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OVERVIEW ON REMOTE SENSING METHODS AND DATA SOURCES FOR FLOODS AND LANDSLIDES MANAGEMENT

BY

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Abstract. A natural hazard is a natural phenomenon that can affect people, infrastructure, buildings, environment etc. and can be geophysical or hydrological. This paper aims to describe the remote sensing data sources and methods for disaster management, presenting at the same time the advantages and disadvantages for each data source and some relevant research done at international and national plan for floods and landslides application. In the last two decades, Romania has gone through several years with flood phenomena, the most affected area being the northeastern part. Regarding the landslides, these phenomena are quite widespread on Romania's territory. The total area subject to landslides is estimated at 900,000 hectares. In this context, it is very important to build an effective workflow for natural hazards monitoring. Using remote sensing data sources and methods, it is possible to generate with high accuracy the limits of the flooded area or the surface displacements in the case of landslides, with less financial and time resources.

Keywords: terrestrial and aerial laser scanning; UAS; satellite images.

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1. Introduction

In 2019, a number of 361 natural disasters were recorded worldwide, including floods, extreme weather, extreme temperature, dry mass movements, landslides, wildfires, volcanic activity and earthquakes, causing a total of 11,719 deaths. Of these, 170 disasters have been caused by floods taking 5,100 lives and only 22 by landslides, taking 719 lives. Moreover, approximately 60,000 people lost their lives in natural disasters each year, although the total number being highly variables from year to year. This represents 0.1% of global deaths (https://ourworldindata.org).

By looking at the high number of deaths and material damages, we can say that there is a weakness in event management. So, in order to reduce losses, a disaster management system is necessary, which is characterized by the following steps: preparing the event that will cause damages by creating the flood hazard and floodplain maps, sending an early warning to limit the effects of the disaster, more resilient infrastructure and management of the situation caused by the disaster.

A natural disaster can be:

- geophysical (earthquakes, tsunami and volcanic activity);
- hydrological (avalanches and floods).

The hazard management process means the application of policies, procedures and practices aimed at identifying risks, analyzing and assessing them, treating, monitoring and re-evaluating risks in order to reduce them, so that human communities can live, work and meets their needs in a sustainable physical and social environment.

Floods are most frequent and most important, as well as in Europe and on Earth, so it is very important to determine with high accuracy the extend of the flooded area and the amount of losses (human lives, damaged buildings, infrastructure etc.). Floods can be caused by intensive precipitation, tsunami and typhoon, glacier melting or dam break and can last several days to even months (Lin *et al.*, 2016).

Landslide refers to the movement of a mass of rocks, mud, debris, or earth down a slope, either steep or gentle slope, under the direct influence of gravity. Landslides can be caused by an earthquake, heavy rainfall, groundwater pressure, or others factors, not always identifiable.

Traditional techniques such as ground survey are time-consuming and very difficult to assess and monitor a disaster accurately and quickly, because of frequently changes. Moreover, most of the countries that have high risk for different disasters, can’t afford field observation, being at the same time costly. So, it is essential for developing countries to use a workflow for rapid response in case of disaster using open-source data and low-cost equipment, with less time effort.

Using remote sensing data sources and methods, it is possible to generate with high accuracy the Digital Elevation Model (DEM), the limits of the flooded area, surface displacement or width of surface cracks, with less financial and time resources, being an alternative to traditional survey.

2. Digital Elevation Model (DEM) as a Principal Component in Hazard Management

Digital Elevation Model that usually refers to terrain altitudes (H values at Earth surface at equal distances along X and Y axes), except for vegetation and artificial objects, is the most important component in many applications such as: forestry, agriculture, land monitoring or flood planning. Accurate elevation information is essential for different stages in hazard management.

