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The impact of the urban expansion on the Jiu floodplain. Case study –Craiova, Romania

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Abstract

The urban expansion of any settlement implies changing natural environment and gradually transforming it into an anthropogenic one to assure the needs of the community. A first step in urban planning is to identify the changes that have been made, and this study reconstructs the anthropogenic changes induced to the Jiu floodplain in the last 150 years, through multi-temporal spatial comparisons, geomorphological characteristics and anthropological and environmental transformation indicators. The processing of historical cartographic materials and current satellite imagery highlights the dynamics of the wetlands and the built-up area in the Jiu floodplain between 1864 and 2017. The urban expansion required flood protection works that were carried out along the canals and lakes resulting from the drainage of the ponds and marshlands. On the course of the Jiu hydro-technical works of straightening, embankment and regularization were achieved, which led to the transformation of the course from a highly meandered one as it was in the second half of the 19th century into a sinuous one in 2017. The study is a useful tool in urban planning, by centralizing the changes in the floodplain, the anthropogenic works carried out and the changes of the Jiu course within the analyzed sector.

Keywords: *Jiu Floodplain, Craiova, Urban Expansion, Sinuosity Index, Urban Geomorphology*

Rezumat. Impactul expansiunii urbane asupra Luncii Jiului. Studiu de caz – Municipiul Craiova, România

Expansiunea urbană a oricărei așezări presupune modificarea mediului natural și transformarea treptată a acestuia într-unul antropic, care să asigure necesitățile comunității. Un prim pas în planificarea urbană îl constituie identificarea schimbărilor produse, iar acest studiu reconstituie modificările antropice induse luncii Jiului în ultimii 150 de ani, prin intermediul comparațiilor spațiale multi temporale, a caracteristicilor geomorfologice și a indicatorilor de antropizare și transformare a mediului. Prin procesarea materialelor cartografice istorice si a imaginilor satelitare actuale se evidențiază dinamica zonelor umede si a ariei construite din lunca Jiului in perioada 1864 – 2017. Extinderea teritoriul urban a impus lucrări de protecție împotriva inundațiilor, ce au fost realizate de-a lungul canalelor și lacurilor rezultate din desecarea bălților si zonelor mlăștinoase. Pe cursul Jiului au fost executate lucrări hidrotehnice de îndreptare, îndiguire și regularizare, ceea ce a dus la transformarea cursului dintr-unul puternic meandrat cum era în a doua jumătate a secolului al XIX-lea, într-unul sinuos în anul 2017. Studiul se constituie într-un instrument util in planificarea urbană, prin centralizarea modificărilor survenite în luncă, a lucrărilor antropice realizate si a schimbărilor cursului Jiului in sectorul analizat.

Cuvinte-cheie: *Lunca Jiului, Craiova, expansiune urbană, indice de sinuozitate, geomorfologie urbană*

Introduction

The most suitable areas for the establishment of human settlements have always been the riparian territories, and the location of the old settlement on the territory of which Craiova now stands is no exception, having been consolidated on the left bank of the Jiu River. The extension of a settlement in the floodplain of a river benefits, on the one hand, from the proximity to a water source that can be used for agriculture, industry or directly for human needs, but, on the other hand, it involves exposure to the risk of destruction of property or human casualties in case of floods or other consequences of the not properly maintained wet zones.

Within the urban environment, man is the landscape creator of what Coates (1976) called "cityscape" and urban geomorphology is the study of man as a physical process of change whereby he metamorphoses a more natural terrain to an anthropogene cityscape (Coates, 1976). On the other hand, the urban geomorphology is described by Cooke as the research of constraints in urban expansion. (Goudie, 2004) defined urban geomorphology in terms of restrictions on urban expansion, constraints represented by landscapes, evolution of geomorphological processes, soil types, water resources or natural hazards, but also through the impact of urban constructions on vegetation, soil, versants and rivers.

The urban expansion in the Jiu floodplain and the consequences of the human-natural interaction will be detailed in the area located in the south-western part of Romania, at the contact of the Getic Piedmont and the Oltenia Plain, on the territory belonging to the town of Craiova.

The study area

Craiova municipality is located in Oltenia Region (Fig.1), has an area of 81.96 km², which covers the floodplain and terraces on the left bank of the Jiu, creating an altitude difference of 130 m between the

Eastern extremity of the town where the height of 199 m is reached and the South-West of the settlement, within the Jiu floodplain, where the minimum altitude is 69 m. The geomorphology of the contact area between the Getic Piemont and the Oltenia Plain favored the development of the settlement on the left bank of the Jiu, on the terraces with a sloping reduced to a maximum of 11°, compared to the right slope of the river, abrupt, with a declivity of 10° - 33° (Alba, Mititelu-Ionus, & Boengiu, 2017).

