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PhD THESIS

- Abstract -

Runoff modelling using GIS. Application in torrential basins in the Apuseni Mountains.

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CONTENTS

Because of irrational land exploitation and lack of flood protection infrastructure, Romania was and is still vulnerable to frequent floods. In the recent years, the number of these events has risen and Romania needed the help of the European Commission. In the summer of 2008, the European Commission gave a financing of11.78 million Euros and in the spring and autumn of 2005 another 71.2 million Euro were offered. According to the European Commission website, the help of EU was used mainly for the costs of emergency intervention and remake of the important flood protection infrastructure.

During a project in "risk mitigation and emergency preparedness in the event of natural disasters" the areas which have accumulation lakes or other discharge control structures and the lower courses of rivers in Romania were reinforced or rebuilt to strenghten the flood protection infrastructure. But most mountain areas still have flooding problems due to little or no maintenance of flood protection infrastructure in these areas. Besides these problems, Romania was also affected by uncontrolled deforestation without the removal of vegetation leftovers from the deforested areas. The massive deforestation in the last decades raised the runoff coefficients and reduced the infiltration and retention, so a higher volume of rainfall becomes runoff which concentrates as flash floods in these areas. Therefore, a high percent of mountain settlements are affected by torents and flash floods.

The path of runoff and occurence of torrents depends on the movement of the convective cell and the variation of rainfall intensity during the storm. Therefore the ellaboration of a method to anticipate the effects of torrential rainfalls based on statistic data (Haidu, 2003; Sohn, 2005) or dynamic models (Ebert, 2005) is needed.

A number of hydrology studies were carried out on the Apuseni Mountains and most of them were PhD theses. These studies include the works of Buta I. (1967), Iacob Ersilia (1971); Aniţan, I. (1974) or more recent ones by Şerban Ghe. (2004), Patko R., (2007), Arghiuş V., (2008), Bilaşco Şt., (2008), Crăciun A.I. (2011).

The surface runoff is the runoff that appears on the surface of the land in streams or as a thin sheet of water flowing over the landscape. The main reason for studying surface runoff is the importance of this phenomenon in the occurrence of flash floods. The runoff that appears flows over the land and quickly accumulates in the nearest watercourse downstream from the source. The fast concentration of water from a large surface makes the receiving stream unable to convey the great quantity of water and causes flash floods.

The flash flood is a flood that follows the causing event (storm) in a very short time and manifests like a sudden increase in the water level and flow speed. The term „flash" is used to suggest the short time between the start of the rainfall and the maximum discharge of the flood, usually between some minutes up to some hours from the event, leaving a very short time for preparations and intervention. Usually, a threshold of six hours is used to distinguish a flash flood from a normal flood which has a slow increase in water level.(Mogil et al, 1978; Georgakakos, 1986a; Gruntfest and Huber, 1991). Most of the flash floods occur in basins with a drainage area of less than 100 km^2 (Kelsch, 2001). These basins have a fast response to torrential rainfall due to the steep slopes, impermeable surfaces, saturated soils and human impacts (deforestation, fires) that cause modifications of natural drainage.

The subject of this thesis is the development of a model that simulates the flash flooding caused by runoff when a torrential rainfall occurs. In time the rainfall exceeds the infiltration rate of soil and runoff appears and starts flowing downstream to the nearest stream. There are several factors influencing the flow path of the water that reduce the effects of runoff: a part of water is lost because of evapotranspiration, another part may be temporarily stored in micro-topographic depressions and some of it may contribute to subsurface flow due to infiltration. The water that is not lost in these processes flows downstream to the nearest receptor like a river, lake, estuary or ocean.

The model will take the presented factors into account and will be able to anticipate the quantity of water available for runoff and route it through the catchment in order to estimate the variation of the discharge that appears. The main purpose of this model is to obtain, knowing the landscape characteristics, the antecedent precipitation and the precipitation forecasted for a certain day, the quantity of water which will generate the flash flood and its distribution over time. The result of applying the model is the runoff hydrograph generated by a specific spatially distributed rainfall event that can damage an inhabited mountainous area. Vulnerability maps for flooding will be generated based on the model results.

The model will use a digital elevation model (DEM), soil maps (which give us the rate of infiltration) and land use maps in digital format. The precipitation data and trends are used to model the surface runoff. The model will be especially focused on ungauged basins, which is rather typical for the small mountainous catchments of the Apuseni Mountains. The model will therefore have to be realistic with regard to expected availability of data. A validation strategy for the physically GIS based rainfall-runoff model will be worked out by comparison with other published models.

