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VERTICAL DYNAMICS OF THE UPPER MUREȘ RIVERBED

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Abstract. Vertical Dynamics of the Upper Mureș Riverbed. This study navigates the intricate landscape of the Mureș River's upper course, specifically through the contrasting terrains of the Giurgeu Depression and the Toplița-Deda Gorge. It examines the unique relief features and substrates that define the vertical dynamics of the riverbed. The investigation focuses on data collected from four pivotal hydrometric stations: Suseni, Toplița, Stânceni, and Gălăoaia. Here, we determine the thickness of the rock layer (hp) by calculating the difference between the water level and the maximum depth, in relation to the gauge's zero plane. Our analysis highlights the riverbed's monthly regradation patterns within these locales. We uncover notable variations in the scope of vertical dynamics, delineate characteristic periods, and decipher both linear and polynomial trends.

Keywords. Cross-section, water level, maximum depth, aggradation, regradation, characteristic period, trend

1. INTRODUCTION

Water, in its ceaseless journey, emerges as the landscape's most dynamic sculptor, wielding a palette of energies to shape the earth. This sculpting prowess is expressed through four distinct types of energies, each defined by the nature of water's interaction and movement: the energies of rainfall, overland flow, concentrated hill slope runoff, and fluvial flow (Pandi, 1997). It is within this intricate interplay of forces—where the erosivity of water meets the erodibility of land—that the landscape is carved and crafted. Of these forces, fluvial flow stands out for its persistent nature, constantly reshaping riverbeds and, by extension, influencing the surrounding slopes. Recognizing this relentless transformation, researchers, predominantly from oceanic and temperate climate zones, have intensified their scrutiny of riverbed dynamics since the late 20th century, contributing seminal works to the field (Castaldini, Piacente, 1995; Paige, Hickin, 2000; Winterbottom, 2000; Amsler, Ramonell, Toniolo, 2005).

Immersed in legend, *'the two brothers'* are said to emerge from the majestic Hășmașul Mare Massif, tracing their separate, destiny-bound paths: the Mureș River meandering northward, while the Olt River carves a course southward. Their waters, siblings in origin, embark on divergent journeys only to converge in the grand

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embrace of the Danube, eventually finding serenity in the tranquil waters of the Black Sea.

Mirroring the famed Danube and other rivers, the Mureș claims dual origins: a touristic source at the well-known locale of Izvorul Mureșului, and a hydrological source nestled in Mount Rez, a segment of the Hășmașu Mare massif, rising at an altitude of 1382 meters (Paraschiv, 2014). Along the steep slopes of Rez, the river is known as Valea Mare. Over a stretch of 110 kilometers, the Mureș River's upper course meticulously sculpts the Giurgeu Depression and the Toplița-Deda Gorge (Ujvari, 1972). The depression unfolds between the Giurgeu and Gurghiu Mountains, presenting a nearly flat relief, set at an altitude of 700 – 800 meters. Here, the riverbed meanders assertively, guided by gentle slopes of approximately 1 meter per kilometer. This fluvio-lacustrine alluvial plain is eroded by a series of debris cones and glacis, testament to the might of its numerous tributaries. Among these, Belchia stands out, making its descent from the Giurgeu Mountains. The depression's genesis is attributed to the erosion of volcanic-sedimentary deposits at the juncture of the Gurghiu's eruptive system to the west and the crystalline structure of Giurgeu to the east (Ciupagea, Paucă, Ichim, 1970).