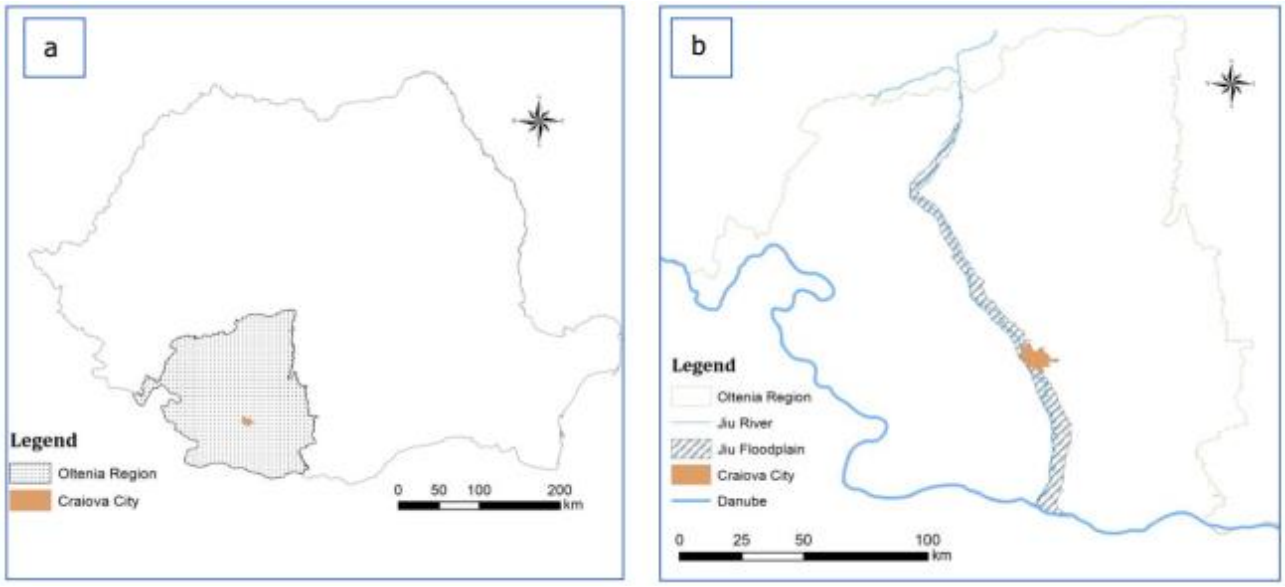

Fig. 1: Location of Craiova in Romanian (a) and Oltenia Region (b)

From a geostructural point of view, the geological unit that also includes Craiova area is the Valahia Platform, the stratigraphy of which involves the existence of two floors: a foundation one - the Cadonmian socle and the upper sedimentary cover (Mutihac & Mutihac, 2010). The tectonics of sedimentary cover of the Valahia Platform sketched a system of faults and blocks that had a differentiated vertical displacement. Some blocks, including the Craiova Depression, were characterized by a more pronounced subsidence becoming graben, functioning as depression sedimentation areas (Mutihac & Mutihac, 2010). The sedimentary cover of the Valahia Platform is approximately 10,000 m thick (Stroe, 2003), but with a non-uniform thickness due to the vertical movement of the blocks, reaching in some points 23,000 m (Ioneși, 1994).

The Jiu River, which has created the proper landscape for the settlement through floodplain and terraces, has a length of 339 km, 52 tributaries, an average talweg slope of 5% and a sinuosity index of 1.85. The multi-annual average discharge in the study area, at Podari hydrometer station, is 85.6 m^3/s. At the exit of the Jiu from the Getic Piedmont, on the territory of Craiova, the Jiu floodplain has an asymmetric aspect and is situated between 69 m downstream and 101 m upstream. The lithological composition of this floodplain sector includes two different structures, the lower one, the channel alluvium, made up of coarse sands, gravel and blocks, and the upper one - floodplain alluvium formed of sands, dusty clay, sands and mud seam (Savin, 1990).

From an administrative point of view, the town of Craiova includes 9 settlements (Craiova town proper and 8 communes), it has 110,207 dwellings, 305,945 people and from the total surface of 81.96 km^2, 70.63km^2 is within the built-up areas. In 2008, Craiova was granted the statute of urban growth pole, which became the center of Craiova Metropolitan Area and represents a polarizing area for Oltenia Region (South-West of Romania).

Material and methods

The reconstruction of the changes, including wetlands and swamps dynamics and the expansion of the built-up areas in the Jiu floodplain, was made by analyzing historical documents and cartographic materials that also include the settlement, by comparing the multi-temporal spatial maps with the actual ones, confirmed by field checks. The list of cartographic materials used is found in Table 1.

Changes in the channel of the Jiu River are highlighted by the dynamics of the sinuosity index values, calculated as the ratio between the real length of the drainage channel and the straight-line length between the extreme points of the sector, from 1864, 1910, 1944, 1974, 1992, 2017.

Table 1: The cartographic materials used for the reconstruction of urban expansion

Map	Source	Publishing date / date of satellite take-over
The Map of Craiova in the 15th century	(A. Georgescu, 1936)	1936
The Map of Craiova in the 18th century	(A. Georgescu, 1936)	1936
Planul Caselor Bănești din Craiova in 1780	(Buce-Răduț, 2011)	2011
Specht Map 1791	http://www.limes-transalutanus.ro	2014
The Second Military Survey 1856 - 1859	http://mapire.eu/en/map/secondsurvey	2014
Charta României Meridionale 1864	http://www.charta1864.ro/charta.html	1864
The Plan of Craiova in 1888	(Buce-Răduț, 2011)	2011
The plan draw of Craiova in 1905	(Buce-Răduț, 2011)	2011
Planurile Directoare de Tragere – file 3042, 1903 – 1925	http://www.geo-spatial.org	2011
The "Austrian" Maps 1910	http://www.geo-spatial.org	2006
The "British" Maps 1944	http://www.limes-transalutanus.ro	2014
Topographic Map of Romania 1:25000	Direcția Topografică Militară	1974
The "Russian" Maps 1976	http://www.geo-spatial.org	2012
Landsat 5, TM (50 m)	USGS	01.aug.1992
Digital Globe / CNES / Astrium	Google Earth PRO	01.feb.2017
Ortophoto	ESRI	10.dec.2017

