ACTA UNIVERSITATIS CAROLINAE
2003 GEOGRAPHICA, No. 1, PAG. 157–166

Transport of suspended sediments in various regions of the Czech Republic

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Abstract

The paper aimed at comparing the transport of suspended sediments in four model river basins, which are mutually comparable as to their area (350–400 km^2) and also represent different geographical environments within the territory of the Czech Republic. For model river basins were developed erosion risk models based on a multi-criterion scale evaluation of chief erosion factors and were implemented as a grid models in the GIS environment. The suspended sediment transport was evaluated for closing profiles of model river basins, mostly for a hydrological period 1985–2000. We defined basic types of run-off situations to characterise the relationship between the content of suspended sediments and the water flow.

Key words: water soil erosion, suspended sediments, Czechia

Introduction

Sediments in a suspension represent an important component in the overall balance of material circulation in river basins. The slope erosion or soil erosion, respectively, is considered to be their main source. The amount of suspended sediments in natural conditions provides information on the intensity of denudation and erosion processes in river basins. The goal of the study has been to compare the transport of suspended sediments in four model river basins of a comparable area (350–400 sq. km), which at the same time represent environments of the Czech Republic mutually different from the geographic point of view. The existence of data sources and availability of geographic data bases in the GIS environment represented an important criterion for selection of the model river basins.

A/ The Blšanka river basin is situated in a region of north-western Bohemia with a warm climate and with a poor volume of rainfalls. Permian and Carboniferous sediments prevail in the subsoil, on which the eutric cambisols and orthic luvisols have developed. The region with low slopes is utilized agriculturally in an intensive manner, hop growing is a traditional activity. 30% of the river basin is wooded. There are no larger residential areas nor industry present in the river basin.
B/ The Loučka river basin is represented by a region of the Bohemian-Moravian Uplands having a rather cold climate. Metamorphed rocks prevail in the subsoil. Dystric cambisols represent the dominant soils. The region with its low slopes is utilized

agriculturally, potato and corn growing is typical. 20% of the river basin is wooded. Nové Město na Moravě is the only larger residential area and an industrial centre.

C/ The Olšava river basin is found in a region of Moravian-Slovak Carpathian Mountains having a warm climate. The subsoil is formed by flysch. Besides the most widespread eutric cambisols, chernozems are present in a greater extent here, as well. The territory is articulated, there are also rather sloped areas here, utilized agriculturally. 40% of the river basin is wooded. Uherský Brod is the only larger residential area and an industrial centre.

D/ The Lužická Nisa river basin is found in the Jizerské Mountains region with a rather cold climate and a rich volume of rainfalls. Granites prevail in the subsoil, on which the podzols and dystric cambisols have developed. The territory is highly articulated, sloped. 50% of the river basin is wooded, arable land occupies only 20% of the river basin area. There are significant agglomerations found in the river basin, namely Liberec and Jablonec nad Nisou, with a significant representation of industry.

Hydrological and precipitation parameters of the river basins studied are provided in the Table 1.

Tab. 1 Hydrological, precipitation and sediments transport parameters of river basins

	Blšanka	**Olšava**	**Loučka**	**Lužická Nisa**
Area of river basins (km^2)	374.06	401.13	385.70	355.60
Precipitation (mm)	508.8	718.6	645.6	896.7
Discharge Q (m^3/s)	0.8	2.18	2.12	5.47
Turbidity c (mg/l)	61.3	64.6	43.7	38.5
Turbidity c-max (mg/l)	4872.0	7500.0	9826.2	1321.6
Outflow of susp. sediments G (t/year)	2840.1	18572.7	8283.4	8058.2

Fig. 1 Delimitation of the model river basins in the Czech Republic

Erosion Risk Modelling

A model of the river basin exposure to erosion has been developed for the river basins observed, based on a multi-criterial point evaluation of the major erosion factors. The goal was to compare the river basin potential for suspended sediments transport and to delimit main risk areas. Four main factors were used for modelling of the erosion

