IOSUD - Politehnica University of Timișoara
Doctoral School of Engineering Studies

THESIS TITLE

Doctoral Thesis – Summary

for obtaining the PhD title at

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in the doctoral field of Civil Engineering and Building Services

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The purpose of the doctoral thesis titled "Advanced methods based on GIS and remote sensing for the evaluation and estimation of flood and erosion susceptibility in hydrotechnical and land improvement arrangements. Case studies: Crișul Alb river basin" is the implementation and application of workflows based on advanced GIS and remote sensing methods in three main research directions: detailed physical-geographical analysis of the basin, evaluation and estimation of flood and erosion susceptibility and hydrological and hydraulic modeling.

To achieve the proposed aim, the main **specific research objectives** were established:

- characterization of the physical-geographical, hydrological, and land-use dynamics in the Crișul Alb basin;
- estimation of flood susceptibility in the Crișul Alb basin;
- spatial modeling of soil erosion using GIS techniques;
- application of hydrological and hydraulic modeling techniques.

These objectives aim to integrate new technologies and geospatial analysis techniques into a comprehensive model capable of providing solutions for sustainable and efficient management of natural risks in the Crișul Alb basin.

The doctoral thesis, titled "Advanced methods based on GIS and remote sensing for the evaluation and estimation of flood and erosion susceptibility in hydrotechnical and land improvement arrangements. Case studies: Crișul Alb river basin" is structured into two main parts, in accordance with current methodological guidelines: The current state of research on the topic and The results of the author’s own research.

Part I, "The current state of research in the field of the topic" is structured into three chapters and provides a synthesis of the main research, theories and relevant contributions from the specialized literature.

The first chapter, entitled **"Introduction and general issues"** is organized into four main sections, each addressing essential aspects of the research.

"The justification of the research topic's relevance" stems from the necessity of using GIS techniques and remote sensing tools to assess flood and erosion risks in the Crișul Alb basin, a territory vulnerable to extreme hydro-geomorphological phenomena. Modern technologies facilitate the sustainable management of natural resources and support the implementation of effective policies for community protection.

"The objectives of the doctoral thesis and their relation to existing research" focuses on the use of advanced GIS and remote sensing technologies for the geospatial analysis of the basin territory and the assessment of flood and erosion risks in the Crișul Alb basin. The thesis offers original contributions by integrating complex statistical and geospatial data and proposes a replicable framework applicable to the sustainable management of natural resources and hydro-geomorphological risks.

In the subchapter ***"Major hydro-geomorphological risk events: definitions, impact and***

relevance in the context of climate change", the importance of studying hydro-geomorphological phenomena such as floods and erosion is emphasized. Their increasing frequency and intensity due to climate change significantly impact the environment and society, necessitating integrated risk management measures.

The final part of the first chapter, entitled ***"Legislative norms applicable in Romania in the fields of land improvement, water and environmental protection"*** outlines the evolution and harmonization of Romanian legislation with European requirements, covering the fundamental regulations in these domains.

Chapter 2 of the thesis addresses **"Floods at global and regional levels: mechanisms, geographic distribution, and geomatic assessments"** This chapter is structured into five sections.

The section titled ***"Mechanisms and factors contributing to flood occurrence"*** provides a detailed description of the mechanisms and factors underlying the occurrence of floods, including the stages of emergence, accumulation and manifestation. It analyzes both natural and anthropogenic influences, such as extreme precipitation, snowmelt, climate change, land use changes and soil erosion, which contribute to heightened risk, impacting the environment and human society.

The subchapter ***"Global analysis of floods"*** explores the global impact and the increasing frequency of floods in recent decades, highlighting the geographic distribution of these phenomena at global and regional scales and offering recent examples of catastrophic events.

The section ***"Flood risks in Romania"*** outlines the country's vulnerability to frequent and devastating floods, analyzing exposed regions, the historical context of floods and measures taken by Romanian authorities for risk prevention and management.

The section ***"Hydrotechnical works and land improvements for flood prevention and mitigation"*** describes essential technical measures for protecting communities and infrastructure, including dams, dikes, diversion channels, drainage works and afforestation, which contribute to flood control and water resource management.

The final section of Chapter 2, ***"Geomatic techniques and methods for flood analysis and prediction"*** details various modern methods based on GIS, remote sensing and machine learning algorithms, used for risk assessment, flood monitoring and prediction. It emphasizes the importance of these techniques and technologies in hydrology and the management of natural disasters.