The highlighting of the urban expansion impact on the Jiu floodplain is also achieved by presenting the dynamic of the environmental transformation index (*Itre*) as a result of the ratio of the natural and the anthropogenic surfaces. *Environmental transformation index (Itre),* used by the Polish researchers Maruszcsak and Pietrzak in 1988 to assess the human impact in the Subcarpathians and the Hills of Poland, was applied, with adaptations according to the type of surfaces, in hilly and plain areas in Romania (Ianaș, 2013; Ionuș, Licurici, Boengiu, & Simulescu, 2011; Mititelu-Ionuș & Avram, 2016; Prăvălie, 2012; Zarea & Ionuș, 2012). In order to reveal the natural / anthropogenic ratio, the calculation formula used, depending on the involved areas, variables such as forest, floodplain or aquatic area, relative to the built or used agricultural area. For the analyzed floodplain sector in this study, we considered the wet surface (S.w.)/ built surface area (S.b.) to be representative of the *Itre*'s multi-temporal calculation.

The development of the settlement on the bank of the Jiu

The current territory of Craiova is considered to be either overlapping the former Pelendava settlement (Vulpe, 1979), or as established in the vicinity of the Geto-Dacian settlement (A. Georgescu, 1936). Pelendava, also known as Pelendova, appears for the first time in Tabula Peutingeriana, a map of the Roman Empire, made around 225 or in the years 251-271, whose copies from the 11 - 12th centuries have been preserved until today (T. Georgescu, Barbacioru, & Florea, 1977; *Izvoare privind istoria Romîniei*, 1964). The location of Pelendava on the bank of the Jiu also defined its toponymy, which includes the "peled" meaning *wet* or *flowing* (Pospai, 2003; Toropu, 1979). Evidence confirming the permanence of the dwelling around, but also on the current territory of Craiova were associated with all the historical periods starting with the Neolithic - about 6000-2500 BC. (T. Georgescu et al., 1977).

The first documentary use of the name of Craiova appears in a document dated July 1, 1475, and as "the town of Craiova" on July 25, 1582, but the archaeological evidence reveals at Craiova the existence of a settlement of economic and administrative importance which had evolved beyond a rural stage, long before the 14th century, being an important point on the commercial road connecting Transylvania to the Danube (T. Georgescu et al., 1977). At the end of the 15th century, the settlement was presented as a borough, developed in the current area of the Old Town Square, towards which several commercial

roads converged. From a geomorphologic point of view, the core of the settlement expansion was on the first terrace of the Jiu (85-110 m altitude Fig. 2).

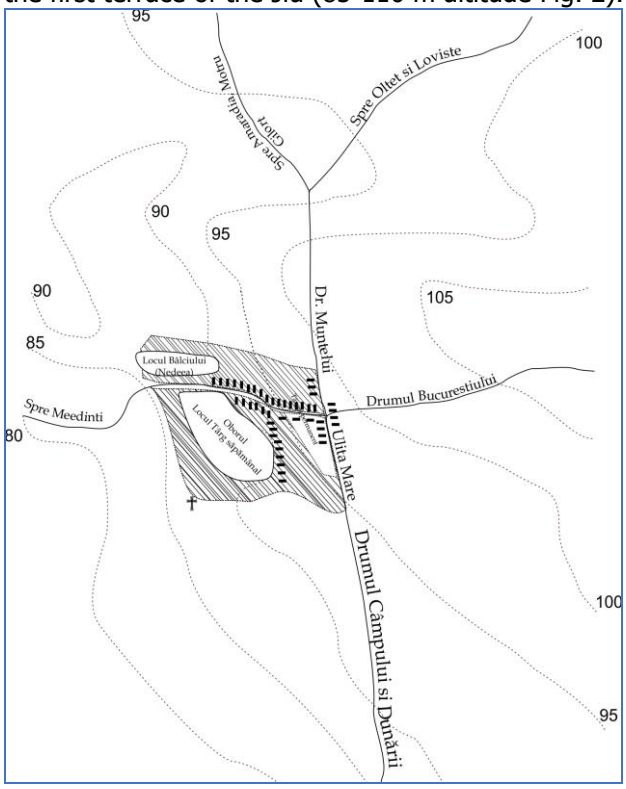

Fig. 2: The map of Craiova in 15th century

On the map achieved during the period September 1790 - May 1791, under the coordination of the Austrian officer Specht, which is considered the "first plan of the town" (Croitoru, 2012), Craiova appears as having a tentacular development on the terraces of Jiu, but not in the floodplain, where marshlands and ponds predominate (Fig. 3).

The end of the 17th century marked the delineation of the streets, the place of the fair, and in the 18th century the tentacular expansion of the city occurred along the main streets, on the entire Jiu terraces system (Nicolaescu et al., 1997). The city's first systematization plan dates from 1855, when the city center was established, the streets and the houses numbered. That same year, part of the streets of Craiova began to be illuminated with lamps (Nicolaescu et al., 1997).

On the first detailed map of Valahia (1: 57600), published in 1864 and based on Szathmári Pop Károly's lithography of *The Second Military Survey*, drawn by Austrians in 1855-1858, it is marked the beginning of the city's territorial expansion in the Jiu floodplain and the reduction of the areas occupied by ponds and marshes. Although the title of the map is *Charta României Meridionale*, it is widely known as the Szathmári *Map* (Fig.3).

