2nd International Conference - Water resources and wetlands. 11-13 September, 2014 Tulcea (Romania); Available online at http://www.limnology.ro/water2014/proceedings.html
Editors: Petre Gâştescu ; Włodzimierz Marszelewski ; Petre Bretcan; ISSN: 2285-7923; Pages: 158-165;

LATERAL CHANGES AND RESPONSES OF CHANNEL AND FLOOD PLAIN IN A SECTOR OF MORAVA RIVER. A DYACHRONIC APPROACH

Gabriela Adina Moroșanu
University of Bucharest/Faculty of Geography
Bucharest, Romania, Email beju_gaby@yahoo.com

Abstract

The present study is based on a spatial and temporal analysis of the active channel and associated floodplain of Morava River between Bezenec Privoz and Rohatec villages using aerial photographs and topographic maps spanning six decades (1953, 1982 and 2005) over a 10 km length. Planimetric changes were analysed longitudinally and temporally in oder to highlight the spatial structures and their evolution through time. The results underline complex changes and space–time pattern in bank erosion, sediment accumulation, channel length and active channel width. Bank erosion and accumulation, but also channel lengthening were greater between 1982 and 2005 than in the first 30 years. Active channel width significantly decreased from 1953 to 2005; in part progressively from upstream to downstream with local widening, but in general the distance between the two river-banks had the tendency to shrink. The interpretation of these changes is complex due to various human pressures acting over different time scales (bank protection, land-use changes) and various natural influences (flood sequences throughout the period, geological setting, reappearance of riparian woody vegetation due to changes in the succession of convex-concave riverbanks). The findings are discussed by means of a comparison between the periods and highlight the important effect of sediment accumulation in modifying longitudinally hydraulic conditions within the channel, but also the functionality of former floodplain lakes, which are nowadays emerged and cultivated or naturally and artificially forested. Variation in thalweg line curvature and also channels planimetry and floodplain characters were considered as having a positive effect on the bank erosion pattern.

Keywords: Morava River, Straznice hydrometric station, meanders, fluvial geomorphology

1. INTRODUCTION

The geographical advances of recent years include the emergence of new methods of ”interrogating” the space through various approaches, such as the geographic information systems and remote sensing. Riverbank morphology is the testimony of river dynamics, and thus, fluvial systems are among the elements of the landscape most vulnerable to human activity and environmental shifts, a fact often reflected in major changes to the entire drainage pattern. In this way, the dynamic nature of a fluvial system requires a soft recognition, involving both past and recent morphology changes, but also continuous monitoring of fluvial system responses. The dynamics of river meanders has been a subject advocated by many researchers (Leopold & Walman, 1960; Ichim et al., 1989; Micheli & Larsen, 2010; Brázdil et al., 2011; Ondruch, 2012).

Meandering processes occur in the case of large rivers, as well as tiny streams evolution, thus leading to the formation of characteristic landscapes (Grecu, 2008). By virtue of lateral erosion and overbank sedimentation over a time period ample enough to be considered valuable for the geomorphological scale, a floodplain may develop. Unconsolidated floodplain sediments encourage subsequent lateral erosion, thus supporting the progression of meanders (Grecu, 2008; Ichim et al., 1989). Sometimes, it is possible that two meanders come along, each one narrowing the other’s neck, which could lead to a breakthrough and to the genesis of abandoned meanders (Rădoane et al., 2003; Grecu, 2008; Richard, 2001).

Fluvial processes typically result from the mechanism of flowing water (permanent or intermittent) on the earth's surface (Leopold & Walman, 1960). Channel processes are only caused by rivers, which consist in essence of fluvial processes, such as land surface erosion, transport and accumulation processes, in which the fluvial landforms are created. River morphodynamics are extremely complex because they include the water agent, the riverbed topography, analyzed both in the plan and in longitudinal section, transported and accumulated deposits (Nanson, 1981; Rădoane et a., 2003). Thus, formation, dynamics and evolution of riverbeds are the result of continuous interaction between water and geological substrate, directly related to the action of gravity and slope.