Chapter 3 of the thesis addresses **"Erosion on a global and regional scale: mechanisms, geographical distribution and geomatic estimates".** This chapter is structured into six sections.

The section ***"Mechanisms and factors contributing to erosion"*** explains the natural and anthropogenic processes of soil erosion, highlighting the contribution of rainfall, wind, soil structure, vegetation and human activities (deforestation, intensive agriculture, urbanization) to the occurrence and/or acceleration of this phenomenon, with negative effects on ecosystems and infrastructure.

"Global analysis of erosion" presents various types of soil erosion and emphasizes the impact of human activities (intensive agriculture, deforestation, overgrazing, urbanization) in amplifying this natural phenomenon on a global scale, affecting soil fertility, agricultural productivity, ecosystems and exacerbating climate change.

The section ***"Risk analysis of erosion in Europe"*** highlights that soil erosion is a significant problem on this continent, particularly affecting mediterranean regions, mountainous areas and regions with intensive agriculture, threatening agricultural productivity, ecological stability and the human environment.

The subchapter ***"Erosion risks in Romania"*** specifies that approximately 43% of the country's agricultural land is exposed to the risk of soil erosion, with an average rate of 2.98

t/ha/year and that climate change may amplify these rates in the coming decades, especially in hilly and plateau regions, underlining the need for soil conservation measures.

In the section ***"Land improvement works for preventing and combating soil erosion effects"***, specific methods and works adapted to different types of land (arable land, plantations, pastures) are described, aimed at reducing soil losses, increasing fertility and protecting infrastructure.

The section ***"Geomatic techniques and methods for analyzing and predicting erosion"*** details various models based on geomatic techniques used to evaluate soil erosion, including empirical models such as USLE and RUSLE, conceptual models like AGNPS and SWAT and process-oriented models such as WEPP, as well as the ROMSEM model designed for Romanian conditions.

Part II of the doctoral thesis presents **"The results of personal research"**, outlined in four chapters.

Chapter 4 of the work is titled "**Geospatial models and techniques in the integrated study of the Crișul Alb basin"** and is structured into six sections.

The first section of Chapter 4 refers to the ***"Purpose and objectives"*** of the research.

The purpose of the research in this section is to develop and apply a complex geospatial analysis model, utilizing GIS techniques and remote sensing tools, to understand the dynamics of the physical-geographical, hydrographic and land use environments in the Crișul Alb basin.

The specific objectives of the research in this chapter include:

- situating the Crișul Alb basin within the region;
- analyzing climatic interactions in hydrogeomorphological risk phenomena;
- soil analysis and associated hydrogeomorphological risks;
- hydrographic assessment of the Crișul Alb basin;
- monitoring and mapping land use changes;
- creating scenarios for future land use in 2035;
- analyzing the impact of land use changes.

The ***"Materials and methods"*** section details the geospatial and statistical data (DEM, basin boundaries, hydrographic network, precipitation quantities and Corine Land Cover datasets) and the software tools used (ArcGIS and TerrSet) for detailed characterization of the Crișul Alb basin and the spatio-temporal analysis of land use patterns. Data processing was carried out using GIS methods, which generated thematic maps and forecasts of land use dynamics for the year 2035.

"Territorial analysis of the Crișul Alb hydrographic basin using GIS methods" shows that this basin, located in western Romania, covers an area of 422,798 ha and has a perimeter of 521,965 m. Elevations range from 82 to 1,587 m (Bihor Mountains), with an average of 323 m. Within the basin, the terrain is varied: plains and hills dominate the western half, while the eastern half is characterized by mountains and forests.

The climate varies by altitude: mountainous areas have multiannual average temperatures of 4 - 6°C and multiannual average precipitation exceeding 1,000 mm/year, while plains have thermal values of 10 - 11°C and annual precipitation of 500 - 600 mm. The spatio-temporal distribution of precipitation across the basin influences the frequency and behavior of hydrological risk phenomena (floods, flash floods).

Soil types range from chernozems (15%), located in low areas, to distric cambisols (14%), found in high hills and mountains. Clay soils pose a high flood risk due to their significant water retention capacity, while sandy soils are prone to erosion due to high porosity.

"Hydrographic and historical assessment of the Crișul Alb river basin" highlights its importance in western Romania, with a length of 234 km and a hydrographic network of 103 rivers totaling 1,667 km. The Crișul Alb river is fed by 42 second-order tributaries (694 km), 48 third-order tributaries (558 km), 10 fourth-order tributaries (103 km) and one fifth-order tributary (6 km), along with the Canalul Morilor (103 km). Major hydrogeomorphological events (in 1970, 1981, 1995, 2000, 2005, 2006 and 2014) underscore the need for careful management to protect infrastructure and natural resources.

