ENVIRONMENT MONITORING USING DIGITAL ELEVATION MODELS BASED ON SATELLITE DATA – A TOOL FOR SUSTAINABLE DEVELOPMENT

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ABSTRACT: With the increasing number of launched satellite missions in the past years, there were developed new methods for receiving and combining satellite data, obtaining very accurate results for mapping the Earth, but also for monitoring the environment in time.
Knowing the environment and having the possibility to analyze its evolution in time represent key elements for a sustainable development.
This paper presents theoretical, economic and social aspects regarding the advantages of using digital elevation models based on satellite data for monitoring the environment, in order to highlight the contribution brought to the sustainable development.

Keywords: sustainable development, DEM, satellite data

JEL Codes: *Q01, Q24, Q56*

Introduction

We are living in a changing society, driven by technological innovation, where the growing demands for resources and energy, the ideas and people are the key elements of the economic evolution. The anthropogenic factor, defined by people and their activities, sometimes has a very important role in producing or amplifying the effects of a natural disaster, but at the same time people have also the possibility to interfere with certain techniques to manage or prevent this phenomenon.

In recent decades, both European states and those on other continents have adopted policies that integrate environmental concerns in all the activities they carry out, in order to get a healthy environment to leave inheritance to future generations.

With the accession to the European Union, to align to the European standards, Romania still has to solve many problems. For this, it is imperative to find more efficient solutions for sustainable development in areas of major interest from both economically and socially point of view.

Nowadays, almost every activity has tangents with geospatial information, the same being the case of sustainable development, where it is imperative to know the spatial distribution of population, natural resources, location in time and space of natural hazards, etc.

The increasing number of satellites, and consequently of the quantity and quality of data have led to the development of new ways of combining data, allowing multi-temporal analysis for achieving high levels of accuracy and detecting thematic changes. These factors help to create an integrated Earth Observation System essential for achieving sustainable development (Kilston, 1998).

An essential element in knowing the environment is the digital elevation model (DEM) which began to be increasingly used in various fields such as precision agriculture, hydrology,

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transportation, urban planning, communications, engineering applications, military applications, etc. Obtaining digital elevation models that correspond as closely as possible to the real topographic surface is a current concern of both the international scientific community and the commercial sector.

This paper has as main objective to present the importance of digital elevation models in preventing and managing the natural disasters such as floods and landslides, in order to provide a suitable basis in determining optimal knowledge-based risk response strategies. A better management of emerging risks minimizes the negative consequences such as material damage, human lives loses and environment degradation.

Digital elevation modeling based on satellite data

Digital elevation modeling involves approximating a portion of the topographic surface based on appropriate mathematical models, by using the 3D coordinates of points (Xi,Yi,Zi). By applying interpolation methods to the 3D coordinates of some points, the coordinates of all the other points from the topographic surface in question can be approximated.

According to the specifications of INSPIRE (Infrastructure for Spatial Information in the European Community) Directive, "the main purpose of a Digital Elevation Model is to provide an elevation property with reference to a specified origin (vertical reference or datum)" (D2.8.II.1_v3.0 INSPIRE Directive, 2013: VI). The required data can be obtained from several sources, the most common being: surveying, aerial photographs, satellite images, laser scanning (LiDAR), topographic maps and plans. Each of these sources has advantages and disadvantages, being more or less suitable for certain types of applications.

In the past years, the interest of the scientific community has turned to the potential of satellite imagery to measure the Earth as accurate as possible and in a shorter period of time, so that the global trend was to launch more satellite missions. European Space Agency, Canada Space Agency and other organizations from countries like India, Spain, Italy, France, Japan, Germany, China, Brazil and many others have launched their own satellite missions for observing and measuring the Earth. At the present, there are hundreds of satellites orbiting the Earth, each of them having a well-defined purpose.

Regarding the subject of this paper, we address only the case of satellite data used for digital elevation modeling. These data could be provided by the optical, radar (more exactly Synthetic Aperture Radar - SAR) and altimetry missions. Of these categories, optical and SAR missions provides altitude data as images.

