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EVALUATION OF DAMAGES CAUSED BY FLOODS, BASED ON SATELLITE IMAGES. CASE STUDY: JIJIA RIVER, SLOBOZIA-DÂNGENI SECTOR, JULY 2010

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Abstract: This research aimed to identify flooded areas following the July 2010 floods, using Landsat 7-ETM + satellite imagery and a more efficient way to extract water bodies. By computing several indices, such as MNDWI, NDWI, NDVI, AWI, WRI and NDMI, it was concluded that, in the present case, the NDWI index was most effective, the data obtained having a very good accuracy. The studied area was the Jijia River Slobozia-Dângeni sector, the Landsat 7-ETM + images were taken on July 3, 2010. The flow rate at this time at the Dângeni station was 473 cm, decreasing compared to July 1, 2010 when the share reached 579 cm. The flooded area obtained is 15.80 km², the maximum extension of the flood area on July 3, 2010 being approx. 1 km on the localities of Durnești and Sapoveni. The study found 143 houses in 19 localities flooded. Of the total flooded areas, the largest share is held by arable land (44.58%), with a surface area of 7.04 km².

Introduction

From hydrological risk phenomena that occur at the level of Romania, the most widespread are floods. Monitoring and analyzing a flood can lead to measures to prevent future damage. Therefore, many researchers at both national level (Cojoc et al., 2015; Diaconu et al., 2017; Hapciuc Oana Elena et al., 2017; Luca & Avram, 2017; Mierlă et al., 2015; Romanescu & Stoleriu, 2013a, 2013b, 2014, 2017; Romanescu et al., 2011, 2012, 2013, 2018a, 2018b, 2018c); and at

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international level (Chen et al., 2018; Li et al., 2016; Radevski & Gorin 2017; Ten, et al., 2017; Testa et al., 2018; Van Leeuwen et al., 2016; Zelenáková et al., 2018) studied floods using the most efficient and accurate methods for their mapping and for assessing the damage.

In the field of mapping and flood analysis, remote sensing has made a significant contribution by introducing Landsat satellite imagery. The combination of Remote Sensing and Geographic Information Systems (GIS) presents a great deal of useful information to identify and analyze disasters resulting from a flood. Landsat images are part of the remote sensing and represent satellite images with high-precision spectral resolution that allows digital analysis with GIS. Using satellite images, Landsat can map and analyze the floods produced with very good precision, method which has been used more and more often in hydrology in recent years. The extraction of information is done by classifying images using the method of several indices such as: MNDWI, NDVI, AWEI, ML or NDWI. Until now, many researchers have used remote sensing and various indices to study the floods. (Banskota et al., 2014; Goetz, Gardiner & Viers, 2008; Wang, Colby, & Mulcahy, 2002; Memon et al., 2015; KK Singh & A. Singh, 2017; Kussul, Shelestov & Skakun, 2008; Feyisa et al., 2014; Rokni et al., 2014).

Thus, with the aid of satellite imagery, flood intensity mapping techniques have been developed that can improve the effectiveness of disaster monitoring and management in the case of floods (Haq et al., 2012). For the elaboration of the disaster management plan, the Landsat satellite images were used and the MODIS (Terra) images from the Pakistan floods in 2012, which were processed using the NDWI and WI indices, for delineating and mapping surface waters (Memon et al., 2015). Another study was conducted to identify the Kashmir floods in September 2014 with the help of HKFCM classification, using the medium values NDVI, NDWI and NDBI (Singh & Singh, 2017) indices. In order to extract as accurately as possible the water bodies from satellite images, the accuracy of the classification in areas including shaded surfaces, has been improved by introducing the AWEI indices, the method being tested on Landsat 5-TM images with different water bodies from several countries (Gudina Feyisa et al., 2014). With Landsat 5-TM, Landsat 7-ETM + and Launched 8-OLI satellite imagery, spatial temporal changes of Iran's Urmia Lake during 2000-2013 were modeled using NDWI, NDMI, WRI, NDVI and AWEI (Rokni et al., 2014). At the level of Romania, in 2017, historical floods before 1990 were mapped, from NE to Romania using the Landsat images (Romanescu et al., 2017a).

This study's aims are mapping, analyzing the flooded area and assessing the damages caused by the July 2010 flood on the Jijia River, Slobozia-Dângenii sector, using the Landsat 7-ETM + satellite images and the NDWI classification index.

