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ASSESMENT OF WATER RESOURCES USING LANDSAT SATELLITE IMAGERY

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Abstract

Observation of surface water is a very important for studying hydrological processes and last advances in satellite-based optical remote sensors have promoted the field of sensing surface water of a certain area or from a catchment area. This paper has considered analysing data from satellite image and geographical information system (GIS) for a catchment area. Banat hydrographical area is situated in the western part and south-western part of Romania and Barzava River basin drains a relatively small area in Banat Hydrographical Area. GIS techniques were used for extract data NDWI, MNDWI, AWEI indexes from in Landsat-8 satellite in images to evaluate their performances for the extraction of surface water. This paper shows the monitoring of Barzava river basin based on the indices resulting from the processing of satellite images. The objective of this research was to extract the surface water bodies from the hydrographic basin of river Barzava. Then, these data are utilized for purpose finding correlation and regression equations between the reflectance of the satellite image and the water parameters. NDWI being an indicator of plant water stress, it is observed that for 2018 compared to 2019 the basin of the Barzava River was affected by the drought.

Key words: catchment, GIS, NDWI, remote sensing, satellite images

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1. Introduction

Modern techniques for surface monitoring based on GIS and remote sensing technology, as well as the use of remote sensing indices resulting from satellite image processing, are increasingly used and with remarkable results in various fields: environment (Liu et al., 2013; Pisleaga and Badaluta-Minda, 2016), agriculture (Herbei and Sala, 2016), geology (Belegante et al., 2015), hydrology (Badaluta-Minda and Cretu, 2010), mining (Dragomir and Herbei, 2012).

The use of remote sensing images in the monitoring (Herbei and Sala, 2020) and evaluation of water resources is a modern technique and should be an alternative to the techniques currently used in government institutions.

The NDWI - Normalized Difference Water Index is an index that shows the water presence from satellite images. Gao, 1996 calculates the NDWI index from NIR - Near Infrared band – which reflects the content of dry matter and SWIR- Short Wave Near Infrared band - reflects the water content of the vegetation. By combining the two NIR and SWIR components, we can improve the accuracy of taking the water content from the vegetation (Ceccato et al., 2001). Short Wave Near Infrared reflectance is negatively related with the leaf water content. The NDWI index is very usefulness in order to monitor the drought areas and early warning (Tucker, 1980; Ceccato et al., 2002; Gu et al., 2007). Because of the use of NIR and SWIR bands it makes it very sensitive to modifications in liquid water content material and in spongy mesophyll of vegetation canopies.

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The AWEIsh index was used primarily to remove shadow pixels, and the AWEInsh index was designed for areas with an urban background. Similarly, vegetation indices were also used to extract water characteristics. In some cases, the combined approach of different indices and growth derivatives were used in order to extract the water characteristics. Similar studies used the combined difference between the NDVI index (Normalized Difference Vegetation Index) and NDWI to improve the contrast between water bodies and surrounding surface characteristics (Lu et al., 2011). Similarly, vegetation indices were used in order to extract the information characteristic for the water areas. For example, in some studies a combined difference was used between the normalized vegetation differentiation index NDVI (Rouse et al., 1973) and the NDWI index in order to improve the contrast between water bodies and surrounding surface characteristics.

This paper presents an approach to water assessment resources in the Barzava river basin, based on the geomatic technologies and television images purchased from the Landsat platform. The results of NDWI are presented in the form of graphs and maps, which are providing very useful information's in relation with the spatial distribution of climate changes and the vegetation and water stress. This NDWI index, that is based on the use of the two types of bands, green and infrared bands, improves the information on the water characteristics, and finally mapping of the water bodies from the analysed river basin.

2. Methodology

2.1. Study area

Banat catchment area is situated in the western part and south-western part of Romania, and it covers a surface of 18,320 km^2; from Banat hydrographical space, can also be found Barzava River catchment. The area of study in this research is Barzava river catchment, drains a relatively small area in Banat Hydrographical Area. The area drained by Barzava River and its tributaries on Romanian territory is 1202 km^2 (Fig. 1).

River Barzava, whose spring is in Semenic Mountains placed at 1190 m altitude, has a general SSV-NNE flow direction, presenting a narrow valley, deep, lacking flood channel and with an average slope of 15 m/km. Downstream of the confluence with river Gropos, the river changes the direction of flow towards west by town Resita, after which in piedmont area and low areas flows generally in the direction SE-NV. Within the Banat hydrographic area predominate forests, which represent approx. 45% of the total. In Fig. 1 is the use of land from the Barzava river basin, there are arable lands, the wetlands, water body, etc. Noteworthy is that urban and industrial areas also occupy 3.89% of the total Banat catchment area.

The topographic map of River Barzava is produced in a 30 m x 30 m grid resolution, this degree of resolution is sufficient for the hydrological modelling. The elevation of the study area varies from 75 to 1.429 m as mentioned above (Fig. 2).