There are multiple data sources for DEM generation, such as: digitization of existing topographic maps, GNSS observation for direct data acquisition, the exploitation of the stereographic model created by means of photogrammetry (image matching), Airborne Laser Scanning (ALS), satellite images, radargrammetry and Synthetic Aperture Radar (SAR) Interferometry (Li *et al.*, 2004). Though, in order to obtain a high precision DEM, it is recommended to use a fusion of interferometric SAR and photogrammetric elevation data (Remondino *et al.*, 2014). Moreover, because of the capacity of detecting small-scale features, many researchers have chosen Terrestrial Laser Scanning (TLS) technology to generate a high-resolution DEM (Muhadi *et al*., 2020). The DEM resolution based on different data sources are listed in (Rahman and Li, 2017).

3. Review on Remote Sensing Data Sources for Natural Hazards Management

3.1. Airborne (ALS) and Terrestrial (TLS) Laser Scanning Technology

Both laser scanners, ALS or TLS, are using the LiDAR (Light Detection and Ranging) measurement technology which is an active remote sensing technology, because it has its own energy source, used to transmit electromagnetic pulses in the object space. The backscattered energy from object space is than recorded by the sensor. It is similar to other known active remote sensing technologies such as RADAR and SONAR. The difference between each of these technologies is the energy source that is used to make measurements. While RADAR uses the energy from the microwave area of the electromagnetic spectrum, and SONAR uses the energy of sound, ALS and TLS uses laser energy (LASER-Light Amplification by Stimulated Emission of Radiation). The advantage of LiDAR technology is the calculation of three-dimensional (3D) points coordinates with high precision, by the method of polar coordinates (angles and inclined distances) to obtain the geometry of the scanned surface (man-made structures, vegetation, or the bare-earth surface). The distance is measured by using the time or the phase difference between the transmitted and the returned pulse.

The difference between ALS and TLS is given by the platform used to carry the sensors over the region of interest. In the case of ALS, the platform can be a piloted airplane, or an Unmanned Aircraft Systems (UAS), either fixed-wing or rotary, whereas, in the case of TLS, the platform can be fixed, like a tripod, or mobile, such as: car or boat. Although, the components and mechanisms are different for the static and mobile terrestrial laser scanners.

The components for each type of laser scanning systems can be found in (Muhadi *et al.*, 2020).

The number of publications that uses LiDAR technology in flood risk management and landslide hazards has an increasing trend from 2010 to present, as high accurate topographic data is a key factor in creating valid flood maps (Hawker *et al.*, 2018) and determining the terrain deformation in the case of landslides. It was demonstrated that the resolution and the vertical accuracy of the DEM has a direct impact on the flood simulation results, especially in urban area (Tamiru and Rientjes, 2005), a DEM with a resolution better than 10 m being recommended.

Studies like (Fewtrell *et al*., 2011; Sampson *et al*., 2012) demonstrate the importance of ALS and TLS data fusion, in order to improve flood models, because small features have a significant impact on the flood propagation and need to be modeled with high accuracy.

3.2. Satellite Images

Satellite images are being used in many stages of a disaster management, since early 1970s. Satellite images can be grouped in two categories according to the wavelengths used to record information: optical and Radar. Also, new classification can be made according to their spatial resolution given by the Ground Sample Distance (GSD) size: low resolution (GSD less than 300 m), medium resolution (GSD between 30 m and 300 m), high resolution (GSD between 3 m and 30 m) and very high resolution (GSD between 0.3 m and 3 m). According to their availability, satellite images can be open-source or commercial.

Optical satellite images are subject of image classification in order to produce land use and cover information, for post-flood analysis, DEM generation through stereo images exploitation, but not for monitoring floods due to cloud cover during flood event and the long revisit cycle.

Based on a time series satellite images over the same area, changes in landscape can be easily detected.

The most used optical satellite images for flood and landslides management are Landsat, Sentinel, IRS, SPOT and Ikonos 2.

Landsat images are the most popular, because it provides continuously data since 1972 (Lin *et al.*, 2016). The spatial resolution of Landsat images is medium, with 80 m for the MSS sensor and 30 m for the TM, ETM and OLI sensors. The Landsat 7 satellite was launched in 1999 and Landsat 8 in 2013, both being acquiring data today.

