AUTOMATED MODEL FOR IMPLEMENTATION OF UNIFIED CRITERIA FOR FLOOD RISK CLASSIFICATION IN BULGARIA

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ABSTRACT

Floods are one of the most common hazards worldwide. Each year they cause considerable damage to people's lives and properties and can have severe environmental consequences.

Floods are natural phenomena but through the right measures we can reduce their likelihood and limit their impacts. As to achieve that the European Commission proposed the Directive 2007/60/EC in year 2006. It requires Member States to assess if all water courses and coast lines are at risk from flooding, to map the flood extent and assets and humans at risk in these areas and to take measures to reduce this flood risk.

As a Member-state the Republic of Bulgaria is following the statements and procedures of the Directive. Criteria and methods for determination and classification of areas with potential significant flood risk are developed to be implemented for each basin management region in the country.

In this paper we present an automated model for implementation of the developed unified criteria for flood risk assessment in Bulgaria. We provide an overview of the geographic information systems (GIS) functionality for gathering data form a variety of sources, its integration into a single information environment and the possibilities for modeling and dissemination of this data. Furthermore, this paper demonstrates the advantages of collaborative GIS platforms for providing valuable information in case of a disaster.

АВТОМАТИЗИРАН МОДЕЛ ЗА ПРИЛАГАНЕ НА УНИФИЦИРАНИ КРИТЕРИИ ЗА КЛАСИФИЦИРАНЕ НА РИСКА ОТ НАВОДНЕНИЯ В БЪЛГАРИЯ

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РЕЗЮМЕ

Наводненията са едни от най-честите природни бедствия в света. Всяка година те нанасят материални щети, отнемат човешки животи и често имат сериозни последици за околната среда. Наводненията са природен феномен, но чрез взимането на подходящи мерки рискът от възникване и потенциалните негативни последици от тях могат да бъдат сведени до минимум. За да се постигне това, през 2006 година Европейската Комисия предлага Директива 2007/60/ЕО. Тя изисква от страните членки да определят зоните, които са изложени на риск от наводнения, както и материални активи и хора в риск, за да се вземат мерки за намаляване на този риск.

Като страна-членка Република България следва процедурите, описани в Директивата. За целта са разработени унифицирани критерии и методи за определяне на зони със значителен потенциален риск от наводнения, които следва да бъдат приложени от всяка от басейновите дирекции в страната.

Настоящето изследване цели да представи автоматизиран модел за прилагане на разработените критерии за оценка на риска от наводнения в България. Разгледани са възможностите на географските информационни системи (ГИС) за събиране на различни видове данни, интегрирането им в обща информационна среда, възможности за моделиране и разпространение на данни, както и предимствата на колаборативни ГИС платформи за информационно обезпечаване при настъпване на бедствие.

1. Introduction

Floods are one of the most common hazards worldwide. Each year they cause considerable damage to people’s lives and properties and can have severe environmental consequences.

According to World Disasters Report (2013) floods accounted for just over half of the 139 million people affected by disasters in 2012. Between 1998 and 2009, Europe suffered over 213 major damaging floods, which have caused some 1126 deaths, the displacement of about half a million people and at least €52 billion in insured economic losses. The coming decades are likely to see a higher flood risk in Europe and greater economic damage (European Environmental Agency). Floods are the most common hazard in Bulgaria as well (about one third of all disasters in the period from 1974-2010).

Floods are natural phenomena but through the right measures we can reduce their likelihood and limit their impacts. In the recent decades geonformation technologies have become a significant tool for flood risk management.

The aim of this paper is to present an automated model for flood risk assessment in Bulgaria.

The development of the model was preceded by the following:

- thorough review of the current European acquits and the equivalent legislation in Bulgaria;
- an overview of the geographic information system (GIS) functionality for flood risk determination;
- an overview of the possibilities for modeling and dissemination of data;

Furthermore, this paper demonstrates the advantages of collaborative GIS platforms for providing valuable information in case of a disaster.

The study area is the territory of East Aegean River Basin Directorate but the model could be applied for any other territory. The model is developed and applied in the framework of project: „Assisting River Basin Directorate with center Plovdiv Town in Defining Areas of Potential Significant Flood Risk (APSFR) in East Aegean Sea River Basin Directorate”.