2.2. Acquisition, pre-processing and processing of satellite images

For the water resources detection remote sensing was used, with the Landsat imagery. The Landsat-8 Operational Land Imagery (OLI) contains 8 multispectral bands with a spatial resolution of 15, 30 and 100 meter as shown in Table 1 (Barsi et al., 2014). In this paper image acquisition Landsat 8 is from portal https://earthexplorer.usgs.gov/. In order to achieve the proposed objectives, 2 scenes from different years were used, namely: Scene with the code "LC81860282019126LGN00" from 05.06.2019 and scene with the code "LC81860282018123LGN00" from 05.03.2018, both scenes having WRS_PATH = 186, WRS_ROW = 28.

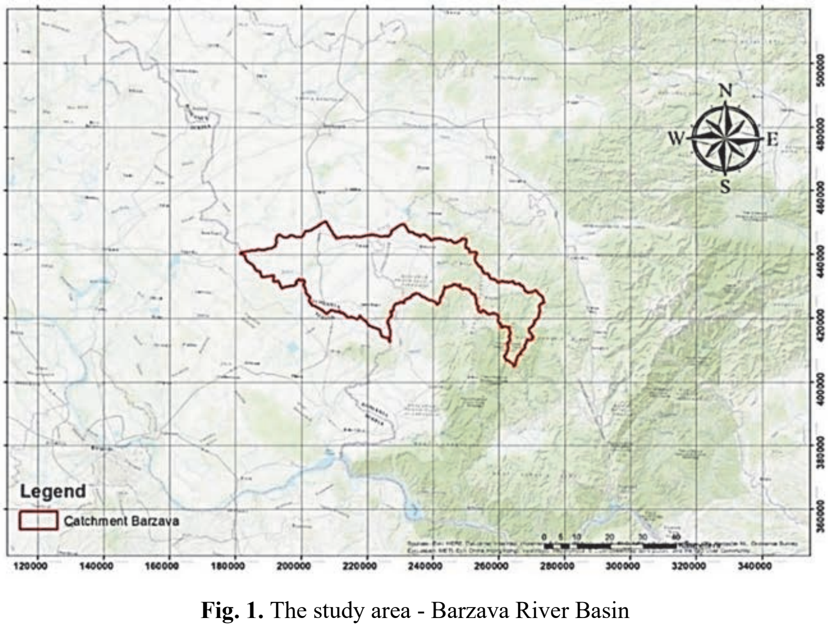


Fig. 1. The study area - Barzava River Basin

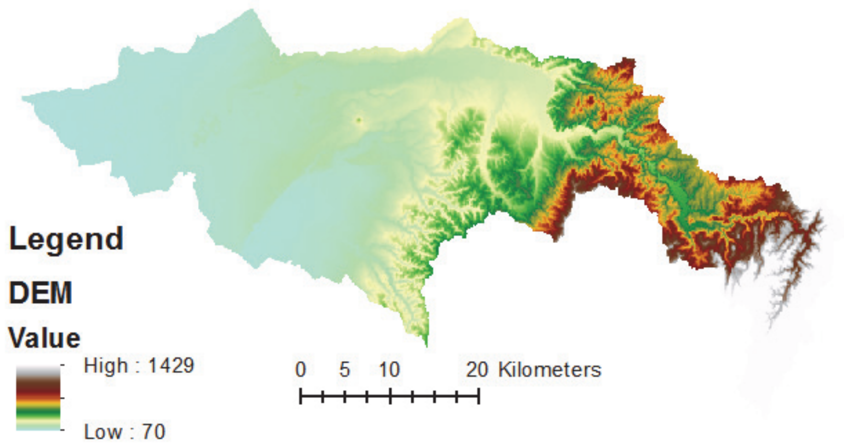


Fig. 2. Barzava river basin

The images were subjected to radiometric corrections in order to calibrate or correct the pixel values. This is a pre-processing process in order to improve the quality of the data from the satellites. Radiometric corrections were made using ERDAS Image software. In order to calculate the indexes of the research, image processing was performed using ArcGIS v. 10.6 software and the *Spatial Analyst Tools - Map Algebra - Raster computer module.*

Table 1. Landsat 8 bands resolution

Band Name	***Name band***	***Spatial resolution***
B1	Aerosol	30
B2	Blue	30
B3	Green	30
B4	Red	30
B5	NIR	30
B6	SWIR 1	30
B7	SWIR 2	30
B8	Panchromatic	15
B9	Cirrus	30
B10	Thermal Infrared (TIRS)	100
B11	Thermal Infrared (TIRS)	100

