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DEVELOPMENT AND APPLICATION OF RISK AND HAZARD MAPS FOR THE DANUBE RIVER IN ROMANIA

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Abstract: *The development and use of hazard and risk maps for the Danube River within the territory of Romania represent an essential component of the integrated management of water resources and the prevention of extreme natural phenomena. The Danube, the most important river in Central and Eastern Europe, crosses Romania for more than 1,000 km, exhibiting significant hydrological, geomorphological, and ecological diversity. This natural complexity, combined with increasing anthropogenic pressures and climate-induced variability, leads to a heightened vulnerability to flooding, bank erosion, accidental pollution, and other water-related risks. The creation of accurate hazard and risk maps relies on modern geospatial technologies such as remote sensing, aerial photogrammetry, LiDAR scanning, and advanced Geographic Information Systems (GIS), enabling the integration and analysis of topographic, hydrological, and climatic datasets. These technologies support the generation of high-resolution digital terrain models, flow simulations, and spatial analyses that are essential for delineating exposed or sensitive areas. Furthermore, the use of UAVs and dedicated processing software—such as Agisoft Metashape, Pix4D, and other photogrammetric platforms—makes it possible to produce detailed orthophotos and 3D reconstructions with centimeter-level accuracy. Such products are invaluable for monitoring geomorphological evolution, evaluating protective infrastructure, and offering decision-makers reliable, up-to-date information. Ultimately, the systematic development of hazard and risk maps contributes to more efficient territorial planning, environmental protection, and the implementation of proactive measures for reducing natural risks along the Romanian stretch of the Danube.*

Keywords: *hazard, risk, Danube, GIS, remote sensing, floods, digital terrain model*

INTRODUCTION

Floods are among the most common natural phenomena with major impacts on the environment, the economy, and human communities. They can cause significant loss of life, destruction of homes, and degradation of soils and ecosystems. Therefore, it is very important to identify areas that have a high risk of flooding and to plan preventive and protective measures in advance.

In this context, modern technologies have become essential tools in the process of analyzing and creating flood hazard and risk maps. Remote sensing, through satellite and aerial images, provides up-to-date information about the condition of the land, watercourses, and the changes that have occurred over time. At the same time, LiDAR (Light Detection and Ranging) technology makes it possible to obtain very detailed digital terrain models (DTMs), which accurately show the shape of the relief, elevation differences, and micro-relief of the studied areas.

Integrating these data into a Geographic Information System (GIS) is a key step for spatial analysis. Through GIS, information from different sources — such as elevation, soil type, land use, and hydrological data — can be combined to create maps that show where flood hazards exist and how frequent they may be.

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Based on these maps, authorities and specialists can make better-informed decisions: they can plan protective dikes, establish evacuation zones, or prohibit construction in high-risk areas. At the same time, this information helps the population understand the risks and be better prepared in case of flooding.

MATERIAL AND METHODS

The FLOOD RISK project has made a significant contribution with regard to the Danube region and the EU policy on flood risk management, especially after the devastating floods that occurred. The project was carried out under the coordination of the Romanian Water Administration, as part of the cross-border Danube FLOODRISK initiative. Each of the responsible authorities for the Danube River Basin participated. Up to now, 19 authorities from Austria, Slovakia, Hungary, and Romania have worked together as project partners, while another 4 joined the project as associate partners.

Project objectives included:

- Developing flood risk maps for the Danube based on a harmonized methodology;
- Transforming these into predetermined pilot risk maps to support stakeholders involved in flood risk management at local and regional levels;
- Supporting proactive decision-making in development and infrastructure planning.

The project was funded through the South-East Europe Program under the Territorial Cooperation Objective of the European Union’s Regional Policy.

During the last century, flood protection along the Danube was generally achieved by building dikes, which created a sense of safety and, consequently, a decrease in public awareness regarding flood risks. The floods of 2002 in the upper Danube catchment, as well as those in 2006 and 2010 in the lower basin, demonstrated once again the limitations of these protection measures, due to overtopping or failure of dikes. These events highlighted the fact that residual flood risks always exist, despite all protective efforts.