Since the dynamics of rivers generally obey the laws of fluid dynamics, with adjustments imposed by the particularities of the channel bed (morphometry, morphography, rock), an important role in the dynamics of water flow is assigned to riverbed processes and the discharge pressure distributed in the channel (Nansen, 1981). In sectors with high speed characteristics, caused by bed or flow path narrowing, water movement produces changes in the silt sediment transport due to water pressure on alluvial bed (Ichim et al., 1989; Grecu, 2008). It is the transformation of energy available in transport activity, which is responsible for modeling alluvial beds. The issued raised by these processes conduct the researchers to a series of experiments, some of them being able to explain the lateral erosion or accumulation of the riverbed. In alluvial beds essential processes are dependent on the redistribution of mobile materials or those easily mobilized (Nansen, 1981; Michalková et al., 2011). The river's lateral erosion produces a quantity of sediment that the river carries from the source area to the deposition. Part of eroded materials, depending on the particular topography, slopes and riverbeds morphometric and hydrological features remain on the slopes or will stay at the basis of meanders' formation (Kondolf et al., 2002).

In terms of hydrology, river channel is used during the medium water phase to reach the level of "bankfull discharge", a limit width of the channel, which is the result of fluid flow and solid action and, in turn, is determined by a number of control variables (geology, relief, climate, land use) on a certain time scale (Ioana-Toroimac, 2009). Keeping the link between fluvial morphology and hydrology, it is worth mentioning that important contributions to the development of this axis of research were made by Leopold and Wolman (1960), Kondolf et al., 2002, Micheli & Larsen, 2010, etc. Their arguments plead in favor of a balance between erosion, transport and accumulation, as key factors leading to the creation of fluvial forms. Other fluvial geomorphology studies moved forward, in order to search for the meandering riverbeds, as particular subjects in this field (Richard, 2001; Rădoane et al., 2003; Ondruch, 2012).

Coming closer from the background of the topic to our study area, a brief explanation about the river sector that we took into consideration is mandatory. In the Czech Republic, there are only two major lowland rivers capable to form large meander belts. Morava River is one of them, being not only a significant fluvial system, but also widely debated in fluvial geomorphology so far (Kadlec, 2009; Brázdzil et al., 2011; Ondruch, 2012).

Morava is a major river running through the eastern part of the Czech Republic at an average altitude of 200-250 m, and springing on the southwestern slope of Králický Snežník Mountain (1380 m altitude). From the entire river, we selected a section, which is extended on almost 10 km length between Bezenec Privoz and Rohatec villages, in the Strážnické Pomoraví area (Figure 1).

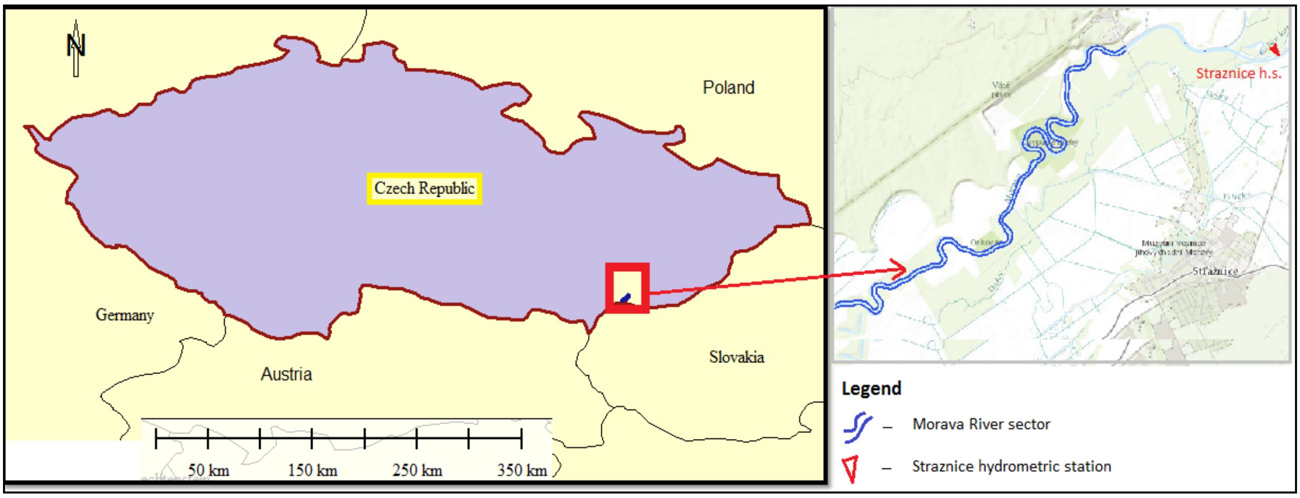

Figure 1. The location of the studied river sector

The study site is proper for such a research due to its meandering aspect, but also due to the presence of Strážnice hydrometrical station, which covers a catchment area of 9147 km^2 (34.4% of the whole Morava catchment). The watercourse sector under study is considered in the literature of topic a meandering lowland river. From this premise, the paper contribution consists in presenting the meanders' evolution in the interval 1952-2005 and the hydrological variability, a relationship which has received little attention, compared to other Czech rivers (Brázdil et al., 2011).