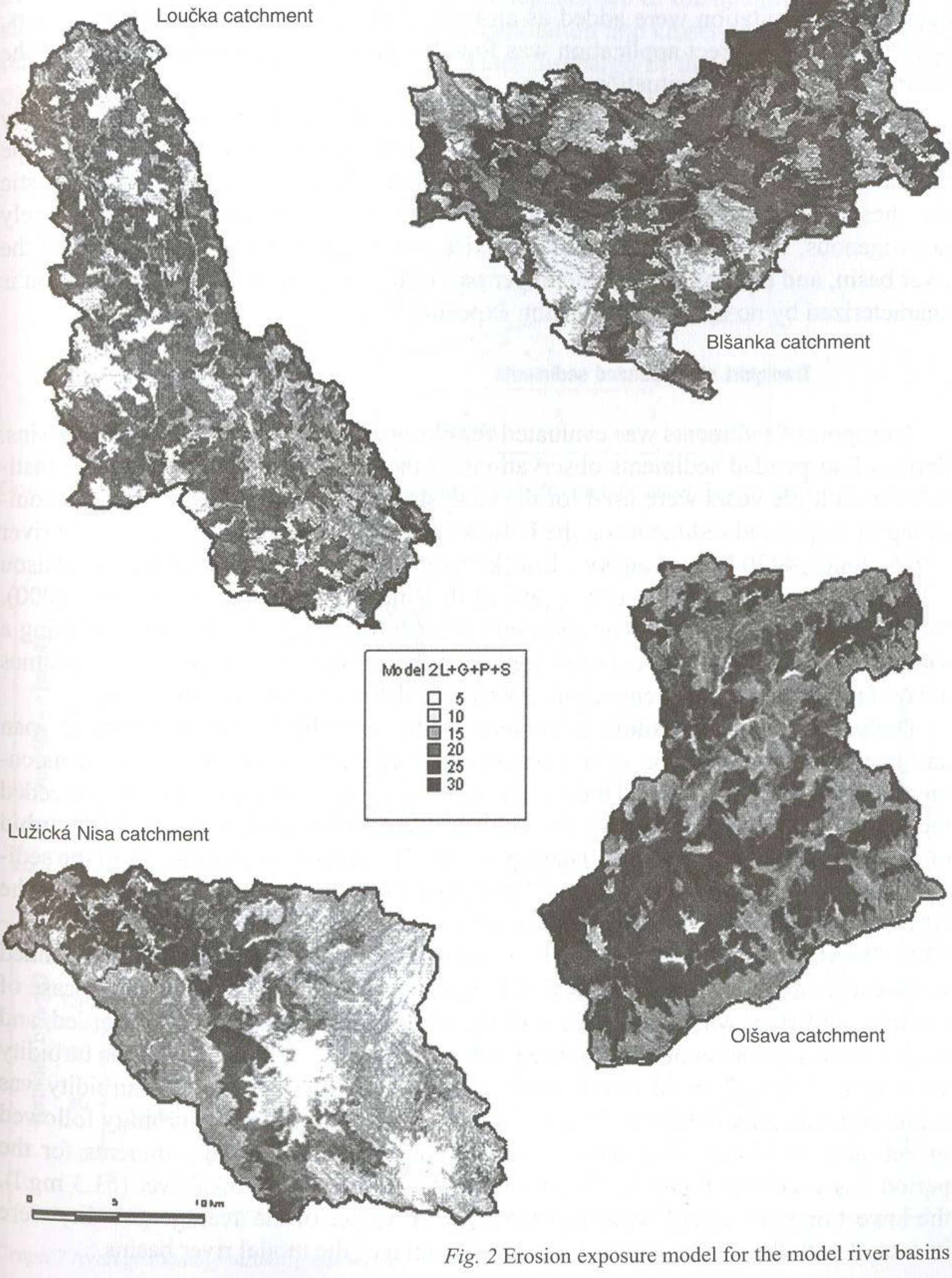


Fig. 2 Erosion exposure model for the model river basins

risk, which affect the involvement and course of the erosion process: *the inclination, the geological subsoil, the soil erodibility, and the land cover*. Individual factors derived from digital ground data were transformed into a uniform grid of the size 100 × 100 m. The basic variant of the model represented a simple sum of points from the four main layers. The overall situation in the river basins was better characterized by a model in which the region cover factor weight was doubled (Fig. 2). The accentuation of this factor substituted in a certain extent consideration of the slope lengths. Data on aggregate precipitation were added as an individual