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REMOTE SENSING FOR DISASTER MONITORING: FLOODS, FIRES AND EARTHQUAKES

Silviu AUREL

University of Agronomic Sciences and Veterinary Medicine of Bucharest, Faculty of Land Reclamation and Environmental Engineering, 59 Marasti Blvd., 011464, Bucharest, Romania, phone: +40 766 525 895, e-mail: aurel_silviu@yahoo.com

Scientific coordinator: Iulia Dana NEGULA

Abstract

The main objective of this study was to test different methods of analysis and interpretation for satellite images used in the monitoring of natural disasters, i.e. floods, fires and earthquakes. The methods were applied on satellite images acquired by different types of missions in terms of sensor (optical and radar), spatial and spectral resolution. We used optical SPOT images with a spatial resolution of 20 m that are acquired in 3 spectral bands, Landsat images with spatial resolution of 30 m, 7 spectral bands and TerraSAR-X radar images with a resolution of 3 m. The satellite data used in this study consist of: Landsat images downloaded from free online archives (© USGS) as well as SPOT and TerraSAR-X that were provided by the Romanian Space Agency (ROSA ©). In order to obtain optimal results, the most appropriate input data should be represented by: radar images for earthquakes and floods and optical images for fires and floods. The first case study focused on the floods in the Eastern part of Romania, namely the Siret river floods on the Nanesti-Silistea sector in July 2005 and the Prut River floods that took place in late July and early august 2008. The second case study was represented by the forest fires of Corsica, which is the third biggest island in the Mediterranean Sea, located at a distance of 170 kilometers south coast of France and 80 kilometers west coasts of Italy. These fires have occurred in August-September 2003, when 27,335 hectares of vegetation were burnt. The third case study consisted of the Haiti earthquake that occurred on January 12, 2010, at 4:53 p.m. local time. It was a major earthquake with a magnitude of 7.0 on the Richter scale. The epicenter was located near the Port-au-Prince capital. The processing methods (image classification and change detection) were selected and adapted for each type of satellite data. In conclusion, remote sensing is very useful in monitoring the effects of natural disasters. A very important aspect is choosing the optimal data depending on the disaster type (floods and earthquakes – optical and radar, fires – optical). Equally important is the resolution of the images in relation to the investigated phenomenon. For example, in the case of the Haiti earthquake, satellite images with a spatial resolution better than 30 meters would have been more useful.

***Key words**: disaster monitoring, earthquakes, fires, floods, satellite images.*

INTRODUCTION

The purpose of this paper was to identify the most adequate methods for the analysis and interpretation of the satellite images used in the monitoring of natural disasters, i.e. floods, fires and earthquakes.

For floods, two events located in the Eastern part of Romania were chosen. The first event occurred in July 2005 on the Nanesti-Silistea part of the Siret River. The second flood event occurred on the Prut River in July-August 2008. Red code alerts were transmitted during the floods that affected the North-East part of the country in 2008, for the populated areas along the Prut River. In Radauti, the river burst its banks and inundated about 5,000 hectares of land in the dammed area.

For the second case study, the forest fires that affected Corsica in August-September 2003 were selected. More than 27,335 hectares of vegetation were burnt. Corsica is the third largest island in the Mediterranean Sea in terms of size and it is located at a distance of 170 kilometers from the southern coast of France and 80 kilometers from the western shores of Italy.

Initially, the third case study focused on the earthquake that hit Bucharest in 1977, but the images from the United States Geological Survey (USGS) archive could not be used because the area of interest was completely covered by clouds. The earthquake occurred at 9:22 p.m. on March 4, 1977 and it had the earthquake lasted 35 seconds devastating effects on Romania. With a magnitude of 7.2

on the Richter scale and lasting about 56 seconds, the earthquake caused 1,570 victims, of which 1,391 in Bucharest only. Across the country about 11,300 people were wounded and about 35,000 houses collapsed. Most property damage concentrated in Bucharest where more than 33 large buildings collapsed.