Before concluding the introductory section, some geographical information should be provided. The river sector under study belongs to the Lower-Moravian Valley, located between the Upper Moravian Valley, the Moravian Field, the Carpathian Mountains and Záhorie Lowland (near Bratislava, Slovakia) and is a couple of kilometers north from the border between Czech Republic, Slovakia and Austria (Ondruch, 2012). Being a dynamic river, the central idea of the study is the geomorphological characteristic of the river, consisting in a riverbed of sandy gravels and fine-grained riverbanks formed of cohesive silts (Kadlec, 2009). The GIS analysis of the integrated cartographical documents gave us a clue as to the diachronic evolution of the Morava River in the sector of interest.

2. METHODOLOGY

Morava River is suitable for analyzing meandering processes, meander migration and alluvial forms generation, due to the fact that it allows for a prediction of river channel behavior, in which variability dictates the evolution in time of every parameter. Such a conclusive study can only be built upon a dyachronic analysis of the riverbed. Thus, we hypothesized that Morava River has a wide potential for such a research and it can provide an ideal opportunity to quantify fundamental channel processes and detect changes in meanders' positions. Moreover, such dynamics, followed on any cartographical document by means of analyzing historical and present-day maps, record the change of meandering patterns, registered in the geometry of alluvial forms and types of vegetation.

The research data that we used were the Czech cadastral maps from the 1950s and 1980s (scale 1:50,000), the orthophotomap from 2005 and the annual and monthly discharges at Straznice station for the period 1950-2009.

After a first eye-view of the historical aspect of Morava sector under study (the delineation of the river channel from the cadastral maps), we digitalized the actual (2005) river bank shape and position directly from the orthophotomap, in an attempt to evaluate the dynamics of Morava river between the intervals taken into consideration (1953, 1982 and 2005).

The preliminary exploration of the maps in ArcGIS was followed by either by the delimitation of bank-forms, or by the delimitation of the successive position of Morava's riverbed. Long-term examination of the alluvial land forms, by digitalizing the left and right river banks of Morava according to the orthophotomap from 2005, was achieved in order to estimate the type of dynamical processes that occur presently along the analyzed river sector.

In addition, the investigation was perfected by using different chromatics and symbols on the resulting meander, meander amplitude, meander radius and alluvial forms maps, that helped us to more easily interpret the environmental changes along the river banks that occured in the studied intervals, the actual riverbank functioning, recent evolution and geographical consequences.

Nonetheless, the study ended with the calculation of certain morphologic coefficients for the three referenced years as well as the appreciation of the meanders' number, their geometry, and the correlations between all these fluvial geomorphological changes and discharge variability, from a statistical approach.

3. RESULTS AND DISCUSSIONS

Overall morphology of a meander depends on its morphometric elements and the meander loop. This is the starting point of our diachronic analysis, since each channel segment can enroll in a curve, which provides us with the necessary information to draw the radius evolution of a river's meanders (Grecu, 2008). Leopold and Wolman (1960) proposed the first classification criteria of meanders, identifying them as straight, meandering and braided.

Using channel vectors digitalized after the three cartographical documents mentioned before, we could formulate our own considerations on the meanders of Morava River.

Firstly, it is welcome to describe the general aspect of meanders in the three referenced years, as it can be plainly seen in Figure 2.

Inspection of the meanders shows that the river retains all basic morphometric features during the entire interval, thus preserving its curving aspect. However, there was an increase in the dynamic until the 1980s (the evolution towards complex forms meanders) and the last 25 years (deadlifts and shortening of the minor bed due to sandy accumulations).

The second step was to calculate the radiusand amplitude of each meander (Figure 3) (defined as the distance measured perpendicularly to the length of the meander).