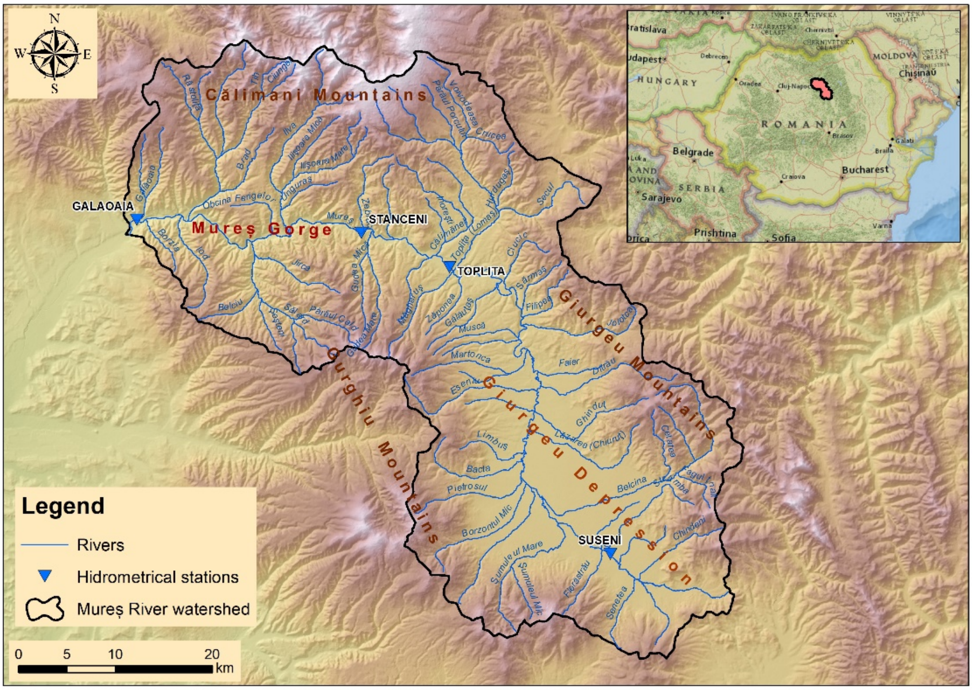

Fig 1. ***The relief units and the location of the hydrometric stations***

At the confluence with Toplița Stream, the Mureș River changes its flow direction towards the west and enters the Toplița – Deda Gorge, which is flanked by the Călimani Mountains in the north and the Gurghiu Mountains in the south. The gorge, stretching for 40 km and with a descent of 210 m, has been carved into pyroclastic materials and andesitic blocks and features a series of narrowings and small structural-erosive basins. (Ujvari, 1972) These basins are the confluence points of numerous tributaries with significant and constant flows (Toplița, Ilva, Sălard, Răstolița, Bistra). The formation of the Toplița – Deda Gorge is attributed to the regressive erosion of the Mureș River from the Transylvania Depression. After breaking through the volcanic chain, the river drained the lake from the Giurgeu Depression (Mihăilescu, 1969).

2. METHODOLOGY

The methods for assessing the dynamics of river channels can be grouped into geomorphological and hydrological methods. The former are based on the analysis of river-transported sediments in terms of the distribution of sediment types along the longitudinal profile and the granulometric evaluation of the particles. Hydrological methods are based on the analysis of water level variations, thus reflecting the aggregate processes of aggradation or degradation, considering the extreme levels.

The present analysis is based on the evaluation of channel dynamics using data from discharge measurements, where the water level and maximum depth are used for calculations. This method has the advantage of allowing the analysis of long periods of time, but the disadvantage is that the analyses are limited to the sections of the hydrometric stations. (Pandi, Sorocovschi, 2009) At each discharge measurement, the water level is recorded, and the maximum depth is measured; the latter element represents the position of the thalweg relative to the water level. The pairs of values H and hmax are related to the same gage datum level of the hydrometric station. The difference between these pairs of values (hp) expresses the thickness of the rock layer between H"0"M and the river's thalweg. (Pandi, 2007)

$$h_p = H - h_{\max}$$

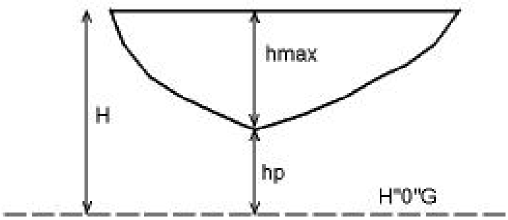

Fig 2. ***Assessing the hp value (Pandi 2007)***

The variation in its value reflects the dynamic nature of the riverbed relative to a hypothetical stationary plane. A reduction in the value of hp signals erosion or degradation of the riverbed, whereas an increase in hp denotes siltation, leading to the aggradation of the riverbed. These geomorphological terms describe changes in the riverbed over extended periods, typically spanning years. (Rădoane M., Pandi, Rădoane N., 2010)

For examining the dynamics of the riverbed, graphs depicting hp as a function of time (T), denoted as hp=f(T), were developed for each individual station. The equation hp=f(T) delineates the correlation between the thickness of the sediment layer (hp) and time (T) for each station.