However, in order to develop a case study for this type of disaster too, the earthquake that occurred in Haiti on January 12, 2010, at 4:53 p.m. local time, was selected. It was a severe earthquake with a magnitude of 7.0 on the Richter scale. The epicenter was located near Port-au-Prince, the capital of Haiti. The greatest damage occurred in the heart of the capital where thousands of persons were reported missing. After the great earthquake, at least 52 aftershocks took place, measuring up to 4.5 degrees Richter. These led to a number of 250,000 residences and 30,000 commercial buildings that collapsed or were severely damaged. On 28 January 2010, the number of victims found under the debris reached approximately 170,000 deaths. On February 4, the total number of victims was estimated at 230,000 dead, 300,000 injured and 1,000,000 homeless people. The United States of America (USA) and many other countries, including Romania gave massive aid to Haiti in order to overcome the tragedy. Also, a large number of organizations around the world contributed financially and by delivering supplies for the people in need.

MATERIALS AND METHODS

The specific processing methods were applied on satellite images acquired by different missions in terms of the type of sensor (optical and radar) and spatial and spectral resolution. Thus, the optical remote sensing data consisted of SPOT images with a spatial resolution of 20 m (three spectral bands) and

Landsat TM images with spatial resolution of 30 m (seven spectral bands). In terms of data acquired by radar remote sensing sensors, a

TerraSAR-X image with a resolution of 3 m was used. Landsat images are available online and can be downloaded for free (© Landsat images are courtesy of the U.S. Geological Survey, http://glovis.usgs.gov/). Subsets of SPOT and TerraSAR-X data were provided by the Romanian Space Agency (© ROSA) for educational purposes only. In addition to the satellite images mentioned before, a vector dataset containing land cover classes was used. The dataset was created based on the Land Cover Classification System (LCCS) developed by the United Nations - Food and Agriculture Organization (UN-FAO). All the land cover classes were identified by the visual interpretation of the Landsat ETM+ images acquired in 2003 over Romania. The LCCS-RO-2003 dataset for the area of interest was provided by ROSA (©).

The processing methods were selected and adapted depending on the type of satellite image. Visual image interpretation was used for the identification of the areas affected by floods. Visual interpretation is a combination of art and science based on intuition and it is used to identify and differentiate the features of objects and phenomena. Advanced visual interpretation requires extensive experience that is developed through specific training and practice over a long period of time (Badea, 2011a). The extent of the floods was delineated on the SPOT and Landsat images using vectorization tools in a Geographic Information System (GIS).

The main processing method used for the identification of the damage caused by fires in Corsica and earthquake in Haiti was change detection. Using this technique, the changes in landscape over a given period of time can be identified and analyzed. Thus, the spatial distribution of qualitative and quantitative information regarding the modifications of the analyzed objects is highlighted in change detection maps (Badea, 2011a), (Shaoqing and Lu, 2008). In order to obtain optimal results and accurate disaster monitoring maps, it is recommended to use optical and radar (HH polarization) images for floods, optical for fires and radar for earthquakes.

Currently, satellite imagery or satellite-derived products are provided free of charge by the following disaster monitoring services: the International Charter on "Space and Major Disasters" (www.disasterscharter.org/), the Emergency Management Service (EMS) of the European Earth Observation Programme – Copernicus (http://portal.ems-gmes.eu/) and the United Nations Platform for Space-based

Information for Disaster Management and Emergency Response, acronym UN-SPIDER (http://www.un-spider.org/). At the moment, all these disaster management services are fully operational (Badea, 2011b).

RESULTS AND DISCUSSIONS

A satellite image acquired by SPOT 2 (Figure 1) was used to study the floods that occurred on the Siret River, in the Nanesti-Silistea sector, in July 2005.The image was provided with the support of the International Charter "Space and Major Disasters".

The SPOT image is projected in the Universal Transverse Mercator (UTM) system, zone 35 North, WGS1984 ellipsoid. The image was acquired on July 16, 2005 and it covers the Nanesti-Silistea area of interest that is defined by the coordinates listed in Table 1.

