THE RECENT EVOLUTION OF THE PRUT RIVER CHANNEL IN THE TERRITORIAL ADMINISTRATIVE UNIT OF PRISĂCANI COMMUNE - IAŞI COUNTY

Daniel George BUTNARIU, Ph.D Student, Eng., „Gheorghe Asachi" Technical University of Iași, Faculty of Hydrotechnical Engineering, Geodesy and Environmental Engineering, daniel.butnariu@tuiasi.ro
Florian STATESCU, Professor, Ph.D Eng., „Gheorghe Asachi" Technical University of Iaşi, Faculty of Hydrotechnical Engineering, Geodesy and Environmental Engineering, Department of Hydroamelioration and Enviromental Protection, fstatesc@hidro.tuiasi.ro
Mihai Ciprian MĂRGĂRINT, Associate Professor, Ph.D, „Al. I. Cuza" University of Iași, Geography and Geology Faculty, Geography Department, margarint.ciprian@yahoo.com
Mihai NICULIȚĂ, Lecturer, Ph.D, „Al. I. Cuza" University of Iași, Geography and Geology Faculty, Geography Department, mihai.niculita@uaic.ro

Abstract: *Representing a direct response of hydrologic, hydrogeologic, geomorphologic, and anthropic factors, the dynamic of river channels has a useful scientific and practical importance, especially for the regions where the rivers play the role of state border. This article presents a detailed analysis of the dynamic of the Prut River channel for the last 125 years, concerning a 26 km sector of the river, which correspond to Prisacani territorial (local) administrative unit (LAU 2nd order), Iaşi County. This segment can be considered as a representative natural border between Romania and Republic of Moldavia along the middle Prut River course, downstream the Stânca-Costeşti anthropic lake. The work consisted in digitization of a large series topographic maps (1893-1894 edition at 1:50,000 scale, 1940 edition at 1:20,000 scale, the 1949, 1960 and 1985 editions at 1:25,000 scale), various remote sensing images: LANDSAT images for the 1990 and 2000 decades, SENTINEL 1A and 2A images for the year 2015 and 2016, LiDAR DEM (acquired in 2012), and Google Earth® high resolution optical satellite images collection. For the last two years, the channel dynamic was validated and completed using GPS measurements.*

Keywords**:** *Erosion, Prut River, Meandering, Remote Sensing, GIS, LiDAR DEM.*

1. Introduction

The dynamic of the river channel represents a direct response of hydrologic, hydrogeologic, geomorphologic and anthropic factors, and it has a useful scientific and practical importance, especially for the regions where the rivers play the role of state border.

Since 1948, Romania's state border with the USSR and, later on, with Ukraine and the Republic of Moldova, was established on the Prut River, between Oroftiana village (the entrance of the river in Romanian territory) and its confluence with the Danube River. Because of the status of national border of the Prut River, the access of individuals performing various activities in the river surroundings is regulated by special juridical regime. The old official treaty between the ancient USSR and the Popular Republic of Romania (a precursory name of Romania from those times) is still enforced today in the absence of a treaty on the Romanian – Moldovan state border. While the state border demarcation is performed only during Joint Border Commissions, the latest check was conducted between 1972 and 1974. These regulations were the reasons for which the study of the dynamics of the river channel was insufficiently conducted in the past 30 years.

The study area is situated in the southern sub-sector of the middle sector of the Prut River at a distance of about 600 km from the rise, in an area characterized by a floodplain with widths of 4 to 8 km.

The channel of the Prut river in the study reach is 26 km long, it widths ranging between 41 and 102 m with an incline ratio of about 0.02 %.(Fig. 1)