2.3. Using GIS methods in water surface extraction

The NDWI - Normalized Difference Water Index was introduces by McFeeters (1996) in order to enhance the water associated features of the landscapes. The NDWI is using NIR - Near Infrared and SWIR - Short-Wave infrared bands. NDWI value ranges from -1 to + 1, McFeeter's (1996), suggested a threshold of zero for extracting water bodies, where all positive NDWI values are categorized as water and values less than or equal to zero (i.e. ≤0) are classified as non-water. NDWI can be calculated by Eqs. (1 - 2):

$$NDWI = (Green - NIR)/(Green + NIR) \tag{1}$$

$$NDWI = (Band3 - Band5)/(Band3 + Band5) \tag{2}$$

The formula of NDWI is then modified by Xu (2005) which introduces the Modified Normalized Difference Water Index - MNDWI, by using the Green and SWIR bands for better quality. MNDWI can be calculated by Eqs. (3 - 4):

$$MNDWI = (Green - SWIR)/(Green + SWIR) \tag{3}$$

$$MNDWI = (Band3 - Band6)/(Band3 + Band6) \tag{4}$$

Automatic water extraction index, introduced by addition and subtraction of bands with the coefficients . $AWEI_{nsh}$ and $AWEI_{sh}$ can visually extract a large portion of the water pixels, eliminating most of the classification errors for shadows and other non-water surfaces, where $AWEI_{sh}$ is for removing shaded pixels and $AWEI_{nsh}$ for the urban areas. The formulas are represented in the Eqs. (5 - 8):

$$AWEInsh=4\times(Green-SWIR1)-(0.25\times NIR+2.75\times SWIR1) \tag{5}$$

$$AWEInsh=4\times(Band3-Band6)-(0.25\times Band5+2.75*Band7) \tag{6}$$

$$AWEIsh=Blue+2.5\times Green-1.5\times(NIR+SWIR1)-0.25\times SWIR2 \tag{7}$$

$$AWEIsh=Band2+(0.25\times Band3)-1.5\times(Band5+Band6)-0.25\times Band7 \tag{8}$$

Another indicator for extracting surface water bodies used in this research is Water Ratio Index. WRI shows values greater than 1 for water (Fang-Fang et al., 2011) due to dominating spectral reflectance of water in green (Band 3) and red (Band 4) bands as compared to Near Infra-red and Medium Infra-red. Water Ratio Index is defined as Eqs. (9 - 10):

$$WRI = (Green + Red)/(NIR + SWIR2) \tag{9}$$

$$WRI = (Band3 + Band4)/(Band5 + Band7 \tag{10}$$

2.4. Statistical analysis

The analysis of measured values can offer the possibility to draw the curve in continuous form between the points that form the pairs and thus the allure of the curve can be appreciated (line, parabola, exponential equation etc.). When a hydrological phenomenon y is related to a factor x in the form of a number of pairs of measured values (x_i, y_i), then the most appropriate analytical expression between y and x is the hydrological empirical equation.

Pearson correlation (Freedman et al., 2007) coefficients between variable *x* and variable *y* (*Rxy*) is defined by (Eq. 11):

$$xy = \frac{n\cdot\sum_{i=1}^{m} x_i\cdot y_i - \sum_{i=1}^{m} x_i\cdot \sum_{i=1}^{m} y_i\cdot}{\sqrt{[n\sum_{i=1}^{m} x_i^2 - (\sum_{i=1}^{m} x_i)^2][n\sum_{i=1}^{m} y_i^2 - (\sum_{i=1}^{m} y_i)^2]}} \quad (11)$$

Pearson correlation analysis was applied to obtain the linear correlation coefficient between two variables. If the correlation coefficient $R > 0$ then there is a positive correlation, while if $R < 0$ we are talking about a negative correlation. If $R= 0$ or approximately, there is no linear correlation between 2 variables. When the Pearson correlation coefficient (in absolute value) it is closer to 1, the intensity of the linear relationship between 2 variables is higher.

According to Colton's rules (1974), we have the following classification:

- A correlation coefficient from -0,25 to 0,25 shows a very weak or zero correlation.
- A correlation coefficient from 0,25 to 0,50 shows a weak correlation
- A correlation coefficient from 0,50 to 0,75 shows a moderate to good correlation
- A correlation coefficient bigger than 0,75 shows a strong correlation.

