

SPACE TIME EVOLUTION OF THE MAIN GEOGRAPHICAL ELEMENTS OF BAIJA MARE DEPRESSION USING GIS METHODS

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ABSTRACT. – **Space Time Evolution of the Main Geographical Elements of Baia Mare Depression Using GIS Methods.** This paper aims at following the time and space evolution of several geographical elements of either physical or human nature in Baia Mare Depression. This action was based on a series of satellite images from Landsat and Sentinel satellites, taken in different years between 1986 and 2017. Significant alterations have been discovered after processing such images. The lower drainage basins of Someș and Lăpuș Rivers have changed; their routes underwent alterations of their meanders on a distance of 500 meters during the period mentioned above (1986-2017). The wooded areas have also been altered, in both a negative (clearances) and positive (plantations) manner. Because Baia Mare was a major mining town, several tailing dumps and tailing management facilities have been established around it. Their evolution has been followed in this article, including the 2000 accident, which was one of the most unprofitable ecologic disasters of Romania. At the same time, the evolution of the city of Baia Mare has been assessed in an analysis where the built-up areas have been considered.

Keywords: *Landsat, Sentinel, rivers, vegetation, urban, catastrophes.*

1. INTRODUCTION

The number of fields where remote-sensing data can be used have increased once the equipment used to secure such data has been modernized. One of the main aims for using such data is the study of terrestrial surfaces. Such data are in fact satellite imaging based on which the information is secured after processing such images.

The main aim of this study is represented by following the time and space evolution of several elements from the natural and man-made environments, based on a set of satellite images taken between 1986 and 2017. The following

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elements have been analyzed: the urban areas, the tailing dumps and the tailing management facilities, the rivers and the vegetation. The NDBI index has been calculated to better emphasize the evolution of urban areas, and the NDVI index has been calculated so as to make a differentiation between the vegetation types.

The use of data secured from remote-sensing and the development of such analyses are critical for addressing different types of environmental issues. For instance, following an analysis of the vegetation correlated with the geological sub-layer and the hydrographic network, one can identify the areas that are suitable for dwelling and building constructions; at the same time, if only one type of vegetation is analyzed, like forestry, one can follow up the clearances or forestation of some areas. Based on the urban area analysis, one can acknowledge the depopulation or overcrowding of some built-up areas. Surveillance and analysis on the extension of several tailing dumps can be useful in taking decisions against closing one dump or for establishing the footprint of such dump so as it would not impact the area where it is located. The analysis of river evolution may be useful for engineers that must decide if a hydropower plant can be developed on the respective river, or in the case of deciding if that river meets the requirements for sports, like rafting. All these issues are critical and addressing such issues is useful for several fields. After reading specific literature, no paper was discovered on this matter, specifically for this particular area, and that is why we intend through this study to take the first step in approaching this topic for the selected study area, bringing some additional information within the field of geography.

The study area includes a part of Baia Mare Depression and the city of Baia Mare. This area has been selected due to the fact that it has been considered relevant for this type of study, and due to a personal reason, the author of this study being a local from Baia Mare, which offered a better understanding of the reality existing in this area.

Description of the area

This part of the paper is critical in a geographical study. The first question “troubling” the geographer is represented by the interrogation “where?”. This leads to the desire of humans to learn where they are, where a particular event takes place or where a particular landform element exists.

The study area overlaps over the central south - western side of Maramureș County, within Baia Mare Depression to be more exact, and to this area the northern side of the town of Baia Mare is added (N of Săsar River), an area framed by Filip S. (2008) as hilly and named as Munceii Baii Mari. At the same time, we should stipulate the fact that the outline of Baia Mare Depression has been performed by using the geomorphological regionalization proposed by Posea G. (2005).

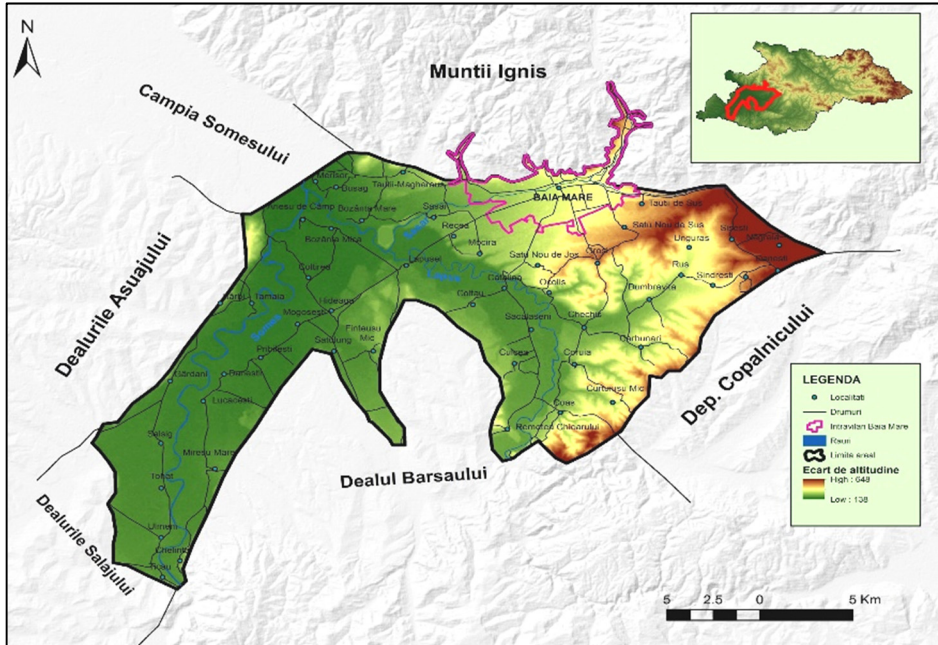


Fig. 1. Location map of the area of study

For an improved positional accuracy, the map of the location (Fig. 1) was prepared, against the surrounding landforms, observing most of the regionalization proposed by Posea G., (2005). In this manner, the study area is delineated on its northern side by the volcanic massif of Neogene age, Igniș Mountains (Borcoș, et al., 1973). The limit in the south-eastern side is Copalnic Depression, the southern limit is Bârsău Hill, the south-eastern one is Sălaj Hill, the western limit is Asuaj Hill, and the north - western limit is Someș River Lower Plain.