2. European acquis and equivalent legislation in Bulgaria

2.1. Directive 2007/60/EC

In 2006 Directive 2007/60/EC was proposed by the European Commission and it entered into force on 26 November 2007. The purpose of the Directive is to establish a framework for the assessment and management of flood risks, aiming at the reduction of the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods in the Community. It requires Member States to assess if all water courses and coast lines are at risk from flooding, to map the flood extent and assets and humans at risk in these areas and to take adequate and coordinated measures to reduce this flood risk. The Directive also reinforces the rights of the public to access this information and to have a say in the planning process (European Commission).

Member States should undertake a preliminary flood risk assessment for each river basin district, based on available or readily derivable information, such as records and studies on long term developments, in particular impacts of climate change on the occurrence of floods, a preliminary flood risk assessment should be undertaken to provide an assessment of potential risks.

Key concepts of the Directive 2007/60/EC

- "flood" means the temporary covering by water of land not normally covered by water. This shall include floods from rivers, mountain torrents, Mediterranean ephemeral water courses, and floods from the sea in coastal areas, and may exclude floods from sewerage systems;
- "flood risk" means the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event;
- areas with potential significant flood risk (APSFR) – each river basin district should within their territory, identify those areas for which they conclude that potential significant flood risks exist or might be considered likely to occur.

2.2. Implementation of Directive 2007/60/EC in the Bulgarian legislation.

As a Member-state the Republic of Bulgaria is following the statements and procedures of Directive 2007/60/EC. The Directive is implemented into the Bulgarian legislation (Water Act) in 2010. This Act regulates the ownership and management of waters within the territory of the Republic of Bulgaria as a national indivisible natural resource and the ownership of the water development systems and facilities. One of the aims stated in the Water Act is to create conditions to prevent or reduce the harmful consequences for human life and health, the environment, cultural heritage and economic activity associated with water-related damage and loss. Following the statements of the Water Act, criteria and methods for determination and classification of areas with potential significant flood risk are developed to be implemented for each basin management region in the country. The methodology „Criteria and Methods for Risk Determination of Areas with Potential Significant Flood Risk (APSFRs)" has been approved by the Minister of Environment and Water on 22 January 2013 and available to open access from Ministry's web site.

3. Application of geoinformation technologies for flood risk determination

3.1. Geographic Information System (GIS) and its application in flood risk management

A geographic information system (GIS) is a system, that consists of hardware and software, database and users, designed to capture, store, manipulate, analyze, manage, and present geographical data with the aim of handling different tasks in a variety of fields such as environmental management, transport, demography, public administration, business etc. (Popov, 2012). GIS to a large extent can facilitate in providing accurate information as it can handle the digital data along with their associated attribute information on physical and environmental aspects for the spatial features. One of the advantages of using GIS for flood management process is the functionality to integrated data from variety of sources: satellite images, aerial photographs, LIDAR data, GPS data, vector and attribute data with different precision. All this source data provides a base for proper decision making and development of different information products (e.g. flood risk classification map). GIS has emerged as a significant support tool for assessing water quality, managing water resources, preventing flooding and better understanding of environmental issues (Maidment, 2002).

Floods are phenomena with spatial dimension and this is the reason why GIS has gained such a prominent role in the field. These technologies are widely used in the process of analysis assessment of risk, mapping and spatial modeling for the purposes of integrated flood risk management. (Nikolova, 2012)

GIS can help oversee the spatial relationships in complex systems, to locate the problems and to plan and evaluate alternatives (Bedfort, 2004), it can identify critical areas and model the flow of water through the hydrological system.

3.2. GIS modeling

The terms 'model' and 'modeling' are fundamental for science, as to a large extend they determine people's idea for the world. M.F. Goodchild (2009) defines the model as a reflection that represents the way people perceive the world around themselves. According to Boerner, et al. (2012) models are a systematical description of an object or phenomenon, which possesses the same characteristics as the prototype in the real world and serves as a mean to explore it. Models are commonly represented as a system of postulates, data, and inferences presented visually, in material form, in mathematical terms, or as a computer simulation and are often used in the construction of scientific theories.