The main objective of this paper is to increase the awareness of the communities living along the Danube regarding their exposure to floods and the inherent risks associated with such events.

The goal of the Danube Flood Action Plan is to increase the level of protection of the population and property against floods, while at the same time improving environmental conditions in the Danube area and its floodplains.

Performance objectives:

- Reducing flood-related damages;
- Increasing flood risk awareness by developing risk maps;
- Improving flood forecasting and early warning systems.

This paper presents areas exposed to flooding, as well as potential risks of damage and flood impacts.

Under these conditions, the work ensures the prioritization of the measures to be taken within the Danube Flood Action Plan through the objective of reducing residual risks. Flood hazard maps indicate the anticipated degrees of flooding represented in shades of blue. In order to quantify the risks affecting population and property during extreme flood events, the maps highlight potential damage.

It is necessary to distinguish between two situations:

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- Areas with flood protection measures designed for more than a 100-year recurrence period (densely populated zones often receive higher levels of protection);
- Areas with reduced flood protection or without protection;
- Areas with High Protection Levels.

Therefore, for some highly protected areas, the study considered scenarios where protective measures fail, presenting negative or residual risk situations. In other areas, such as Vienna, this situation is considered unlikely due to the high level of protection and was therefore not included to avoid unrealistic negative scenarios.

Areas with Little or No Protection

In these areas, medium and extreme floods overflow the protection structures, and where such structures do not exist, frequent floods affect low-lying areas such as the floodplains in Hungary and the Danube Delta. For these regions, residual risk analysis was not required.

Target Areas

Depending on the surrounding terrain and river development, the Danube is divided into the following sections, which differ in their flood protection levels:

Upper Danube

-Germany, Austria;
-Valley areas with sections carved into rocky terrain;
-Flood protection dikes (HQ100 level).

Middle Danube (Vienna – Iron Gate)

-Austria, Slovakia, Hungary, Croatia, Serbia;
-Valley areas with wider floodplains;
-Flood protection dikes in most regions;
-Polders of various sizes.

Lower Danube (downstream of Iron Gate)

-Romania and Bulgaria;
-Area almost entirely protected by dikes;
-Polders of various sizes.

Danube Delta (downstream of Ceatal Ismail)

-Three navigable branches with flood protection: Chilia, Sulina, and Sfântu Gheorghe;
-Total area: 564,000 ha;

Most settlements generally have local protection through diking.

Figure.1 Dyke protection work (source: Romanian Waters)

Flood hazard maps were developed for three flood scenarios:

- Events with a flood occurrence frequency over a period of 30 years (HQ30);
- Medium events with a flood occurrence frequency over a period of 100 years (HQ100);
- Extreme events with a flood occurrence frequency over a period of 1,000 years (HQ1000);
- 30-Year Flood Limit (HQ30).

These areas along the river are flooded frequently. The flood hazard is well known. In general, floodplains, marshlands, forested areas, and agricultural lands are affected. Usually, construction in flood-prone areas with a recurrence interval of 1 in 30 years should be avoided, and existing structures should be adapted to possible flood conditions.

Flood-prone areas should be used for retention purposes in order to reduce the overall flood risk. These retention zones are often valuable biotopes, such as those in Hungary or in the Danube Delta.

100-Year Flood Limit (HQ100)

A 100-year flood is generally accepted as the standard for designing flood protection measures along the Danube.

In most cases, the flood hazard in areas between HQ30 and HQ100 is known, especially by long-term residents. These areas often include older buildings adapted to flood risks, as well as newer buildings with higher potential for damage. Agricultural land predominates in these zones; construction permits should be issued only in exceptional cases and with the application of preventive building measures.

Due to the transition from aquatic to terrestrial vegetation, these surfaces also represent valuable ecological habitats.