The entire depression is drained by several rivers, and the final common outlet is Someș River, which is located on the western side of this area, being south to north oriented. Lăpuș River drains the central and eastern sides of the area, draining the secondary outlet, Cavnice River. Other major rivers, which have been included on the map so as to observe the selectivity principle critical in preparing a map, are set forth below: Săsar River, crossing Baia Mare from East to West, Firiza River flowing from the northern side of the town and draining into Săsar River, and Craica Stream.

In order to pinpoint the study area accurately, including for individuals not familiar with this region, I have tried to stipulate the exact geographical coordinates with the help of Global Mapper 17.2. Thus, the coordinates are:

- North 47°43'05" northern latitude
- South 47°36'16" northern latitude
- East 23°46'27" eastern longitude
- West 23°15'18" eastern longitude

2. MATERIALS AND METHODS

This section describes the steps taken to achieve the results.

Initially, the foundation of the research consisted of the satellite imaging Landsat 5, 7 and 8, as downloaded from USGS and Sentinel 2-A. The image overlapping the study area has been selected. The images with low cloud cover have been selected from the rich archives. The selected images are from different years (1986, 1999, 2000, 2006, 2016, 2017) and all from approximately the same period of a year, namely August-September.

The second step consisted of image processing. Initially the ERDAS IMAGINE 9.2 software has been used. The stack of images has been first created. The atmospheric corrections followed. The RMSE has been calculated so as to verify the overlapping level of these satellite images, where the maximum value for Landsat images was 0.2 pixels (maximum value). Next, these were reproject from WGS84 coordinate system in the national Stereo 70 system, by using ArcMap 10.2.2, and later the images have been cut off by using a preestablished outline.

The third step consisted of extracting the information from satellite imaging. For this aim, the ArcMap 10.2.2 software has been used so as to digitize the main studied elements (rivers, woods, town, tailing management facilities), and subsequently the surfaces from several satellite images from different years have been measured, together with the use of supervised classifications. The resulting data have been integrated in drawings and Excel tables. NDVI and NDBI indexes have been calculated and processed with ArcMap 10.2.2.

The most used methods:

- Analysis Method - used to extract data.
- Summary Method - this is dialectical to the first method. After territory analysis, the data have been recomposed so as to explain the geographical events.
- Mapping Method - used to draw the maps necessary for the study.

The selected topic consists of a space-time analysis of the geographical elements in Baia Mare Depression. This required the use of history (time evolution), spatiality and causality principles.

3. RESULTS AND DISCUSSIONS

Space-time evolution of Someș and Lăpuș Rivers

One of the geographical processes with an elevated space-time dynamic is represented by the riverbeds. The riverbed is one of the most dynamic landforms, as there is a permanent interaction between the hydraulic energy of the watercourse and the material resistance of the riverbed (Hosu, 2009; Rădoane, 2001).

In this study, one of the elements studied from the space-time perspective was the riverbed of Someș and Lăpuș Rivers overlapping the Baia Mare Depression. After processing several Landsat (5, 7, and 8) satellite images, one was able to see that the dynamics in this sector of riverbeds was high. This is due to several factors, but the most important ones are the sloping and the geological sub-layer. Thus, Batuca et al. (1989) stipulates the fact that the slope is one of the most important parameters leading to meandering. The occurrence of meanders is explained based on this, due to the fact that within the study area there is a passing from hilly areas (Sălaj Hills, Groși Hills, and hills of Copalnic Depression) to lower areas, similar to plain areas and overlapping Baia Mare Depression. At the same time, the passing to Someș Plain occurs here, a plain included in the Western Plain geomorphological unit.

A second important parameter in the evolution of riverbed dynamics is represented by sub-layer. Thus, it has been proven in a scientific manner by expert researches in the riverbeds morpho-dynamics that the river meandre is developed within sectors overlapping a sub-layer consisting of fine particles, especially sands and clays (Batuca, et al, 1989; Mac, 1976; Rădoane, 2001). This can be proven by reading the geological map 1:2000000 -Baia Mare Sheet (Borcoș, et al 1973), where this sub-layer is proven to exist.

The information on the evolution of Someș and Lăpuș River Beds has been extracted by digitization, using two Landsat satellite images. Due to selection reasons and in order not to overload the mapping materials, a comparison between the two riverbeds was done for only two moments in time (1986 and 2016). The 1986 image was taken by Landsat 5 Satellite on August 8th, 1986 and the în data de 8 august 1986, and the 2016 image was taken by Landsat 8 Satellite on August 26th, 2016. Thus, the 30-year evolution of the respective riverbeds has been followed.

The area has been divided in several sectors (A, B, C, D) so as to ease the reading of the mapping materials and to follow in detail the evolution thereof, as presented in the following map.