3. Results

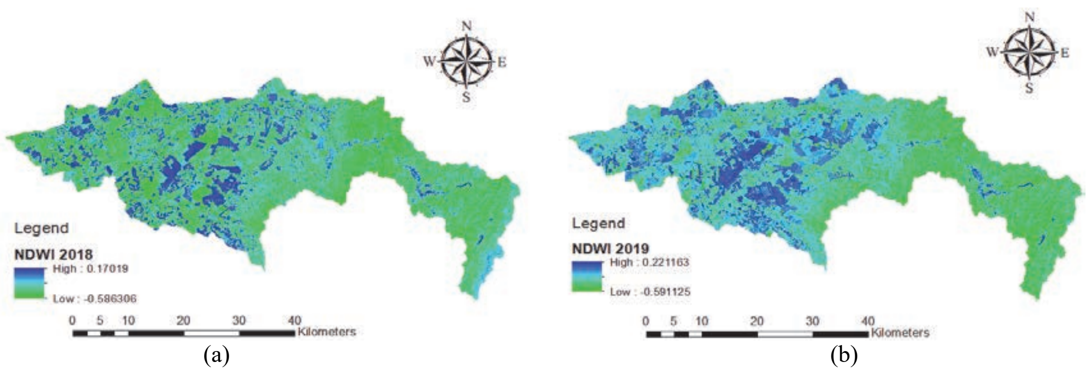
In this paper, Barzava catchment area was analysed from Landsat 8 Operational Land Imager in order to determine Normalized Difference Water Index (NDWI). Based on satellite images were calculated NDWI and MNDWI indexes (Gu et al., 2008; Hanqiu, 2006) were calculated in order to evaluate their performances for the extraction of water surface. (Sun et al., 2012). Indexes were determined for the water-covered surfaces for the years studied using the raster calculator. After obtaining these indices and reclassification was performed, where the positive values were identified as being covered by water and the negative values being dry / land surfaces. The extraction of information on water is important for the study and the evaluation of water resources, the protection of wetlands, etc. from a catchment area (Jiang, 2014). The estimation results for NDWI (Fig. 3a-b) and MNDWI (Figs. 4-b) values in the catchment area are represented below. Then AWEInsh (Figs. 5a-b) and AWEIsh (Figs. 6a-b) indexes have been calculated from the catchment of Barzava river, both for the elimination of shadows and for the urban area in order to obtain images of a higher quality than the previous indices.

In addition, compared to the indices calculated above, Water Ratio Index – WRI (Figs. 7a-b), was determined based on which only the clear surface water bodies are extracted, this indicator having no satisfactory results, being an index complementary to the other indices. Based on the results obtained from the indices, a correlative analysis was performed, the data obtained is presented in Table 2 and Table 3.

Based on the correlation matrix, the best correlations were found between indices $AWEI_{NSH}$ - MNDWI and NDWI - WRI. Subsequently, a series of regression analyses were performed that facilitated the prediction of one index according to another index. Regression analysis facilitated $AWEI_{NSH}$ index prediction based on MNDWI index under condition $R^2 = 0.8263$ (Fig. 8) and WRI index prediction based on NDWI index under condition $R^2 = 0.9387$ (Fig. 9).

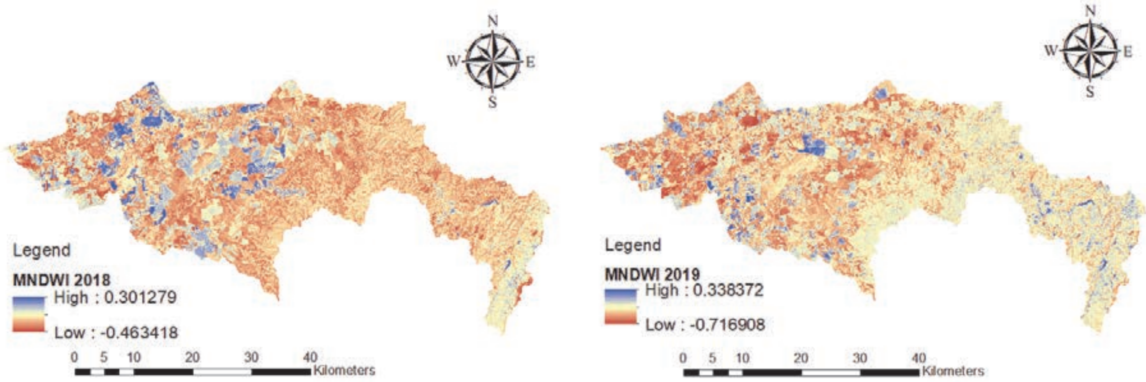
4. Discussion

According to McFeeters, NDWI is useful for characterizing open water areas or delimiting areas affected by floods. This paper has determined the synthesis parameters NDWI, WRI, AWEI and MNDWI, covering the entire Barzava river basin for the years 2018 and 2019. NDWI being an indicator of plant water stress, it is observed that for 2018 compared to 2019 the basin of the Barzava River was affected by the drought.