variant input to the four factors, nevertheless their direct application was found to be not very suitable considering the overall distortion of the situation.

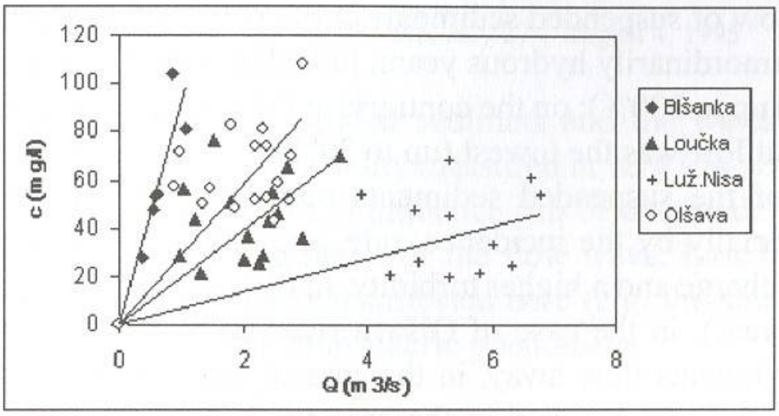
The Olšava river basin was shown to be most liable to erosion, markedly higher than other river basins studied, followed by the Blšanka river basin and the Loučka river basin. Even distribution of the erosion risk in the territory is characteristic for these river basins. The Lužická Nisa river basin was shown to be entirely heterogenous, where a significant erosion risk is concentrated in the lower part of the river basin, and on the contrary, the upper part of the river basin rich in precipitation is characterized by no up to slight erosion exposure.