At the basin level, land improvement works, carried out from the interwar period to the present, have focused on drainage, irrigation and modernization to prevent flooding and support agriculture.

The section ***“Trends and projections in land use”*** demonstrated that the Crișul Alb basin experienced notable changes in land use between 1990 and 2018, with significant increases in arable land (+18,150 ha) in plains and low hills and an expansion of forested areas (+6,089 ha) in pre-mountain and mountain regions. Grasslands, important components of the land fund, showed significant fluctuations during the analyzed period, driven by various funding programs and agricultural policies.

Projections for 2035 indicate an increase in arable land (+10.24%) and forested areas (+1.36%), alongside a decrease in grasslands (-5.97%), complex crops (-63.82%) and agricultural land with natural vegetation (-21.71%).

The use of GIS technologies and remote sensing data enabled the development of a complex model for analyzing the Crișul Alb basin, offering a detailed understanding of geographic and hydrological dynamics with implications for the occurrence and manifestation of hydrogeomorphological risk phenomena.

Chapter 5 of the study is titled **"Advanced methods for flood susceptibility assessment based on GIS and remote sensing, in the context of land improvements. Case study: Crișul Alb basin"** and is structured into eight sections.

The purpose of the research in this chapter is to apply a comprehensive spatial analysis model that integrates GIS, remote sensing data and the Analytic Hierarchy Process (AHP) to identify and map flood-prone areas within the Crișul Alb river basin.

The specific objectives include:

- collecting and processing spatial data;
- implementing and adapting the AHP model;
- spatial analysis and modeling of flood susceptibility;
- cartographic representation;
- proposing management measures and policies to reduce flood risk in the identified areas.

In the ***"Materials and methods"*** section, the data and software used for flood susceptibility analysis in the Crișul Alb basin are described. Various datasets were utilized, including DEM, average rainfall from 2013 - 2022, Sentinel 2A satellite imagery, the hydrographic network and Corine Land Cover data from 2018 edition. The data were processed using ESA SNAP, ArcGIS and QGIS.

The methodology, based on MCDA and AHP, integrated five criteria (hydrological, morphometric, soil permeability, land use and anthropogenic factors) represented by ten variables: atmospheric precipitation, drainage density, elevation, slope, distance to rivers, topography, soil types, land use patterns, vegetation cover and distance to roads. These factors were represented as raster maps with a spatial resolution of 25 m in the Stereographic 1970 projection. The maps were reclassified into five levels of susceptibility (from very low to very high) and the weight of each factor was determined using the AHP method. The final flood susceptibility map was generated by combining the ten factors using the Weighted Overlay tool in ArcGIS.

The section ***"Geospatial analysis of flood-contributing factors"*** involved an evaluation based on the ten relevant factors. Precipitation levels, ranging between 923 - 1048 mm in mountainous areas and drainage density, higher in the southern and northern regions (1.8 - 3.1 km/km^2), increase flood susceptibility. Low elevation (82 - 206 m) and gentle slopes (0 - 4^o) facilitate water accumulation, while short distances to rivers (0 - 100 m) amplify the risk. Areas with high TWI values (14.8 - 33.3) and clayey soils have low permeability, while agricultural land and sparsely vegetated areas are more vulnerable. Land located 0 - 50 m from roads has a higher flood risk than areas over 300 m away.

In the ***"Weighting relevant factors using AHP"*** section, flood susceptibility assessment in the Crișul Alb basin is achieved by assigning specific weights to the ten key factors. The distance to rivers (14%), TWI or landscape wetness index (14%) and precipitation (13%) have the greatest impact, followed by elevation (12%) and slope (10%). Other factors, such as drainage density (9%) and soil types (9%), contribute moderately to the flood susceptibility estimation procedure.

The section ***"Flood susceptibility assessment in the Crișul Alb basin"*** reveals that 61% of the basin's area falls into the moderate flood susceptibility class, particularly in low hills and plains. Meanwhile, 25% has low risk and 12% and 2% show high and very high susceptibility, respectively. The most exposed areas are depressions and low plains, where many settlements and agricultural lands are located.

The section ***"Impact analysis of potential floods on land use classes"*** shows that, out of the 422,103 hectares analyzed, the majority of areas are at moderate flood risk (64%). Built-up areas and arable lands are predominantly exposed to moderate and high risk (71–76% moderate risk and 24–27% high risk), while vineyards and orchards are primarily at low and moderate risk (53–81% moderate risk). This situation highlights the need for tailored protective and management measures for each land use category.