Sentinel 2 images can be downloaded for free through the Sentinel Scientific Data Hub (https://scihub.copernicus.eu/) and have a spatial resolution varying from 10 m, 20 m to 60 m, according to their bands (13 bands in the visible, near infrared, and short wave infrared part of the spectrum). The constellation is composed of two twin satellites, Sentinel-2A and Sentinel-2B, operating since 2015 and 2017, respectively.

IRS (Indian Remote Sensing Satellites) were made available to a larger international community in 1995. The IRS-P5 CartoSat-1, launched in 2005, has a spatial resolution of 2.5 in panchromatic and CartoSat-2 launched in 2007, has a spatial resolution less than 1 m in panchromatic.

Spot (Satellite Pour l'Observation de la Terre), is a commercial high-resolution optical satellite system. The last generation of satellites are Spot 6 and 7, launched at the same orbit as Pleiades 1A and Pleiades 1B in 2012 and 2014, respectively, having 1.5 spatial resolution in panchromatic and 6 m in multispectral.

Ikonos 2 is a commercial high-resolution imaging satellite with a spatial resolution of 1 m panchromatic (0.82 m at nadir) and 4 m multispectral, launched successfully on Sept. 24, 1999.

A table that summarizes the optical remote sensing satellite used in flood monitoring, presenting for each one the spatial resolution, the methods used and some relevant studies, can be found in (Rahman and Li, 2017).

Similar to the optical images, radar images can also be used for land use and land cover classification and DEM generation through interferometry or radargrammetry. Moreover, radar data are used for damage assessment such as building or infrastructural damage assessment and terrain deformation.

From the available radar images, Sentinel 1 are the most used in disaster management, being open-source and also because of the open-source "SNAP" software provided by ESA to get through the workflow of image processing. Sentinel 1 images have a spatial resolution of down to 5 m and a temporal resolution of 12 days.

A table that summarizes the bands and polarization, the spatial resolution, the temporal resolution, the methods used and some relevant studies for each of the most frequent used satellite is presented in (Rahman and Li, 2017).

3.3. Aerial Images

Because of their high spatial resolution (GSD), that can be calculated based on camera focal length, sensor size and flight height, aerial images can provide valuable information for disaster management in general. By processing the aerial images, we can obtain a DEM, a DSM (Digital Surface Model) based on point clouds obtained by image matching, with high density and accuracy, the orthophoto, land cover and land use maps over the study area, but with high costs, because the aerial flights are done by specialized companies at demand.

3.4. UAS Images

Technological progress in recent years has boosted the development of UAS, but also of optical sensors by providing geosciences with a new data acquisition tool with direct applications in assessing various risks.

The most important advantages of using UAS in landslide risk assessment are: providing data in near real time, flexibility in selecting the most suitable sensors, low cost, high resolution and the ability to obtain data even in difficult environmental conditions (Peterman, 2015).

Recent landslide assessment studies using images taken from UAS platforms confirm that by combining quantitative photogrammetric acquisitions of an unstable area acquired at different times, it is possible to measure surface deformations with a vertical accuracy of several centimeters (Farina and Rossi, 2017).

Landslide monitoring is not possible with conventional systems in areas where ground movement is active. In this case movements must be monitored using remote measurements. In these situations UAS are important tools in determining the speed and directions of landslide movements. In addition, landslide movements can be monitored in real time with the use of UAS, allowing decisions to be made and precautions to be taken (Servet *et al.*, 2018).

Another great advantage of photogrammetric measurements compared to classical tachymetric measurements is completeness of data. Displacement vectors can be calculated for landslides as a whole not only for random points of interest. This allows geologists to analyze the influence of the meteorological events such as the amount of precipitation in landslide dynamics and possibly landslide forecasting, based on weather forecast and continuous monitoring of risk areas.

The main advantages and disadvantages of remote sensing data sources for floods and landslides management are summarized in Table 1.