The territorial expansion of the city continued under the power of economic and social progress and during the 1875-1906 period, Craiova deeply transformed, culminating with the "public works campaign", initiated in 1891 under the administration of Mayor Ulysse Boldescu (Ciobotea et al., 1999). The increase in the number of inhabitants due to the migration of the villagers from neighboring villages and of foreigners from Central and Western Europe led to the permanent expansion of the town limits, so that in 1899, in the Jiu floodplain, the radius of the town increased by 280 m on the Breasta Barrier (Cernele), 500 m on the Bucovăţ Barrier and 200 m on the Calafat Barrier (Balta Verde - Mofleni), compared to the limits from 1855 (Nicolaescu et al., 1997).

The presence of ponds and swamps in the southwestern part of the town has always been a source of insalubrity, infections and epidemics, which has made their drainage a mandatory assignement for the local administration. The first important work was the upheaval of all swamps from the Jiu floodplain between Balta Corniţoiu, Balta Verde, Fântâna Popova and the slope near the Bibescu Garden, according to the plans developed by G. Savopol in 1887 (Nicolaescu et al., 1997).

Although in 1904 a "neutral", peripheral area was established to separate the town from the neighboring villages, the realization of the collector canal (1896) created favorable conditions for the extension of the dwellings beyond the neutral zone, in the Jiu floodplain - on the Bresta Barrier, which led to a new resizing of the town (Nicolaescu et al., 1997).

Until the beginning of WWI, a series of anthropogenic works materialized in the floodplain sector of Craiova: the creation of the collector canal, the drainage of the southwestern swamps, the shaping of new boulevards on the site of the former streams, the designing of some discharge canals towards the main collector canal that crosses the floodplain longitudinally, the appearance of new constructions in the Eastern part of the collector canal.

In the interwar period, the urban renewal works, the city water supply, the sewerage, the pavement and the maintenance of green and recreation areas continued, including the designing of the Mofleni Park (14 ha) located within the Jiu floodplain.

In the second half of the 20th century, the image of Craiova and the floodplain sector it occupied was radically changed due to the works that aimed the streams planning, the regularization and the embankment of Jiu (the dyke from the right bank was built between 1978-1980 and the one on the left bank between 1981-1984), increasing the capacity of the collecting canal to keep up with the industrial development of the town, the improvement of pluvial water collection (Avram, Barbu, Ciobotea, & Osiac, 2005).