In the literature there are a large number of studies that documented the possibilities and the advantages of using satellite data and digital elevation modeling in a wide range of domains like hydrology, where DEMs can be used for extracting the drainage network (Seyler et al., 2009) and overland flow areas that contribute to sediment loads (Lane et al., 1994), flood analysis (Youssef et. al., 2010); and for generating risk map; archaeology where using detailed DEMs helps determine subtle changes due to previous human activity in the subterranean (Menze et al., 2006), (Agapiou et. al., 2014); analysis of topographic surface deformations, after earthquakes (Massonnet et. al., 1993), (Sansosti et. al.,1998), (Patrick et. al., 2006), (Fernandez et al., 2002); analysis of glaciers movement using multi-temporal DEMs (Huang and Li, 2011), and many other domains.

Considering the fact that natural disasters cannot always be anticipated, sometimes the society is facing with situations which impose quick measures. In order to manage this sort of situations, current and accurate data are needed. The satellite missions solved this problem by the possibility of providing almost real time data. Of the many advantages of satellite data, we can bring into discussion that they cover large areas in a very short time and they are collecting from above the sky, so they are not limited by the possibility of access in the affected area.

For a long time, the optical images were the only source of accurate information about the earth, being used in all applications requiring very precise results. An alternative to optical systems are the radar ones. Radar (Radio Detection and Ranging) is an active system based on the principle of electromagnetic wave propagation. Providing its own "illumination", it is operational both day and night, regardless the weather conditions.

Radar records are complex images containing in each pixel two types of information: the amplitude and the phase of the electromagnetic wave. Radar images obtained with SAR sensors (Synthetic Aperture Radar) are very sensitive on rendering the topographic surface, this property being used to define three technologies known as: radargrammetry, interferometry and radarclinometry.

Radargrammetry exploits the information about the amplitude of SAR images, while radar interferometry exploits the phase difference of backscattered SAR signals.

To obtain the 3D position (X, Y, Z) of the recorded elements by using the radargrammetric technique, two SAR images taken from two different positions of the sensor and which have a double cover area (stereogram) are needed.

3D position determination is based on the relationship that exists between land elevation and longitudinal parallax measured between homologous points on a stereogram. The geometric relationship between the height of a point and the longitudinal parallax can be seen in (fig.no.1).

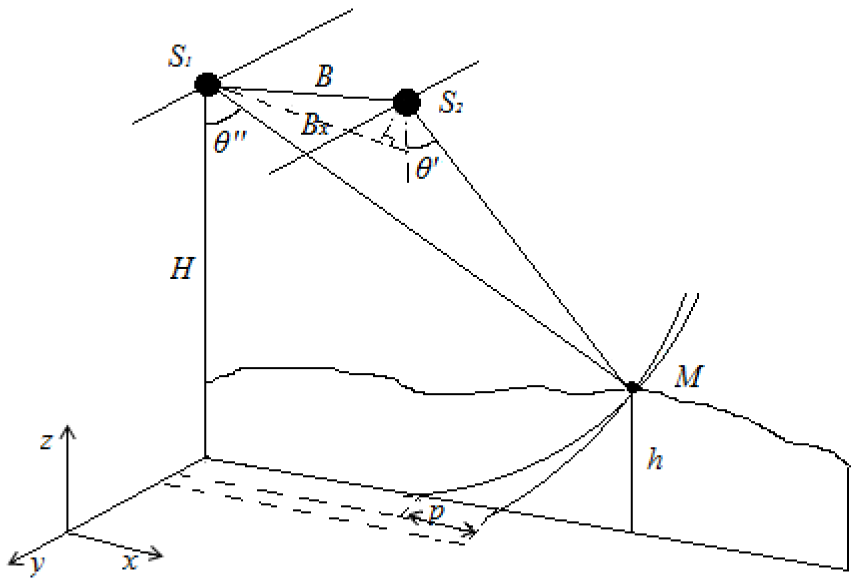

Fig. no. 1 Geometric relation between the point elevation and parallax
Source: Adapted (Maitre, 2008, p.248)

S_1, S_2 are the sensor positions at the time of acquisition, B is the acquisition baseline, and H is the sensor height above the reference plan.

m' and m'' represent the image point of the ground point M, and the p distance is called parallax and is directly proportional to the height h of the point M.