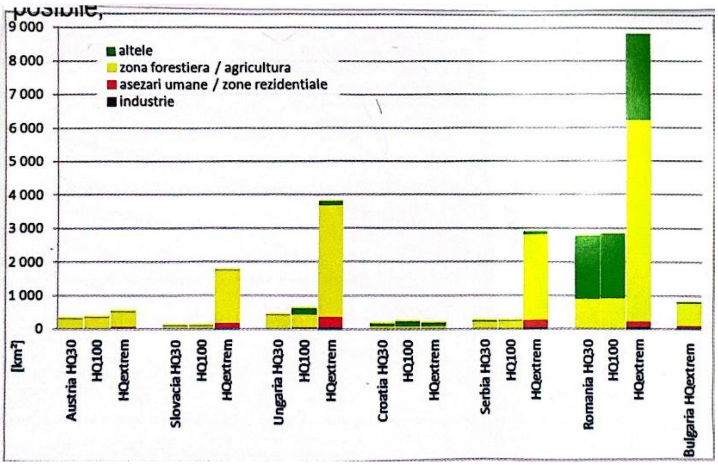

Figure.2 Area with flood potential [km²]

Limits and Levels of Extreme Flooding – 1 in 1000 Years (HQ1000)

During these extremely rare events, the extent and depth of flooding are significantly greater than any previously observed. Existing flood protection structures may be overtopped or may fail, which represents a residual risk scenario. For areas within the HQ100–HQ1000 range,

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there are no strict restrictions on land use; however, certain flood prevention strategies and emergency response plans must be taken into consideration, especially for vulnerable sites. Since potential preventive measures (such as evacuation plans) depend largely on flood depth, both the boundaries of flood-prone areas and the flood depth ranges are illustrated here.

Assumptions Used in Hazard Calculation.

Different hydrological and topographic conditions along the Danube require the adaptation of hazard calculation assumptions for different river sectors. Existing land-use conditions were taken into account.

For the upper Danube, between the source and Bratislava, calculations are based on historical flood magnitudes, while downstream of Bratislava the model results are generally based on maximum discharge levels. Upstream of Bratislava, historical maximum water levels were recorded in 1850, 1899, and 1954. During the floods of 1965, 1975, and 2002, nearly all dikes failed, leading to the flooding of Bratislava. In the same region, the winter flood of 1876 was devastating, destroying 3,350 meters of dikes and inundating more than 60,000 hectares of land, including numerous villages and settlements. More recent floods, in 2006 and 2010, affected the lower Danube basin in Romania, Bulgaria, and Ukraine.

The assessment of flooded areas and flood depths is based on hydraulic assumptions. Despite the variability of flood characteristics, dikes, channels, or historical flood damage were generally not considered in detail. Since the proposed map scale allows only a general-level assessment, the highlighted flood scenarios must be interpreted in a broader context.

Calculations for flood-prone areas were combined with digital terrain models derived from LiDAR data, field measurements, and 1:5,000 – 1:25,000 topographic maps. The resulting flood zone data were then generalized for representation at a 1:100,000 scale.

Flood extent calculations in Hungary used a simplified method based on national flood maps that also considered the likelihood of dike resistance. For this reason, this map is not identical to Hungary's official national flood maps. Germany contributed existing flood hazard maps corresponding to the 100-year recurrence period.

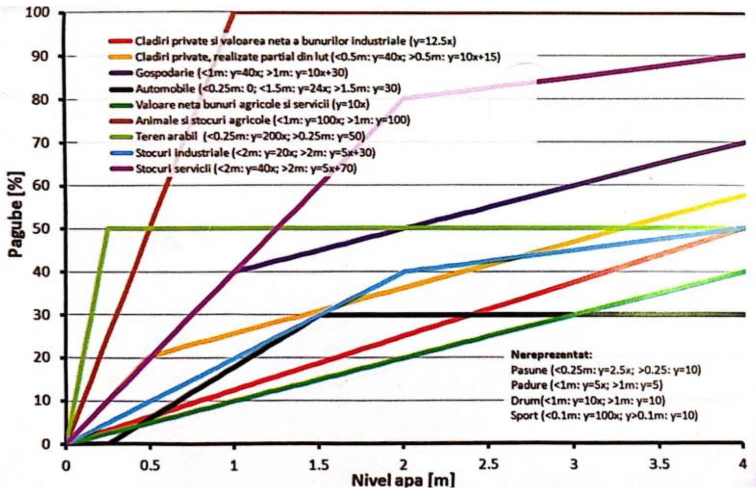

Figure.3 Damage functions used for calculating damage assessment.