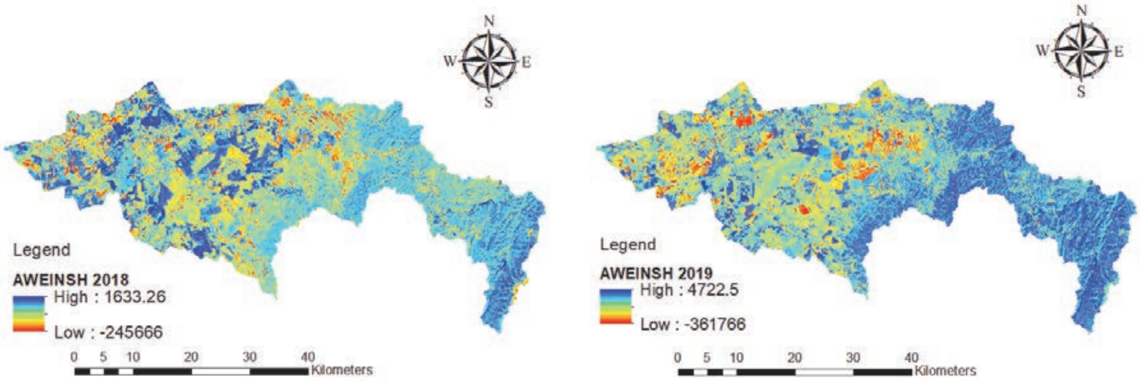
(a) (b)

Fig. 3. (a) NDWI index for 2018 year, (b) NDWI index for 2019 year



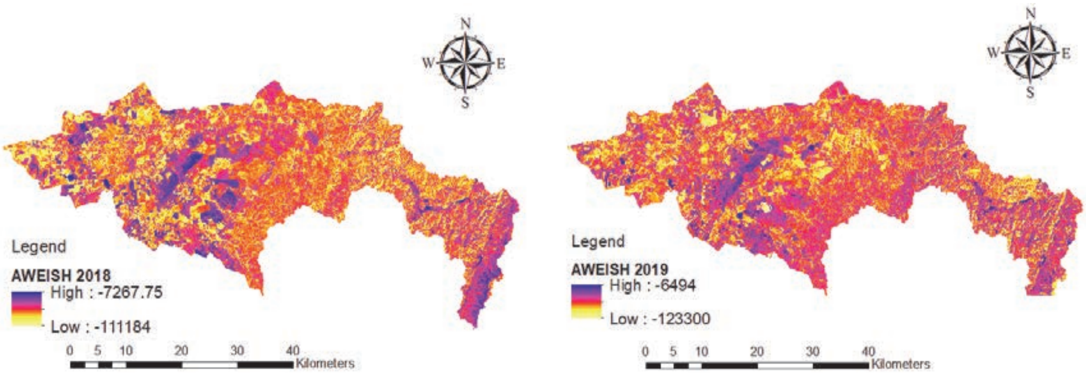
(a) (b)

Fig. 4. (a) MNDWI index for 2018 year, (b) MNDWI index for 2019 year



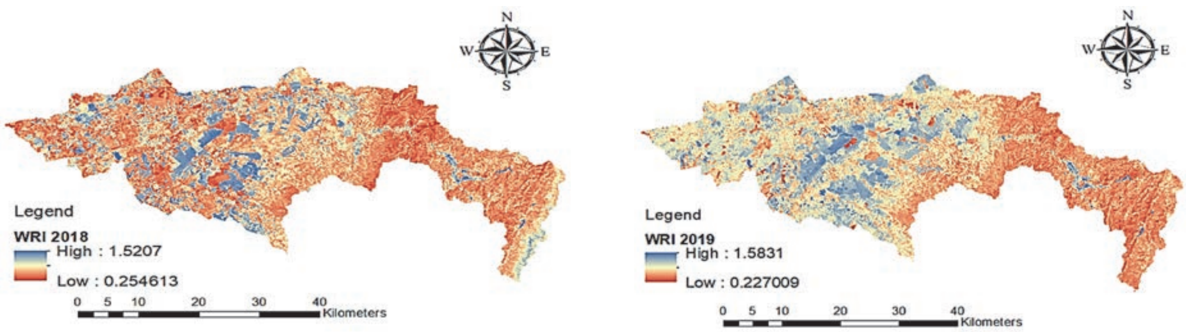
(a) (b)

Fig. 5. (a) $AWEI_{nsh}$ for 2018 year, (b) $AWEI_{nsh}$ for 2019 year



(a) (b)

Fig. 6. (a) $AWEI_{sh}$ index for 2018 year, (b) $AWEI_{sh}$ index for 2019 year



a) b)

Fig. 7. (a) WRI index for 2018 year, (b) WRI index for 2019 year

Table 2. Correlation analysis for 2019 year

	AWEISH 2019	*AWEINSH 2019*	*MNDWI 2019*	*NDWI 2019*	*WRI 2019*
AWEISH 2019	1				
AWEINSH 2019	0.71217	1			
MNDWI 2019	0.563251	0.859712	1		
NDWI 2019	0.327984	-0.63092	-0.29584	1	
WRI 2019	0.404521	-0.48916	-0.1102	0.964806	1

Table 3. Correlation analysis for 2018 year

	AWEISH 2018	*AWEINSH 2018*	*MNDWI 2018*	*NDWI 2018*	*WRI 2018*
AWEISH 2018	1				
AWEINSH 2018	-0.0189	1			
MNDWI 2018	0.14521	0.86465	1		
NDWI 2018	0.73119	-0.63959	-0.33175	1	
WRI 2018	0.77642	-0.52476	-0.19017	0.97897	1

