USING LANDSAT IMAGES IN MAPPING AND MONITORING WATER BODIES IN MĂGURA BASIN

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ABSTRACT. - Using Landsat Images in Mapping and Monitoring Water Bodies in Măgura Basin. The work is part of a wider range of interdisciplinary studies undertaken in Măgura catchment, a right-side tributary of Bahlui River. The Măgura River flows from the massif Great Hill-Hârlău. Before the year 2000 there were 11 lakes, and today are only 4. The purpose of this project is to determine the accuracy of the simple techniques in digital image processing for mapping and monitoring lakes and wetlands. Landsat 7 ETM + and Landsat 8 OLI TIRS data sets are used. The paper highlights the bands' thematic classification accuracy using minimum technical and digital (software) resources. The water bodies' delineated boundaries of each digital classification procedure were compared with the limits obtained by digitizing the topographical plans (1973) and aerial images (2008). The comparisons show that the Landsat data can be used to map accurately the water bodies. It is a simple method of determining the silting degree, especially for lakes with an area of at least 1 ha. Măgura basin has a high archaeological potential (prehistory up to the modern period), part of the national and international cultural heritage. Creating a GIS database, in order to analyze the human-environment relationship, began by studying the hydrological variables. This factor has an important role in the society's development, both prehistoric and current.

Keywords: Landsat 8, thematic bands, unsupervised classification, small water bodies, Măgura – Iași.

1. INTRODUCTION

The interdisciplinary study undertaken in the Măgura basin is part of a series of geoarchaeological researches, centered on Bahlui River basin and a large area from the Moldavian Plateau; monitoring the landscape evolution under the impact of human communities, without excluding the fact that the relationship between the human community and the environment is interdependent, the human factor being aware of the important features or items within the landscape.

One of the most important features is represented by the water. Along with the geological, geomorphological, pedological and biological elements; the hydrological aspects have always influenced the development of human communities. The presence of watercourses or lakes, proximity to sources of drinking water and salt springs (used for food preservation); water resources are one of the determining factors in the establishment and development of a settlement (Ridd; Liu J., 1998) [6].

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Using satellite imagery, the aerial images and classical, topographic map materials, represents the foundation of any GIS database. A geoarchaeology study uses this information to analyze every interdependent aspect of the Human - Environment relationship. Monitoring the evolution of a natural element, using remote sensing has a wide applicability, including land use, natural hazard analysis, changes of forest or vegetation cover, urban development and not least, hydrological features. The data package offered by each satellite, contains spatial, spectral and different temporal information; constitutes a basic resource for water bodies' detection and monitoring.

Satellite image processing techniques have been developed in the last decade to highlight and evaluate hydrologic data. The methods used for analyzing single spectral images are using value ranges to extract hydrological elements. In this case, the errors are common due to mixing pixel values pertaining to water bodies with similar values of other types (Du, Linghu, 2012)[1]. Error frequency decreases in the case of multispectral images, although similar techniques are used for classification. The advantage is given by the inclusion of different reflectivity values in the algorithm, but also the opportunity to identify and correct errors for each band, separately. The **Normalized Difference Water Index** (NDWI) algorithm, applied in the Măgura case study is corrected by using near infrared band (NIR) to eliminate building, vegetation or soil pixels (Xu H., 2006)[12].

This paper aims to develop and establish classification techniques or methods for determining the hydrological classes, using satellite imagery from Landsat 5 TM, Landsat 7 ETM and Landsat 8 OLI + TIRS flights. Comparing Landsat water bodies' contours to the limits obtained by digitizing topographical plans (edition 1973) and aerial images (2008), will represent the silt rate analysis for the lakes in Măgura basin.

2. MATERIALS AND METHODS

2.1. Study area

Măgura is one of the nineteen right-side tributaries of Bahlui River. The basin is located in the Northeastern part of Romania, in the NW of Iasi County. In administrative terms, the territory spreads in eight localities (Cotnari - most of the basin area, Todireşti, Vânători, Siretel, Scobinți, Ceplenița, Costești and Cucuteni). It has its source in Sticlăriei Hill (Dealul Mare - Hârlău) and meets Bahlui River in Hodora (Cotnari locality). The basin spreads between 47°18'-47°25' Northern latitude and 26°47'- 27°00' Eastern longitude. It has an area of 78 km² and the river is 25 km long. Măgura valley overlaps the following morphological subunits (Fig. 1):

• Suceava Plateau (Dealul Mare - Hârlău Massif - 65%);
• Moldavian Plain (Hârlău-Hodora Depression and Sârca Hills - 35%).