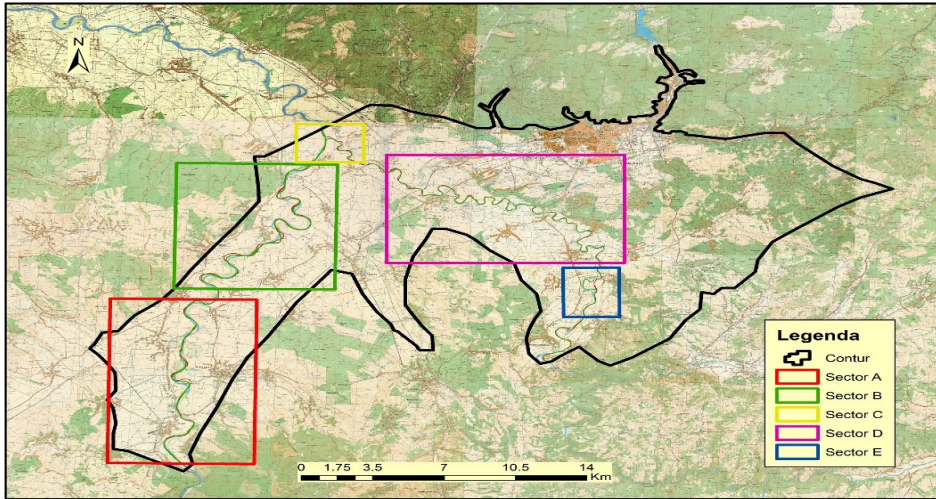


Fig. 2. Map of studied sectors

For comparison purposes, the topographic map 1:25000 has been used as background.

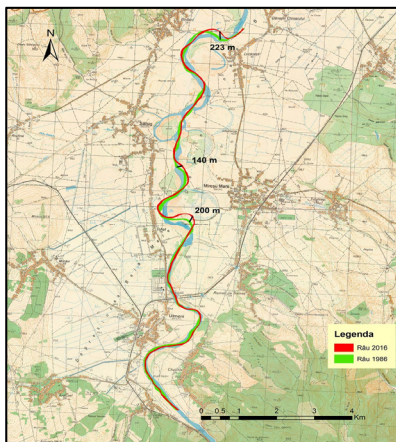


Fig. 3. Sector A

Sector A overlaps the Someș River course between Ulmeni and Dăneștii Chioarului localities. In order to emphasize the morphodynamic evolution, the riverbeds in 1986 and 2016 have been digitized, and a measurement has been performed for the key sectors by using ArcMap 10.2.2, in order to stipulate the value with which they “migrated” during this period. One can see that as compared to 1986, Someș riverbed evolved with values totaling 200 and 140 m towards east and northeast, near Mireșu Mare locality. At the same time, an evolution towards north is observed, with a value of 223 m near Lucăcești locality.

Sector B overlaps the route followed by Someș River between Dăneștii Chioarului and Ardușat localities. After analyzing the map, one can see alterations of the riverbed within several key sectors. Thus, the route has altered since 1986 mark with 170 m towards north-west near Fărcașa Commune, 150 north-west near Tamaia locality, 180 m south-east and 186 m east near the same locality (Tamaia) and 113 m south near Colțirea locality.

Sector C is located near Arieșu de Câmp and Busag localities. By analyzing the specific map of this sector, one can see a significant movement of the discharge area of Lăpuș River upon entering Someș River. This moved towards north with 182 meters. One can also see a movement towards northeast of Lăpuș River route from 2016 with 126 meters.

Sector D overlaps the route followed by Lăpuș River between localities of Bozânta Mare and Săcălășeni. The route crosses an area of terraces. After analyzing the specific map of the sector, one can see an alteration of the river bed from 2016 with 186 m towards south upon confluence with Săsar River, 90 m towards north - east near Lăpușel, 105 m and 97 m respectively near Mocira, and 66 m towards south near Săcălășeni.