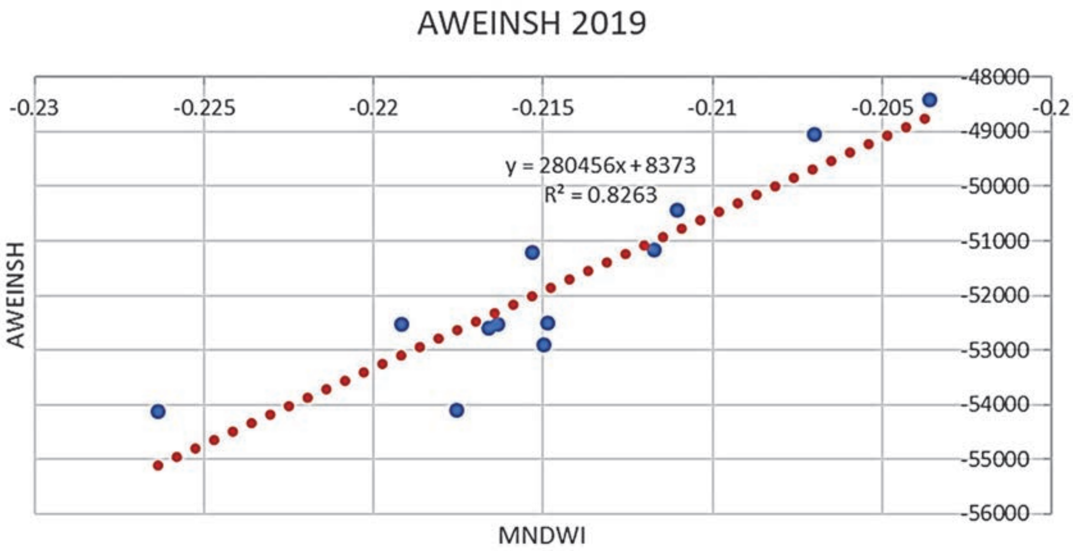


Fig. 8. Prediction of $AWEI_{NSH}$ based on MNDWI

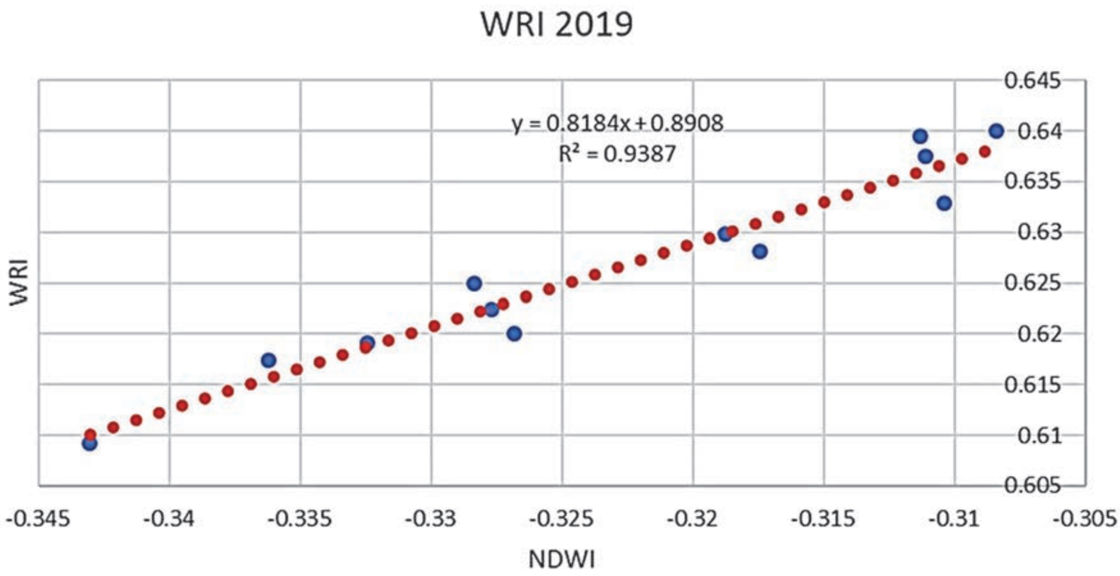


Fig. 9. Prediction of WRI based on NDWI

Very low values of NDWI (negative values) were recorded especially in the upper part of the Barzava river basin, being an area that was highlighted by a water stress. The study highlights the coverage of areas with surface water bodies in the river basin of the Barzava River, using high resolution images. This remote sensing and GIS application in hydrology is useful in many studies related to hydrology.

The MNDWI parameter was used to identify surface water bodies and saturated water in the Barzava river basin. This parameter was more effective in consolidating the values of water bodies, values that did not overlap with other types of land cover in the study area.