The thesis consists of eleven chapters corresponding to the following stages of research: determination of the objectives – the actual level of research in the field – the study of possibilities in modeling the phenomenon - the construction of the database – the development of an automated algorithm to discretize the study area – the development and automation of the model to generate the forecasts on flash floods generated by torrential rainfall – the validation of the model using measured discharge from the field.

Chapter 1 presents an introduction to the hydrologic situation in the Apuseni Mountains, Romania, the reasons why such a model will be useful and the structure of the study. The following chapter consists of a presentation of the objectives and the geographic location of the study area used to apply the GIS models that I create.

Chapter 3 presents some theoretical concepts related to spatial models. During this chapter, the meanings of the word “model” from a GIS perspective are discussed and different classifications of models are presented. The utility of spatial modeling and the process to be followed when creating a spatial model are discussed. The last part of the chapter focuses on presenting the processes that can be modeled in a hydrologic model and the way these processes interact.

Chapter 4 presents and the actual stage of the rainfall-runoff modeling research in the world. A short history of rainfall runoff models is presented and the evolution of these models through time is followed since the first attempts at runoff modeling in 1851 until the newest developments in the field. Different concepts related to runoff modeling are fixed and the different possibilities in creating such a model are analyzed.

Chapters 5 to 8 present the possibilities for hydrologic modeling offered by the actual technology.

Chapter 5 presents the GIS data representations specific to hydrologic modelling and a data model created for this purpose at the Center for Research in Water Resources (CRWR) from Texas: ArcHydro. ArcHydro is a data model designed especially for hydrologic modeling by ESRI and CRWR. ArcHydro contains standards for representing hydrologic data in spatial databases and a set of functions user for processing these data. The processing functions available for use with the ArcHydro data model are presented in short. The ArcHydro data model and the functions available with it were used in the scripts and models created in this study.

Chapter 6 presents different possibilities of spatial modeling using GIS. The coupling (way in which models are connected) with GIS is presented and the different ways of creating spatial models are presented in short Graphical modeling is presented along with some examples of modeling possibilities offered by different GIS products. Modeling using scripts is also presented and the Python scripting language is discussed.

Chapter 7 presents the interoperability between different GIS products that can be obtained by creating scripts that call libraries from these GIS products. The reasons why the user would need functions present in different GIS products are presented, then some common Python libraries are presented and the way these libraries work with data from multiple GIS products is shown. The model created for this study also uses some of the libraries presented in this chapter.

Chapter 8 presents a series of GIS specific functions and modules coupled with GIS created especially for runoff modeling. Unlike the functions for data processing presented in chapter 5, which are used for any kind of hydrologic data processing, these functions and modules are specific for surface runoff modeling. Some of these were used in the hydrologic model that makes the subject of this thesis.

Chapter 9 presents the database created for the study and the construction of this database. The database includes GIS datasets related to the topography of the terrain and its hydrological characteristics and the methods of obtaining and using these data are presented. The different data structures that can be used on representing the same spatial data are discussed and the representations chosen for the present study is presented. The extraction of soil data from paper maps, land use data from the CORINE Land Cover database and climate data from the NCDC GSOD database and the methods used to extract these data are discussed.

Chapter 10 presents the implementation of some algorithms of spatial discretization of the study area according to the drainage network as GIS modules. These algorithms are used to create a topological structure for the catchment representation that can later be used for runoff routing and discharge modeling. The study area is split into sub-catchments and the correct topological relations between these catchments is obtained. Other important information is also obtained by the module presented in this chapter: outlets of each sub-catchment, the stream order of the stream segment corresponding to each sub-catchment and the link in the drainage direction between the catchments. The module can also be used to create catchments of a specific stream order if needed in an analysis.

Chapter 11 presents two approaches in the modeling of floods generated by runoff created for this study. The first model is based on the time-area method (which implies the determination of the travel time and concentration time for runoff, the determination of discharge generated in different sections of the basins and the generation of the runoff hydrograph by linear routing and accumulation of the discharge towards the outlet). The discharge for each cell is calculated using the SCS Curve Number method for determining the runoff depth and runoff coefficients at cell level. The results include GIS datasets for runoff depth, runoff coefficients, runoff volume, travel time, time-area diagrams for runoff for each basin and finally hydrographs of discharge obtained by integrating the runoff in different sections of the catchment. Two application examples in the Apuseni mountains for this model are presented along with their results. The second model is based on a runoff routing based on the Saint-Venant equations for shallow water flow and automatic generation of the discharge tables used for plotting the hydrographs.

The full scripts used to create the modules presented through the thesis are included in the Annexes for later usage. Tables of values for the coefficients used (Curve Number and Manning's n) are also included.