To mitigate the effects of residual fluctuations and potential inaccuracies in reading the values H or hmax, five-day moving averages were computed, leading to the formulation of graphs represented as hp5=f(T). The term hp5=f(T) denotes the correlation after applying a five-day moving average, which refines the data by smoothing out short-term irregularities and reducing the influence of momentary variations or measurement inaccuracies.

Through scrutinizing these graphs, researchers can discern patterns and trends in the dynamics of the riverbed over time. This analysis enables the identification of phases during which the riverbed is predominantly undergoing erosion (degradation), accumulating sediment (aggradation), or maintaining relative stability. Employing linear and polynomial trend analyses aids in comprehending the general tendencies throughout the observation period, offering insights into the enduring behaviours and potential forthcoming alterations in the dynamics of the riverbed. (Pandi, Horvath, 2012)

The analysis pertains to the first four hydrometric stations along the Mureș River: Suseni, Toplița, Stânceni, and Gălăoaia (Fig. 1). The first is located in the Giurgeu Depression, while the others are in the Toplița – Deda Gorge. The area of the catchment basins increases significantly, from 160 km² to 2135 km². The average altitudes do not change substantially due to the succession of different relief forms that make up the basins. The difference in altitude between the gauge at Suseni and that at Gălăoaia is substantial: over 260 m. These morphometric data, along with the flow regime of the rivers and the petrographic composition of the relief, influence the dynamics of the riverbeds.

Table 1. ***Stations morphometric characteristics***

Hidrometric station	A (km^2)	Hm (m)	L dwn. (km)	Lup upstream. (km)	Plan ”0” G (m)
Suseni	160	987	19	744	743.55
Toplița	1071	935	77	684	651.81
Stânceni	1532	967	98	670	618.71
Gălăoaia	2135	988	127	640	481.50

(A-area, Hm – mean altitude, L-length, dwn-downstream, up-upstream, Plan 0 – gage datum level)

The database contains values of water level and maximum depth extracted from summaries of liquid discharge measurements. For each month, a pair of data was extracted, which was used to calculate hp and hp5. The analysis periods do not overlap exactly but cover sufficiently long intervals. The longest period is at the Suseni hydrometric station (37 years), while the shortest is at the Gălăoaia station (17 years).

Generally, the appearance of the graphs and the characteristic periods of riverbed regradation are influenced by both natural and anthropogenic factors. (Pandi, Horvath, 2019) In the analysed river sector, there are no major anthropogenic factors that influence these graphs.

3. RESULTS

3.1. Analysis of the Hydrometric Station Sections

Upper river courses typically exhibit relative stability. The Suseni station, however, is an exception. Despite being only 19 km from the source and encompassing a hydrographic basin of just 150 km², it is located in an area with friable deposits of the Giurgeu Depression. Consequently, there is a significant dynamic range, nearly one meter (Δhp = 90 cm). This difference narrows to 81 cm when considering moving averages. Three periods of aggradation, one of degradation, and two of relative stability can be identified. Following the severe floods of 1971, there is a short, three-year period with a strong aggradation tendency. The two periods of relative stability, lasting 7 and 9 years respectively, are interspersed with short phases of degradation and aggradation. Notably, the last aggradation period, lasting 11 years, shows a very large range (84 cm).

The linear trend indicates aggradation, with a range of 25 cm. The 6th-degree polynomial trend highlights the strong aggradation following 1970 and the lengthy aggradation beginning in 1995.