Many interpretations of the term model exists, but most of all it is considered to be an artificially created representation of a real object (or of some of its characteristics) with a certain purpose. This definition contains the following key aspects:

1) the model is a representation of a real object

2) the model represents specific features of the object, which means that each model is created with a purpose and can be used for solving limited range of specific tasks;

3) the model represents real objects with a certain degree of accuracy (adequacy, isomorphic, identity) and it is possible that one and the same model could represent different objects, as well as one object could be represented by different models, depending on which features and with what degree of accuracy these features are to be represented.

The automated model in this article represents the flood events as real object with the purpose to determine the risk level within a certain degree of accuracy.

On the other hand, modeling refers to both development and interpretation of the models. The process of modeling in the framework of a research usually goes though the following stages:

- Identification of objects, phenomena and their features that are of an interest for the stated aim of the research; (e.g. identification of past or potential flood events)
- Analysis and identification of objects or phenomena as to determine their most important features (through generalization and abstraction); (e.g. risk criteria of flood events)
- Analysis and verification of the model; (e.g. application of the developed risk criteria).
- Interpretations of the results, achieved by the use of the model (Popov, 2012). (e.g. interpretation or presentation of results in the form of maps).

Spatial modeling does not differ much from the above presented modeling. The main difference is the fact that the term model could be related to any real object and the spatial modeling is referred to processes and phenomena that occur on the Earth's surface or near it. Regarding this, the data used for the development of spatial models should reflect the spatial variables of the objects and phenomena that are being modeled. (M. Goodchild, 2005).

Two types of spatial or geospatial models could be differentiated – analog and digital. Examples of analog spatial model are the well-known paper maps, texts and tables. The digital form of representation of geographical objects and phenomena from the real world has a major advantage over the traditional ways of analog representations (Popov, 2012). Such a statement could be supported by many facts, concerning the possibilities of storage, manipulating and analysis of the data and the results of its modeling in a computer environment. The possibility of interactive representation of real world is pointed out by the majority of scientists as the main advantage. In our case the automated model is digital model and the final output (a paper map) is analog information product.

Modeling spatial phenomena in a computer environment is the most distinctive feature of GIS. Object of the process of modeling is the geographic space. The spatial specificity and the opportunities for modeling differs modern GIS from any other types of information systems (Kotsev, 2008). This is the reason why GIS is especially good platform for modeling.

In the geoinformation and GIS related terminology, the terms "modeling" and "model" are used mainly in two different aspects – modeling of data and spatial (analytical) modeling.

The modeling of data is related to the development of representations of the real-world objects and phenomena into a geographical database. The data model is orientated towards the object. The model is developed on three different abstraction levels - conceptual, logical and physical (Popov, 2012)

The spatial (analytical) modeling is related to the use of specialized GIS programs or models of complete GIS software packages, designed for presentation and prognosis of statistical and/or dynamic characteristics of objects, phenomena and processes in the real world. Key role in spatial modeling plays the model of processes, that is orientated towards solving certain tasks by the use of GIS functionality and GIS spatial-analytical software.

For this study a digital analytical model for the interpretation of flood risk phenomena and its characteristics has been created. On several steps of the model development difficulties with the gathered source data were faced such as: accuracy and methodology of economic estimates, precision of reported location, date information, lack of data on some of the criteria. By evaluating the methods for data collection in similar environments we have identified the option of usage a collaborative GIS platforms. Although collaborative GIS functionality hasn't been used within this particular study we consider the importance and relevance of these technologies in the flood management process. The following description provides a brief overview on the subject.

3.3 Application of collaborative GIS for flood management

Public participation in the decision making process is one of the options to ensure more socially acceptable and sustainable solutions. The usage of collaborative GIS or public participation GIS is significantly growing in the recent years with proven record of many successful projects. Examples include open street map initiate, many governmental programs that have shifted data collection efforts towards the citizens, the emerging of commonly used terms like “citizen science” and “grass root” data gathering. In the field of environment and emergency management there are many implementations worldwide with key ideas behind to incorporate information from large amount of data providers/citizens (e.g. EyeOnEarth portal, created by the European Environmental Agency – for citizen reporting in key environmental themes), to provide fast data collection and dissemination (e.g. Ushahidi platform for map related data from different sources). For flood risk assessment and management we can take advantage of these trends and technologies based on several important principles:

- Taking into consideration the feedback of the public for the decision making process;
- Improving decision by incorporating local knowledge into existing knowledge base;
- Getting legitimacy for decisions – not to present or impose decisions;

The collaborative tools can be applied in every stage of the flood management process (or any other type of disaster management): with the help of GIS people can map and model potential disaster locations, visualize potential consequences to human life, economic activities, cultural sites, potential hazard locations and critical infrastructure. Collaborative GIS platforms can help the localization of past events (e.g. local knowledge for past floods), can identify critical infrastructure with up to date condition (e.g. damage dike facility, not operational bridge, closed road, etc.) or can map quickly the situation after an event (optimal route based on existing infrastructure, evacuation needed, safe locations, supply gathering points, etc.). The application of such approaches in form of structured methodology is yet to be explored and is a subject to further research with the constant change of technology.

4. Development of an automated model for flood risk classification

4.1. Study area

The East Aegean River Basin District (EARBD) with center Plovdiv is one of the four river basin districts within the territory of the Republic of Bulgaria. It is situated in the central part of the southern part of the country with area of 35 227 km2.

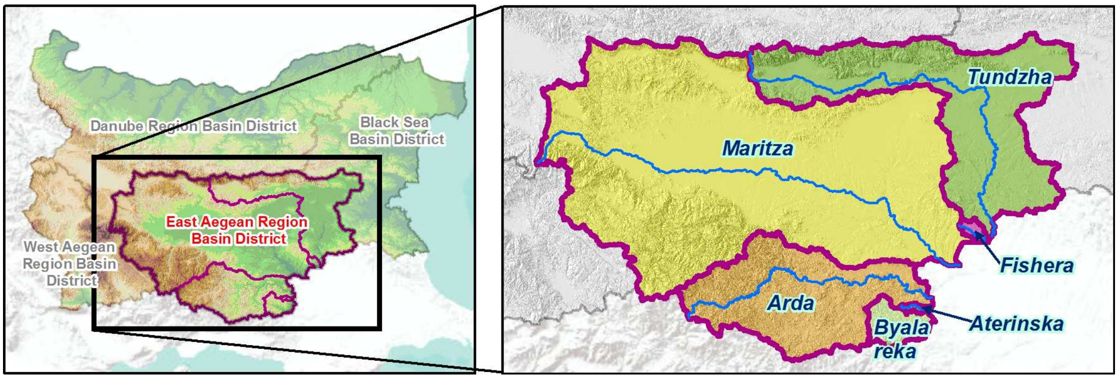

Fig.1. Study area – East Aegean River Basin District

The region includes the following river basins:

Table 1. Main river basins in the East Aegean river basin district

№	Basin	Area (km^2)
1	Maritza river basin	21292
2	Tundzha river basin	7901
3	Arda river basin	5213
4	Byala reka river basin	636
5	Aterinska river basin	59
6	Fishera river basin	126

(http://www.bd-ibr.org/ - East Aegean River Basin Directorate)

4.2. Place of the model in the process of APSFR determination

The realization of the project „Assisting River Basin Directorate with center Plovdiv Town in Defining Areas of Potential Significant Flood Risk (APSFR) in East Aegean Sea River Basin Directorate" has gone through the following stages:

- Analysis of the available data from EASRBD;
- Development of a geo-database with information for the significant past and potential future flood events;
- Determination of APSFRs;
    - Application of unified criteria for flood risk classification for determination of PAPSFRs (preliminary areas with potential significant flood risk);
    - Determination of the final APSFRs after detailing its borders;
- Development of a final geo-database for APSFR;
- Presentation of the final data in a table, necessary for the preparation of a report (according to the Directive);
- Preparation of maps of each APSFR;

The automated model presented in this paper is developed within the stage "Application of unified criteria for flood risk classification for determination of PAPSFRs" and plays a key role in the realization of the whole project. In case of any changes in the source data the model enables fast and easy application of the unified criteria to the new data. Furthermore, it reduces the possibilities of errors which may easily occur in the process of dealing with a large amount of tabular data and number of calculation procedures. Errors of this kind could lead to false results in the further stages of the project.

