^{-1} in the Dworski stream (see Tab. 1). In the Stara Rzeka bed, the values recorded at the same time reached 13,298 mg l^{-1}. A similar situation occurred in the catchment of Kubaleniec, where the concentration of suspended particulate matter on the paths reached 308 mg l^{-1}, in field furrows up to 25,416 mg l^{-1}, within the valley bottom meadows 11 mg l^{-1} and in the bed of the Kubaleniec stream 166 mg l^{-1} (Wójcik, 1994). The material moved on the slopes (mainly in ploughing furrows and on the roads) is mostly accumulated at the foot of the slopes, on the borderline between ploughed fields and meadows (see Phots 1 and 2). The analysis of clastic material pathways from the summit areas, through the small streams beds to the main streams, indicates step increases of concentrations in the main streams. In the bed of Stara Rzeka, deeply incised in the valley bottom, at slightly higher flow rates, the stream can be supplied with particulate matter originating from river banks. The supply of clastic material is facilitated by the winding course of

Fig. 7. Monthly loads (in tons) of suspended particulate matter exported from the Stara Rzeka River catchment in 1993-1996.

Rys. 7. Miesięczne ładunki wyniesionej zawiesiny ze zlewni Starej Rzeki w latach 1993-1996 (w tonach).

Fig. 8. Monthly loads (in tons) of suspended particulate matter exported from the Dworski Potok Stream catchment in 1993-1996.

Rys. 8. Miesięczne ładunki wyniesionej zawiesiny ze zlewni Dworskiego Potoku w latach 1993-1996 (w tonach).

Phot. 1. Clastic material exported from ploughed fields and deposited on the meadow at the foot of the slopes in the Kubaleniec stream valley after intense precipitation on April 1-7, 1994 (total precipitation of 75 mm).

Fot. 1. Materiał klastyczny wynoszony z pól ornych i deponowany na łące u podnóża stoków w dolinie Kubaleńca po intensywnych opadach o sumie 75 mm w dniach 1-7 kwietnia 1994 r.

the river with numerous bank undercuts. It is also worth mentioning that the beds of small foothill water courses are mostly vegetated and that during high flow events, the reserves of material available for transportation are quickly exhausted (see Fig. 6). The suspended particulate matter exported from a foothill catchment originates from a small percentage of the total catchment area. The indexes of mechanical denudation (sediment yield) are rightly criticized for they do not provide comprehensive information on the export processes over short periods of time. They are however applied in literature. In the area investigated the indexes ranged from 4.96 to 43.04 tons km^{-2} per annum in the Dworski stream catchment and from 9.54 to 59.67 tons km^{-2} per annum in the Stara Rzeka catchment.

6. Relations between the types of material exported

The course and intensity of morphogenetic processes related to running water in a particular catchment can be well illustrated by the relationships between the types of material transported (Walling, Webb, 1981; Kostrzewski et al., 1994). In the area

Phot. 2. A fragment of the colluvial cone at the foot of a slope in the Kubaleniec Stream valley formed after the high flow event in April 1994.

Fot. 2. Fragment stożka proluwialnego u podnóża stoków w dolinie Kubaleńca, powstałego podczas wezbrania w kwietniu 1994 r.

studied the ratio between dissolved material (Ld) and suspended matter load (Ls) exported from the Stara Rzeka catchment ranged between 49.0:51.0 and 75.5:24.5. In the Dworski stream catchment this ratio ranged from 63.2:36.8 to 90.9:9.1. Assuming that Ls = 1, the ratios between the loads discussed are as follows:

	1993	1994	1995	1996
Stara Rzeka River (Ld:Ls)	1.43:1	0.96:1	3.08:1	1.01:1
Dworski (Ld:Ls)	9.97:1	4.50:1	4.46:1	1.71:1

The above values show the domination of chemical denudation processes over mechanical denudation. In larger catchments such as Stara Rzeka, chemical denudation may exceed mechanical erosion by a maximum of 300%. In 'wet' years however, mechanical denudation may be equal to the chemical process or become even more intense. In smaller catchments chemical denudation exceeds mechanical denudation by 170 to 1000%. Based on the data above it may be concluded that in the area of the Carpathian Foothills (at least in its marginal zone) chemical denudation exceeds mechanical denudation. This situation is thus different from that in the Beskid part of

Fig. 9. Percentage contributions of the winter (a) and summer (b) seasons in the export of suspended particulate matter from the Stara Rzeka River and Dworski stream catchments in 1993-1996.