Study area

The Jijia River is a tributary of the Prut River and is located in the north-eastern part of Romania, being part of the Botosani and Iasi counties (Fig. 1). The length of the Jijia River reaches 211,942 km, the Slobozia-Dângenii sector being part of the upstream Jijia River sector.

The annual rainfall is relatively low, with the annual average being between 550 and 600 mm per year. Over the summer months, rainfall can reach up to 80 mm/m² (89.7 mm/m²), water quantities that facilitate flooding.

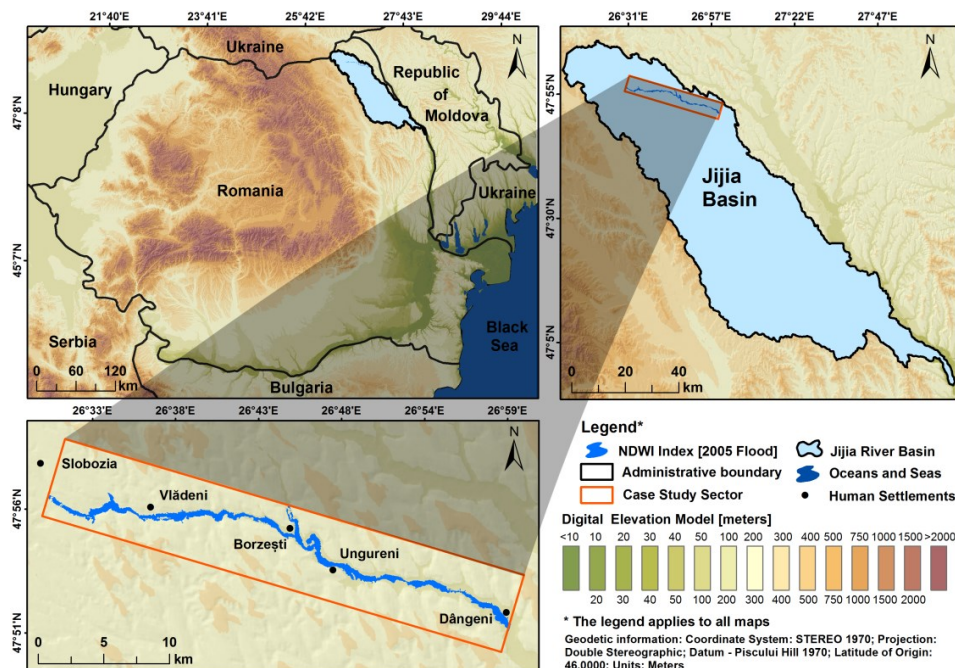


Figure 1: Map of the Slobozia-Dângenii sector of the Jijia River

The average multi-annual flow rate recorded on the Jijia River is 0.83 m³/s. The Slobozia-Dângenii sector is located between the Dorohoi and Dângenii hydrometric stations. The maximum flows recorded on the studied sector exceed 100 m³/s, the maximum produced at the Dorohoi hydrometric station being 190 m³/s, registered on 28 June 2010. It has a probability of occurrence of 2.08%, according to the Weibull formula. Other flows over 100 m³/s were recorded in 1969, 1979 and 1974 with flows of 170 m³/s, 127 m³/s and 102 m³/s and frequencies of 4.16%, 6.25% and 8.33%.

The hydrometric station Dângeni, downstream of the studied sector, has maximum flows of over 100 m³/s. Thus, the maximum recorded flow is 155 m³/s on 21.06.1985, with an recurrence of about 3%. The following recorded maximum flow rates are 138 m³/s, 117 m³/s and 108 m³/s with assurances of less than 10%.

Methodology

For this study, two important steps were taken: the data acquisition and processing stage (Fig. 2). Thus, in the first stage, a set of data was gathered, both in raster format (satellite images) and in vector format (land use and buildings).