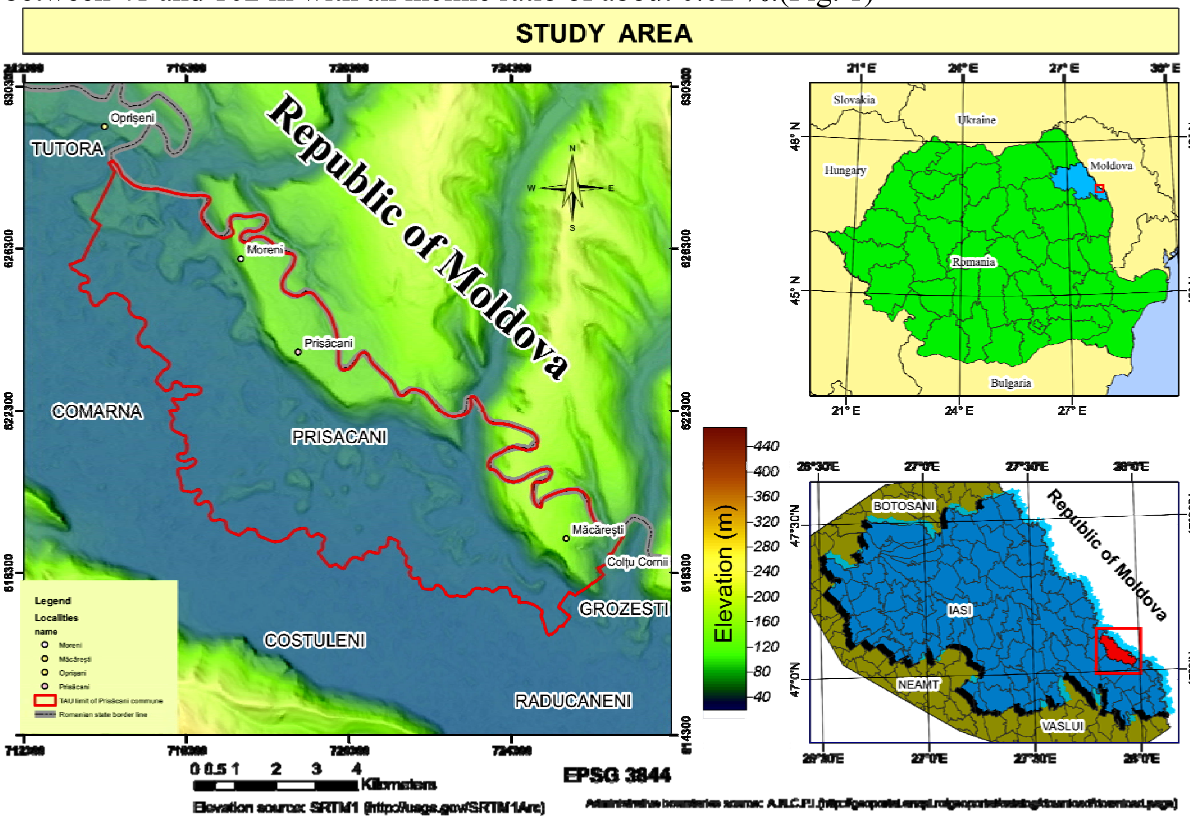

Fig. 1. The study area – Prut river channel in the Prisăcani LAU

This article presents a detailed analysis of the dynamic of the Prut River channel for the last 125 years, focused on a 26 km sub-sector of the Prut River, which represent the north-eastern limit of the Territorial (Local) Administrative Unit *(LAU 2nd order)* of Prisăcani Commune, Iaşi County, and also a part of border between Romania and Republic of Moldova.

In the study area, and downstream the Stânca Costeşti reservoir (which is located 102 km upstream from the study area), the Prut river channel is of meandering type, with lateral migration and scrolled floodplain (Rădoane et al., 2008; Huffington and Montgomery, 2013; Hooke, 2013). The river channel has sectors of tortuous and irregular meanders. The meanders are in progression and multiple cutoffs occurred in the last 200-300 years, some oxbow lakes remaining as evidences in the proximity of the actual channel. The meander types are dominated by compound asymmetrical ones, with cases of simple symmetrical. The channel topography is characterized by the presence of riffle-pools with concave banks, point bars and chutes. Although the meanders are free, embankments were built after 1860, nowadays the channel being confined between continuous levees, downstream Stânca-Costeşti reservoir (Fig. 2).