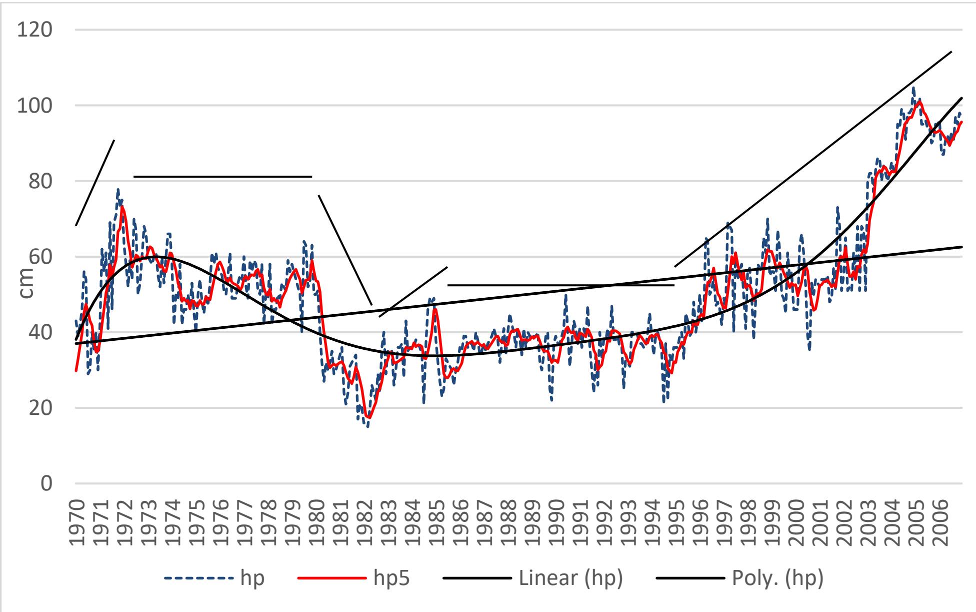

Fig 3. ***Regradation of the Riverbed at the Suseni Hydrometric Station***

The Toplița station is located at the entrance of the Toplița – Deda gorge. The area of the basin expands significantly to 1071 km², with the average altitude slightly lower than that of Suseni (935 m compared to 987 m). The petrographic composition, consisting of the hard rocks of the Călimani and Gurghiu mountains, has not allowed for significant regradation of the riverbed. The hp variation is only 52 cm, and it decreases to 41 cm for hp5. This is reflected in the delineation and characteristics of the four periods. Only in the first five years is there a period of more pronounced degradation, followed by a period of aggradation. This is followed by two lengthy periods of mild degradation and relative stability (8 years and 6 years, respectively).

The linear trend indicates a downward trajectory, with a range of 23 cm. The 6th-degree polynomial trend highlights the initial strong degradation, followed by the riverbed's relative stability.