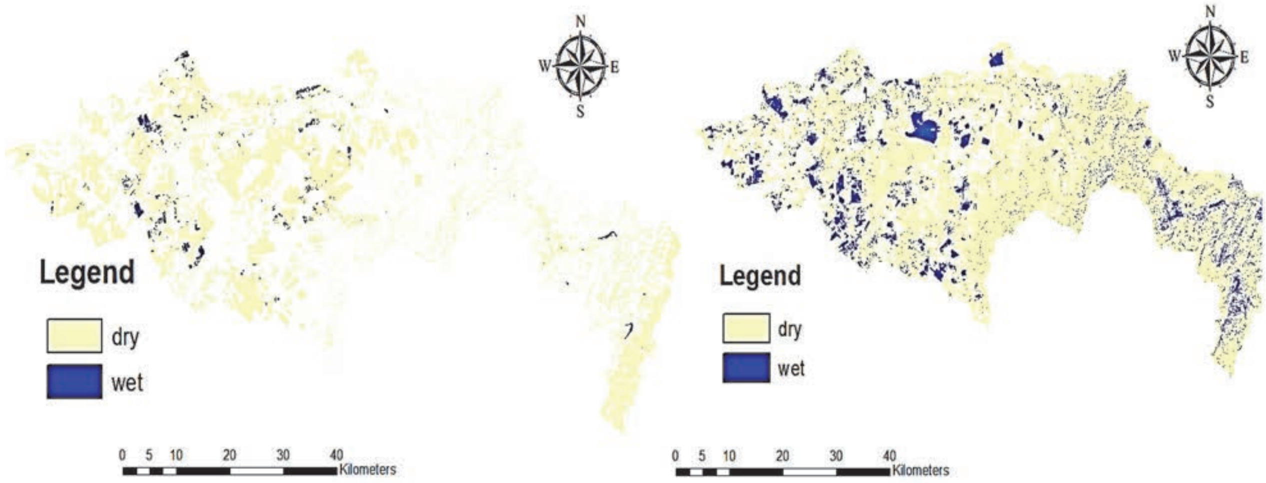
As can be seen from the two maps resulting from a reclassification for the years 2018 and 2019 (Fig. 10), the visual inspection did not find any major difference between the MNDWI and NDWI images, but with the specification that there is a better extraction result for the MNDWI parameter.

To obtain a better water extraction result, the threshold values for the MNDWI parameter are lower than those of the NDWI, suggesting the use of zero as the default threshold value may lead to a better water extraction accuracy for the MNDWI than for the NDWI parameter (Fig. 11).

5. Conclusions

In this research, the relationships between the parameters and the water indices of the spectral images are analysed, using data from satellite images provided by the Landsat 8 system. Monitoring of land surface water bodies and their distribution in time and space is important for understanding the hydrological processes / hydrological cycle and for a sustainable development of the water resources in Barzava river basin.

The coefficient of correlation between NDWI, MNDWI, AWIR and WIR was used as a statistical measure of how successful the fitted regression model was in explaining the variation of the observed data.



(a) (b)

Fig. 10. (a) MNDWI index for 2018 year, (b) MNDWI index for 2019 year

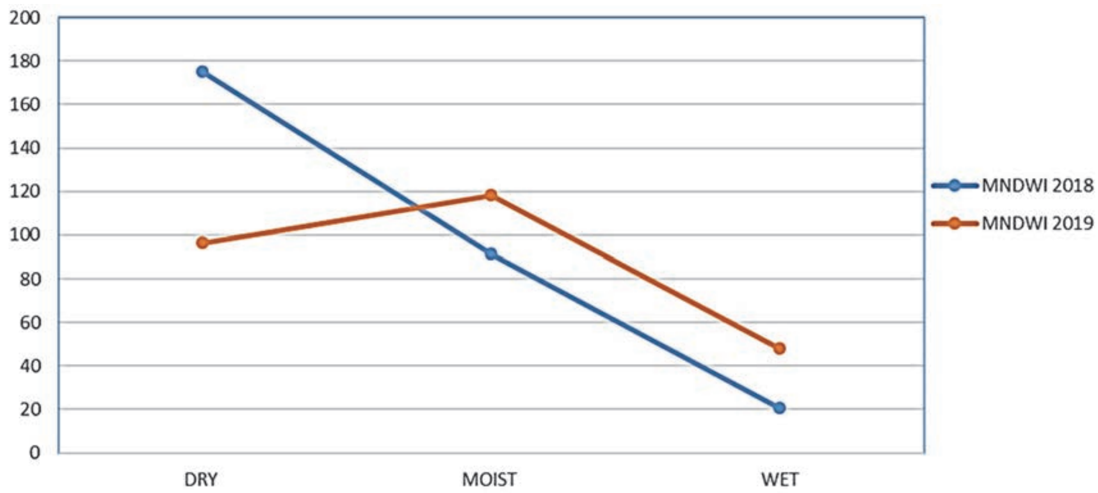


Fig. 11. MNDWI index for 2018 year, MNDWI index for 2019 year

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References

Badaluta-Minda C., Cretu G., (2010), Management of accidental flooding risks, *Environmental Engineering and Management Journal*, **9**, 417-423.