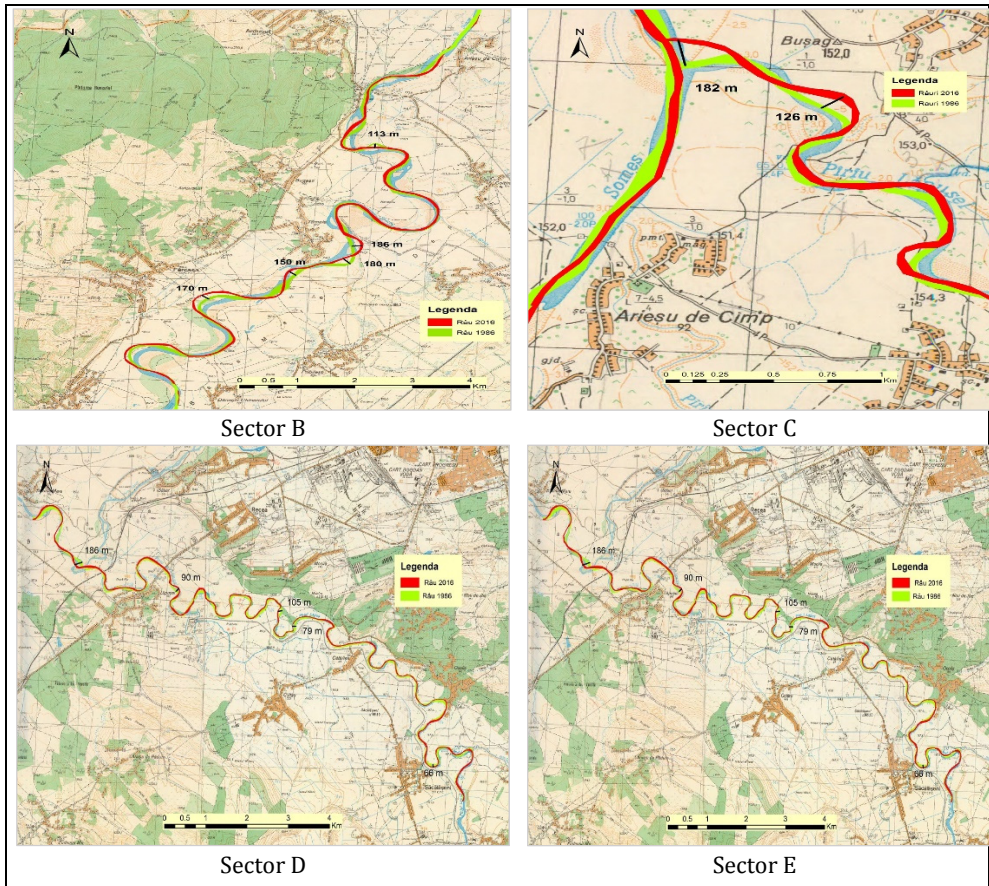


Fig. 4. Other sectors

Sector E represents the last study area of the riverbed dynamics. This sector covers the area between localities of Săcălășeni and Remecioara. Here, one can see the highest level of evolution. This is represented by the cut of a meander loop from 1986 towards the route followed in 2016. The difference between the meander and the relatively linear route from 2016 is 571 m. In addition, a cut meander was identified near Coaș, but this is at a lower scale than the first meander, i.e. only 164 m.

Spece-time evolution of forest

Another physical-geographical element resulting in an elevated dynamics within time and space is represented by the vegetation. Amongst these, a rapid evolution is seen at the vegetation areas overlapping farming lands, orchards, and forested areas. Two Landsat satellite images from 1986 and 2016 have been compared so as to see the time and space evolution of the wooded parcels existing within Baia Mare Depression. A supervised classification has been carried out so as to identify and calculate the wooded parcels, and subsequently a raster-to-vector conversion allowing calculation of the surfaces in ha, by applying the calculate geometry function on the accompanying table.

In order to summarize the information efficiently, the wooded parcels have been numbered as presented in the following map.

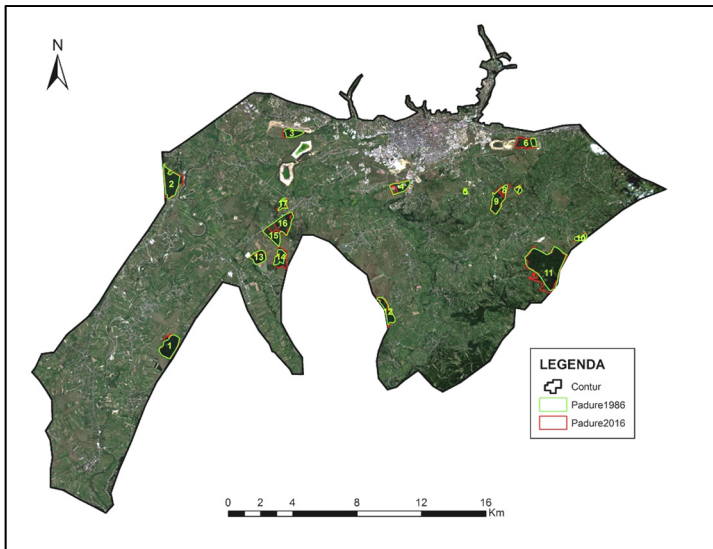


Fig. 5. Localization and coding of forest plots

The following data resulted from calculating the area of parcels by using the Calculate Geometry function as applied to the attribute table in ArcMap 10.2.2, being summarized in the table below.

Table 1. The area of the forest plots of the Baia Mare Depression

	The forest area 2016 (ha)	The forest area 1986 (ha)
Zone 1	117.403	112.055
Zone 2	139.909	127.687
Zone 3	50.909	42.952
Zone 4	57.243	66.452
Zone 5	4.301	5.361
Zone 6	70.976	14.832
Zone 7	16.680	15.147
Zone 8	25.755	29.875
Zone 9	78.476	82.596
Zone 10	19.873	17.906
Zone 11	425.141	392.543
Zone 12	60.420	64.666
Zone 13	52.063	59.487
Zone 14	79.351	45.774
Zone 15	62.152	84.152
Zone 16	92.912	114.912
Zone 17	25.505	18.855

A chart has been prepared to facilitate the comparison of the evolution of surfaces between 1986 and 2016.

After analyzing the above chart, and extension of the wooded areas is noted within areas (Z1, Z2, Z6, Z7, Z10, Z11, Z14, Z17), the most evident one being within Z6 area. This area overlaps a former tailings dump near Tăuții de Sus village, a dump that has been rehabilitated and partially reforested. In the case of the remaining areas, a reduction of wooded areas was noted.

In order to observe the other vegetation alterations, the calculation of a NDVI (Normalized Difference Vegetation Index) satellite index was done for satellite images from 1986, 2000 and 2016. The index was calculated in ArcMap 10.2.2 software by using the methodology proposed by the site: http://earthobservatory.nasa.gov/Features/MeasuringVegetation/measuring_vegetation_2.php. An NDVI calculation has been performed also on a Sentinel 2-A satellite image so as to have up-to-date data, by observing the same methodology as presented above.