Table 1
Advantages and Disadvantages of Remote Sensing Data Sources for Floods and Landslides Management

Pros	Cons	Pros	Cons
Aerial images		**Satellite images**	
High resolution	Not open-source	Multiple bandwidths in the electromagnetic spectrum, not only visible (both optical and RADAR)	High resolution images (pixel size less than 1 m) are very expensive
Can be used to create the DTM and the DSM of the study area with very high accuracy, based on point clouds obtained by image matching	Not available for all areas	High temporal and geometric resolution	-
Covers large areas with one flight	Can be acquired only by commercial aircrafts	Open-source such as Landsat and Sentinel	-
UAS images		**ALS point clouds**	
High resolution	Acquisition depends on atmospheric conditions (wind, rain, fog)	High density	Needs commercial software to process the point clouds
Can be used to create the DTM and the DSM of the study area with very high accuracy	Not open-source	Can be used to create the DTM and the DSM of the study area with very high accuracy	Large data volume
Low-cost equipment	Needs flight permission	Covers areas on regional scale	-
The ability to obtain data even in difficult environmental conditions	Needs commercial software to process the images	-	-
TLS point clouds			
Ultra high density	Depending on the size of the study area, numerous station points are needed	-	-
Can be used to create the DTM and the DSM with very high accuracy	-	-	-

4. Review on Remote Sensing Methods for Natural Hazards Management

4.1. Radargrammetry

Radargrammetry, is the methodology of extracting 3D geometric information from SAR (Synthetic Aperture Radar) images. Similar to photogrammetry, radargrammetry creates and exploits the stereoscopic model created based on two radar images taken from different angles (different / opposite pick directions or different angles of incidence).

SAR satellite systems provide users with information independently of ground constraints (as in the case of ALS data acquisition, for example), lighting (daylight) and weather conditions (clouds). In the case of SAR data, two different approaches can be considered: phase-based interferometric techniques and amplitude-based radargrammetric techniques. Knowing that radar interferometry can suffer from a lack of coherence, the two methods are therefore complementary to obtain the most accurate and complete results.

4.2. SAR Interferometry

In 1974, Graham first reported that a pair of SAR images, taken over the same area from the same or slightly different positions, could be used to form an interferogram, and the phase differences measured on the interferogram in radians and recorded in fringes each representing a 2π cycle, can be used to create a topographic map of the earth's surface (Li *et al*., 2004; Graham, 1974) and to measure the terrain deformation. This technology is called InSAR or SAR interferometry.

A SAR signal contains amplitude and phase information, so both parameters can be used as change indicators.

Ground changes, at centimeter level, are detected based on low-coherence areas, as the Interferometric SAR (InSAR) phase is sensitive to changes in the spatial distribution of scatterers within a resolution cell.

For accuracy assessment of the obtained results, reference measurements obtained for example with GNSS, levelling or other systems are used.

5. Flood Characteristics and Specifics in Romania

A frequency analysis indicates that floods in Romania occur most frequently in spring (30-50%) and less frequently in autumn (10-20%) and winter (5-10%). Remarkable for the floods that occur on interior rivers of the country is their torrential nature.

Flood occurring in the vulnerable areas of the river basins may have a variety of causes, of which the more important include:

– Limited forecast capability for local hydro-meteorological events due to the absence of an automated surveillance for hydraulic infrastructure during floods and other risk events;

– Limited capacity to manage maximum flows in the secondary riverbed while such flows are typically exceeded with an annual frequency of about 30-50%, in Romanian rivers;

– Poor maintenance of streambeds especially in the vicinity of bridges and localities (failure to remove clogging and vegetation from the secondary riverbed and waste dumping in the main and secondary beds);

– Declassified dam structures due to exceeded transport capacity or undersized design. Poor maintenance and rehabilitation of flood control works affected by floods in recent years;

– Inadequate location of buildings in flood exposed areas, due to the lack of flood pattern studies.

– Location of unauthorized buildings in areas exposed to torrents and in the secondary riverbeds.