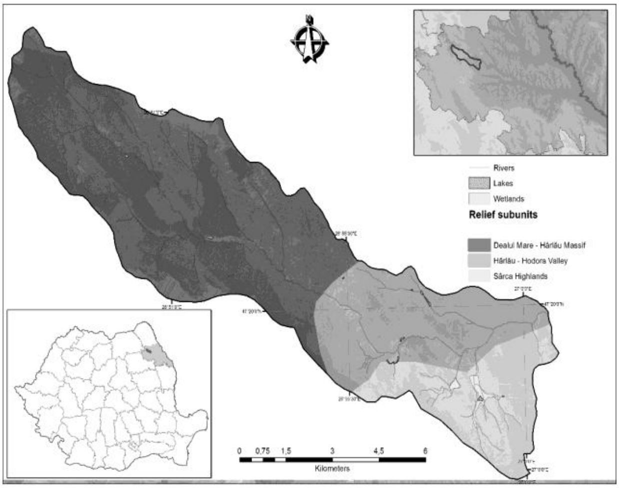

Fig. 1. ***Măgura basin on morphological subunits.***

The research aims to study the evolution of lacustrine areas, in the mentioned basin, using remote sensing, satellite imagery processing and interpretation in a GIS environment. The study was conducted using maps and satellite data sets, on a 40-year period (1974-2014).

Table 1. ***Investigated lakes in Măgura basin***

FID	NAME	POSITION		AREA (ha)	PERIMETER (m)	BOUNDS (Stereo 70)			
1	Zbereni	47°22'30.63"N	26°49'49.28"E	0,7	349	**638274,866**	654432,621	638405,835	654529,195
2	Lebăda	47°21'11.03"N	26°51'55.19"E	1	425,42	**640940,76**	652045,025	641119,618	652123,342
3	Cîrjoaia 1	47°20'34.38"N	26°52'28.25"E	0,13	149	**641598,833**	650921,355	641657,041	650950,989
4	Cîrjoaia 2	47°20'33.41"N	26°52'22.15"E	0,3	223,4	**641711,016**	650943,58	641802,033	650991,206
5	Coasta Măgurii	47°19'7.54"N	26°56'32.72"E	1,45	1250	**646734,67**	648366,798	647137,102	648590,636
6	Coasta	47°19'29.93"N	26°56'46.38"E	0,6	447	**647162,82**	649024,871	647305,695	649158,221
7	Horodiştea	47°20'29.11"N	26°55'18.34"E	0,16	164	**645303,345**	650867,092	645354,939	650918,686
8	Pîrîul Sărat- Iaz 1	47°20'16.19"N	26°57'3.37"E	0,2	221	**647494,982**	650518,414	647572,769	650573,183
9	Pîrîul Sărat- Iaz 2	47°20'12.81"N	26°57'18.93"E	0,56	369	**647827,564**	650392,208	647929,958	650531,908
10	Pîrîul Sărat- Iaz 3	47°20'4.92"N	26°57'26.93"E	1,3	751	**647937,101**	650069,945	648160,146	650360,458
11	Hîrbului	47°18'30.38"N	26°58'45.07"E	1,27	514	**649665,143**	647400,36	650518,778	647432,771

The 11 surveyed water bodies (Table 1) were inventoried using 1: 2000 plans and 1: 25000 maps, editions from 1970 to 1980 (Table 1). The smallest area considered has 0.13 ha and a perimeter of 150 m and the largest area measures 1.45 ha, with an initial perimeter of 1250 m. The total area of water bodies represented 7.7 ha, amounting to a total perimeter of 4863 m. There were also traced the outlines of two wetland surfaces, situated in the lower part of the basin, which measured 7.7 ha, respectively 35.6 ha, the latter surrounding Hîrbul Lake.

2.2. Datasets

The database was extended with sets of satellite images. They correspond to the following periods: August 1989, September 1999, April 2002, August and December 2013, February and July 2014. Also, we mention the zone's aerial images, processed in 2008. The sets are divided by satellite generation: 1 set Landsat- 5 TM (1989), 2 data sets Landsat 7 ETM + (1999, 2002) and 4 sets Landsat- 8 OLI (TIRS). The data were obtained using Global Visualization Viewer interface, on the US Geological Survey (USGS) platform.