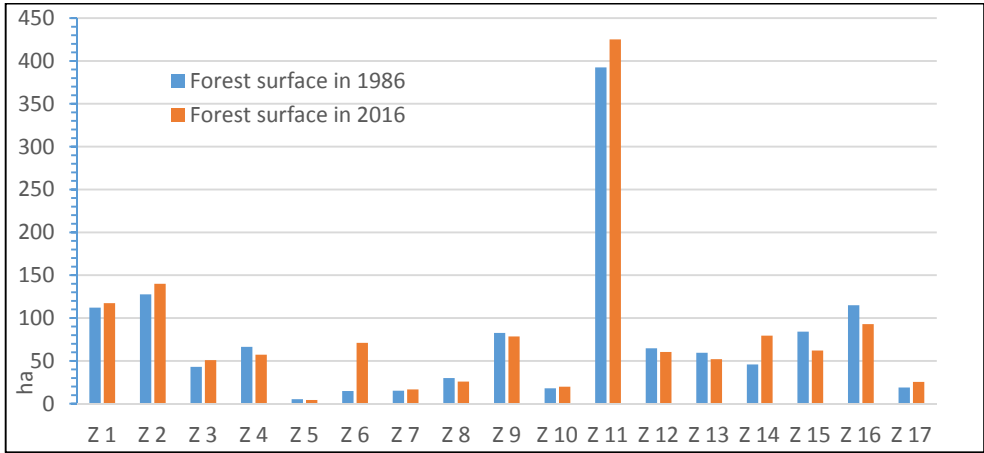


Fig. 6. Chart of forest surface

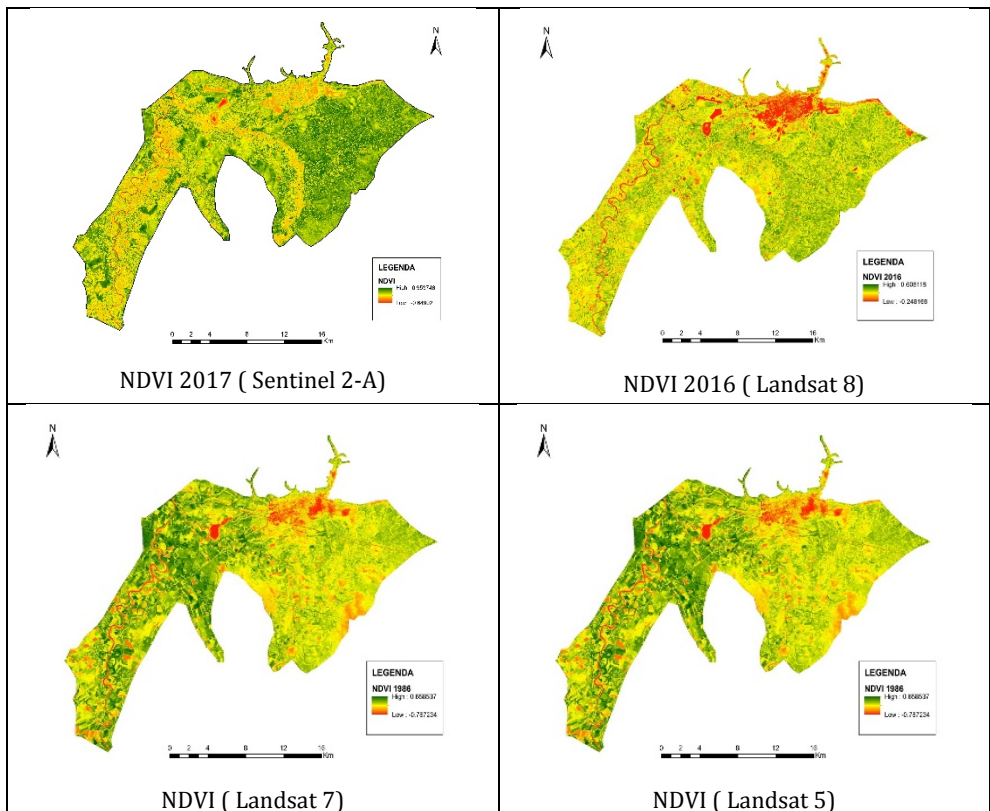


Fig 7. NDVI

The resulting values are comprised between -1 and 1. The values close to -1 express a lack of vegetation and they are presented with red color, and the values close to 1, express a higher density of vegetation and are presented with a dark green color.

After analyzing the three maps, one can see that the areas with no vegetation (red color) overlap the built-up area of Baia Mare, the tailing dumps and the riverbeds. One can see by comparing year 1986 with year 2016 that the western area of the study region (overlapping the Someș meadow) presents a higher density of vegetation (dark green color) in 1986. This may be because agriculture was critical for Romania's economic system during that particular period, and all land positions with a certain agricultural potential have been used. Currently, many of the farming lands are no longer worked by peasants, and this is how the low values of NDVI for 2016 can be explained.

Space-time evolution of tailing dumps

An application of remote-sensing technology within the Baia Mare Depression is represented by the research of the space-time evolution of the tailing dumps and tailing management facilities. Baia Mare was famous for its intense activity on mining non-ferrous ores (gold, silver, zinc, copper, lead, etc.) The surplus was stored at different tailing management facilities, together with the substance used in processing these ores, loaded with cyanide. One can see that these facilities have had an elevated dynamics after analyzing the satellite imaging. Maybe the most important dynamic, in a negative manner, was the failure of dams of one of the tailing management facilities operated by SC AURUL SA on January 30th, 2000. In order to identify clearly each tailing management facility (TMF) whose evolution we are describing here, we have used the encoding presented on the following map.