Transport of suspended sediments

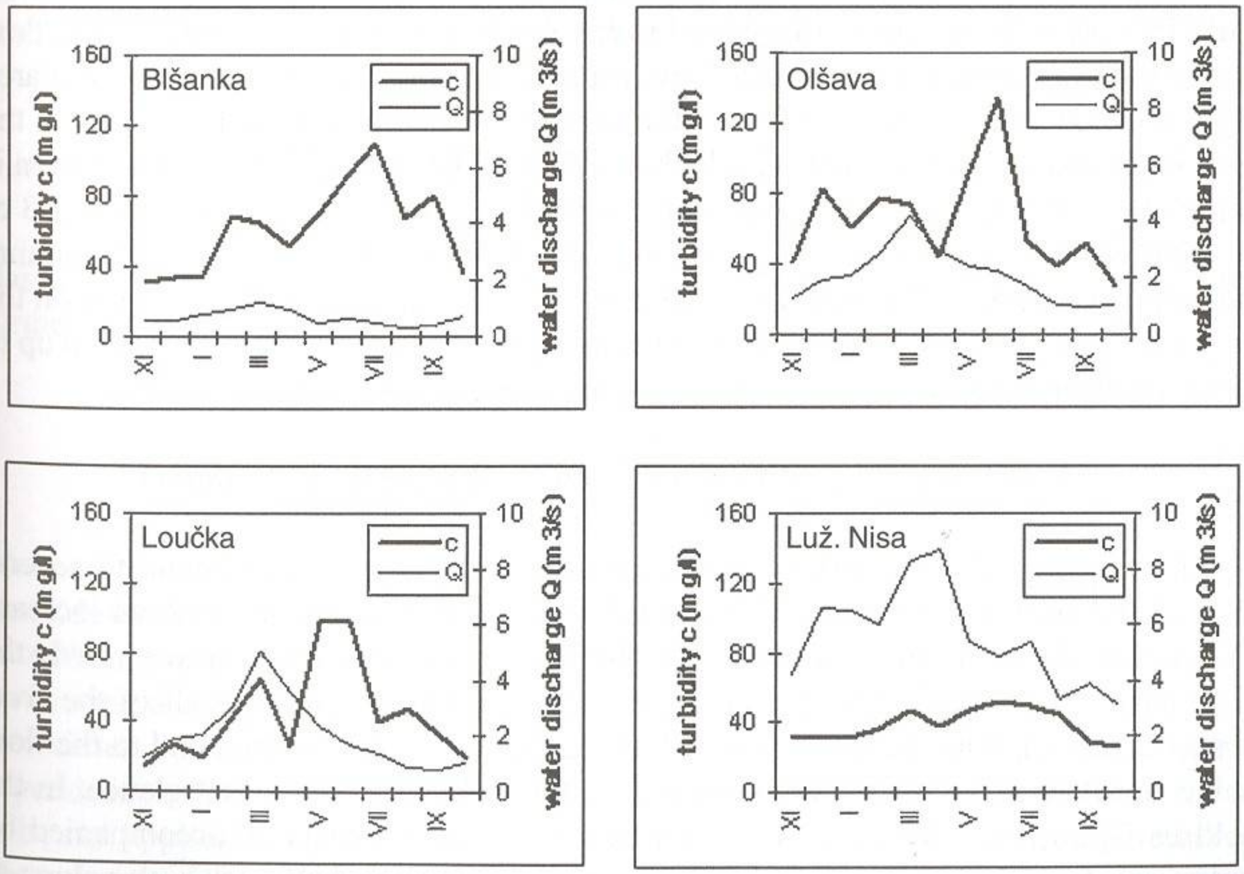
Transport of sediments was evaluated for closure profiles of the model river basins. Series of suspended sediments observations of the Czech Hydrometeorological Institute for multiple years were used for the analysis, as well as data from our own monitoring of suspended sediments on the Blšanka river: 4180 Uherský Brod – Olšava river (1985–2000), 4470 Dolní Loučky – Loučka river (1985–2000), 3200 Hrádek nad Nisou – Lužická Nisa river (1985–1997), and 2170 Holedeč – Blšanka river (1995–2000). Water samples were taken using the same procedure, namely by the observer using a sampler, by means of the integration method in the vertical, once a day or several times a day if needed. The sediments content was then determined in the laboratory.

Daily values of the sediments content (or the turbidity) showed a marked span and instability in the course of the period observed. Low levels of the sediments content up to 20 mg/l were found most often. In the long-term average, turbidity exceeded the value of 70 mg/l in 60 days per year; in the Loučka river, which is least turbid most of the year, it was only in 30 days per year. The maximum daily levels of the sediments content exceeded the values of 5000 mg/l; the highest value was observed in the case of Loučka river – 9826.2 mg/l, the lowest one in the case of Lužická Nisa river – 1321.6 mg/l. In case of turbidity levels above 1000 mg/l, 40–50% of the total suspended sediments amount was carried away. A different situation was observed in the case of Lužická Nisa river where high values of the sediments content were not recorded, and 62.3% of the total amount of suspended sediments were drifted away with the turbidity value up to 100 mg/l. In the rivers observed, the highest average monthly turbidity was achieved identically in May to July, the second period of the highest turbidity followed in February to March. The highest average content of suspended sediments for the period observed was found in Olšava river (64.6 mg/l) and Blšanka river (61.3 mg/l), the lowest one in Lužická Nisa river (38.5 mg/l). Values of the average turbidity were in accord with the total calculated erosion potential of the model river basins.