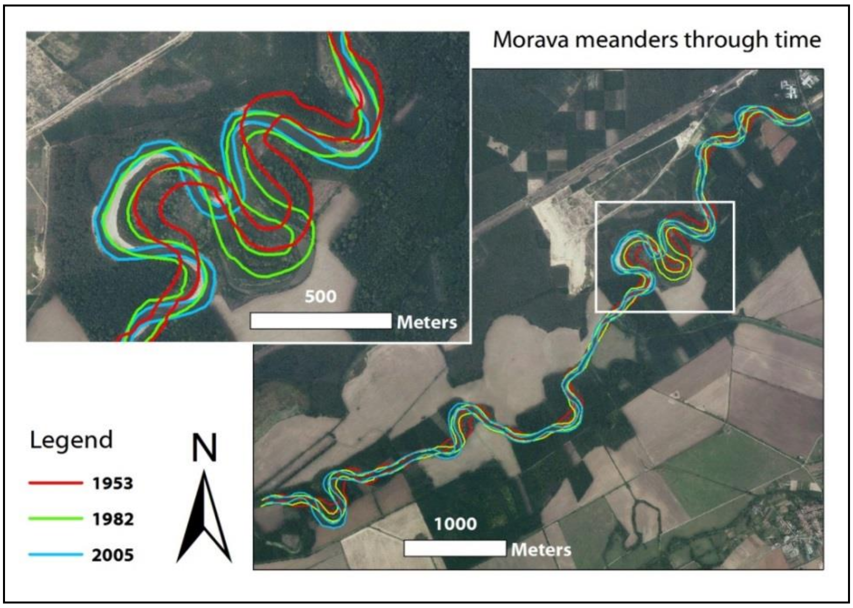

Figure 2. The meandering channel of Morava River sector under study between 1953 and 2005

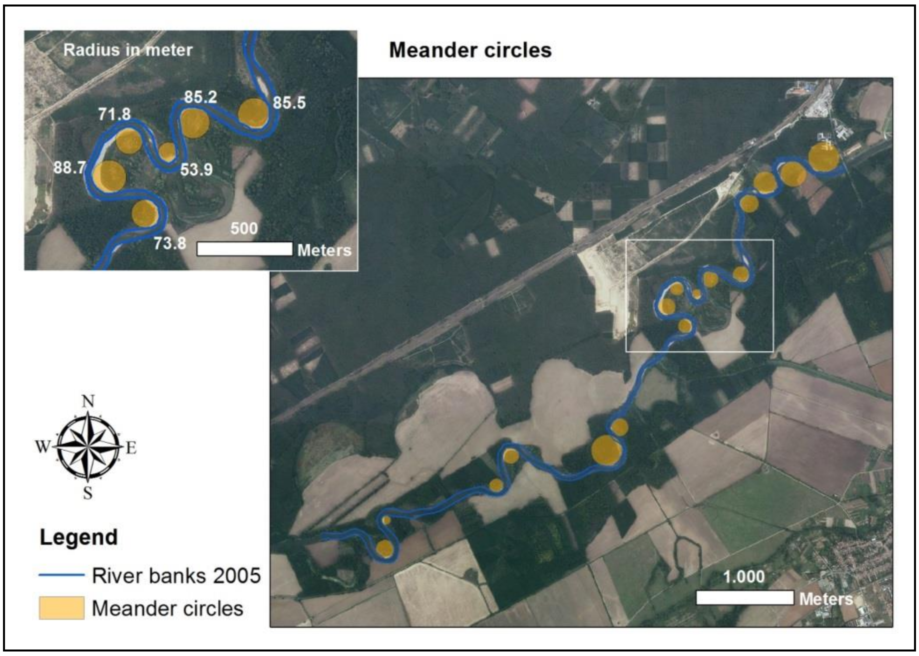

Figure 3. Map of meanders' radius

The peculiarities appearing on the meanders from one period to another were relevant from the point of view of alluvial plain formation, which is characterized by alluvial deposition created exclusively by lateral erosion processes and fluvial transport and not influenced by slope.

From the first map, we were able to calculate the number of meanders and the sinuosity index. For the first parameter, we observed that the number of meanders was constant (8 meanders) in all three situations, while the sinuosity index surpassed the critical value of 1.4 (the limit between sinuous and meandered rivers) and increased progressively from 1.46 (1953), to 1.62 (1982) and 1.73 (2005).

For a more rigorous examination of the meander radius, we constructed three box plot graphs (for each year), and tried to estimate the differences between them (Figure 4a). On the right side, a zoom-in on the most complex meandering sub-sector is illustrated, nominating a site were the river migration was active (Figure 4b).