Table 1. Coordinates of the Nanesti-Silistea sector

UTM WGS84	Values (meters)
N	5,050,000
S	5,025,000
V	531,000
E	568,000

In order to monitor the evolution of the flooded areas in the following period of time, Landsat 5 TM (Thematic Mapper) images acquired between July 16 and July 30, 2005 were also used. The images were downloaded from the USGS archive and they have the same projection system as the SPOT image.

The first performed operation consisted in the extraction of the water mask through the visual interpretation of the SPOT image that captures the maximum extent of the floods in July 2005. Next, the area affected by floods in the Nanesti-Silistea sector was delineated using GIS vectorization tools. Based on the LCCS-RO-2003 dataset, the assessment of the flooded areas by land cover classes was made. The two GIS layers, namely the water mask derived from the SPOT image and the land cover classes, were overlaid and thus a water mask containing land cover classes was obtained. The new water mask (Figure 2) was represented on the SPOT image showing the land cover classes that were affected by floods. Based on the LCCS-RO-2003 dataset, the number of hectares affected by floods, for each land cover category, was computed. The results are presented in Figure 3 and Table 2.

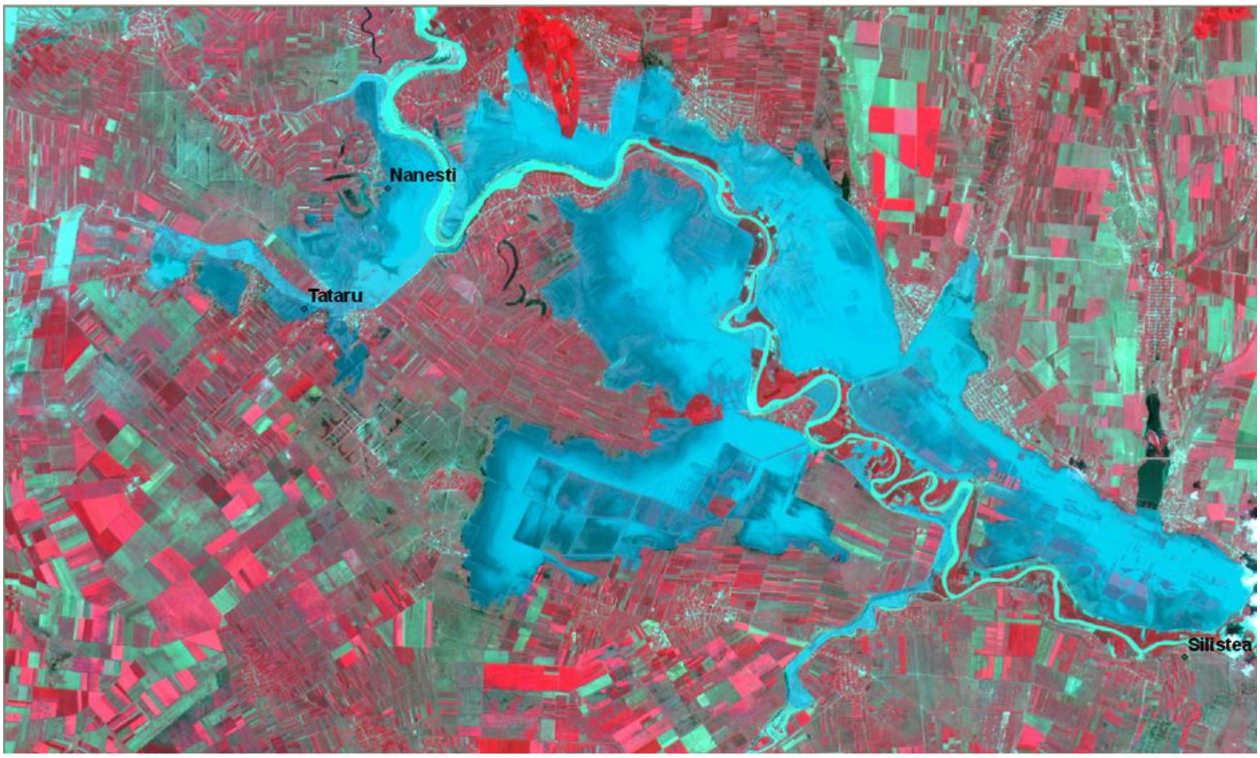

Figure 1. Water mask derived from SPOT 2 image acquired on July 16, 2005
Nanesti-Silistea sector, Siret River