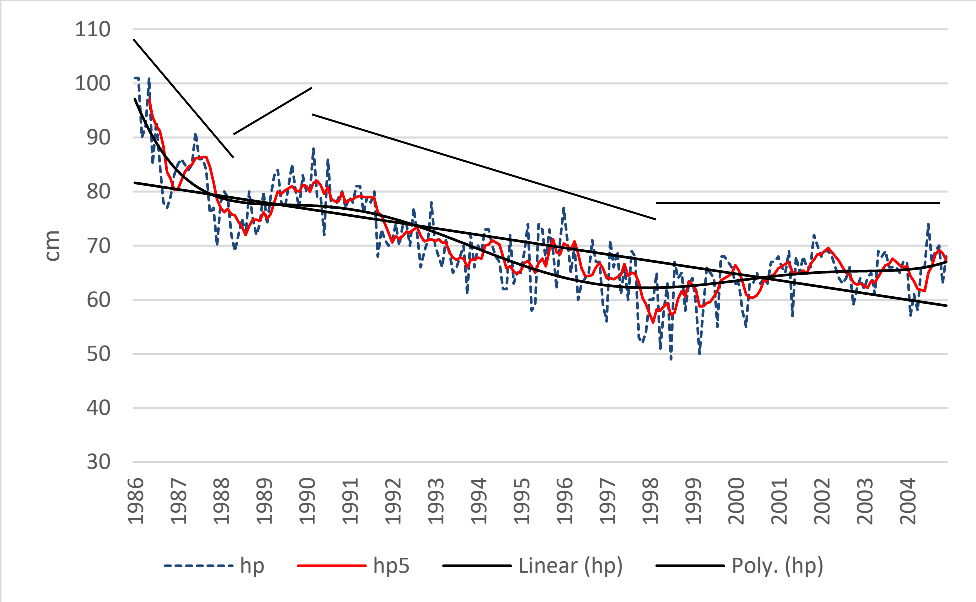

Fig 4. ***Regradation of the Riverbed at the Toplița Hydrometric Station***

The Stânceni hydrometric station is positioned within the gorge but in a small basin at the confluence of several streams. This location has significantly influenced the vertical dynamics of the riverbed, resulting in a large regradation range (Δhp = 90 cm, Δhp5 = 80 cm). Four characteristic periods in the riverbed's evolution can be identified. Like the riverbed at Suseni, a period of relative stability follows post-1972, succeeded by degradation. Subsequently, after a short but intense period of aggradation, there follows a prolonged period of deepening of the riverbed.

The linear trend is downward, with a difference of 46 cm between the extremes, which is double that of Toplița. The 6th-degree polynomial trend follows the same pattern of riverbed deepening, illustrating the sinuosity of the process.