Barsi J.A., Lee K., Kvaran G., Markham B.L., Pedelty J.A., (2014), The Spectral Response of the Landsat-8 Operational Land Imager, *Remote Sensing*, **6**, 10232-10251.

Belegante L., Cazacu M., Timofte A., Toanca F., Vasilescu J., Rusu M., Ajtai N., Stefanie H., Vetres I., Ozunu A., Gurlui S., (2015), Case study of the first volcanic ash exercise in Romania using remote sensing techniques, *Environmental Engineering and Management Journal*, **14**, 2503-2514.

Ceccato P., Flasse S., Gregoire J.M., (2002), Designing a spectral index to estimate vegetation water content from remote sensing data, Part 2. Validation and applications, *Remote Sensing of Environment*, **82**, 198-207.

Ceccato P., Flasse S., Tarantola S., Jacquemond S., Gregoire J.M., (2001), Detection vegetation water content using reflectance in the optical domain, *Remote Sensing of Environment*, **77**, 22-23.

Dragomir L., Herbei M., (2012), Monitoring the subsidence phenomenon in Petrosani city using modern methods and technologies, *Environmental Engineering and Management Journal*, **11**, 1349-1354.

Fang-Fang Z., Zhang B., Li J., Shen Q., Wu Y., Song Y., (2011), Comparative analysis of automatic water identification method based on multispectral Remote Sensing, *Procedia Environmental Sciences*, **11**, 1482-148.

Freedman D.R., Pisani R., Purves R., (2007), *Statistics*, 4th Edition, W.W. Norton & Company, New York, 415.

Gao B.C., (1996), NDWI – A normalized difference water index for remote sensing of vegetation liquid water from space, *Remote Sensing of Environment*, **58**, 257-266.

Gu Y., Brown J.F., Verdin J.P., Wardlow B., (2007), A five-year analysis of MODIS NDVI and NDWI for grassland drought assessment over the central Great Plains of the United States, *Geophysical Research Letters*, **34**, 6407-6413.

Gu Y., Hunt E., Wardlow B., Basara J.B., Brown J.F., Verdin J.P., (2008), Evaluation of MODIS NDVI and NDWI for vegetation drought monitoring using Oklahoma Mesonet soil moisture data, *Geophysical Research Letters*, **35**, 22401 -22408.

Hanqiu X., (2006), Modification of normalized difference water index (NDWI) to enhance open water features in remotely sensed imagery, *International Journal of Remote Sensing*, **27**, 3025-3033.

Herbei M., Sala F., (2020), Evaluation of urban areas by remote sensing methods in relation to climatic conditions: Case study City of Timisoara, *Carpathian Journal of Earth and Environmental Sciences*, **15**, 211-222.

Herbei M., Sala S., (2016), Classification of land and crops based on satellite images Landsat 8: Case Study SD Timisoara, *Bulletin UASVM Series Agriculture*, **73**, 29 -34.

Jiang H., Feng M., Zhu Y., Lu N., Huang J., Xiao T., (2014), An automated method for extracting rivers and lakes from landsat imagery, *Remote Sensing*, **6**, 5067-5089.

Liu Y., Wang N., Wang L., Zhao Y., Bo Wu X., (2013), Application of GIS in regional ecological risk assessment of water resources, *Environmental Engineering and Management Journal*, **12**, 1465-1474.

Lu S., Wu B., Yan N., Wang H., (2011), Water body mapping method with HJ-1A/B satellite imagery, *International Journal of Applied Earth Observation Geoinformation*, **13**,428–434.

McFeeters S.K., (1996), The use of the normalized Difference Water Index (NDWI) in the delineation of open water features, *International Journal of Remote Sensing*, **17**, 1425-1432.

Pisleaga M., Badaluta-Minda C., (2016), The flood impact assessment from Ilisua catchment area on the environment, *Procedia Engineering*, **161**, 2168-2172

Rouse J.W., Haas R.H., Schell J.A., Deering D.W., (1973), *Monitoring Vegetation Systems in the Great Plains with ERTS*, ERTS Third Symp., NASA SP-351 I, 309-317.

Sun F., Sun W., Chen J., Gong P., (2012), Comparison and improvement of methods for identifying water bodies in remotely sensed imagery, *International Journal of Remote Sensing*, **33,** 6854-6875.

Tucker C.J., (1980), Remote sensing of leaf water content in the near infrared, *Remote Sensing of Environment*, **10**, 23-32.