The section ***"Management measures for reducing flood risk"*** in the Crișul Alb basin outlines key measures, including: rehabilitating hydrotechnical infrastructure and building new protective structures; soil and vegetation management through sustainable agricultural practices; reforestation; territorial planning and zoning to avoid construction in high-risk areas; implementing monitoring and early warning systems; public education and awareness; effective inter-institutional collaboration; supporting research and development in advanced flood management technologies.

The study conducted on the Crișul Alb basin highlights significant flood vulnerability in plains and depressions. In these areas, preventive and management measures are essential to protect communities and natural resources.

Chapter 6 of the work is titled **"Spatial modeling of soil erosion using GIS techniques, with applications for land improvements. Case study: Crișul Alb basin"** and is structured into seven sections.

The aim of the research presented in this chapter was to apply a complex spatial analysis model, based on GIS techniques, to identify areas susceptible to surface soil erosion and to determine the intensity of this phenomenon in various sub-areas of the Crișul Alb basin, providing solutions for land improvement.

The specific objectives of the research include:

- collecting and processing relevant spatial and statistical (descriptive) data for the Crișul Alb basin;
- applying and calibrating the soil erosion model;
- spatial analysis of erosion susceptibility;
- assessing the impact of erosion on agricultural and non-agricultural land;
- proposing measures for land improvements and sustainable land management.

The ***"Materials and methods"*** section specifies the materials, software and methods used in conducting the research. The data utilized includes climatic data, soil data, a Digital Elevation Model and Sentinel-2 satellite images, processed using specialized software such as ESA SNAP, ArcGIS and QGIS.

For estimating surface soil erosion, the Universal Soil Loss Equation (USLE) was applied, adapted for the study area. This equation involves five factors: R (rainfall erosivity), K (soil erodibility), LS (topographic factor), C (land use factor) and P (erosion control practices factor).

Each factor was spatialized into raster maps with a spatial resolution of 25 m. By combining these five factors in GIS environment, a soil erosion susceptibility map was generated for the basin, classified into five intensity classes: very low (<3 t $ha^{-1}yr^{-1}$), low (3.1 - 10 t $ha^{-1}yr^{-1}$), moderate (11 - 20 t $ha^{-1}yr^{-1}$), high (21 - 40 t $ha^{-1}yr^{-1}$), very high (>41 t $ha^{-1}yr^{-1}$).

The ***"Spatial modeling and analysis of contributing factors to soil erosion"*** involved estimating the average annual soil loss based on factors such as: rainfall erosivity (R): ranging from 275.85 - 571.59 MJ mm $ha^{-1}h^{-1}yr^{-1}$, higher in mountainous areas; soil erodibility (K): between 0.04 - 0.6 t $ha^{-1}MJ^{-1}mm^{-1}$, peaking near rivers; topography (LS): values between 0 - 16.56, higher on steep slopes; land use (C): ranging from 0.03 - 1.41, with maximum values in plains and minimum in forested mountains; conservation practices (P): values between 0.2 - 5.2, highest in hilly and mountainous areas.

The section ***"Estimating soil erosion susceptibility in the Crișul Alb basin"*** reported an average soil erosion rate of 2.60 t/ha/year, lower than national estimates (2.98 t/ha/year). The erosion distribution ranges from 0 t/ha/year to over 41 t/ha/year.

Land classification shows that: 74% of the land has very low erosion rates (<3 t/ha/year); 14% low (3.1 - 10 t/ha/year); 7% moderate and 4% high and very high rates (>21 t/ha/year).

The pre-mountain and mountain regions, characterized by heavy rainfall and steep slopes, exhibit the highest annual erosion rates.

The section ***"Impact assessment of erosion on land use"*** highlights that soil erosion, exacerbated by human activities, impacts mountainous and plain areas differently, affecting agriculture and infrastructure. Mountainous areas are the most vulnerable due to slopes and precipitation, while erosion is lower in plains (0 - 3 t/ha/year).

Within the Crișul Alb basin, most sub-basins have very low erosion rates (0 - 3 t/ha/year), such as Valea Nouă Chiser (100%) and Trei Holamburi (99%). However, some sub-basins exhibit high erosion rates (21 - 40 t/ha/year) like Valea Laptelui, and very high rates (>41 t/ha/year) in Valea Satului (5%).