The mathematical relations for determining the points height using parallaxes are described in detail in (Maitre, 2008).

The main equations and formulas underlying the determination of terrain altitude using the radargrammetric techniques (eq. 1-6), according to the author of (Maitre, 2008, p. 249-250) are:

$$p = \sqrt{x^2 + (H-h)^2 - H^2} - \sqrt{(x-B_x)^2 + (H+B_z-h)^2 - (H+B_z)^2} - B_x \text{ , (1)}$$

where p is the parallax between the two positions of M point in the stereo images.

Starting from parallax equation, the height h of point M is determined by the relationship:

$$h = \frac{2H(B_x+p)^2-\left(p^4+4\Delta\right)^{1/2}(B_x+p)+2B_x B_z(x+p)+B_z p^2}{2(B_x^2-B_z^2+2pB_x+p^2)}, \quad (2)$$

where:

$$\Delta = -x^2p^2 + p^3B_x + H^2(B_x+p)^2 + B_x^2p^2 + HB_zp^2 + x^2B_z^2 + xB_xp(B_x - 2x + p) + 2HB_xB_z(x+p) \quad (3)$$

If the acquisition baseline is horizontal (Bz = 0), equation (2) becomes:

$$h = \frac{2HB_x + 2Hp - \sqrt{4H^4B_x^2 + p\Lambda}}{p + B_x}, \quad (4)$$

where $\Lambda = 8B_x(H^2 - x^2 + xB_x) + p(4B_x^2 + p^2 + 4pB_x) + 4p(H^2 - x^2 + xB_x)$ (5)

If the platform altitude H is very large compared to parallax p - the satellite platforms case – equation (4) can be simplified according to the two incidence angles θ_1 and θ_2 :

$$h = \frac{p}{ctg\theta_2 - ctg\theta_1} \quad (6)$$

In order for an observer to perceive an object 3D, the two images that form a stereogram must be sufficiently similar so that the image quality tones, illumination, texture being comparable (Leberl, 1989).

Digital elevation modeling based on radargrammetric processing is a complex process, the main steps being shown in the diagram from (fig. no. 2).