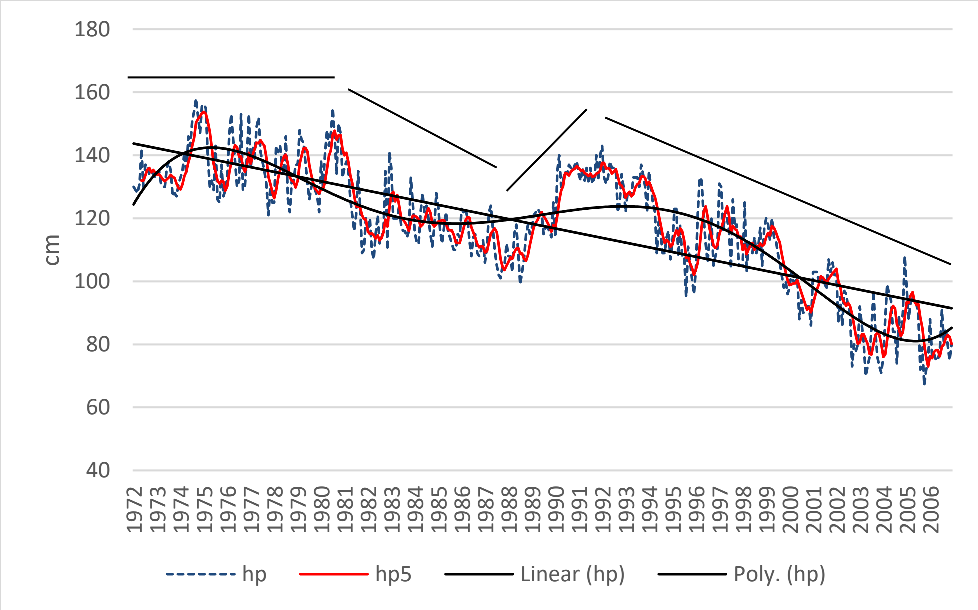

Fig 5. ***Regradation of the Riverbed at the Stânceni Hydrometric Station***

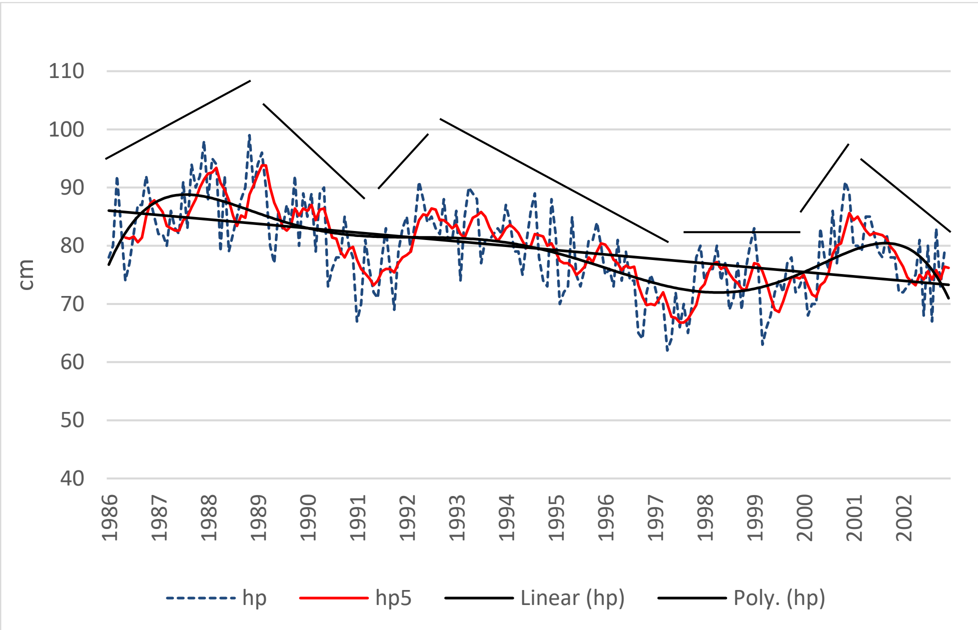

Fig 6. ***Regradation of the Riverbed at the Gălăoaia Hydrometric Station***

The Gălăoaia station profile exhibits the highest stability. Here, the role of the hard deposits in which the Mureș River has carved its bed is most evident. The maximum regradation difference is only 37 cm. In the case of the five-day moving average, this decreases to 27 cm. Seven characteristic periods can be differentiated, but their range is small. There are two pairs of ascending-descending sequences, followed by a period of relative stability. Subsequently, another ascending-descending sequence is observed, slightly more abrupt than the previous ones.

The linear trend is also descending, but the range of the line is only 13 cm. The curve of the 6^{th}-degree polynomial trend is steeper at the beginning and end of the analysis interval, with only mild undulations in between.

3.2. Stations comparative data

The channel dynamics at the four hydrometric stations differ based on the number of characteristic periods delineated. The Suseni and Gălăoaia stations have the most periods (six and seven, respectively). The other two stations each have the same number of periods (four). In total, 21 characteristic periods have been delineated at the four hydrometric stations, with 8 each for degradation and aggradation, and 5 for relative stability. Considering only one type of evolution period the following observations can be made:

- For degradation, Suseni has only one period, while Gălăoaia has three.
- Aggradation is characteristic in only one period at Stânceni, and in three periods at Gălăoaia.
- For relative stability, Suseni has two periods, while each of the other three stations has only one.

Tabel 2. ***Characteristic Periods of the Riverbed Evolution***

Hydrometric station	Analysed interval	Degradation	Aggradation	Relative stability	Number of periods	Linear trend range
Suseni	1970-2006	1980-1981	1970-1971	1972-1979	6	+25 cm
			1982-1984	1985-1995		
			1996-2006			
Toplița	1986-2004	1986-1987	1988-1989	1999-2004	4	-23 cm
		1990-1998				
Stânceni	1972-2006	1981-1986	1987-1991	1972-1980	4	-46 cm
		1992-2006				
Gălăoaia	1986-2002	1989-1990	1986-1988	1997-1999	7	-13 cm
		1993-1996	1991-1992			
		2001-2002	2000			

The linear trend is positive only at Suseni, located in the Giurgeu Depression. At the other three stations, which are situated in the Deda – Toplița Gorge, there are general trends of riverbed degradation. The maximum amplitude of the linear trends is at Stânceni (46 cm), and the smallest is at Gălăoaia (13 cm).

For the 6th-degree polynomial trends, cyclic patterns cannot be differentiated due to the insufficient length of the databases. At the first two stations, the curves have fewer inflections than at the downstream stations. These characteristics depend on the number of delineated periods and the amplitude of each period.