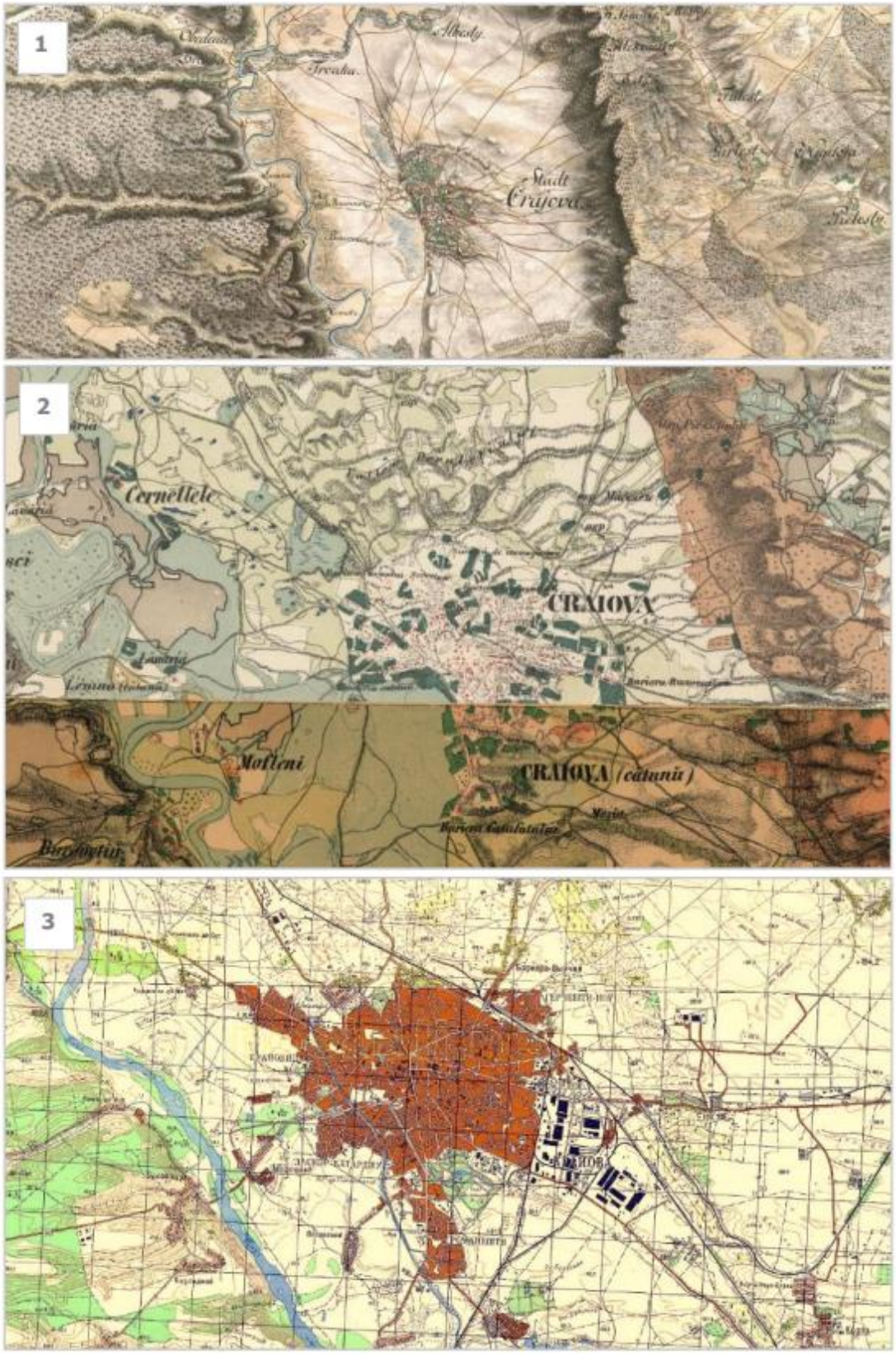

Fig. 3: The Dynamics of territorial expansion of Craiova

1 (1791) Tentacular development on terraces, Specht`s Map / Source: http://www.limes-transalutanus.ro
2 (1864) The beginning of expansion in floodplain, "Charta României Meridionale" /
Source: http://www.charta1864.ro/charta.html
3 (1976) The City of Craiova on "Russian Maps" / Source: http://www.geo-spatial.org

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Results

In its geological evolution, the Jiu presented a permanent movement of the course to the West, and one of the consequences of this movement was the formation and maintenance of marshes and ponds on the site of old courses.

The floodplain sector, which overlaps the present administrative territory of Craiova municipality, has an area of 39.79 km², a surface we have reported during the morphometric analysis and will be referred to as "the surface of the floodplain".

The visual dynamics of wetlands in the floodplain sector, represented by marshes and ponds a small part of which were later maintained as lakes intended for taking-over of pluvial waters or recreation, is synthesized in Fig. 4, having being rendered in the ArcGIS application based on historical maps: *Charta României Meridionale/ Chart of the Meridional Romania* published in 1864, British Map from 1944, Military Topographic Map, 1st edition, from 1974 Landsat Satellite Maps (1992), Google Earth (2017) and ortophoto 2017.

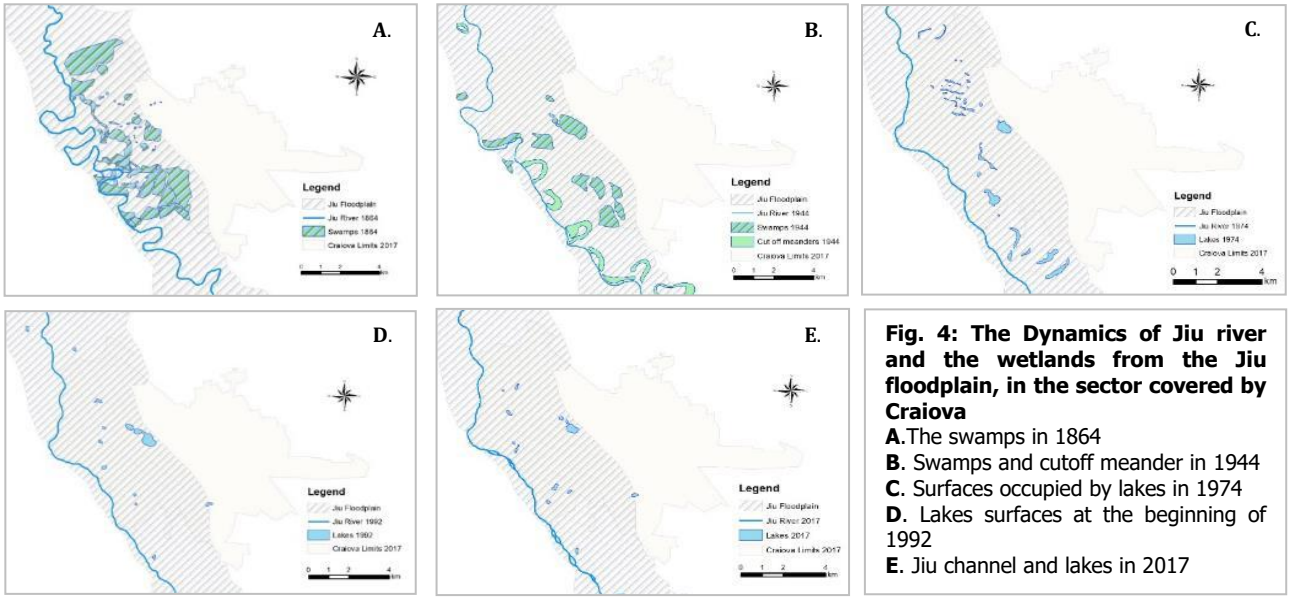

Fig. 4: The Dynamics of Jiu river and the wetlands from the Jiu floodplain, in the sector covered by Craiova
A.The swamps in 1864
B. Swamps and cutoff meander in 1944
C. Surfaces occupied by lakes in 1974
D. Lakes surfaces at the beginning of 1992
E. Jiu channel and lakes in 2017

In the second part of the 19th century, more than 28% of the floodplain surface was occupied by swamps – 11.37 km². Besides the impediment for development, they represented a source of insalubrity and maladies, their sewerage, drainage and systematization being a must. As a result of the public works launched by the authorities in 1891 and carried on constantly (except for the periods of the two World Wars), the decrease in wetlands occurred in an accelerated manner between 1900 and 1974 (Fig. 5).