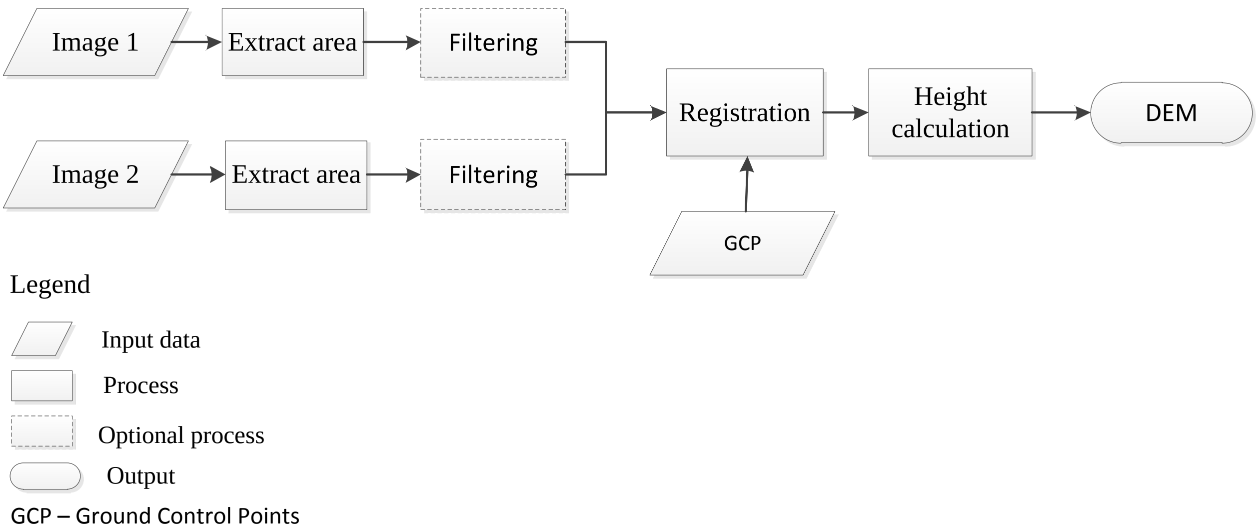

Fig. no 2 Radargrammetric processing of SAR stereo images

Source: Own creation based on the principle of radargrammetry

After the acquisition of the stereo images, the area found in both images is extracted. Further, some filters may be applied to remove the speckle noise (e.g. Lee, Frost, Kuan, Median, etc.). The registration process is one of the most difficult one because the two images must be brought in the same coordinate system and also the connection between the images and terrain must be established. The relationship between the images and the terrain is made by using some ground control points (GCP) which are points with known coordinates in both image and world coordinate system. Bringing the images in correspondence is usually done by applying correlation methods.

This requires defining a window around the pixel to which the correspondent searches. In another picture, a window is moving in the same search. For each trip is calculated the correlation between the two windows.

Although the digital elevation modeling of land based on radar images and the possibility of improving the accuracy of the results was an important concern among researchers in the filed since the launch of the first space mission equipped with SAR sensors, the automation of the process is far from realization. The new satellites launched in the past few years provide high accuracy data, making it possible to use it in a wide range of application. But still, starting from the principle of radargrammetry it is necessary to find new methods or to improve the existing ones, especially for correlation or image filtering, in order to fully exploit the potential of radar images.

The socio-economic impact of digital elevation modeling in the context of sustainable development

In a world facing with an increased risk of natural hazards and other disasters, developing models being able to predict the time and place of such an issue is a priority at national and international level (Sandric, 2008). One of the specific objectives of Romania's sustainable development is to reduce the risk of natural disasters that have a direct effect on population by implementing preventive measures (National Sustainable Development Strategy. Romania 2013-2020-2030, 2008).

The disasters, even if we refer to the natural ones (floods, landslides, earthquakes, etc.) or to the industrial accidents (spill of harmful substances, explosions and fires, etc.) have significant impact on population, both from economic and social point of view. Here we can remind loses or damages to economic assets, private properties and infrastructure (transportation, communications), casualties and diseases, environment damages.

The impact of disasters may be reduced by adopting measures and actions preceding the occurrence of the phenomenon, through optimal management during the flood and by establishing an action plan for the period after the incident (reconstruction).

The measures for preventing the occurrence of disasters must be established based on a set of methodologies, instruments and tools, such as risk identification, mapping and assessment.

Risk maps are the key element in establishing the preventive action in areas prone to disasters. Also, based on these maps, the organizations in charge prioritize the risks for which preventive action should be taken.

Digital elevation modeling is the first step of risk map realization, having a dual-role: to present the morphological properties of the terrain and to sense the changes dues to the natural or anthropogenic influences.

The role of digital elevation models in floods situations

It is well known that in the recent years, Romania has faced with a series of floods that have led to numerous casualties and material losses. In order to establish feasible measures to prevent the future occurrence of similar situations are necessary digital elevation models that closely match the real surface. In this situation, a digital elevation model is used for modeling the hydrographical basins, but also to establish quick access routes for the intervention teams. Using digital elevation models and different hydrological parameters, 3D flood simulation can be performed to delineate the areas with flood risk.

From an economically point of view, accurate delineation of areas most vulnerable at floods will reduce the material damages by taking protective measures, and will also create the premises for promoting investments for defense works (dikes, barrages) in areas with high risk of flooding.

From a social point of view, the safety in the residential areas will increase, reducing the number of casualties and material.