Satellite	Sensor	Path/ Row	Date	Band	Resolution (m)/ Pixel dimesion	Wavelenght (µm)
				1	30 (28.5)	0.45 - 0.52
				2	30 (28.5)	0.52 - 0.60
Landsat- 5	TM	183/27	18.08.1989	3	30 (28.5)	0.63 - 0.69
				4	30 (28.5)	0.76 - 0.90
				5	30 (28.5)	1.55 - 1.75
				6	30 (28.5)	10.40 - 12.50
				7	30 (28.5)	2.08 - 2.35
				1	30	0.45 - 0.515
				2	30	0.525 - 0.605
				3	30	0.63 - 0.69
Landsat- 7	ETM+	183/27	23.09.1999	4	30	0.75 - 0.90
		183/27	01.04.2002	5	30	1.55 - 1.75
				6	60	10.40 - 12.5
				7	30	2.09 - 2.35
				8 (Panchrom.)	15	.52 - .90
				1	30	0.43 - 0.45
				2	30	0.45 - 0.51
				3	30	0.53 - 0.59
				4	30	0.64 - 0.67
Landsat- 8	OLI (TIRS)	183/27	04.08.2013	5	30	0.85 - 0.88
		182/27	03.12.2013	6	30	1.57 - 1.65
		182/27	05.02.2014	7	30	2.11 - 2.29
		182/27	31.07.2014	8 (Panchrom.)	15	0.50 - 0.68
				9	30	1.36 - 1.38
				10 (TIRS)	100	10.60 - 11.19
				11 (TIRS)	100	11.50 - 12.51

Table 2. ***Satellite data technical information.***

One of the main criteria in choosing the data sets was the cloud coverage percent, preset at "*less than 10%*". This option reduced by more than 70% the initial data volume.

2.3. Pre-processing of satellite images

The research aimed to study the lake surfaces' spatial evolution, in Măgura Basin. The initial limits were traced using topographic maps from the years 1970-1980, and the largest water body had a 1.45 ha area. Thus, aiming at an accurate determination of small areas, it is required a pre-processing correction for the "raw" satellite images. The correction implied a reprojection to the national coordinate system-Stereographic 1970; radiometric calibration and atmospheric correction, resizing and cropping individual data sets, using the basin contour. The reprojection of each raster, which represents a single band from the image set, it was used ArcGIS's *Raster Project* batch-mode function, allowing us to handle multiple rasters at once. The function transformed the georeference system from WGS 1984 (Datum: WGS 1984 spheroid: WGS 1984), to Stereo 70 system (Datum: Piscului Hill 1970, spheroid: Krasovsky 1940). The radiometric calibration process involved converting digital-numeric values into radiance values, at the impulse recording time. Subsequently, these values were converted to values of reflectance. For both methods were used Landsat calibration functions, available in the Envi 4.7 software. The values required to calculate the two transformations types (sun angle, image registration date, maximum and minimum values per band, gain and bias etc.) can be found in file metadata, assigned to each set. The study resorted to transformation from digital data (RGB: 0-255) to values of reflectivity, in order to work with rasters containing elements with the same spectral pattern. Referring particularly to small aquatic areas, which are not distinguished by a specific color (green, dark blue etc.), the composing pixels blend easily with the pixels associated with forests or soils; thus, the study endeavors to individualize the objects through spectral patterns (signatures). The pictures are from different seasons, recorded at different times. The radiometric corrections are trying to build links between the values of the same object. A final advantage of the atmospheric correction procedures is to reduce the workload for supervised classification of the pixels or better defined classes, in the case of automatically generated clusters. Finally, the bands were integrated into a single raster image - with an initial resolution of 30x30 m/px. For the data sets from Landsat 7 and 8, the complex rasters were improved, generating a new "panchromatic-corrected" image; using the "Pan-sharpened Raster" function in ArcGIS and band 8 (panchromatic) of each set. The final rasters have a 15x15 m/px. resolution.

2.4. Indices water surface contouring.

Water bodies' area evolution in Măgura basin were observed in a temporal interval of 40 years, through satellite data sets from different years. Delimitation and individual surface analysis was performed after digitizing the rasters, using the indexes of each satellite band, generated using the values in algebraic operations (Raster Calculator).

We have created four types of raster-index: Normalized Difference Water Index **(NDWI)**, Water Ratio Index **(WRI)**, Automated Water Extraction Index **(AWEI)** and the Humidity index (Wetness) (Table 3). The latter is particularly useful for shaping wetlands, including the calculation of the three biophysical KAUTH indexes (greenness, brightness and wetness), highlighting even the water in plants (Romanescu et al., 2008) [7].