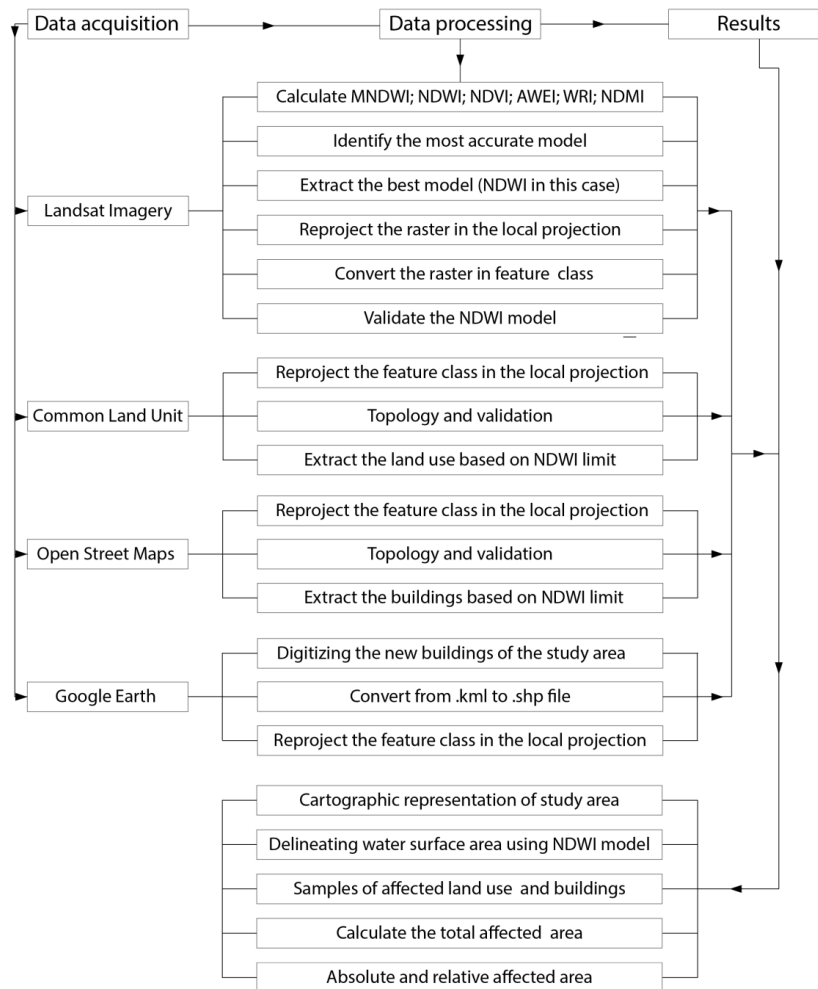


Figure 2: Landsat 7-ETM + image processing scheme for flooded surfaces

To obtain vector layers corresponding to the use of land and buildings as well as for satellite images, open source data sets were used. For buildings vector layer, an existing database was used (OpenStreetMap database), but it was not updated for the 2018 situation, therefore, the buildings in the study area were updated by manual digitization, using the Google Earth software.

The data processing step involved a series of operations that included raster and vector files. Six indices for water body identification (MNDWI, NDWI, NDVI, AWI, WRI and NDMI) were calculated in the first phase. This operation was necessary to get the model with the highest accuracy. Of the six calculated indices, the NDWI index was chosen. The next step was to extract the flood limit of the indices, that was also used for future processes. The limit obtained was validated and brought to the local projection system.

Regarding the vector layer, they were also brought to the local projection system, followed by the validation of each layer using appropriate methodology. A last step was to extract the land use, based on the flood limit of the chosen indices, calculate the flooded areas, generate descriptive statistics on the comparisons between the categories of land use flooded, but also to create representative cartographic material (Romanescu et al., 2017b; Romanescu, 2018).

Results and discussions

The flood produced at the end of June and early July 2010 had a 7-day extent. The flood wave has resulted in countless damages, the water level reaching a maximum of 874 cm in Dorohoi, 274 cm higher than the flood rate, and at 579 cm in Dângenii, 96 cm more than the flood rate, the flood totally destroying dozens of homes. The cause of the flood in the studied area is the torrential rain from June 30, 2010 in the villages of Ungureni, Sapoveni, Epureni and Vicoleni, the water flowing over the river's upstream waters.

On June 30, between 6:00 and 14:00, when the flow trend was still increasing, in Dimăcheni commune, 50 ha of arable land were estimated to be affected, 70 ha of pastures, 27 km of flooded and/or affected roads and 4 destroyed debris, and in the communes of Ungureni and Dângenii, 23 dwellings were affected, with floods in Dângenii and 322 ha of arable land and 370 ha of pastures. The national road 29 Ungureni-Plopenii Mari was blocked for a distance of about 200 m and the county road 296 was flooded between Plopenii Mici and Borzesti on a distance of about 500 m and between Călugărenii Vechi and Călugărenii Noi, approx. 500 m.

On the Buhăceni-Dângenii sector, on 1 July 2010, the waters of the Jijia River stretched over one kilometer wide. The entrance to Hulub village was blocked, the road, the bridge and the railways were left underwater, the flooded surface width was 2 km. On a length of approx. 100 m, Dângenii-Strahotin road was flooded, the

bridge was underwater, and the county road leading to Ungureni village was also submerged.