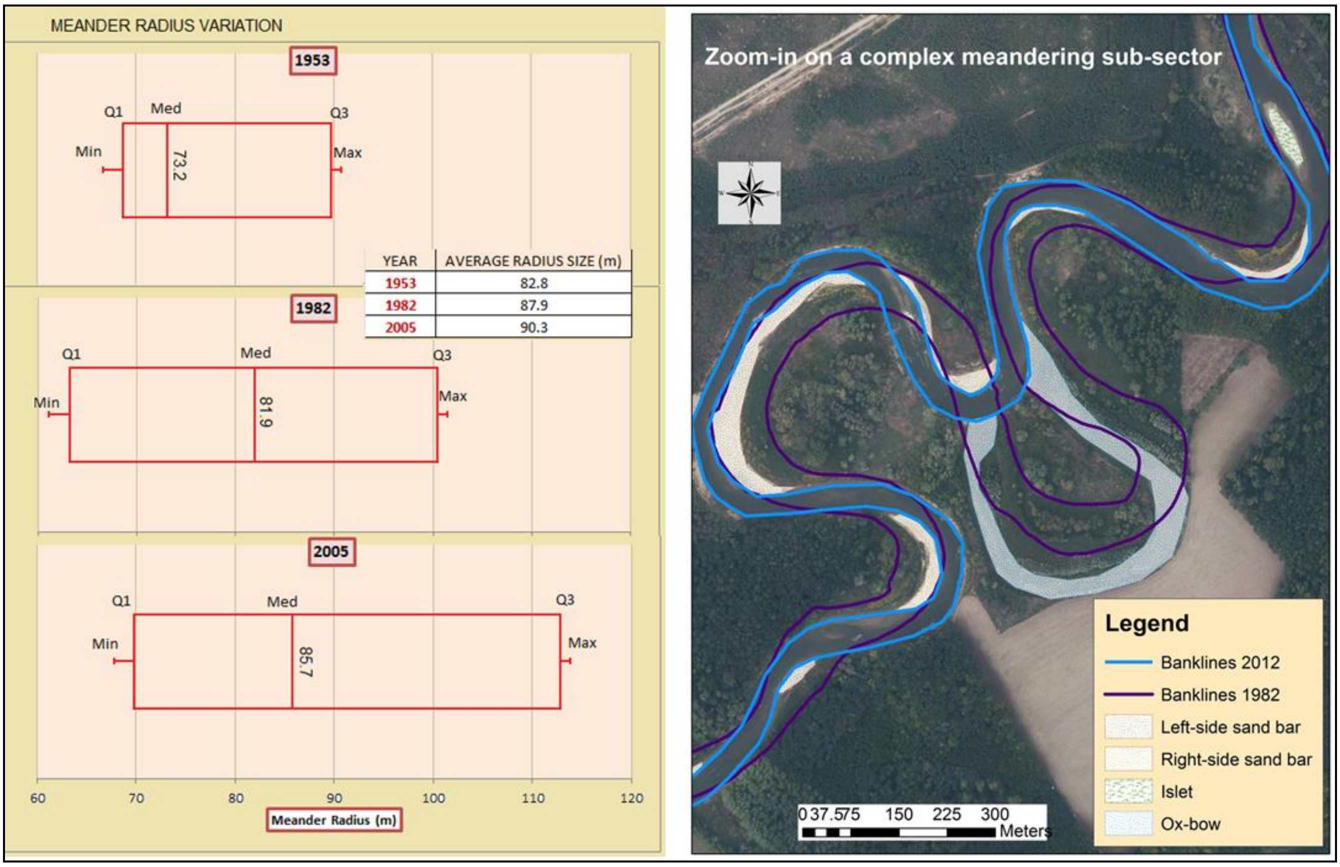

Figure 4. Box-plot of the meander radius variation (a) and meander loop zoom-in (b)

By reading the graph, it is possible to notice an increase in the meander radius from a value of 82.8 m (1953), to 90.3 m (2005). This finding may be explained through the accumulation process on the sides of the forested river banks, where meander loops tend to become even more convex and curved. However, riverbed morphology seems unbalanced by the presence of shallows, islets and sand shores. Excessive meandering leads to reduced slope meanders and a decreased capacity of streams to carry sediments from the bottom. In this way, meanders rapidly evolve and, even if we do not have a large number of cartographical witnesses, we may deduce where the point stream will create a new meander loop, as shown in Figure 4b. The complexity of the chosen meander, as shown on the map, is also demonstrated by the differences in position between the last two meanders (1982 and 2005) and by the various alluvial forms (ox-bows, sand bars, etc.). The oscillatory current of water can restore old meanders or even predict the in-training and erosion. Besides, meander irregularities (asymmetrical and more developed on the right side than on the left side) may be at the origin of the development of a new generation of meanders. Migrating meanders have a positive effect on water balance, flood mitigation and represent a habitat for floodplain biodiversity (Micheli & Larsen, 2010). Figure 5 indicates that the meanders' amplitudes from the right side are more ample, and this aspect is confirmed by the higher significance of the trend line equation. More precisely, on the left side, there are more powerful fluvial processes, especially accumulation ones, emphasized by the big meander curves and the formation of a large ox-bow in the interval between 1982 and 2005, when the river advanced more. Following this episode, it rapidly moved to the right, leaving behind a former meander now partially flooded, partially vegetated.