Flood Risk Maps

The maps showing potential damages contain values expressed in Euro/m² for different types of land use. The underlying information is based on a harmonized dataset concerning assets and population density.

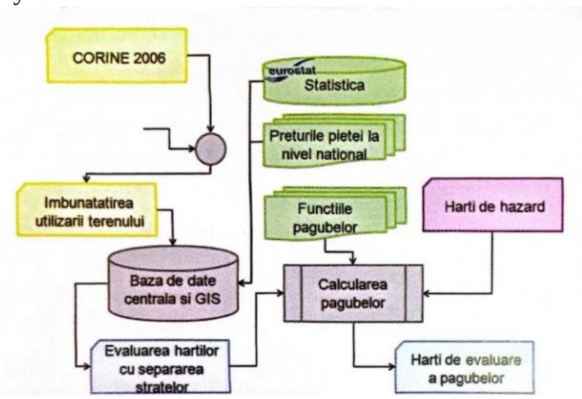

Figure 4. Data used for calculating assets and damages

Assumptions for Risk Assessment

Certain assumptions are necessary in order to explain the situation along the entire Danube River.

Only assets for which material damage could be evaluated were taken into account.

The results are based on the network value concept, which reflects the current market value of an asset (excluding restoration costs or insurance-covered values).

Land value was not included, as it is assumed that the land retains its value after the occurrence of a flood event.

External planning costs (e.g., construction permits) were not included, since they do not apply in the case of simple post-event restoration.

Costs associated with the interruption of activities were not considered.

Damage mitigation measures were not taken into account.

Costs for emergency prevention and intervention, as well as damages to flood protection structures, were not included.

Data Used to Generate Information on Assets and Population Density

To obtain comparable results, existing information from European databases (e.g., Eurostat) was primarily used. Additional values from other sources (national statistics, industry, and scientific studies) were also integrated. All values were expressed in Euros and calculated using the official EU exchange rate.

Steps for Calculating Damage Assessment

The calculation of potential damages is based on the following steps:

- Determining the number of people exposed to flood-prone areas;
- Identifying the assets and values located in the flooded areas (for each land-use category);
- Applying damage functions for each asset category;
- A damage function represents the damage as a percentage of the total value corresponding to a specific land-use type;

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- Different land-use categories may have different levels of flood susceptibility;
- In the same area, several asset categories may coexist (e.g., residential buildings and other structures).

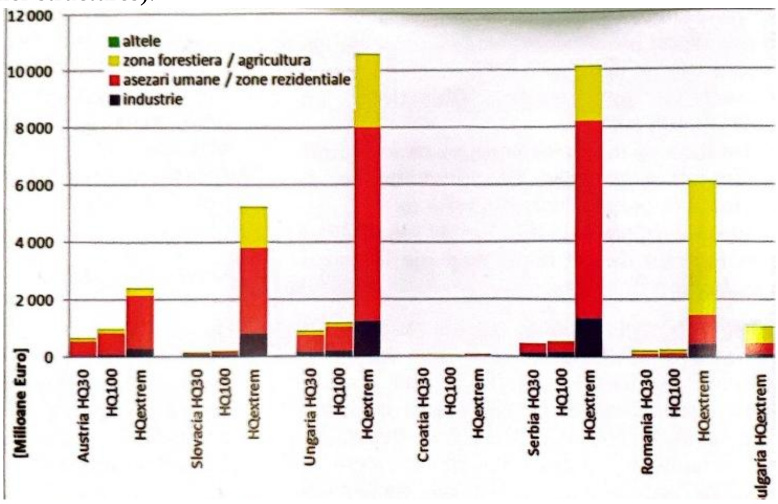

Figure.5 Potential damages

RESULTS AND DISCUSSIONS

On the territory of Romania, the Danube River covers a distance of 1,075 km.