For the assessment of the areas a variety of band permutations were used, from the original sets (without the atmospheric correction), the new contrasts highlighting the water bodies. Using an unsupervised classification function, new pixel classes were generated.

Index	Formula	Result
Normalized Difference Water Index	**NDWI** = (Green - NIR) / (NIR + Green)	Water body> 0
Water Ratio Index	**WRI** = (Green + Red) / (NIR + MIR)	Water body> 1
Automated Extraction Water Index	**AWEI** = 4 × (Green-MIR) - (0.25 × 2.75 × NIR + SWIR)	Water body> 0
Wetness	**Wetness** = 0.13929 * 0.22490 * Green + Blue + Red + 0.25178 * 0.40359 * 0.70133 * NIR- SWIR1- 0.45732 * SWIR2	

Table 3. ***Formulas to generate the 4 indexes used to contour water bodies.***

Applying this quick method raises an inconvenience regarding the small aquatic areas, which could not be well individualized, confounding with the adjacent spaces. All four methods use within the formula, the Near Infrared band (NIR: 4th band in Landsat 5 and 7 sets; 5th band for Landsat 8). Near Infrared is strongly absorbed by water, but, in the same extent reflected by terrestrial vegetation and/or dried soil (Sun, F.; Sun, W.; Chen; Gong, 2012) [10].

Table 4. ***Band correspondence between Landsat 7 and Landsat 8 images.***

Landsat 7			Landsat 8		
Band Name	**Bandwidth (µm)**	**Resolution (m)**	**Band Name**	**Bandwidth (µm)**	**Resolution (m)**
			Band 1 Coastal	0.43 – 0.45	30
Band 1 Blue	0.45 – 0.52	30	Band 2 Blue	0.45 – 0.51	30
Band 2 Green	0.52 – 0.60	30	Band 3 Green	0.53 – 0.59	30
Band 3 Red	0.63 – 0.69	30	Band 4 Red	0.64 – 0.67	30
Band 4 NIR	0.77 – 0.90	30	Band 5 NIR	0.85 – 0.88	30
Band 5 SWIR 1	1.55 – 1.75	30	Band 6 SWIR 1	1.57 – 1.65	30
Band 7 SWIR 2	2.09 – 2.35	30	Band 7 SWIR 2	2.11 – 2.29	30
Band 8 Pan	0.52 – 0.90	15	Band 8 Pan	0.50 – 0.68	15
			Band 9 Cirrus	1.36 – 1.38	30
Band 6 TIR	10.40 – 12.50	30/60	Band 10 TIRS 1	10.6 – 11.19	100
			Band 11 TIRS 2	11.5 – 12.51	100

2.5. Remote sensing methods for shaping water bodies

The evolution of water surfaces is determined by comparing individual contours, generated by the above mentioned indexes. For each case, we created an unsupervised classification, isolating the water bodies of the remaining elements. For the interpretation of the "wetness" index, it needed to reshape the values of the obtained intervals, creating only two classes: one negative and the other with values above 0. The result is showed monochromatic, the operator will only have to differentiate areas with vegetation from the aquatic ones, both being displayed in bright shades. It represents the drawback of this method. These bright objects delineate the lakes' shape, which can be adjusted by using a simple editing tool. The chronologic analysis is limited to a map made up of these shapes, from 1970 up to date.

3. RESULTS AND DISCUSSION

Table 5. ***Lakes evolution phase in Măgura Basin***

ID	NAME	EVOLUTION PHASE (2014)
1	Zbereni	Silted
2	Lebăda	Water surface
3	Cîrjoaia 1	Silted
4	Cîrjoaia 2	Silted
5	Coasta Măgurii	Wetland+ Water surface
6	Coasta	Water surface
7	Horodiștea	Silted
8	Pîrîul Sărat- Iaz 1	Silted
9	Pîrîul Sărat- Iaz 2	Silted+ Wetland
10	Pîrîul Sărat- Iaz 3	Wetland + Water surface
11	Hîrbului	Wetland