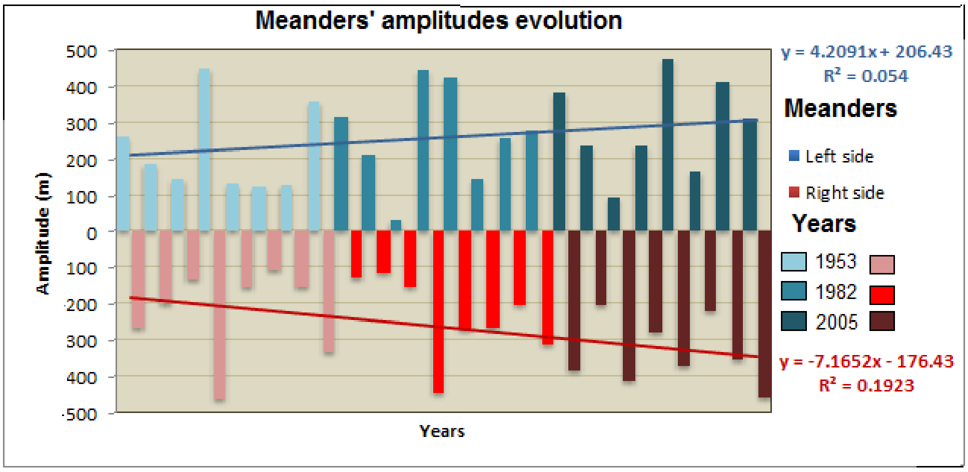

Figure 5. The meander amplitude graph

The comparability between the three years is evident, as demonstrated by the upward trend of the amplitude as we near the present date, but there is a slight dissimilarity between the two sides, confirming once again the tendency towards a more profound development of meanders on the right side. Furthermore, the connection between the lateral migration of Morava River and the evolution of bank forms is exemplified by the **Figure 6**.

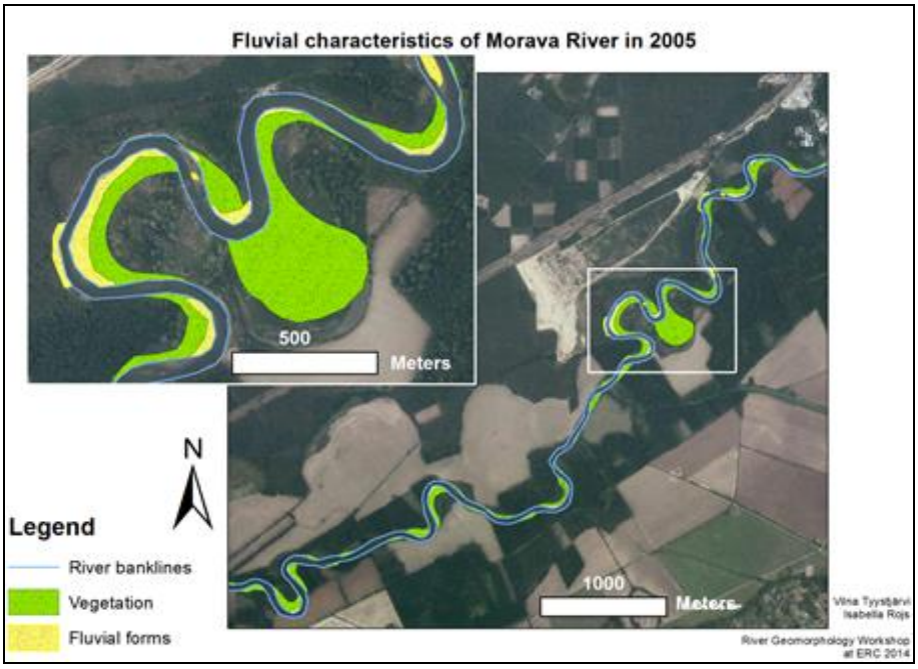

Figure 6. Newly formed sandy bars and vegetation in the study interval

Throughout the period, we calculated a rate of revegetation of 0.014 Km^2/year,which could be easily overlooked if we do not take into account the rate of alluvial sand bars formation, which is much lower, of only 0.002 Km^2/year. This could be an indicator of the regeneration potential of the alluvial system from this sector of Morava River, despite its dynamics and hydrological activity. As for the new forms of relief, three small islets appeared in the last 25 years and one one ox-bow was formed. The changes in morphology obviously brought about environmental alterations; therefore, the modifications that took place in the riverbed certainly had a domino effect on the surroundings.