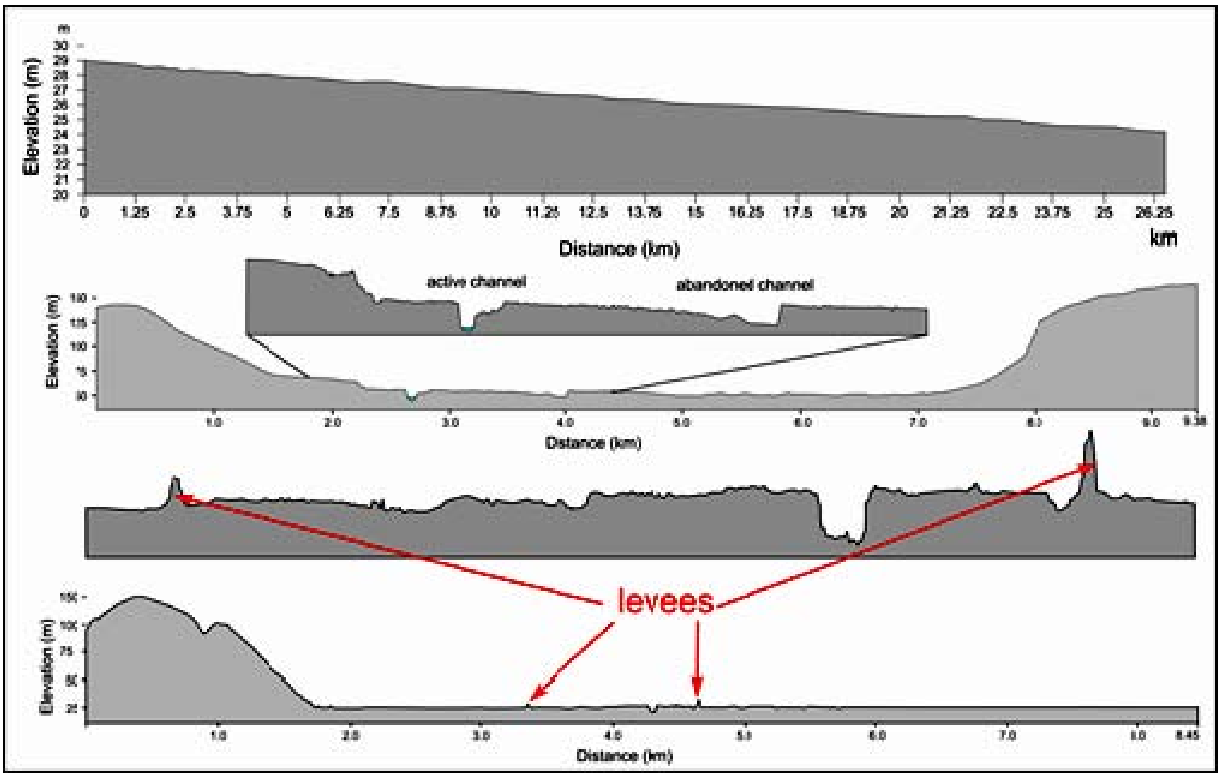

Fig. 2. Topographic profiles in the Prut River floodplain and channel: longitudinal profile (above), transversal section trough unconstricted channel (middle), and transversal section trough constricted channel between embankments (bottom)

2. Materials and methods

The various topographic and Remote Sensing (RS) spatial data were used to digitize the channel boundaries (Oguchi et al., 2013). Topographic maps were georeferenced by third degree polynomial transformation method to optimize local accuracy (Imbroane, 2012). In a first stage, the topographic maps (at 1:25,000 scale) 1949, 1960 and 1985 editions, were georeferenced using the planimetric rectangular Gauss-Krüger coordinates of trapezoids corners and intersection points of the kilometric grid (84 – 104) points transformed into planimetric rectangular coordinates in the Romanian Stereographic Projection System (Pulkovo 1942 Geodetic Datum), using the Matlab programming language (Moca et. al. 2012). For the topographic maps from 1893-1894 edition (at 1:50,000 scale) and 1940 edition (at 1:20,000 scale) a large number of corresponding points have been used to fit into the topographic map at 1:25,000 scale, 1985 edition (Fig. 3).

a b c d

Fig. 3. Topographic maps used for channel network extraction: a) 1893 – 1894 edition, b) 1918 - 1940 edition, c) 1949 edition, d) 1985 edition.

Beside the topographic maps, various RS images were used: LANDSAT images acquiered on 17th of August 2000, SENTINEL 2A images dated 1st of April and 9th of August 2016, ortophotomaps realized in the year 2005 and between 2008-2010, 2010 – 2013 and 2013 – 2015 periods, LiDAR DEM (acquired in 2012), and Google Earth® high resolution optical satellite images collection. All RS images were transformed in Romania Stereographic Projection System (Pulkovo 1942 Geodetic Datum) by using the ArcGIS software. For the last two years, the channel dynamic was validated and completed using GPS measurements performed with Leica 1200 GPS System.