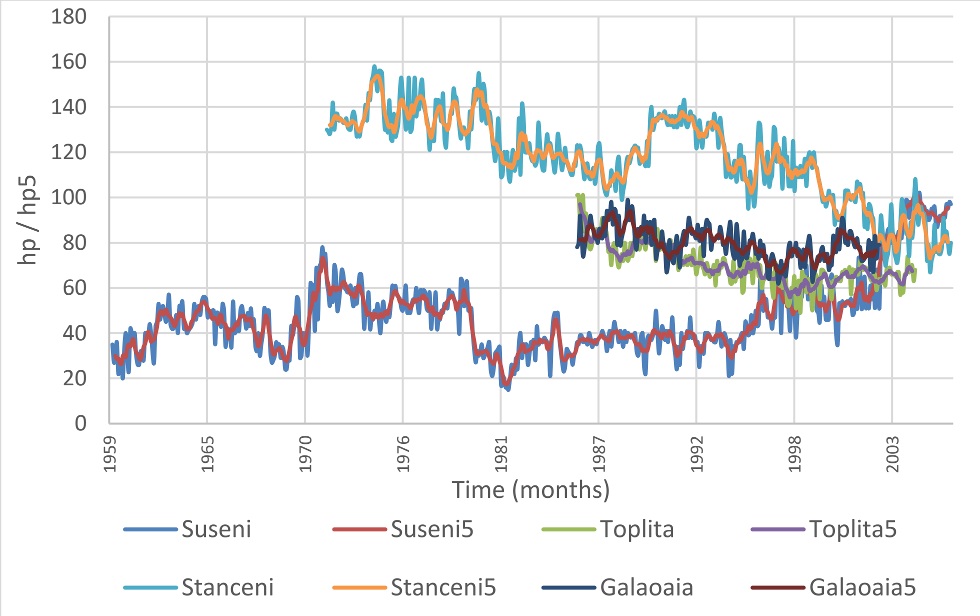

Fig. 7 h_p and h_p5 variation over time

The charts illustrate the hp values and their 5-month moving averages at each station over time. Each station's data reveals distinct trends, underscoring unique local influences. Notably, the hp changes across stations are not synchronized, suggesting minimal linear correlation and emphasizing the impact of local factors on hp values.

Table 3. h_p values by station correlation matrix

	Suseni	Toplita	Stanceni	Galaoaia
Suseni	1	-0.418	-0.508	-0.46
Toplita	-0.418	1	0.336	0.368
Stanceni	-0.508	0.336	1	0.07
Galaoaia	-0.46	0.368	0.07	1

Table 4. h_p5 values moving average by station correlation matrix

	Suseni5	Toplita5	Stanceni5	Galaoaia5
Suseni5	1	-0.515	-0.545	-0.618
Toplita5	-0.515	1	0.389	0.567
Stanceni5	-0.545	0.389	1	0.111
Galaoaia5	-0.618	0.567	0.111	1

Regarding both hp and its 5-month moving average, the stations generally exhibit negative correlations. This means an increase in hp at one station doesn't consistently align with an increase at another. While there are instances of positive correlation (notably between Toplita and Stanceni for hp, and Toplita5 and Stanceni5 for hp5), these are relatively weak. This pattern highlights that the hp values at each station predominantly move independently, without a strong direct relationship with the values at other stations.

4. Conclusions

The upper Mureș River's channel dynamics display distinct characteristics, shaped by the diverse relief units it traverses and the varying resistance of the underlying substrate. At Suseni and Stânceni, the river flows over friable rocks, resulting in a significant regradation range (90 cm). In opposition, in areas like Toplița and Gălăoaia, where the river encounters more durable rock formations, the alteration in the riverbed's height is less pronounced (52 cm and 37 cm, respectively). This variation in regradation range highlights the river's sensitivity to the geological substrate.

Moreover, the number of characteristic periods of alteration nearly doubles, marking a notable differentiation in the behavior of the river's course. A particular point of interest is the Suseni hydrometric station, nestled in the Giurgeu Depression. Here, the riverbed primarily exhibits aggradation, leading to a meandering path in certain parts of the depression. In contrast, at the other three stations, the riverbed shows a tendency to deepen.

Overall, the statistical analysis underscores an independent behaviour of the thalweg depth at each station, suggesting that local factors distinctly influence each segment of the river. This nuanced understanding of the river's dynamics is crucial to highlight the complexity of natural systems, where each component plays a unique role in shaping the overall landscape.

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