A total of 28 flood risk maps have been created for Romania at a scale of 1:100,000, and in this paper we will present two maps, from the locality of Gruia to the locality of Basarabi, as shown in the figures below.

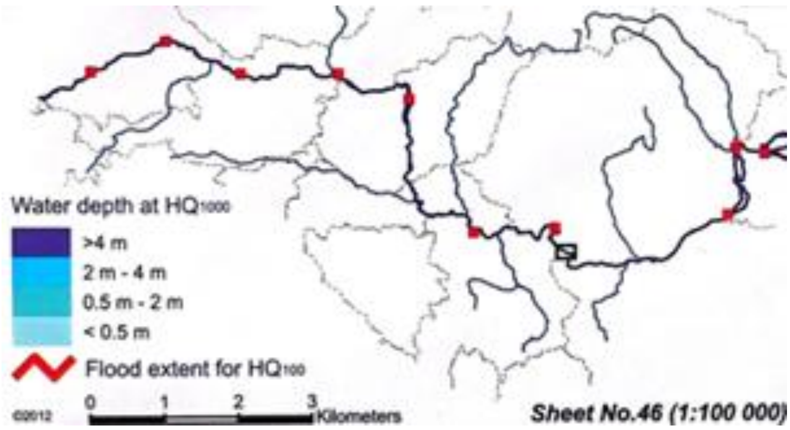

Figure.6 Water depth at HQ 1000

In the first map, the water depth is analyzed, and the color red symbolizes the extent of the flooding when the water discharge exceeded 100 m^3/s.

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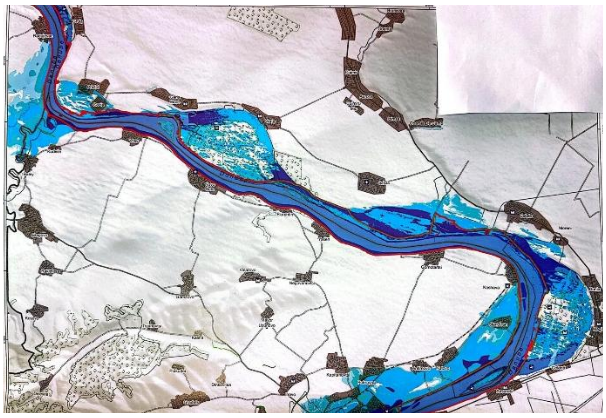

Figure.7 Flood Hazard Map for the Gruia – Basarabi Sector.

The area shown in the map above illustrates the built-up areas of several localities, such as Cozia and Basarabi, which would be directly affected in the event of flood expansion.

These hazard and risk maps can help prevent human and material losses for the areas represented. The area of interest studied is located downstream of the town of Orșova on the Romanian territory, and on the right side, in the direction of water flow, lies Serbia. The border between the two countries is marked by the dotted line.

In the second map analyzed in this study, we aim to assess, along the same section of the river, the potential damages for the area between Gruia and Basarabi, as illustrated in the map below.

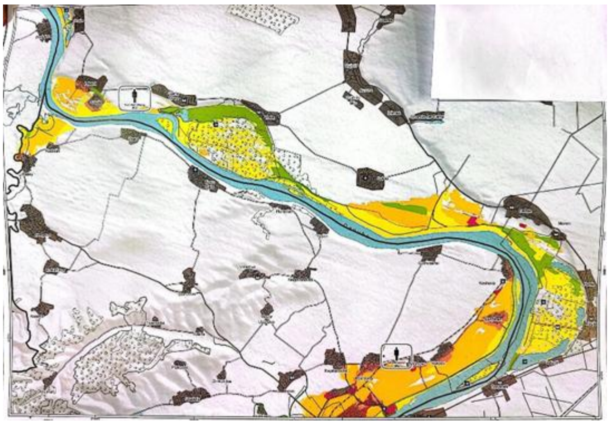

Figure.8 Flood Risk Map for the Gruia – Basarabi Sector.