Rys. 9. Procentowy udział wyniesionej zawiesiny ze zlewni Starej Rzeki i Dworskiego Potoku w półroczach: zimowym (a) i letnim (b) w latach 1993-1996.

the Carpathians (Froehlich, 1975). The idea that the degradation of the Carpathian Foothills due to the river export of suspended matter is definitely higher than in the Beskid Mountains (Łajczak, 1989, 1992) should also be verified. Mechanical denudation in the Foothills has until now been defined (due to the lack of other data) on the basis of values of fluvial denudation indicators calculated for transit rivers flowing through the area (Łajczak, 1989, 1992). These rivers (eg. Skawa, Raba, Dunajec) are fed in other regions and transported material comes in great measure from their channels. Calculated indicators of fluvial mechanical denudation can be considerably overestimated. The values calculated by A. Łajczak (1989) for the Carpathian Foothills, relative to the values registered for the Stara Rzeka catchment situated within the Foothill area are 25-40 times higher. Comparing results from around Łazy and values in the literature (Maruszczak, 1984; Łajczak 1989, 1992) leads to the conclusion that mechanical denudation in the Foothills is lower than in the Beskids (by between two and a dozen or so times).

7. Conclusions

In the Wieliczka Foothills the valley floors are broad and flat. They are cut with deep, steep-sloped channels, in which the stream beds are formed. The slopes are mostly occupied by ploughed fields and the bottoms of the valleys are covered with grasslands. Such relief and landuse pattern cause the stream beds to be weakly supplied with clastic material from the slopes. The material displaced on the slopes is mostly accumulated at the foot of the slopes and mainly originates from the beds of the water courses. Such a process leads to a widening of the channels which cut the valley floors. The relatively high diversity of the suspended particulate matter concentrations in particular streams depends on the stage of development of their beds and the supply of material from the surrounding area. Another discernible regularity is that the concentration of suspended particulate matter during high flow events increases with the increase in size of the stream bed. As in other areas, the role of high flow events in the export of matter from a particular catchment area is tremendous.

On the basis of several years of field studies and literature data on foothill catchments it may be concluded that the maximum values of suspended particulate matter concentrations in the Wieliczka Foothills are definitely lower than the corresponding values recorded in the rivers of the Beskid Mountains. Chemical denudation generally dominates over mechanical one. The direct geomorphological transformation of this area is however more dependent on mechanical denudation.

The studies carried out in the surroundings of the Research Field Centre in Łazy led to the conclusion that in the Carpathian Foothill area, chemical denudation dominates over mechanical one. Literature on the Beskid Mts., part of the Carpathians, indicates a reverse situation. The results obtained to date suggest that mechanical denudation in the area of the Wieliczka Foothills is significantly lower than in the Beskid Mountains.

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Transport materiału rozpuszczonego i zawiesiny w zlewniach Pogórza Wielickiego w okolicy Łazów

Streszczenie

W opracowaniu przedstawiono zróżnicowanie i sezonową zmienność transportu materiału rozpuszczonego i zawiesiny w wybranych zlewniach Pogórza Wielickiego. Na podstawie czteroletnich badań stwierdzono duży wpływ rzeźby pogórskiej na ograniczone przemieszczanie materiału klastycznego od grzbietów do koryt potoków. Na Pogórzu Wielickim dna dolin są szerokie i płaskie. Rozcięte są głębokimi rynnami o stromych zboczach. Materiał klastyczny, uruchomiony na stokach, zatrzymywany jest w większości u podnóża stoków i w obrębie płaskich den dolin. Transportowany materiał zawiesinowy w potokach pochodzi w dużym stopniu z samych koryt. Taki proces prowadzi do powiększania rynny, która rozcina dno doliny.

Na podstawie kilkuletnich badań terenowych i literatury dotyczącej zlewni pogórskich można stwierdzić, że maksymalne wartości koncentracji zawiesiny w rejonie Pogórza Wielickiego są zdecydowanie niższe niż analogiczne wartości uzyskane dla

rzek beskidzkich. W badanym terenie denudacja chemiczna ogólnie przeważa nad mechaniczną. Jednak o bezpośredniej transformacji geomorfologicznej tego obszaru decyduje w większym stopniu denudacja mechaniczna. Dotychczasowe wyniki badań sugerują, że denudacja mechaniczna na Pogórzu Wielickim jest zdecydowanie mniejsza niż w Beskidach. Wyniki te są więc odmienne od sugestii prezentowanych w literaturze z końca lat 80.