The multispectral RS images were used for obtaining the maps of Normalized Difference Water Index (NDWI). Using thresholds of the values of this index, we have delineate the channel line (Herbei, 2013) and, also for the right bank.

The normalized difference water index was calculated using the following formulas:

NDWI = (NIR – G) / (NIR + G) = (B4 - B2) / (B4 + B2) *for LANDSAT TM* **(1)**

NDWI = (NIR - G) / (NIR + G) = (B8 – B3)/(B8 + B3) *for Sentinel 2A* **(2)**

This index is also useful for mapping bodies of water, for visualization of turbidity differences and vegetal content of water, alluvial soils or for differentiation of water content from vegetation (Herbei M., 2013). The index is based on usage of green and near-infrared spectral bands for computing the values that are comprised between -1 and +1. The dark gray levels (close to -1) express the water surfaces, bright gray levels (close to +1) express dry lands, and intermediate gray levels (close to 0), the lands containing intermediate moisture (Fig. 4).

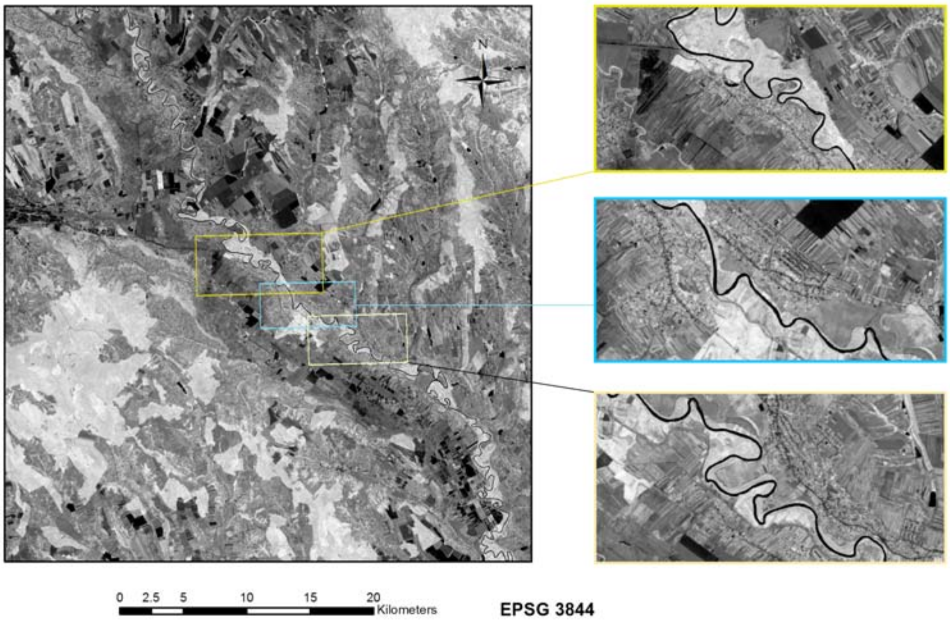

Fig. 4. NDWI_2016 map of the study area

The reference terrain surface of Prisăcani LAU, was considered the one defined by the territorial-administrative boundary during the last cadastral demarcation (2012) and the right bank of the Prut River digitized on topographic maps at 1:25000 scale edited in 1949 (Fig. 2c) which was used to establish the state border line between the People's Republic of Romania and the Government of the Union of Soviet Socialist Republics. The terrain surfaces of the Prisăcani LAU used to conduct the comparative study, were determined on the basis of administrative territorial limits and the right bank of the Prut river, digitized based on the topographic maps at 1:25 000 scale, 1960 and 1985 editions, maps at 1:5000 scale, 1991 edition, ortophotomap at 1:5000 scale, 2005, 2008-2010, 2010 – 2013, and 2013 – 2015 editions, maps of the normalized difference water index (NDWI) dated 17th of August 2000, 1st of April 2016 and 9th of August 2016 and LiDAR DEM acquired in 2012. The surfaces thus created, were compared with the reference surface using Symmetrical Difference analysis function of the ArcGIS software (Fig. 6).