The section ***"Management measures for reducing and combating soil erosion effects"*** includes key measures such as: managing rainfall through terraces and small dams; reducing soil erodibility through soil improvement and conservative plowing techniques; managing topography through terracing and ditches on steep slopes.

Other actions focus on crop rotation, strip farming conservation, continuous monitoring of erosion, and community education, alongside strict regulations and financial incentives for soil and natural resource conservation.

Locally adapted interventions, supported by education and policies, are essential for protecting soil and maintaining agricultural productivity.

Chapter 7 of the work is titled **"Application of geospatial methods and hydraulic modeling in the study of watersheds"** and is structured into five sections.

The research objectives in this section can be divided into two main directions. The first direction involved applying geospatial models of hydrological analysis to the Cigher river basin, a tributary of the Crișul Alb river, to determine essential characteristics such as water flow direction, water accumulation, identification of hydrographic networks, watershed delineation and more. The second research direction involved applying one-dimensional hydraulic modeling techniques on a section of the Cigher river to model water flow under different scenarios.

The specific objectives were:

- determining the water flow direction in the Cigher river basin using a Digital Elevation Model (DEM) with a 25 m resolution;

- identifying water accumulation points within the basin to map the hydrographic network;

- correcting and validating results obtained through geospatial models by comparing them with existing data and adjusting the model to minimize errors;

- identifying and delineating the hydrographic network and sub-basins within the Cigher river basin using spatial analysis and geospatial data interpretation techniques;
- applying one-dimensional hydraulic modeling techniques to a section of the Cigher river to simulate water flow under various hydrological scenarios and assess the river's hydraulic behavior.

The section ***"Materials and methods"*** specifies the materials, software and methodes applied in conducting the research.

Various datasets were utilized: hydrological data and digital elevation models (DEMs) with resolutions of 25 m and 1 m, including detailed topographic surveys and aerial images (UAV). Data processing was conducted using ArcGIS and HEC-RAS.

The methodology includes two stages: hydrological modeling (on a 25 m DEM) and hydraulic modeling (on a 1 m DEM). Hydrological modeling involved determining flow directions and possible accumulations, generating the hydrographic network and delineating the basin and its sub-basins. Hydraulic modeling was applied to an 18.3 km stretch of the Cigher river, with four simulation scenarios (S1 - S4) for different flow rates (8 m^3/s, 23 m^3/s, 41 m^3/s, 60 m^3/s) and water levels (3 m, 3.2 m, 3.35 m, 3.5 m). The model was run under subcritical conditions and results were interpreted in tabular, graphical and cartographic formats.

In the section ***"Stages and methods of hydrological modeling using GIS. Case study: Cigher basin",*** a DEM with a 25 m spatial resolution, with altitudes ranging from 95 to 792 m, was used to analyze water flow direction and accumulation. The corrected DEM was used to determine flow direction using the D8 algorithm and potential accumulations. After applying specific corrections, the hydrographic network was identified and ranked using the Strahler method. Basin and sub-basin delineation finalized the modeling process, which is essential for hydrological and hydrographic characterization and water resource management.

The next section, ***"Stages and methods of hydraulic modeling for steady flow analysis. Case study: Cigher river"***, focuses on a stretch of the Cigher river (18.3 km), using one-dimensional hydraulic modeling with HEC-RAS software to analyze steady flow. Simulation scenarios (S1 - S4) included flow rates of 8, 23, 41 and 60 m^3/s and water levels between 3 and 3.5 m, corresponding to return periods of 1, 5, 10 and 15 years. The 32 cross-sections plotted in HEC-RAS showed variations in river morphology and allowed for the calculation of essential parameters such as water velocity and flow area. In the maximum scenario (S4), the flow area reached 67.43 m^2 and water velocity increased to 2.53 m/s at cross-section ST1.

Modeling indicated critical points of potential erosion and extensive flood-prone areas in high-flow scenarios (S3 and S4), highlighting the need for flood prevention measures in vulnerable segments.

The integration of GIS methods and hydraulic modeling provides a comprehensive and rigorous approach for predicting risk phenomena and sustainably managing hydrological resources, contributing to more precise planning adapted to climate and socio-economic changes.

In conclusion, the research provided a solid foundation for understanding flood and erosion risks in the Crișul Alb basin and the proposed recommendations will guide future research directions and the development of effective solutions for sustainable natural resource management and environmental protection in similar contexts.

The studies conducted in this work open new perspectives in advanced geospatial analysis, offering a solid basis for future studies dedicated to assessing flood and erosion risks in watersheds.

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