We need to stipulate that the wet surface of the TMF has been measured, being the one with the highest dynamics. The TMF bodies suffered no major alterations in time. In order to see the wet body accurately, we have used a combination of 432 bands, in the case of images taken by Landsat 5 and 7 and a combination of 543 bands in the case of images taken by Landsat 8.

The TMF no.1 belonged to SC AURUL SA, and substances resulting from gold processing have been stored at this TMF. This TMF is older than 1986 and its surface decreased from 43 ha in 1986, down to 13 ha.

An abnormal evolution has been seen with TMF no. 2 that resulted in serious environmental damages in 2000, when over 100,000 m³ of substances with cyanide have been spilled. One can see on the following table a comparison between 1999 and 2000.



Fig. 8. Map of tailing ponds and tailing dumps

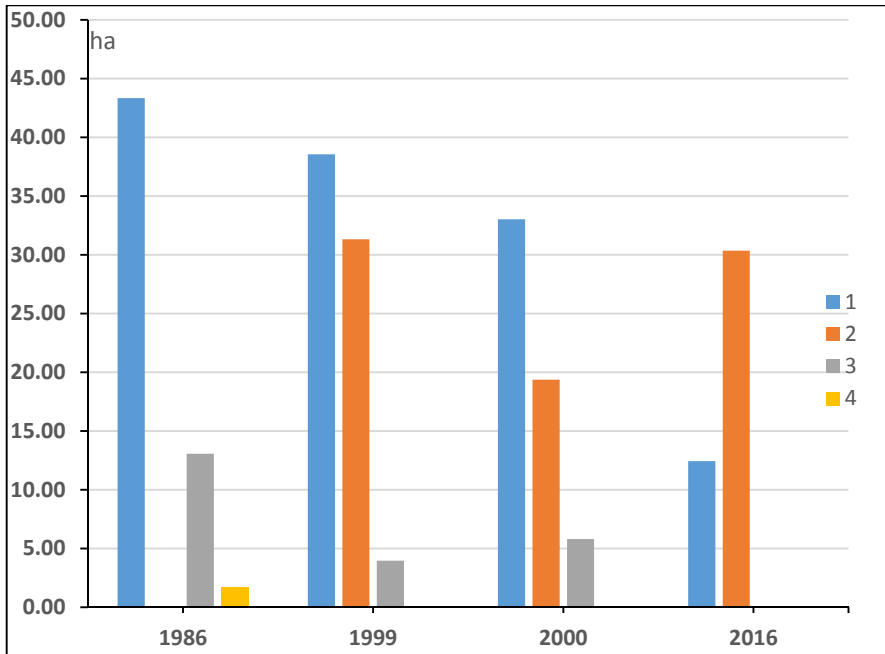


Fig. 9. Chart of tailing dumps surface evolutions

The tailings dump no. 3 is located east of Baia Mare, within the area of Tauții de Sus.

As it can be seen on the chart, the dump reduced its surface down to a complete disappearance, currently being a rehabilitated dump and undergoing a reforestation process.

The TMF no. 4 has been decommissioned in the late 80s. The TMF no. 2 has been built near this TMF no. 4 and commissioned in 1999.

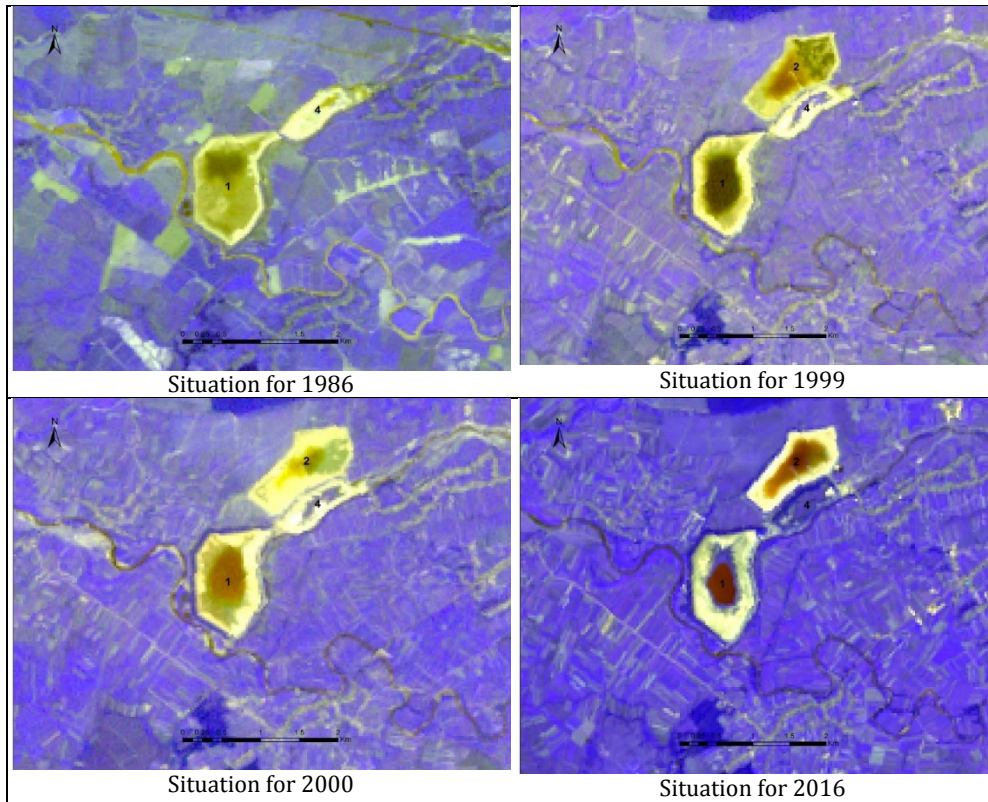


Fig. 9. Evolution of TMF in the Bozânta-Săsar area

Space-time evolution of built-up areas in the town of Baia Mare

The geographical element with the highest dynamics is represented by the Baia Mare built-up area. This evolution can be seen without detailed analyses based on satellite imaging and maps. By merely observing at a particular period of time, one can see the dynamics associated with the increase of the surface covered by the built-up area.