Overall variability of discharge for the whole period (Straznice station), in relation to the channel development, was calculated with the aid of the Mann-Kendall test and the nonparametric Sen's method (Salmi et al., 2002). The statistical model performed a cumulative distribution and defined a trend in the discharge, using the absolute value of Z, its significance and the difference between each consecutive year, in order to detect the correlation with the planimetric changes in the channel network (Figure 7).

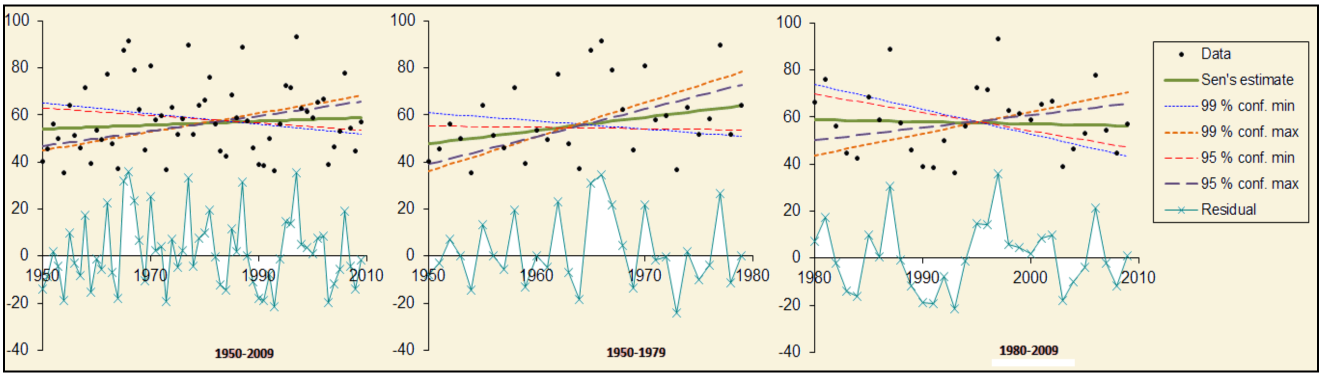

Figure 7. Graph time series with MAKESENS (1950-2009; 1950-1980; 1980-2009)

Research has attempted to establish mathematical relationships between meandering and river discharge. In general, we found out that the meandering process influences the flow, as a high significance (0.05, 0.01 and more than 1 level of significance) was obtained for nearly all the time series (monthly and annually). The role of the hydrological factor in the genesis and dynamics of meanders was validated by the results in Table 1.

Table 1. Trend statistics for Straznice station (1950-2009)

	1950-2009			1950-1979			1980-2009		
Months	***Test Z***	***Signific.***	***Q(mc/s)***	***Test Z***	***Signific.***	***Q(mc/s)***	***Test Z***	***Signific.***	***Q(mc/s)***
I	**1.70**	**+**	**0.37**	1.28		0.80	0.00		0.01
II	**0.40**		**0.11**	0.00		-0.06	0.29		0.16
III	**2.09**	*	**0.64**	0.89		0.94	1.36		1.61
IV	**0.12**		**0.05**	0.39		0.61	0.79		0.60
V	**-1.33**		**-0.30**	0.29		0.15	-1.68	**+**	-0.75
VI	**-0.87**		**-0.14**	1.25		0.65	-1.50		-0.52
VII	**-1.08**		**-0.18**	0.61		0.34	-0.96		-0.44
VIII	**-0.30**		**-0.04**	1.75	**+**	0.52	-0.93		-0.46
IX	**0.61**		**0.08**	1.50		0.40	-0.96		-0.41
X	**-0.24**		**-0.03**	1.46		0.36	-0.39		-0.14
XI	**0.30**		**0.04**	1.21		0.60	0.57		0.16
XII	**-0.84**		**-0.16**	1.28		0.77	-1.71	**+**	-0.61
Annually	**0.75**		**0.08**	**1.86**	**+**	**0.56**	**-0.29**		**-0.09**

All in all, there is a slight increase (+0.08 m^3/s) of the discharge on the whole period (1950-2009), which is not very eloquent, but if we were to refer to the last interval (1980-present), there is a downward trend of the discharge, proved by the increasing accumulation process and river channel narrowing. Moreover, the upward trend of the discharge evolution between 1950 -1980 is linked to the oscillations of river meandering that can be translated as a continuous lateral pendulation due to increasing flow power.