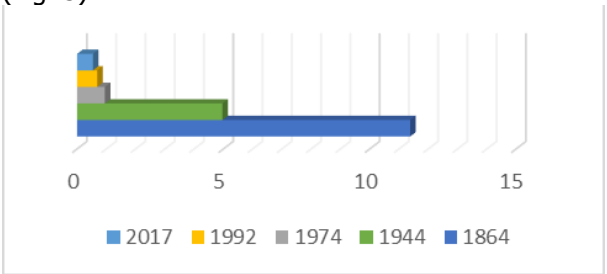

Fig. 5: The Dynamics of wetlands within the Jiu floodplain in period 1864-2017 (km²)

If in the 1860s the swamps covered about 28% of the floodplain, in 1974 they represented only 2.37%, and in 2017 the surface of the lakes in the floodplain totaled only 0.53 km², covering 1.35%.

A simulation of the cover of the current built area with the wet surfaces of the mid-19th century that dominated the Jiu floodplain is shown in Fig. 6.

The presence of the swamps covering the southwestern part of the town is easily observable.

Beginning with 1887 with the upheaval of all swamps from the Jiu floodplain, the drainage works included the creation of a channel system at surface or underground, wherethe water pond was pumped in, with discharge directly into the Jiu or in the Collector Channel (resulted by transformation of the Craiovița Stream, with a length of 11.2 km in order to take over the rainwater, industrial and domestic waters of the town).

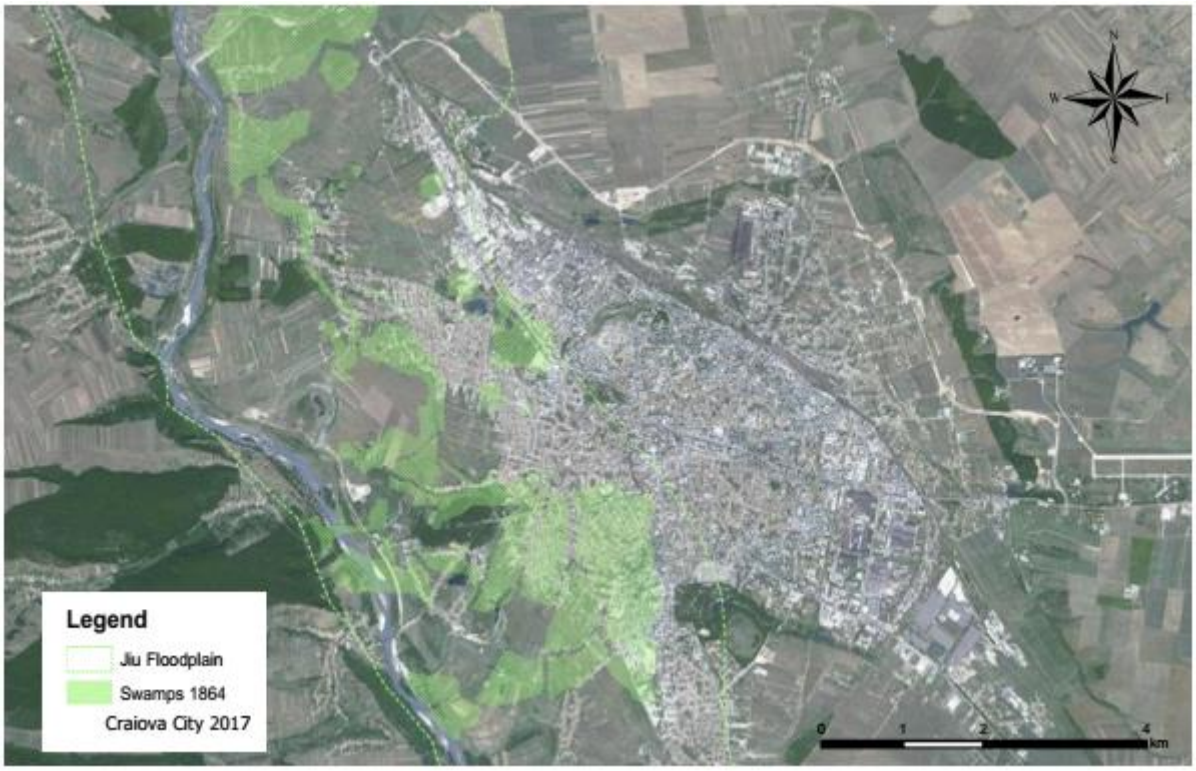

Fig. 6: The overlap of the swamps of 1864 on the current territory occupied by the city

The mitigation of the risk of pond reappearance and protection of the land, buildings and water supply fronts of the town, was achieved by the complete embankment of the left bank of the Jiu and also by the creation of the protective dyke around Lake Craioviţa, which was the source of Craioviţa stream, and has the role of collecting rainwater from the surroundings. The banks of Amaradia near the confluence with Jiu, as well as the Collector Channel in the upstream sector, were embankment. The anthropogenic works that permitted urban extension in the Jiu floodplain were reconstituted on the map in Fig. 7.