4.3. Source data for the model

EASRBD with center Plovdiv provided the data needed for enabling the process of determination of areas with significant potential flood risk within the framework of the project. Data for significant past and potential future flood events within the territory of EARBD was used for the development of the automated model. This data is a result of a preliminary flood risk assessment (PFRA), according to the Directive 2007/60/EC and the Water Act. It is organized into two tables – one for significant past and one for potential future flood events. Each event has its own unique code in the table as well as information about actual/potential damages. According to the methodology the unified criteria for classification of the risk for determination of APSFRs are divided in 4 categories:

- **Human health**
    - Affected inhabitants (victims);
    - Affected critical infrastructure elements or affected buildings of public significance (hospitals, schools, etc.);
    - Wells and pumping stations for public drinking water supply.
- **Economic activity**
    - Motorways, class I and II, railways, bridges, airports, transmission grids and other linear infrastructure;
    - Motorways, class I and II, railways, bridges, airports, transmission grids and other linear infrastructure;
    - Affected agricultural areas;
    - Summarized economic value of damages (for past floods);
- **Environment**
    - Sewage systems of settlements – discharge of municipal sewerage systems or urban waste water treatment plants;
    - Affected protected areas: drinking water, areas under the Protected Areas Act, Natura 2000;
    - Industrial Pollution Control (IPPC) and prevention of chemical accidents SEVESO (Council Directive 96/82/EC) enterprises, Pollutant release and

transfer registers (PRTR) of Environment Executive Agency, Ministry of Environment and Water;

- **Cultural heritage**
    - Cultural and historical monuments of UNESCO and such of national significance;

The unified criteria for flood risk classification in Bulgaria are the same for each river basin district and thus the automated model is applicable for each one of them.

4.4. Work procedures for the model development

The model is developed with a Model Builder application in ESRI ArcGIS 10. The tool enables the creation of automated workflows to increase your productivity by combining variable input data with applications / tools and output data.