For the estimation of the lateral migration rates a raster approach was followed (Niculiţă and Niculiţă, 2007). The approach described further was performed using SAGA GIS (Conrad et al., 2015). The median axis line of the polygon digitized channel extension was used to create a raster. The raster, with 5 meters spatial resolution, has values of 0 for the pixels corresponding to the median axis line and null values for the other pixels. Using this raster, the distance from the channel centerline was computed using (Fig. metodlogie_migare.png) the Euclidean distance (in SAGA 2.2.2, Imagery Toolbox, ViGrA library, Distance function). The distance raster was multiplied with a raster created from an intersection between the bounding box polygon and the channel line, with attributes values of 1 for the polygon to the right and -1 for the polygon to the left of the channel. In this way the distances of lateral migration to the right remain positive, and those to the right become negative. The Profile from lines function of SAGA GIS was used to sample the distance raster of t_1 (1890 for eg.) along the t_2 channel (1940 for eg.). The plotting of the lateral migration data was done in R stat (R Core Team, 2015).

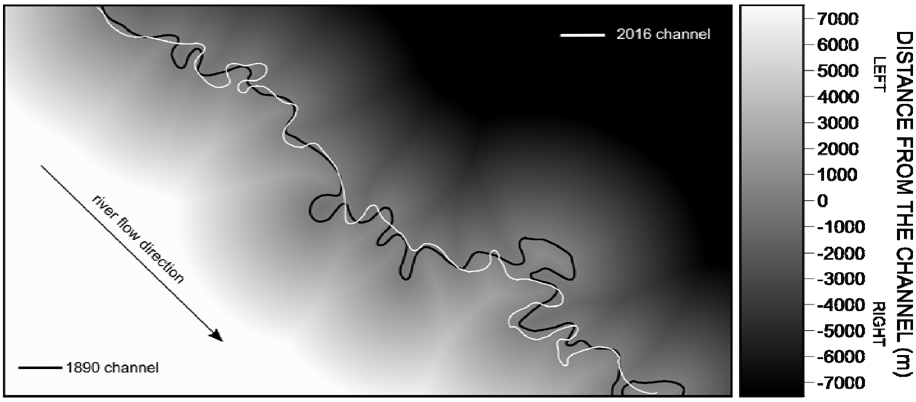

Fig. 5. The raster approach for estimating river channel lateral migration rates

3. Results and discussion

The evolution of river channels is made through lateral migration, especially in the case of meandered channels. In this case beside the lateral migration rate, the areas with erosion and deposition can be evaluated (Hooke and Yorke, 2010) (Fig. 6). The administrative surface of Prisăcani commune evolved because of the lateral migration of the Prut River, the evolution being presented in *Table 1*. The detailed statistics of erosion (E) and deposition (D) patterns for every analyzed time period is presented in *Table 2*.

Table 1. Terrain surface of the Prisăcani LAU in the analyzed period of time

Year	Surface area of TAU Prisăcani ($m^2 * 10^6$)
1949	58.9350
1960	59.3932
1985	59.0723
1991	59.1432
2000	59.0339
2005	59.0608
2010	58.9690
2012	59.0550
2013	59.0716
2015	59.0308
Apr 2016	59.0536

Table 2. Morphodynamic annual values to each period

PERIOD	E (m^2 $*10^6$)	D (m^2 $*10^6$)	AP (m^2 $*10^6$)	T (m^2 $*10^6$)	E/D
1940 - 1949	0.60	1.97	1.37	3.93	0.31
1949- 1960	0.14	0.60	0.46	1.20	0.23
1960- 1985	0.52	0.20	-0.32	0.41	2.58
1985 - 1991	0.13	0.20	0.07	0.41	0.65
1991 - 2000	0.29	0.18	-0.11	0.37	1.60
2000 - 2005	0.16	0.19	0.03	0.38	0.86
2005 - 2010	0.11	0.02	-0.09	0.04	5.31
2010 - 2012	0.02	0.11	0.09	0.22	0.21
2012 - 2013	0.02	0.04	0.02	0.08	0.59
2013 - 2015	0.06	0.02	-0.04	0.04	3.11
2015 – Apr 2016	0.04	0.06	0.02	0.12	0.63

E = eroded area, **D** = deposited of sediments area, **AP** = area formated by both process, **T** = total morphodynamics, and **E/D** = ratio of eroded and deposition areas

We have also calculated the following parameters: the area formed by both processes (AP) - comprises in case of cutoff or avulsion, the central portion of floodplain between deposited area, (paleochannel) and eroded area (new course), the total eroded and deposited areas (T) and the ratio of eroded and deposited areas(E/D). These values are used to analyse spatial land temporal variations in the intensity of processes involved in channel changes and affecting the floodplain (Morais, 2016).