The digitization based on Landsat satellite images from 1986, 2000, 2006, and 2016 has been used so as to emphasize with exact data the town dynamics, together with the space covered by urban constructions of Baia Mare. The evolution is seen on the following map, where the polygons on those four years are marked.

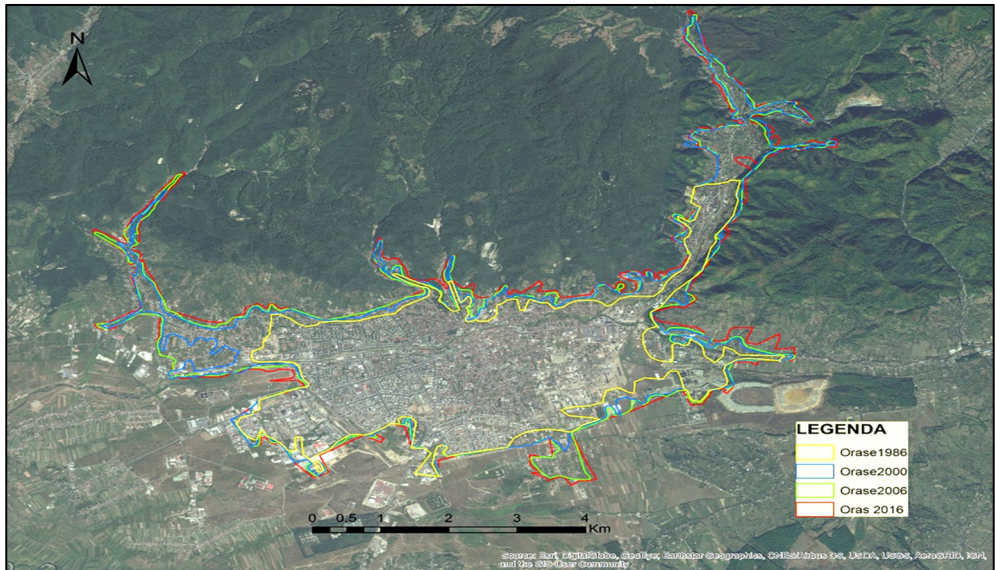


Fig. 10. Evolution of Baia Mare

The values of the surfaces from each year are summarized in the chart and table presented below.

Table 2. Evolution in time of the surface covered by Baia Mare

Year	Area (km ²)
1986	15.344
2000	20.844
2006	22.435
2016	24.464

The town increased its surface with about 10 km² between 1986 and 2016, as resulting from the analysis of this material. This is a paradox because during this period, according to the National Institute of Statistics, the town suffered a major decrease of population, from approximately 155,000 in 1991, down to approximately 120,000 in 2011.

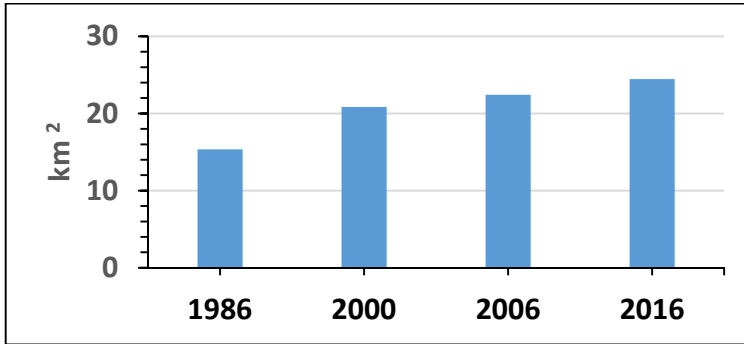


Fig. 11. Chart of urban surface

In order to emphasize the extension of the town during several years, the map of 1787 of the town was used against the current map. The map was secured from and its scale was adjusted by using the website <http://mapire.eu/en/>.

It has been established by using the calculation of surfaces from this site that Baia Mare had a surface of only 3 Km² in 1787. Thus, from 1787 to date, Baia Mare extended its area 9 times.



Fig. 12. The expansion of the city in 1787 and 2016
(source: Joseph II maps accessed on <http://mapire.eu/en/>)

Aside NDVI index for vegetation, the NDBI index (Normalized Difference Built Index) has also been used. The calculation of this index has been performed by observing the methodology proposed by Nitin, et al. (2014) for Landsat 8 and Mihai, et al (2012) for Landsat 7.