4. CONCLUSIONS

The dyachronic analysis of Morava River, although only along a 10 km length, discloses real changes of its channel, governed by meander evolution over almost 60 years. After a deep comprehension of the results of our study, a number of ideas should be retained. Most importantly, during the analyzed interval (1953-2005) Morava river evolved, first from right to left, then again to the right, but with a greater pace in the recent times. Nowadays, we can witness a period of accumulation in the river geomorphology, with a strong revegetation of the areas that were occupied by former river meanders. Besides, the amplitude and radius of meanders grew in the last decades and we expect larger meanders in the near future, as this sector is now in an intense lateral activity. We also noticed an equilibrium between the sand bars along the newly formed meanders and the vegetation growth, which is produced very fast and prevents the erosion of the fragile sandy forms of relief. Ultimately, the erosional process occurs only where there is little or no arborescent vegetation, but the accumulation process prevails and it is responsible for the stability of the alluvial forest along the river and for the formation of small islands in shallow waters. In the end, the correlation between discharge and meander formation rhytm is strong enough to make us consider that there is a slight possibility that the meandering processing may depend not only on geological and morphological features, but also on hydrological variability.

5. ACKNOWLEDGEMENTS

The author would like to express her gratitude to the students who participated in the workshop ”Assessing Environmental Effects of Changing Morphology with GIS in Morava River”, I held on the 1st – 3rd of April at the Eastern Geography Congress in Zderaz, Czech Republic: Katharina Schelter, Hendrik Weiler, Isabella Rojs, Nora Hilbert, Kees Stiggelbout, Vilna Tyystjärvi, Cosmin Mincu, Anna Caballero-Alonso, Jakub Široký. The remerciments are also addressed to the organisers, especially to Jakub Ondruch (Masarykova University, Brno), who provided the cartographical data for the studied river sector.

REFERENCES

Brázdzil, R., Máčka, Z., Řezníčková, L., Soukalová, E., Dobrovolný, P., Matys, T. 2011, Floods and floodplain changes of the River Morava, the Strážnické Pomoraví region (Czech Republic) over the past 130 years, *Hydrological Sciences Journal*, **56**:7, 1166-1185

Ioana – Toroimac, G. 2009, *Dinamica hidrogeomorfologică a râului Prahova (România): funcționarea actuală, evoluția recentă si consecințe geografice*, Phd Thesis, Université Lille 1, Lille

Grecu, F. 2008, *Geomorfologie dinamică,* Editura Credis, Bucureşti, 232p.

Ichim, I., Bătuca., D., Rădoane, M., Duma, D. 1989, *Morfologia şi dinamica albiilor de râuri*, Ed. Tehnică, Bucureşti, 408p.

Kadlec, J. 2009, Morava River flood plain development during the last millennium, Strážnické Pomoraví, Czech Republic. *The Holocene*, **19** (3), 499–509

Kondolf, G.M., Piegay, H., Landon N. 2002, Channel response to increased and decreased bedload supply from land-use change: contrasts between two catchments, *Geomorphology*, 45, 35-51

Leopold, L. B. & Walman, L. 1960, River meanders, *Bulletin of the Geological Society Of America*, **71**, 769-794

Michalková, M., Piégay, H., Kondolf, G.M., Greco, S.E. 2011, Lateral erosion of the Sacramento River, California (1942–1999), and responses of channel and floodplain lake to human influences, *Earth Surf. Process. Landforms* **36**, 257–272

Micheli, E.R. & Larsen, E. W. 2010, River Channel Cutoff Dynamics, Sacramento River, California, USA, *River. Resources and Applications.*

Nanson, G. 1981, New evidence of scroll-bar formation on the Beatton River, *Sedimentology*, v. **28**, n. 6, 889-891

Ondruch, J. 2012 , Development of a cut-off meander in the lowland reach of the Morava river after spring floods in 2006**,** *The European Geographer*, Vol. **8**, ISSN: 1605-6566

Rădoane., M., Rădoane, N., Dumitriu, D. 2003, Geomorphological evolution of river longitudinal profiles, *Geomorphology*, **50**, Elsevier, Olanda ,293-306.

Richard, G., A. 2001, Quantification and prediction of lateral channel adjustments downstream from Cochiti Dam, Rio Grande, NM, Colorado State University, Fort Collins, Colorado, 244p.

Salmi, T., Määttä, A., Anttila, P., Ruoho-Airola, T., Amnell, T. 2002, Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen’s slope estimates - the excel template application Makesens, *Publications on air quality*, Finnish Meteorological Institute, Helsinki, 35p.

http://www.bafg.de/GRDC/EN/02_srvcs/21_tmsrs/riverdischarge_node.html . Last viewed: 23th April 2014