The role of digital elevation models in landslides situations

Another problem faced by Romania in the recent years is related to the landslides. These, as the flooding, lead to destruction of transport infrastructure, agricultural crops, residential zones, and even loses of human life. So it is imperative to find ways to prevent such situations or to reduce the damages. To monitor the areas prone to such events by using ground measurements involve very high costs and it is a time-consuming procedure.

As mentioned in the previous section, different studies have demonstrated the potential of SAR data to determine the displacement of the topographic surface in time. This technique is called differential interferometry (DInSAR) and is based on the exploitation of the phase signals information. The role of a digital terrain model in this situation is to remove the influence of topography. Thus, depending on the accuracy of the available data, millimeter displacements can be determined.

By performing multi-temporal analysis based on satellite data for monitoring the evolution of topographic surface displacement, with the help of DEMs, can be established strategies to prevent the occurrence of landslides (e.g. by planting trees or plants, using geotextile nets or geosynthetic, informing the population in the area, etc.), as well as intervention plans for evacuating people in case of need.

The satellite data providers have an archive where they keep all the data collected. So there are big chances to find in those archives old data, acquired prior the occurrence of a specific flood or landslide. Having data before and after the disaster, a damage analysis can be conducted, the results playing an important role in understanding the phenomenon. A good understanding of the phenomenon is critical for enhancing the prevention and intervention measures.

*Socio-*e*conomic impact*

The satellite data and the new discoveries in the field of processing them, make it possible to obtain accurate digital elevation models, with less effort in terms of collecting data and with lower costs compared with other methods of generating DEMs with similar accuracy. The more accurate the digital elevation model is, the better risk maps will be obtained.

Having risk maps which show the areas prone to flooding or landslides, the organizations responsible with the protection of population and the assurance companies can establish a reasonable amount of money to be spent in such cases, so as a result of having precise information

Natural disasters, especially floods and landslides, besides personal property can destroy crops and can degrade soil. If the disaster is spread over a larger area, its effects are likely to increase the price of food and loss of jobs for people working in agriculture in the area.

Being aware of the possibility of disaster, might determine the people to find solutions to protect themselves. Being better informed, will lead to a better reaction in the critical moment of phenomenon, minimizing the number of casualties. At the same time, knowing exactly the problems related to a specific area, the people could avoid to build their homes or to develop their business in in major water plain or in areas with unstable terrain.

Not all the risk areas must be evacuated. In some cases, the construction of protective structures may be an efficient solution. These constructions are a good opportunity to create new jobs, helping people to integrate into the labor market.

DEM plays an important role also after a disaster when it can be used in the construction/reconstruction of the transport infrastructure, in land planning and for analyzing the event in order to improve the existing risk map.

Conclusions

The only way to know what is happening with the environment and how we can protect us against the natural phenomenon is to measure and monitor the Earth. Improving the ways in which we can observe the world help us to better understand the risks of our world and to find efficient measures to minimize their consequences.

With the launch of the latest satellite missions, the use of satellite data became more and more frequent and proved to be an important element in the context of sustainable development of the main social, economic and environmental areas.

DEM based on satellite data has been proved to be an essential element for measuring and monitoring the environment, representing a basic element for 3D simulations of real situations (floods, landslides, etc.) and for calculating the morphological parameters of land necessary for taking important decisions on the construction of certain elements of infrastructure (for transportation, rural development, flood prevention, landslides, etc.).

In the context of risks and natural hazards, DEM was proved to be the key element in establishing measures and actions to be taken in areas prone to disasters, being the first step for risk maps realization. Accurate delineation of areas most vulnerable at disasters, using DEMs obtained from radar images is of great importance to reduce the material damages and casualties by helping the process of establishing the protective measures, the action plans during the phenomenon and the reconstruction strategies.

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Acknowledgement

This paper has been financially supported within the project entitled “Horizon 2020 – Doctoral and Postdoctoral Studies: Promoting the National Interest through Excellence, Competitiveness and Responsibility in the Field of Romanian Fundamental and Applied Scientific Research”, contract number POSDRU/159/1.5/S/140106. This project is co-financed by European Social Fund through Sectoral Operational Programme for Human Resources Development 2007-2013. Investing in people!