As a result of the evolution of the Prut River channel, the temporal modification processes of the right bank was highlighted by thematic maps created using the ArcMap module, in order to compare different evolution stages using as reference the 1949 year. Fig. 6 presents the thematic map regarding the evolution of the right river bank of Prut River as a result of the dynamic of the channel between 1949 and 2016 in the Prisacani LAU.

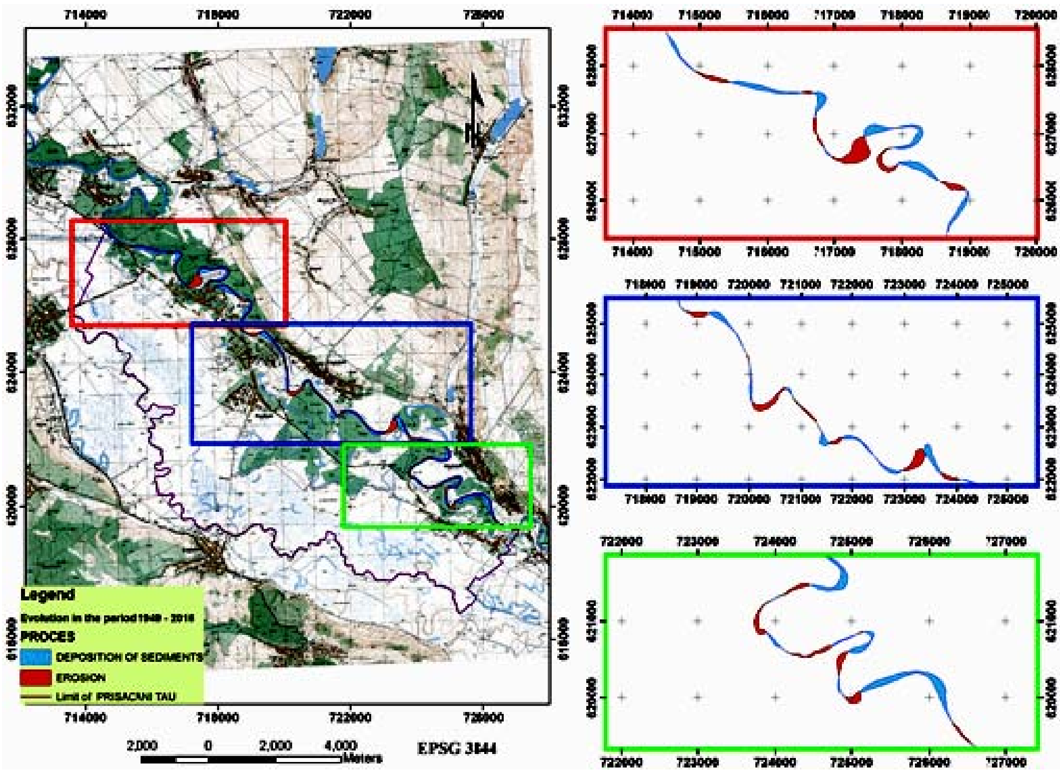

Fig. 6. The erosion and deposition areas of Prut river channel between 1949 and 2016

After the rainy period registered between 1970 and 1980, the solid discharge decreased continuously, and consequently has generated an obvious degradation of the channel downstream Stânca-Costeşti reservoir, with some aggradation downstream main tributaries, were additional sediments are deposited (Rădoane et al., 2008). The liquid discharge nowadays is bigger than in the ’90s but did not reached yet the levels from the ’70s-80’s.

Downstream Stânca-Costeşti reservoir, the gentle slope of the floodplain and the sandy sediments allow the presence of a meandering channel (Rădoane et al., 2008). Before the rehabilitation works made after the World Second War, the Prut River channel meanders evolved with great mobility in natural conditions. After the rehabilitation work, made during the communist period (1960-1970), the sediment delivery was decreased (by reservoir construction and anti-erosional measures), but also the levees (constructed for protection against floods) created a casing around the river channel.