Flood damage caused directly by flash floods, has led to increased economic losses, as well as to hindering population evacuation procedures, as in the case of the village of Dângeni, where during floods a lightning burned the electrical transformers, and the population remained without electricity.

Following the study of the Landsat 7-ETM + satellite imagery of July 3, 2010, the total flood-affected area is 15.80 km², equivalent to 59% of the total Jijia river bed in the Slobozia-Dângeni sector (Table 1).

Table 1: Areas affected by flood in July 2010, related to the flooded area and the total area of the meadow of the Slobozia-Dângeni sector

Land use category	Floodplain surface		Flooded affected		Floodplain affected	Affected land use category
⁴ Code	km ²	%	km ²	³ %	² %	¹ %
1121	1.61	6.00	0.13	0.80	0.47	7.87
1113	0.17	0.65	0.17	1.04	0.62	95.40
1212	0.56	2.10	0.41	2.56	1.51	71.80
1211	0.44	1.62	0.17	1.05	0.62	38.24
2321	0.84	3.13	0.18	1.14	0.67	21.39
2331	0.08	0.30	0.02	0.13	0.08	26.20
2111	11.12	41.44	7.04	44.58	26.26	63.38
6221	0.02	0.07	0.01	0.06	0.03	47.72
3411	0.31	1.14	0.21	1.36	0.80	70.33
3131	0.07	0.26	0.00	0.03	0.02	5.99
4221	10.86	40.50	6.88	43.52	25.64	63.31
9111	0.59	2.21	0.54	3.42	2.02	91.01
9121	0.04	0.14	0.03	0.19	0.11	81.91
9113	0.01	0.06	0.01	0.09	0.06	100
7111	0.10	0.39	0.003	0.02	0.01	2.50
Total	26.83	100	15.80	100	58.91	58.91

¹Values were calculated by reporting to each land use category; ²Values were calculated by reporting to the floodplain area; ³Values were calculated by reporting to the entire flooded area; ⁴**1121**–Low density urban fabric; **1113**–Industrial or commercial units; **1212**–Railways; **1211**–Road network; **2321**–Complex cultivation patterns; **2331**–Land principally occupied by agriculture with significant areas of natural vegetation; **2111**–Non-irrigated arable land; **6221**–Bare rocks and rocks debris; **3411**–Transitional woodland and scrub; **3131**–Other natural & semi natural broadleaved forest; **4221**–Dry grasslands without trees; **9111**–Permanent running water courses; **9121**–Permanent separated water bodies; **9113**–Highly modified natural water courses and canals; **7111**–Inland freshwater marshes.

Although the Jijia River's levels were down, reaching 326 cm at the Dorohoi Hydrometric Station and 473 meters at the Dângenii Hydrometric Station on 3 July