Besides the sediments content, resulting flows of suspended sediments through the given profiles were affected in the case of the rivers observed by the overall water discharge of the water courses. The relationship between average yearly contents of suspended sediments and average yearly flows of water is shown by the synoptic graph. In spite of the lowest water discharge out of the water courses studied, Blšanka river reaches a high average turbidity value. The lowest turbidity connected with a high average flow of water and absolute mutual independence of the quantities observed is shown by Lužická Nisa river. The tangent inclination and closeness of the regression relationship are affected by the different water discharge of the water course, and by different conditions for water erosion in the model river basins (Graph 1).



Graph 1 Relationship between average yearly values of turbidity and the water flow in the period observed



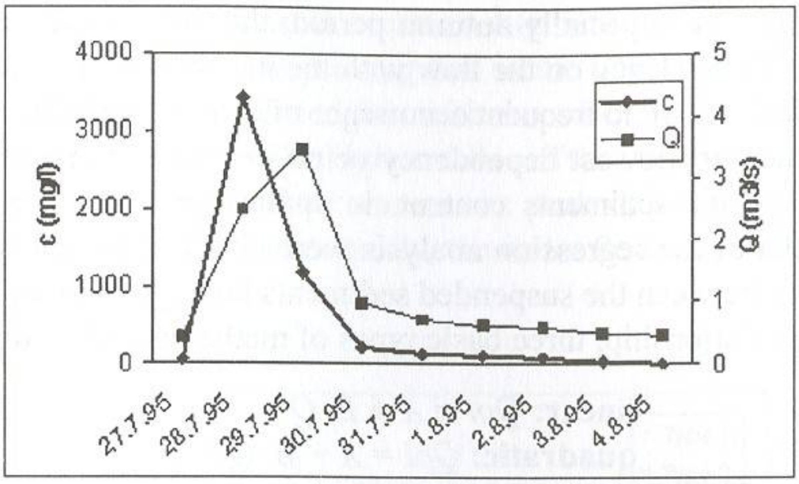
Graph 2 Average monthly turbidity and water flow values for the period observed

The highest average outflow of suspended sediments in the period observed was seen in the case of Olšava river (18572.7 t/year), and it was roughly equal to the sum of the sediments outflow in the remaining river basins. Almost an identical value of the average yearly outflow of suspended sediments was seen in the case of Loučka river and Lužická Nisa river, in spite of different conditions of the sediments transport. The lowest outflow of suspended sediments with a high average turbidity was seen in Blšanka river (2840.1 t/year). With regard to the fact that the river basin is almost identical, similar relationships hold also for the specific outflow of suspended sediments. If we considered only the arable land area as the main source area of transported sediments, the average specific outflow of suspended sediments would be as follows (in t/sq. km/year): Olšava river – 106.9; Blšanka river – 15.7; Loučka river – 36.4; Lužická Nisa river – 99.2!. The yearly outflow of suspended sediments in the period observed reached the highest values in the extraordinarily hydrous years, linked to higher yearly aggregate volumes of precipitation (up to 300%); on the contrary, in the extraordinarily little hydrous years the sediments outflow was the lowest (up to 20%).

The extent of the suspended sediments outflow in the course of the year was determined especially by the incidence, rate, and nature of outflow situations with a higher water discharge and a higher turbidity. In discharges Q_{30} (reached and exceeded in 30 days per year), in the case of Olšava river up to 89.4% of the yearly amount of suspended sediments flow away, in the case of Loučka river it was 76.9%, in the case of Blšanka river 69.3%, and in the case Lužická Nisa river it was only 37.5%. This provides evidence about the relationship between the amount of the sediments transported and the water flow, and it confirms the main origin of suspended sediments from areal sources linked to erosion processes in the river basins. In the case of Lužická Nisa river, we can attribute the lower value of the suspended sediments outflow and of turbidity in the case of higher flows especially to the high degree of wooded area representation in the river basin. The sediments outflow in the vegetation half-year in the river basins observed exceeded slightly the outflow in the cold half-year. The situation is somewhat different from the viewpoint of main year seasons, nevertheless about 1/3 of the outflow fell on the spring, 1/3 on the summer, 1/4 on the winter and 1/8 on the autumn. A certain exception in this scheme is represented by Loučka river where 1/2 fell on the very spring, in spite of elimination of the extreme situation from May 1985 when up to 235% of the average yearly amount of suspended sediments had flowed away.