In the period that followed the construction of the Stânca-Costeşti dam (1974-1978), beside the levees, low sediment discharge regulated the meander evolution. This evolution was characterized by the deepening of the channel, in some cases with up to 4 m (Rădoane et al., 2008), which limited the lateral migration of the channel (and the point bar formation), but sometimes favored chutes and cutoffs.

The majority of the meanders evolved trough downstream progression (lateral movement, translation, simple and confined migration or irregular lateral activity), with cases of progression and cutoff, retraction and cutoff, growth through extension, enlargement, and lobbing (Fig. 7). There are also stable bends with little change over time, especially along embankments.

Overall after 1890, the Prut river channel presented a great mobility in a buffer zone of up to ±400 m (Fig. 7, 8), but mainly after 1980, this mobility decreased and the channel being in a stable state regarding the lateral migration, with a slow tendency of vertical degradation (Rădoane et al., 2008). In the Prisăcani sector we can state that the degradation phenomenon is more pronounced; between 1981 – 2015 it was registered a value of - 100.37 cubic meters/meter of this process (Butnariu, 2016)

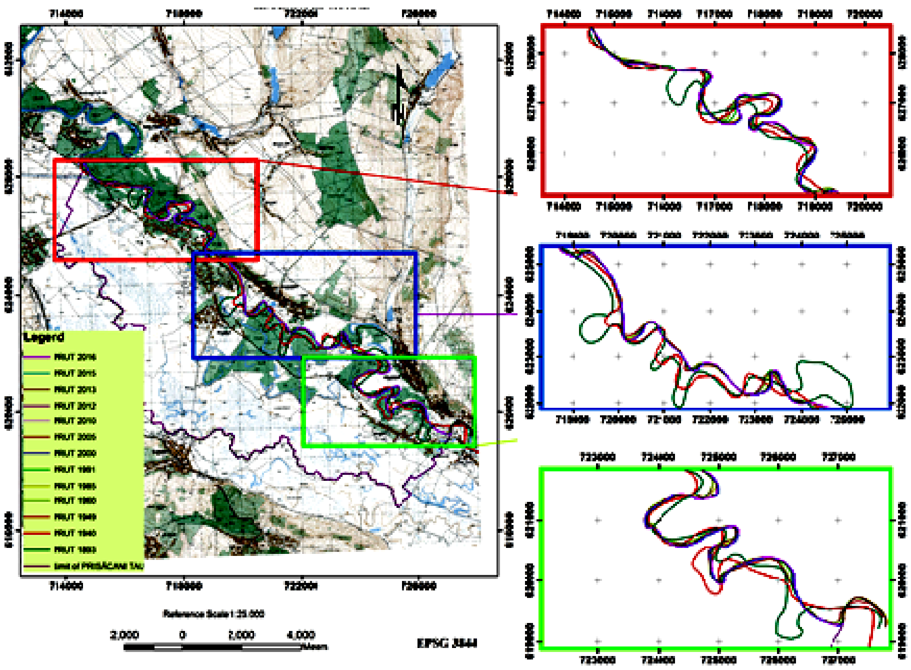

Fig. 7. The evolution of the Prut river channel between 1893 and 2016

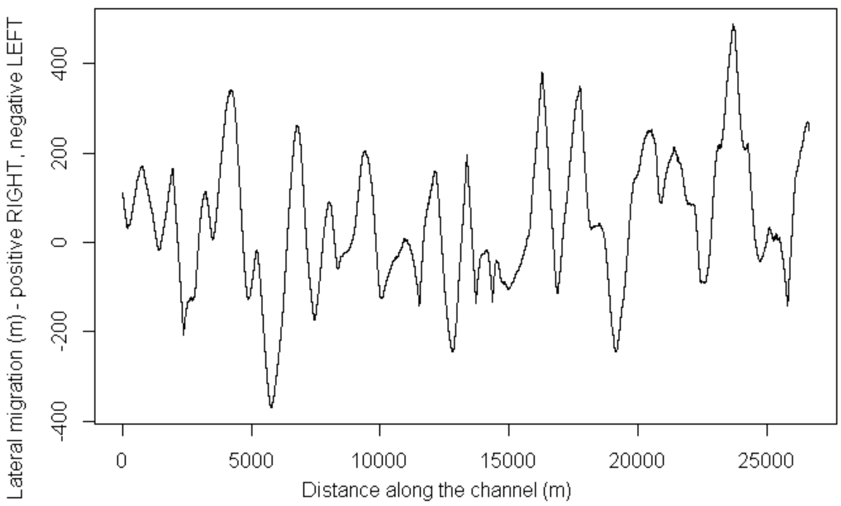

Fig. 8. The lateral migration rates of Prut river channel between 1893 and 2016

4. Conclusions

This study identified certain particular features of the channel typology of the Prut River, which have evolved in different conditions during the last century. The Prut River channel evolved as a natural meandering channel and after the construction of the Stânca-Costeşti dam and its associated reservoir, the continuous degradation of the channel and the levees casing generated a freeze in the evolution of the meanders. Thus - after the 1980 period only shifts of up to 50 m appeared along the banks (in some exceptional cases, up to 80 m). The direct influence of discharge regulation by the reservoir and of the droughts registered in the eastern Romania after the '90s is seen in the low mobility of the meanders and the channel degradation. This trend is stable despite the maximum historic flooding from 2010.

Considering the impact of climate changes, future rainy periods could increase the mobility of the channel and pose risks to the communities which live on the floodplain in the close proximity of the river channel, and create border demarcation issues, since the river is the natural border between Romania and the Republic of Moldova.