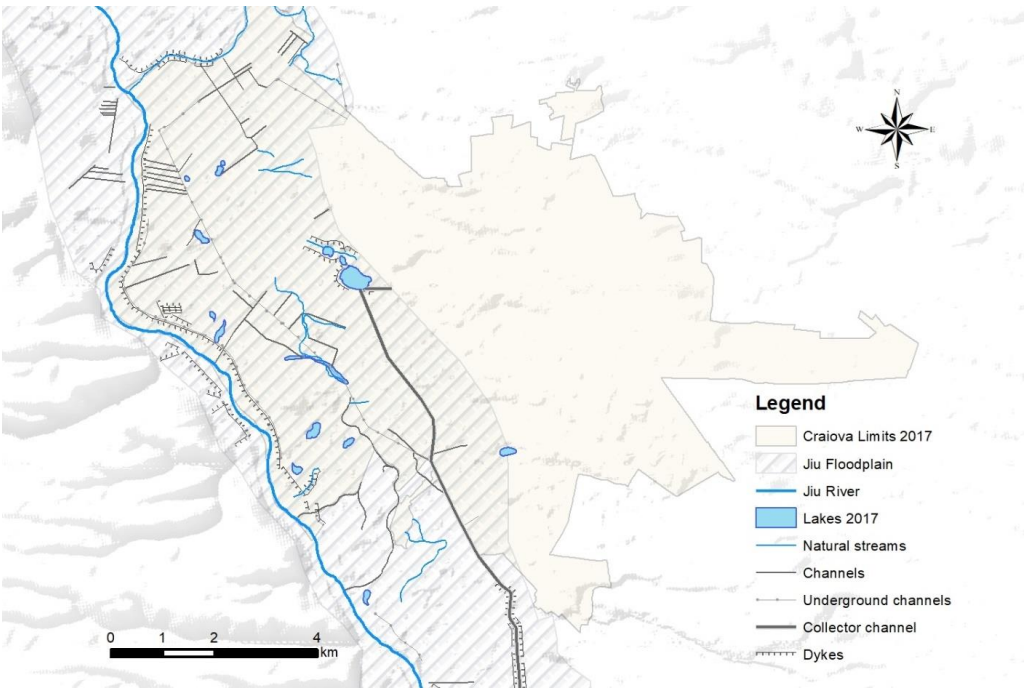

Fig. 7: The anthropogenic works realized for the swamps drainage in Jiu floodplain

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Starting with 1864 from a built-up area of 3.21 km² representing 8.08% of the surface of the floodplain and a swampy surface of 11.37 km², covering more than 28% of the floodplain, the inhospitable land of the floodplain was conquered step by step through the drainage of the ponds, the sewage of the streams and the extension of infrastructure and constructions. The expansion of the built area in the Jiu floodplain was directly proportional to the massive reduction of wetlands surfaces, while at the same time increasing the degree of safety by performing the flood protection works of the floodplain water courses. The city systematization started in 1855, including the construction of a Collector Channel in 1896, and allowed the expansion of dwellings along the roads in the East of the town, in the Jiu floodplain, and the further intensification of urbanization has increased the proportion of the built area to over 30% in the 1970s, to the detriment of wetlands that decreased to about 2% of the surface of the floodplain. The complete embankment of the Jiu banks during the period 1978-1984 favored the constant expansion of urban constructions, reaching 37% in 1992 and approximately 50% in 2017 (Fig. 8).

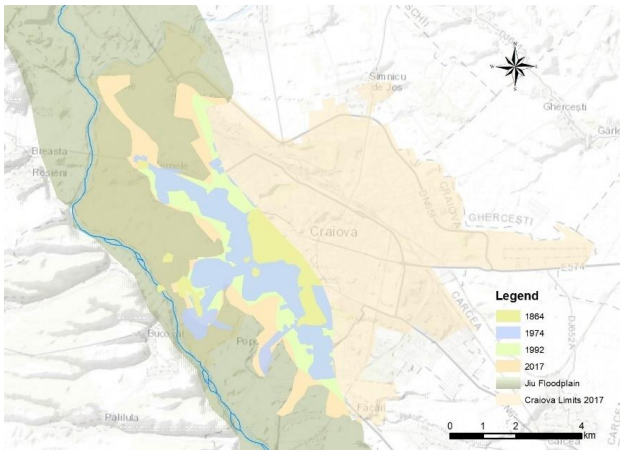

Fig. 8: The Dynamics of built surfaces in Jiu floodplain in period 1864 – 2017

On the former marsh land of the Jiu floodplain were built over the past 150 years many public utilities: the Lunca Jiului Park (now Tineret), the Mofleni Ecological Warehouse, Ion Oblemenco Stadium and the Polivalent Hall (Fig.9), the Botanical Garden, the Faculty of Agronomy, the Faculty of Physical Education and Sport, the County Hospital, the Army House, the Art High School, the House of Culture, hotels, as well as private buildings and dwellings.

Fig. 9: A - 1967. Geanoglu Swamp in drainage process - view towards center. Source: Omnia Library Craiova
B - The place of former Geanoglu Swamp in Dec. 2017 – view towards City Center. Source: C.D. Albă

The area of the broadleaf forest previously existent on the bank of the Jiu, in the southwestern part of the town, was put to use by its transformation, initially into a natural park, and from 1935 to 1936 in the Lunca Jiului Park.

To highlight the transformation made in the Jiu floodplain, the Environmental transformation index *(Itre*) was calculated for the last 150 years. *Itre*'s calculation formula has been adapted to the use of land from the Jiu floodplain, considering that the dominant areas in this case are relevant: wetlands representing natural areas and the built area representing anthropogenic surfaces. *Itre* dynamics, relevant to the expression of changes in the floodplain through urban expansion, is represented in Fig. 10.

$$I_{tre} = \frac{S_n}{S_a} = \frac{S_w}{S_b}$$

I_{tre} = Environmental transformation index;

S_n = Natural surface / S_a = Anthropogenic Surface;