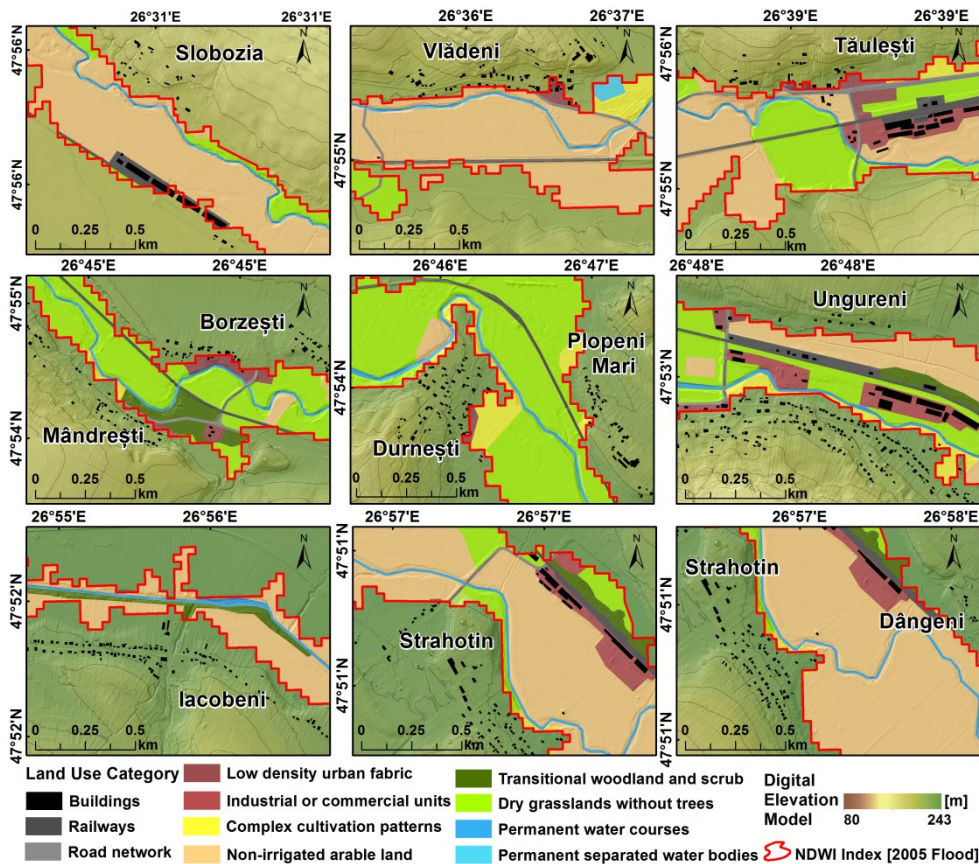


Figure 3: Areas affected by the floods in July 2010 obtained using the NDWI index

2010, the flood was still widening. At Dimănchieni, the Jijia River flows along the left bank of the minor bed with 632 m, flooding households and farmland. In the locality of Corlățeni, the flood extended into the floodplain, passing by the left bank of the river bed, by 580 m and to the right, by 610 m. In the locality Mateeni locality, Jijia extends into the floodplain, reaching a width of about 500 m, the same situation being present in the localities of Vlădeni and Tăulești. In Călugăreni, the width of Jijia River narrows, reaching a value of approx. 320 m, but at Măndrești and Borzești returns to the same average of 500 m wide. Between the Plopenii Mici and Durnești, on the right side of the river, the flood extends approx.

1 km (950 m), after which the flood extension decreases in the localities of Durnești, Plopenii Mari and Ungureni, the extension of the flood reaching a width of approx. 400 m at Sapoveni the flood extends to the left of the minor bed by about 1 km, and it will decrease in the districts of Epureni and Vicoleni to 200 m. In Strahotin and Dângenii the flood extends over a width of about 700 m (Fig. 3).

From the point of view of land use, the total flooded area, low density urban fabric occupies an area of 0.13 km², which represents 0.80% of the flooded area and 0.47% of the total area of the meadow. Of the total population of low density urban fabrics in the meadow, flooded residential areas account for 7.87% (Table 1). Dwellings affected by the flood amount to a total of 143 in the whole sector studied.

Industrial or commercial units are associated with a flooded area of 0.17 km², accounting for 1.04% of the flooded area, 0.62% of the total meadow of the studied sector and 95.4% of the total industrial and commercial units present in the meadow of the studied sector (Table 1).

Railways and associated lands were flooded at a rate of 71.80%, on an area of 0.41 km², representing 2.56% of the flooded area and 1.51% of the total floodplain. Road network and associated land represents a share of 1.05% of the total flood, with a surface area of 0.17 km². Of the total road network present in the studied meadow, 38.24% is flooded (Table 1).

Non-irrigated arable land shows a flooded area of 7.04 km², which represents a share of 44.58% of the total flooded area, 26.26% of the total meadow and 63.38% of the total arable land present in the meadow of the sector. Dry grasslands without trees occupy a flooded area of 6.88 km², with a share of 43.52% of the total flooded area. Areas with flooded pastures occupy 25.64% of the total meadow and 63.31% of the total pastures present in the meadow (Table 1).

Conclusions

Landsat images are becoming more widespread in the field of hydrological research, providing accurate data to identify water bodies. With the help of Landsat 7-ETM + satellite images and the NDWI indices, the affected surface by the flood in July 2010 was extracted from the Slobozia-Dângenii sector. The study involved working with Landsat images from July 3, 2010, and the flooded area from the study is of 15803 km².

The damages estimated from the study, add up to a total amount of 143 buildings. The largest share of flooded areas is owned by arable land followed by pasture, with areas of 7.04 km² and 6.88 pastures, representing 44.58% and 43.52% of the total flooded area. Railways and road network, although having a small share of the total flood area, 2.46% and 1.05%, lead to blocking access to the affected

localities, making it difficult to evacuate the population or access food and drinking water to other areas.

The maximum extension of the flood on July 3, 2010, occurred in the localities of Durnești and Sapoveni, where the river flowed into the main riverbed with approx. 1 km, at this time the waters are in retreat, the maximum share at Dângenii being 473 cm, compared to the maximum share of 579 cm registered on July 1, 2010.

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