The map analyzes four types of land-use categories, as follows:

- Yellow represents forestry and agricultural areas;
- Light red to dark red represents residential areas and buildings;
- Dark red to brown indicates risk levels for industrial zones;
- Light green and dark green represent other types of constructions.

For the industrial and residential zones, three risk categories are included: low, medium, and high, as shown on the map.

For the agricultural areas and other constructions, two categories are used: low and high. Similar to the two maps presented in our study, such maps have been developed along the entire Romanian sector of the Danube River, helping to prevent and reduce the impact of natural disasters.

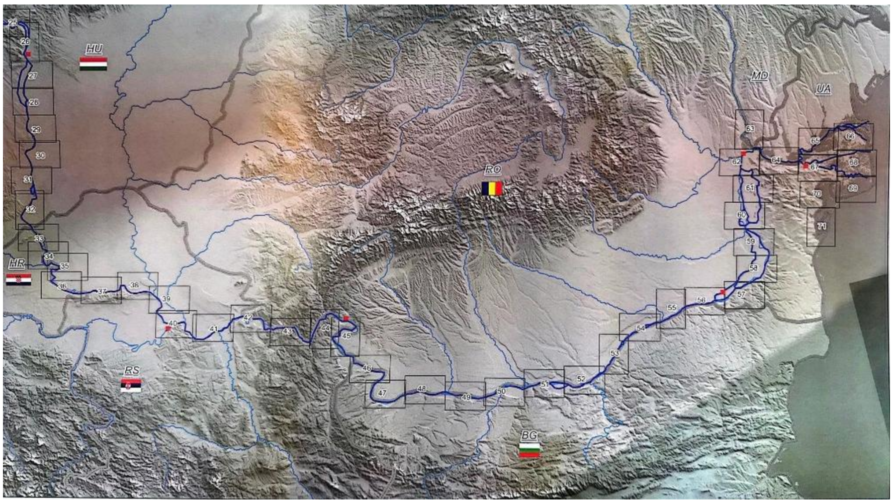

Figure 9. Hazard map

Maps numbered from 42 to 71, as shown in the image.

CONCLUSIONS

Analysis of Flood Hazard and Risk Maps

The analysis of the flood hazard and risk maps for the studied valley sector highlights the fact that the examined area presents a high vulnerability to flooding, particularly near the main riverbed and in the low-lying floodplain zones. The digital terrain model and hydrological data show that, in the event of a flood with a low probability of occurrence (HQ1000), water depth may exceed 4 meters in certain sections of the riverbed, while adjacent areas exhibit moderate flood levels, with water depths between 0.5 and 2 meters. A comparison between the land use map and the flood extent map indicates a significant overlap between inhabited/agricultural areas and zones with a high flood risk. Settlements located within the floodplain (as highlighted on the map) are directly exposed to flooding hazards, and the road infrastructure near the river represents a vulnerable element in the case of extreme events.

The modern technologies utilized—remote sensing, LiDAR data, and their integration in GIS—enabled the creation of a detailed and accurate spatial representation of potential flood scenarios. This demonstrates the importance of geospatial information infrastructure in assessing natural risks and supporting land management decisions.

Recommendations

Responsible Land-Use Planning

It is recommended to avoid new construction in areas identified as having a high flood risk and to adjust urban development plans so that the expansion of settlements occurs in less hazard-prone zones.

Improvement of Protection Infrastructure

Constructing or reinforcing dikes and flood protection walls, as well as restoring riparian vegetation, can reduce the severity of flood impacts.

Monitoring and Early Warning Systems

Implementing automated hydrometric monitoring systems and providing timely alerts to the population can help reduce both material and human losses.

Public Education and Awareness

Local communities need to be informed and trained regarding prevention measures, emergency behavior, and evacuation procedures to increase their response capacity during flood events.

Periodic Updating of Hazard Maps

Natural changes in the river course and infrastructure development require regular revisions of flood risk maps to ensure that data remain accurate and relevant for decision-makers.

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