Thus, the formula to calculate the index is:

$$NDBI = (IR - NIR) / (IR + NIR)$$

The NDBI values vary depending on the spectral signatures from middle infrared (high reflectance of soil humidity, vegetation, rocks, including building materials) and narrow infrared (high reflectance of chlorophyll). The values are comprised between -1 and +1. The pale colors (positive values) symbolize the land positions with constructions. The dark colors (negative values) symbolize the other landscape elements woods, farming land, etc. (Nitin et al., 2014)

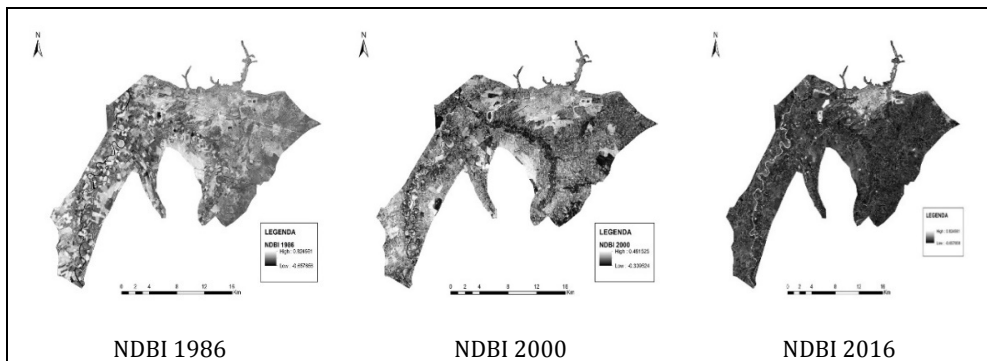


Fig. 13. NDBI index

By analyzing these three situations, one can see that the highest values overlap the built-up area of Baia Mare and localities, and the lowest values overlap farming lands and land position with no constructions.

4. CONCLUSIONS

The following conclusions have been drawn after studying the space-time evolution of the main geographical elements from Baia Mare Depression:

- The two rivers, Someș and Lăpuș, whose alteration has been studied, presented an evolution meeting the general geomorphological descriptions of a water course in a depression. Thus, by crossing an area with a low sloping, they developed meanders that altered between 1986 and 2016. Many changed their position, but there were situations in which a meander was cut, becoming in this manner an abandoned river branch.

This can be explained with the fact that a river “seeks” to alter its route and “selects” the easiest path, with a low consumption of energy. The evolution of rivers was easily followed from the maps with the help of the two situations of the lower river beds (1986-2016)

- In the case of vegetation, one could see that there is a situation of national paroxysm in some areas, i.e. some forested areas extended in 2016 as opposed to their surface in 1986. After tracking the evolution of NDVI index, one could see a negative evolution within the Someş meadow area. The density of vegetation being higher in 1986 because the area overlaps an area of fertile soils and the farming policies in place at that time required maximum use of these parcels.
- The space and time evolution of Baia Mare emphasized an extension of its surface from 1986 with approximately 10 km². In 2016, the surface covered by the town was 24.4 km². Again, this is paradoxical due to the fact that the population decreased during this period. Notable evolution has been observed within the northern side of the town, a place where the following quarters have been built: “Sub-Dura”, “Valea Roşie” and “Valea Borcutului”, as well as the East and South of the town where major alteration of the industrial facilities have been noticed.
- After analyzing the evolution of tailing dumps and TMFs located within the eastern and western side of Baia Mare, a general trend of reduction of the tailings covered surfaces has been observed. A different evolution has been recorded for Aurul’s TMF commissioned on 1999 and, shortly after, a major dam failure occurred in year 2000 that led to the reduction of its footprint covered with substances, resulting in an environmental catastrophe. Many of these dumps and facilities have been subjected to a landscaping and ecologic reconstruction program, leading to their disappearance, leaving only a footprint on the newer satellite imaging.

As a general conclusion, one can state that the easiest method to be used in studying the space-time evolution of geographical elements overlapping a particular space is to analyze the satellite images and not only those. The detailed processing and analyze of such images provide to researcher a big picture of current situation compared to a previous situation.

REFERENCES

1. Bătucă, D., Ioniță, I., Rădoane, Maria, Duma, D., (1989), *Morfologia și dinamica albiilor de râuri*, Editura Tehnică, București
2. Borcos, M., Lang, B., Peltz, S., Stan, N., (1973), *Geological map of Gutai Mountains*, published by Geological Institute, Bucharest
3. Filip, S., (2008), *Depresiunea și Munceii Băii Mari. Studiu de geomorfologie environmentală*, Presa Universitară Clujeană, Cluj-Napoca
4. Hosu, Maria (2009), *Valea Someșului între Dej și Țicău-Studiu geomorfologic*, Edit.Presa Universitară Clujeană, Cluj-Napoca
5. Mac, I., (1976), *Geomorfologie. curs*, Cluj-Napoca
6. Mihai, V., Octavian, L., Oncia, Silvia, (2012) *Using satellite images Landsat TM for calculating normalized difference indexes for landscape of Parang Montains*, RevCAD
7. Nitin, K., Saad, S., B., (2014), *Built-up area extraction using Landsat 8 OLI imagery*, GIScience & Remote Sensing, Vol. 51, No.4, p 445-467, Pathumthani-Thailand- accesat online pe https://www.researchgate.net/.../273886729_Builtup_area_extraction_using_Landsat8
8. Posea, G., (2005), *Geomorfologia României relieful, tipuri, geneză, evoluție, regionale*. Ediția a II-a, Editura Fundației României de Mâine, București
9. Radoane, Maria, Dumitru, D., Ichim, I., (2001) *Geomorfologie Vol II*, Editura Universitatii Suceava, Suceava
10. <http://glovis.usgs.gov/>
11. http://earthobservatory.nasa.gov/Features/MeasuringVegetation/measuring_vegetation_2.php
12. <http://www.insse.ro/cms/>
13. <http://mapire.eu/en/>