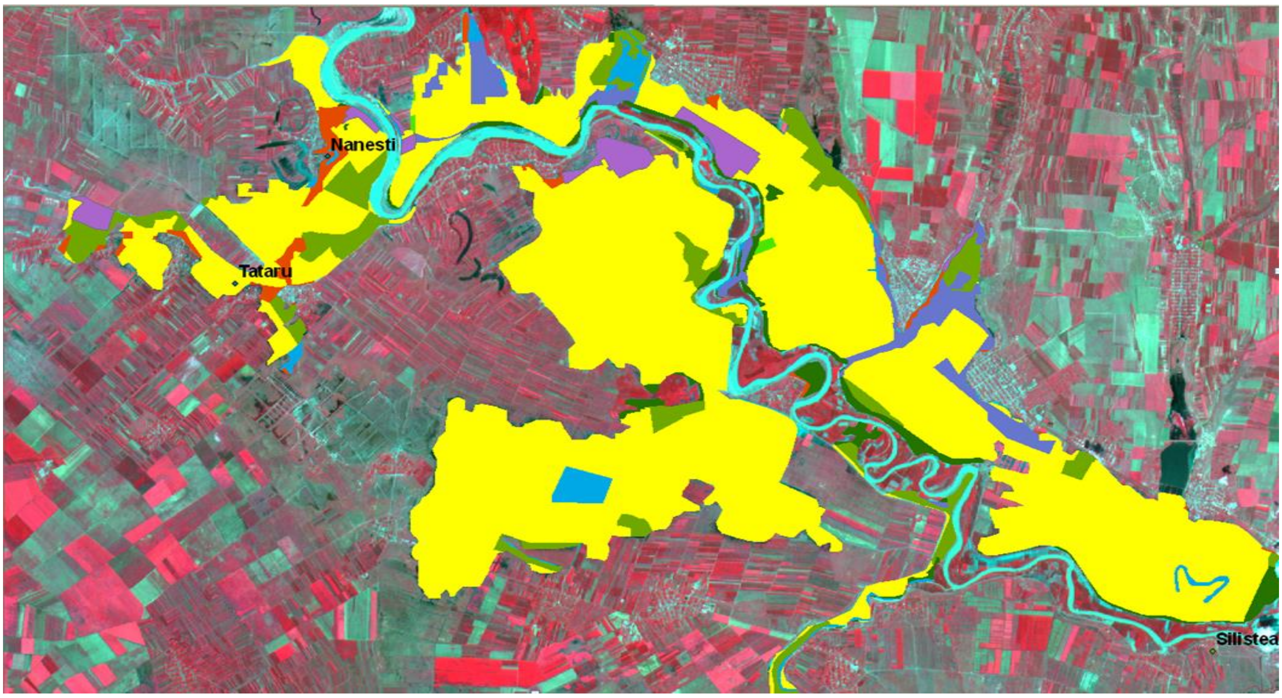

Figure 2. Flooded areas by land cover categories (water mask containing the LCCS 2003 land cover classes). Nanesti-Silistea sector, Siret River, July 2005