S_w = Wetlands / S_b = Built surface

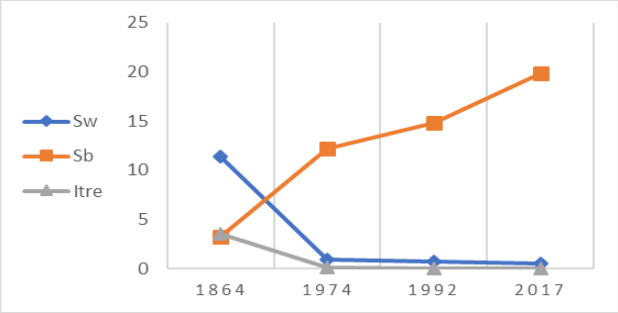

Fig. 10: Environmental transformation index (*Itre*) 1864 - 2017

The *Itre* value is much higher as the natural surface dominates the landscape. For the year 1864 the *Itre* value was 3.53, in 1974 went down at 0.07 and in 2017 this value dropped at 0.02. The much subunitary value of the past 50 years highlights the dominant anthropogenic landscape and the drastic reduction of natural surfaces.

In order to characterize the Jiu channel transformations over the last 150 years, the sinuosity index was calculated, representing the deviation of the course from a straight line and its value is expressed by the ratio between the actual length of the channel between two points and the straight line distance between the respective points (Aswathy, Vijith, & Satheesh, 2008). Depending on the static and dynamic characteristics of the course, Leopold and Wolman (1957) identified three river categories divided by the value of the sinuosity index value: straight rivers with an index of less than 1.1, sinuous rivers characterized by values of the sinuosity index ranging from 1.1 to 1.5 and meandering rivers with values higher than 1.5 (Dey, 2014).

At the exit of the Getic Piedmont and entrance into the plain area, the geomorphology of the area favored the course meandering before the anthropogenic intervention. In this sector, the Jiu River also presented a permanent movement to the West, forming the terraces and the floodplain and also several generations of meanders.

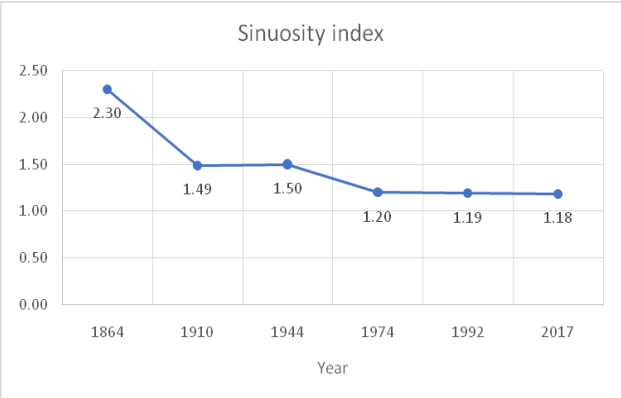

Fig. 11: The Sinuosity index of the Jiu River between 1864 – 2017

Until the first hydro-technical works on the course, the Jiu river presented on the analyzed sector a value of the sinuosity index of 2.3, being included in the category of highly meandered river (Fig. 11).

Since the first hydrotechnical works, performed at the beginning of the 20th century there has been a radical decrease of the index of sinuosity, which has an approximate value of 1.5 thus determining the inclusion of the river in the sinuous category around 1910. As a result of special hydrological events produced in 1953 and an exceptional flood in October 1972 with a flow of 2000 m³/s at the Podari hydrometric station, the regularization and straightening of the course continued and the index of sinuosity has a further diminished value in 1974. New floods occurred in 1977, which led to the planning of the complete embankment of both banks of Jiu, works that were carried out between 1978 and 1984.

The protection offered by the consolidation of the left bank and the regularization works favored the expansion of the constructions in the floodplain area, eliminating the risks of flooding for fields and constructions.

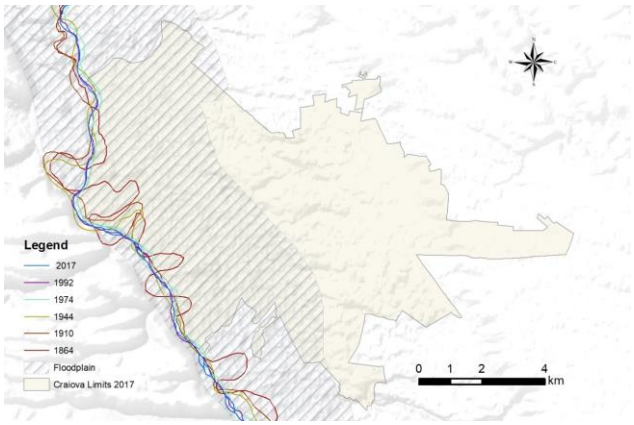

Fig. 12: The Jiu River between 1864 - 2017

Course changes recorded between 1864 and 2017 are presented in Fig. 12 where a relative stability of the course over the last 50 years can be observed.

Conclusions

Over the past 150 years the Jiu floodplain has undergone some complex morphological changes that have led to the replacement of the marshes and ponds that characterized it until the middle of the 19th century with land suitable for urban constructions. Until the beginning of the 20th century, the geomorphology of the floodplain constituted an impediment in the extension of the settlement. The human intervention began with the city's first plan of systematization in 1855 and

materialized through the drainage and channeling of the floodplain, the mudding removing and embankment of Jiu and other water bodies with a potential flood risk, allowed constant urban expansion in the floodplain sector. The metamorphosis of marshy areas that favored insalubrity was achieved by creating a canals system, by building new roads, public infrastructure elements and private facilities.

We believe that the reconstruction of past conditions and the dynamics of changes in a radically transformed urban sector such as the floodplain sector of Craiova, as well as the visual exposure of anthropogenic works and changes in the field are a useful tool for good urban planning.

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