The database analysis, using the four algorithms on the 2014 image sets, reveals five silted lakes, four wetlands (three of them are mixed); and three water surface areas, two of them mixed (wetlands). We have considered two different areas for illustrating the advantages and disadvantages of using the four indexes. It was taken into account Swan Lake, as a clear water surface area and Pond 3- Salt Stream as mixed area - silting and wetland. Coasta Lake covers an area larger than Swan Lake, but has a much smaller depth, so the results' quality is much lower than the index analyzes undertaken on Swan Lake. A final argument supporting the use of two test areas is their direct observation on the field. Pond 3 (Salty Stream) silting rate was about 5 m/year in 1980, 10 m/year from 1990 to 2002, then increased to 20 m/year in the last decade(Fig. 2.). Currently 90% of the lake has been replaced by a wetland (Fig. 2- Outline 2014), a small part of the water body exists only in the SE region. Shape processing was conducted based on the AWEI index analysis for the sets in August 1989, April 2002, August 2013 and July 2014; also using the 2008-edition aerial photographs of the area. The four indexes calculus- Normalized Difference Water Index, Water Ratio Index, Automated Extraction Water Index, Wetness, using recalibrated satellite data from different periods, provides precise information about the surface of water bodies, that have a minimum area of 0.7 ha, the image set has a cloudiness percent below 5% (ideally) and the possibility of establishing the lake's position in advance, in order to avoid some confusions in the results' interpretation. The study reveals that Swan Lake (Bottomless Lake – local toponym), located at the forest's end between Cârjoaia and Cireşeni villages, having a constant area of 1 ha, located in the upper basin is easily identifiable, even in monochromatic displays.

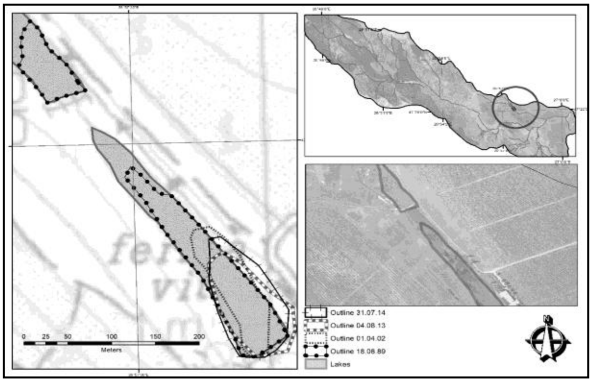

Fig. 2. ***Water surface evolution. Pond 3-Salty Stream***

Easily shown in all four types of index analysis, although it has a much smaller area than the downstream lakes. It is recommended to use a combination of these four indexes, along with preliminary analyzes performed by permutations of thematic bands, in the same raster.

Using imagery sets in a GIS environment, in order to identify water bodies and observe their evolutionary stage, involved working with software and algorithms, on the pixel values reclassification. Alternatively, we attempted to use only those indexes that could be generated in a short amount of time, without laborious pre-processing and also, the results can be reintegrated in other algorithms or calculus. Thus the four indexes were taken into account: Normalized Difference Water Index, Water Ratio Index, Automated Water Extraction Index and Wetness. The working rasters were pan-corrected images, with a 15 m pixel resolution and the indexes' values were shown in monochrome, the white pixels representing water bodies or wetness. It is recommended that the analyzed surface to be studied on the field and the corrections to be made according with "natural color" rasters. Plotting small aquatic areas based only on the indexes' values has its difficulties due to the low resolution. To highlight strictly the water bodies, one can rely on vegetation indexes corrections (e.g. Normalized Difference Vegetation Index - NDVI) or just recreating the raster based on Red and Infrared bands, thus distinguishing vegetation from water.The analysis of the four indexes and the raster processing by combining themed bands allows a quick assessment of the surfaces of at least 1 ha, highlighting the lakes' outline.

4. CONCLUSIONS

The study of lacustrine areas in Măgura basin, was focused on using minimum resources of data and devices, in order to track the water bodies' surface evolution. Subsidiary, the lakes' delineation were monitored using contour indexes, particularly those with an area of 1 ha or less. The integrated GIS database, consisted of satellite imagery (spatial missions Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 OLI), topographic maps and plans (1970-1980 editions) and the aerial images, 2008 edition. The data sets were processed using Envi 4.7 and ArcGIS 10.1. The research highlighted that the silting process affected 7 out of 11 existing lakes in the early 1970s. Only Swan Lake has not undergone noticeable changes. Using the Wetness index analysis, it revealed the installation of wetlands, on former lacustrine areas, some of which are used in agriculture (in SE basin). Inventorying, monitoring and exploiting water resources has always been a major concern in order to improve human settlements, from prehistoric eras until today. The research is part of a series of studies aimed at Măgura basin archaeological heritage, especially the Cucuteni culture.

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