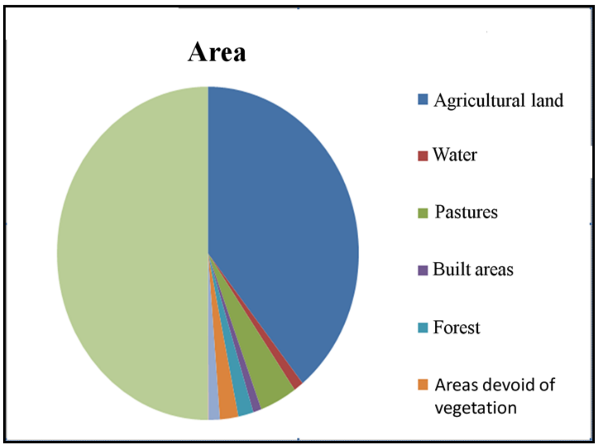

Figure 3. Areas affected by floods in Nanesti-Silistea

Table 2. Flooded areas on the Nanesti-Silistea

Land cover classes LCCS-RO-2003	Area (ha)	Percentage (%)
Agricultural land	17,265.62	78.42
Water	463.57	2.11
Grassland	1,751.79	7.96
Built-up area	392.46	1.78
Forest	718.24	3.26
Bare area	865.99	3.93
Vineyard	530.51	2.41
Orchard	28.09	0.13
Total	**22,016.27**	**100.00**

For monitoring the floods on the Prut River that occurred in late July - early August 2008, a Terra-SAR-X image was used. In order to isolate the areas affected by floods, the image histogram was interactively stretched. The obtained mask contains not only the flooded areas (circled in red in Figure 4) but also the Prut River and other water bodies.

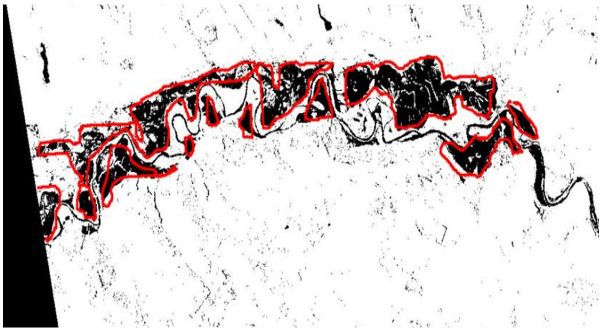

Figure 4. Water mask generated by interactive stretching of the TerraSAR-X image histogram. Prut River, July-August 2008

Two Landsat images were used for the study of the fires (Figure 5) that affected Corsica in 2003. The images were selected and downloaded from the USGS archive. One image was acquired on July 14, 2003 (before the fires) and the other one on September 16, 2003 (after the fires). These two images were acquired at different moments in time so they can be used to detect the Earth's surface changes. After image download, the spectral bands were composed for each image in order to obtain single-image files.

Figure 5. Fires in Corsica, 2003

For a detailed analysis of the burnt areas, the Landsat images were cropped (Table 3).

Table 3. Coordinates of the subset images - Corsica

UTM WGS84	Values (meters)
N	4,669,800
S	4,647,100
E	508,500
V	484,600

Once the Landsat images have been cropped, the change detection procedure was applied.
In the resulting image, the areas affected by fires are highlighted in red (Figure 6).

Figure 6. Result of change detection: the areas affected by fires are highlighted in red. Corsica, 2003

The earthquake that struck Haiti (Figure 7) in 2010 was also studied based on two Landsat images downloaded from the USGS online archive. In order to apply the same change detection procedure, the images were selected one before the earthquake (on November 26, 2009) and the other one after its occurrence (January 29, 2010).

Figure 7. Earthquake damage in Haiti, 2010

Similar to the case study described above, the first phase consisted in the composition of spectral bands for each Landsat image. Next, the images were cropped for enabling a more detailed study over the Port-au-Prince city. The coordinates of the area of interest are presented in Table 4.

Table 4. Coordinates of the subset images - Haiti

UTM WGS84	Values (meters)
N	2,056,000
S	2,050,000
E	785,000
V	780,600

In the next step, the changes between the two subset images were automatically detected. The change detection map (Figure 8) shows the damaged areas symbolized in yellow.