– Silted, undersized, poorly maintained storm water sewers, unable to cope with torrential flow regimes

– Massive wood cutting operations. Limited promotion of new flood control and forestation works.

6. Review on Public Administration Activity in Romania for Floods Management

In the last two decades, the National Administration “Romanian Waters” (NARW) implemented the following most important projects for floods management:

a) DESWAT PROJECT: “Hydrological System for warning and forecasting” (2005-2014).

The distinguishing features of the DESWAT (Destructive Waters Abatement and Control Project) are:

– A comprehensive system of automated hydrological observation stations, complemented by rain gauge stations to enhance forecasting accuracy and speed;

– Hydrologic modeling capabilities to cover both flash floods in small and medium-sized basins and river forecasting in larger basins;

– Interface DESWAT with SIMIN (National Integrated Monitoring System) products and other data sources.

b) WATMAN PROJECT: “Water Management Integrated System” (2007-2013).

The WATMAN component was centered on technology, equipment and organizational structuring to address water management issues throughout Romania. These problems included floods, droughts, dam safety, acid mine drainage, pollution, accidental spills, public involvement and environmental impacts.

c) EAST AVERT: “The prevention and protection against floods in the upper Siret and Prut River Basins, through the implementation of a modern monitoring system with automatic stations” (2007-2013).

Protection of the border areas in the upper Siret and Prut River Basins against the flood risk, other natural dangerous hazards of water cycle and accidental pollutions and reducing the environmental, economic and social vulnerability of targeted localities from the border region against flood risk.

d) RO-FLOODS: “Technical support for the preparation of flood risk management plans for Romania” (2019-2022).

Overall approach to flood risk management:

– Developing Programs of Measures to operationalize Integrated Flood Risk Management;

– Integrating climate change into flood risk management;

– Addressing the risk of pluvial floods, flash floods and coastal flooding and dike breaches;

– Improving flood damage and flood risk assessment;

– Promoting green infrastructure for flood protection;

– Facilitating active stakeholders’ engagement and inter-institutional collaboration;

– Fostering flood resilience in marginalized and poor communities.

7. Conclusion

The most frequent natural disasters widespread in Romania and on world are floods and landslides. For developing countries, the high price of fine resolution data used for natural disaster management, might represent a challenge. Thus, using remote sensing data sources and methods, it is possible to obtain with high accuracy the desire results, with less financial and time resources. To overcome the limitation of using one remote sensing data source, the fusion of more data sources is tested in many studies. The principal component in hazard management is the DEM of the study area. The coarse resolution of the DEM is directly influencing the accuracy of the results, being recommended a DEM with a resolution better than 10 m.

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STUDIU ASUPRA METODELOR ȘI SURSELOR DE DATE DIN TELEDETECȚIE PENTRU MANAGEMENTUL INUNDAŢIILOR ŞI ALUNECĂRILOR DE TEREN

(Rezumat)

Un pericol natural este un fenomen natural care poate afecta oamenii, infrastructura, clădirile, mediul etc. și poate fi geofizic sau hidrologic. Această lucrare își propune să descrie sursele de date și metodele de teledetecție pentru gestionarea dezastrelor, prezentând în același timp avantajele și dezavantajele pentru fiecare sursă de date și unele cercetări relevante efectuate pe plan internațional și național în domeniul inundațiilor și alunecărilor de teren. În ultimele două decenii, România a trecut prin câțiva ani cu fenomene de inundații, zona cea mai afectată fiind partea de nord-est. În ceea ce privește alunecările de teren, aceste fenomene sunt destul de răspândite pe teritoriul României. Suprafața totală supusă alunecărilor de teren este estimată la 900.000 de hectare. În acest context, este foarte important să se construiască un flux de lucru eficient pentru monitorizarea pericolelor naturale. Folosind surse și metode de date de teledetecție, este posibil să se genereze cu o precizie ridicată limitele zonei inundate sau deplasările de suprafață în cazul alunecărilor de teren, cu resurse financiare și de timp mai mici.