Relationship of the Sediments with the Water Flow and Causal Phenomena

The majority of the suspended sediments amount transported is bound to several days of the year. The period of higher turbidity is usually connected with an increase of the water flow caused by rainfalls, possibly also by melting of the snow cover in the river basin, accompanied by precipitation. The situation is similar in all of the river basins observed, with the exception of Lužická Nisa river where the bond to the flow value and thus to the causal phenomena is not as evidential at the first glance. In the cold half-year, high values of the water flow are usually observed, accompanied by lower values of turbidity; on the contrary, in the vegetation half-year high values of turbidity are found, accompanied by rather lower values of the water flow.



Graph 3 Situation of type 1 – Blšanka, July 27 – August 4, 1995

The relationship between the suspended sedimets and the water flow is further affected negatively by high values of turbidity measured in very low water flows, based on which a certain direct anthropogenous influence can be assumed, as well as lower values of turbidity in the descending phase of the flow wave. Last but not least, the momentary nature of the river basin is manifested here (e.g. the state of agricultural utilization), and the course of causal atmospheric phenomena.

In general, the suspended sediments content rises with the increasing flow. We can come to this conclusion when we work for example with the values of group averages. Exploring of the direct relationship between daily values of turbidity (c) and the water flow (Q) was problematic. Out of the regression dependencies, classical types of mathematical models were tested:

linear: $c = A + B \cdot Q$ (1)

quadratic: $c = A + B \cdot Q + C \cdot Q^2$ (2)

power function: $c = A \cdot e^{B.Q}$ (3)

Based on knowledge obtained from the time series analysis, dependency models were further applied in the form:

linear: $c = A + B \cdot \Delta Q$ (4)

quadratic: $c = A + B \cdot \Delta Q + C \cdot \Delta Q^2$ (5)

linear: $c = A + B \cdot Q + C \cdot \Delta Q,$ (6)

where ΔQ is the quotient $Q/Q-1$ (the flow increase expressed by the quotient of the given daily flow against the previous day flow).

Although a convenient closeness of the relationships observed was not reached, certain trends appeared. The best results of the regression analysis were obtained for the winter period, using models (1) and especially (2), which confirmed a certain dependency of the turbidity value on the water flow. However, these models were found to be not applicable for the remaining part of the year in which case a more marked dependency of the turbidity value on the water flow increase compared to the previous day ΔQ (4) was found on the contrary.

For the summer and especially autumn period, the linear model of the suspended sediments content dependency on the flow with the member ΔQ (6) was tested with the highest quality. With regard to frequent occurrence of extreme turbidity values, the spring period showed the very lowest dependency or no dependency, respectively, between the water flow and the sediments content, in application of different models. More satisfactory results of the regression analysis were obtained by means of observation of the relationship between the suspended sediments flow Qpl and the water flow Q. In searching for the relationship, three basic types of mathematical models were tested:

$$\textbf{linear: } Qpl = A + B \cdot Q \quad (7)$$

$$\textbf{quadratic: } Qpl = A + B \cdot Q + C \cdot Q^2 \quad (8)$$

$$\textbf{power function: } Qpl = A \cdot e^{B.Q} \quad (9)$$

The dependency was best characterized by the quadratic model (8). The power function relationship, in spite of higher values of the correlation coefficient, did not describe sufficiently especially the higher values of turbidity. A higher level of closeness was achieved especially for the winter period, the lowest one for the spring period.