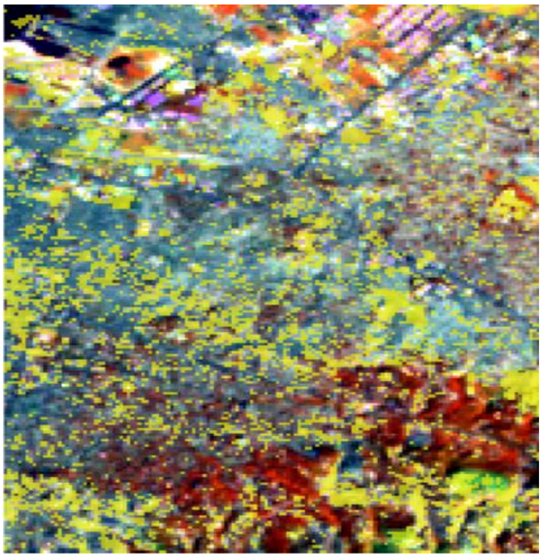

Figure 8. Result of change detection: the areas affected by fires are highlighted in yellow. Haiti, 2010

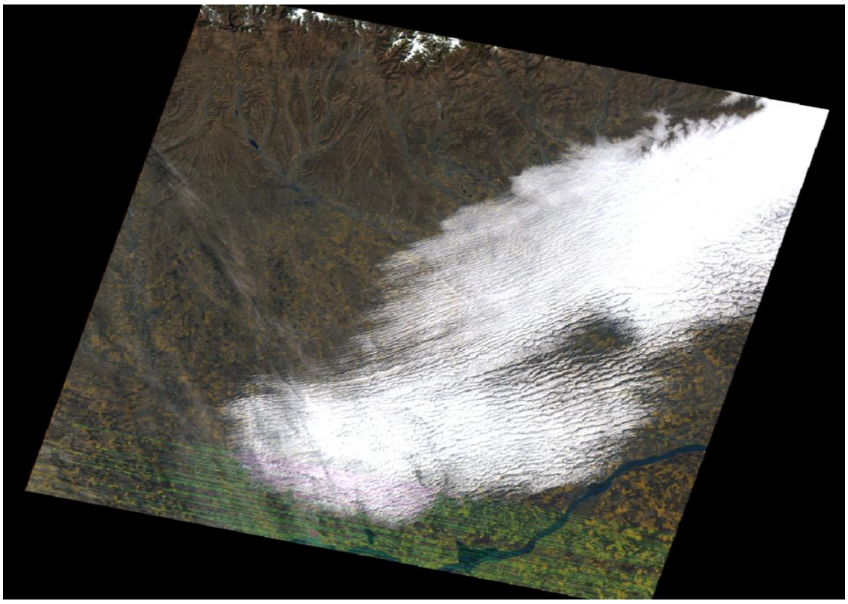

Figure 9. Satellite image acquired by Landsat over Bucharest, March 12, 1977

Initially, this case study was intended for the devastating earthquake that hit Romania in 1977. Unfortunately, all the relevant images from the USGS archive could not be used due to their significant cloud coverage. The figure above (Figure 9) illustrates the Landsat image acquired on March 12, 1977, when Bucharest was fully covered by clouds.

CONCLUSIONS

Disaster monitoring based on satellite images has considerable advantages in comparison with other investigation techniques due to the large coverage and the short revisiting time provided by the current specialized services. The results offer a clear view on the disaster extent and a fast assessment of the damages.

In conclusion, remote sensing is very useful in monitoring the effects of natural and man-made disasters. The key factor in obtaining accurate results is represented by the choice of optimal satellite data depending on the type of disaster. Hence, best results are obtained when using optical remote sensing imagery for the monitoring of fires and radar remote sensing imagery for the assessment of the damage caused by earthquakes. In the case of the floods, both optical and radar data can be used for disaster monitoring. Moreover, equally important is the resolution of the images in relation to the investigated event. For example, in case of the Haiti earthquake, images with increased spatial resolution would have led to much better results.

ACKNOWLEDGMENTS

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