5. References

1. *Buffington, J.M., Montgomery, D.R. – Geomorphic classification of rivers. In: Shroder, J. (Editor in Chief), Wohl, E. (Ed.), Treatise on Geomorphology. Academic Press, San Diego, CA, vol. 9, Fluvial Geomorphology, pp. 730–767, 2013.*
2. *Butnariu, D. – Analiza şi evidenţierea proceselor care determină modificarea malurilor râului Prut. Research Report, Technical University Gheorhe Asachi Iaşi, 03/2016.*
3. *Conrad, O., Bechtel, B., Bock, M., Dietrich, H., Fischer, E., Gerlitz, L., Wehberg, J., Wichmann, V., Böhner, J. - System for Automated Geoscientific Analyses (SAGA) v. 2.1.4, Geoscience Model Development, 8, 1991–2007, 2015.*
4. *Herbei, M., – Sisteme informatice geografice, aplicaţii. Editura Universitas, Petroşani, 2013.*
5. *Hooke, J.M., Yorke, L. – Rates, distributions and mechanism of change in meander morphology over decadal timescales: River Dane, UK. Earth Surface Processes and Landforms 35(13), 1601 – 1614, 2010.*
6. *Hooke, J.M. – River meandering. In: Shroder, J. (Editor in Chief), Wohl, E. (Ed.), Treatise on Geomorphology. Academic Press, San Diego, CA, vol. 9, Fluvial Geomorphology, pp. 260–288, 2013.*
7. *Imbroane, A. M. – Sisteme informatice geografice, Volumul I, Structuri de date. Presa Universitară Clujeană, ISBN 978-973-595-417-8, Cluj-Napoca, 2012.*
8. *Moca, V., Oniga, V. E., Cardei, M. – Georeferentiation of the graphic fund for topographic plans drawn up on geodesic trapezia at general cadastral works. Scientific symposium with international participation "Horticulture science, quality, variety, harmony", 24- 26 May, 2012, U.S.A.M.V. Iasi.*
9. *Morais, E. S., Rocha, P.C., Hooke, J. – Spatiotemporal variations in channel changes caused by cumulative factors in a meandering river: The lower Pixe River, Brazil. Geomorphology 273,348 – 360, 2016.*
10. *Niculiţă, M., Niculiţă, I.C. - The determination and graphical representation of lateral fluvial channel migration rates using a raster approach, Seminarul Geografic "D. Cantemir", 28, 7-11, 2007.*
11. *Oguchi, T., Wasklewicz, T., Hayakawa, Y.S. – Remote data in fluvial geomorphology: characteristics and applications. In: Shroder, J. (Editor in Chief), Wohl, E. (Ed.), Treatise*

on Geomorphology. Academic Press, San Diego, CA, vol. 9, Fluvial Geomorphology, pp. 711–729, 2013.

12. *R Core Team - R - A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, available at: https://www.R-project.org/ (last access: October 2016), 2015.*
13. *Rădoane, M., Rădoane, N., Cristea, I., Gancevici-Oprea, D. – Evaluarea modificărilor contemporane ale albiei râului Prut pe graniţa românească, Revista de Geomorfologie, 10:57-71, 2008.*