Situations with the Turbidity Higher than 500 mg/l

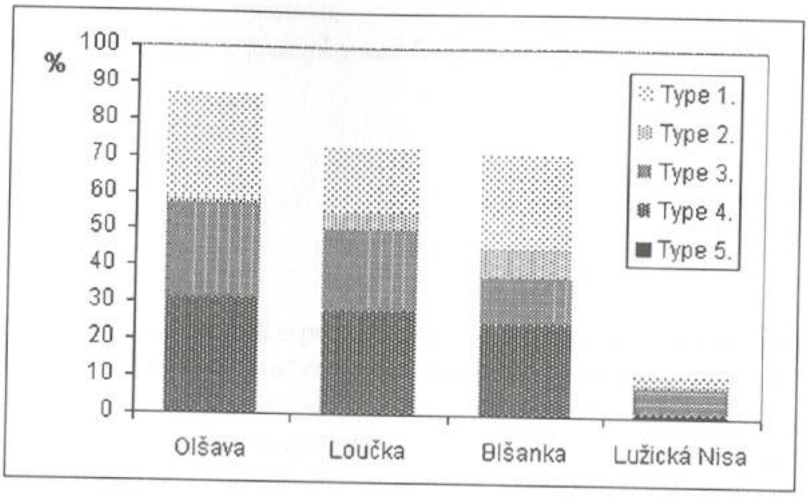
A special attention was devoted to situations in which the turbidity value of 500 mg/l was achieved and exceeded. The situations were delimited based on the time course of daily turbidity values and the water flow. The suspended sediments outflow in the course of these situations reached more than 70% of the total amount of suspended sediments carried away, with the exception of Lužická Nisa river. At the same time, standardization of these situations was performed in individual river basins. In general, they can be characterized as follows:

SITUATION TYPES

1. Intensive summer, short-term (one-day or two-day at the maximum) rainfalls in the whole river basin, causing sudden increases of the water flow multiple times, in which the highest turbidity were measured. With regard to the previous period with no rainfalls, the water flows usually did not reach the highest values.
2. Local intensive summer rainfalls which did cause higher turbidity but in effect they were not manifested by the water flow increase in the main water course bed.
3. Several days lasting rainfalls in the whole river basin causing the highest water flows, however, turbidity did not reach the highest values.
4. Melting of snow in the river basin with subsequent rainfalls causing higher flow situations and increased turbidity due to the river basin saturation with water.
5. Anthropogenous influence on the turbidity, without perceptible manifestations in the water flow and rainfalls.

It can be observed in the graph that proportions between individual situation types remain roughly similar in the river basins examined. In Blšanka river, local rains were manifested in the higher values of turbidity; in Lužická Nisa river, a certain anthropogenous effect was apparent.

In the case of outflow situations, the relationship between turbidity and water flow was re-examined. We succeeded in proving that in the time of the ascending phase of the flow wave, turbidity values were higher with the water flow being the same than in the time of the descending phase. The highest value of the suspended sediments content was reached in the course of the flow wave at its peak or very often it preceded this peak. While turbidity declined rather rapidly, the water flow returned to normal values rather slowly.



Graph 4 Share of situation types in the total suspended sediments outflow

Conclusion

The suspended sediments transport in the river basins observed represented especially a natural process, without a rather significant direct anthropogenous effect, with the exception of Lužická Nisa river. The differences in the sediments transport represent a manifestation of different conditions of the soil erosion. The resulting outflow of the suspended sediments is affected in a considerable extent by the different rainfall-outflow balance of individual river basins. The highest outflow of the suspended sediments was found in the case of the Olšava river basin most exposed to erosion. The Blšanka river basin, in spite of the high erosion risk, showed the lowest suspended sediments outflow with regard to the low average water content. In the case of Loučka river, comparable with Olšava river from the viewpoint of the average yearly water discharge, the generally lower but uniformly distributed level of the erosion risk was shown in the resulting suspended sediments outflow. The Lužická Nisa river basin was found to be entirely specific, with the generally lowest level of the erosion risk, high average rainfall and water content, and with the found independence between turbidity values and the water discharge.

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