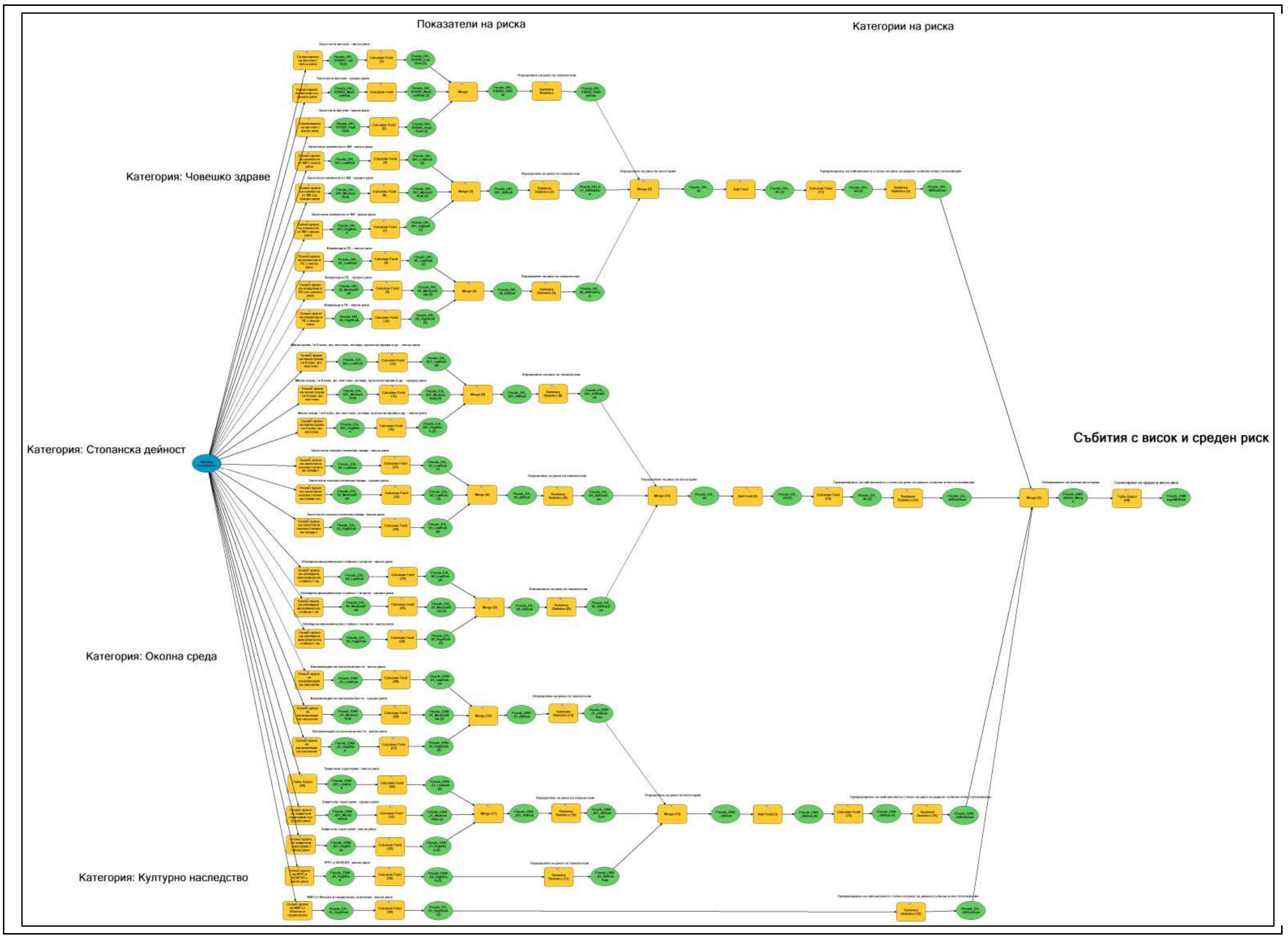

Fig.2. Automated model – detailed overview

The model includes the following key steps:

1) **Risk calculation for each criterion.**

This step includes attribute selection, based on the predefined values in the Methodology and the assignment of low, moderate or high risk for each criterion and each value range. For example for the category Human health, the affected inhabitants (victims) greater or equal to 300 and less than 1500 the risk is assigned to low, for greater or equal to 1500 and less than 3000 the risk is assigned to moderate, for more or equal to 3000 the risk is assigned to high. All the records are combined using “merge” function in order to create one common table for each criterion.

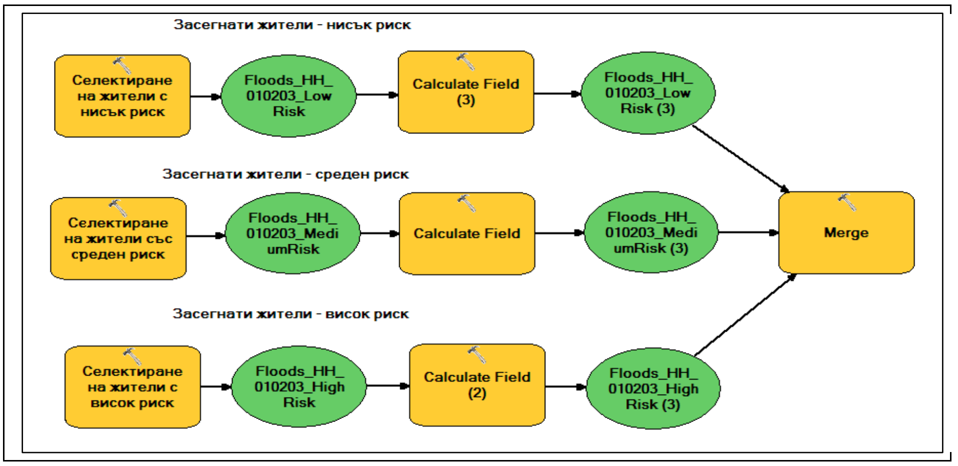

Fig. 3. Risk calculation for each criterion (e.g. category Human health, affected inhabitants).

Following this approach each criterion is calculated and the result is presented in 10 intermediate tables.

2) **Risk calculation for each category**

This step includes risk calculation for each category with highest risk for each individual criterion within the category. We have applied a statistical method for a summary statistics calculation using maximum value for each record. All records from each criterion with maximum value are combined on a category level, which results in 3 intermediate tables, for Human health, Economic Activity and Environment. The Cultural Heritage category is not included at this step, because there is no individual criterion within this category.

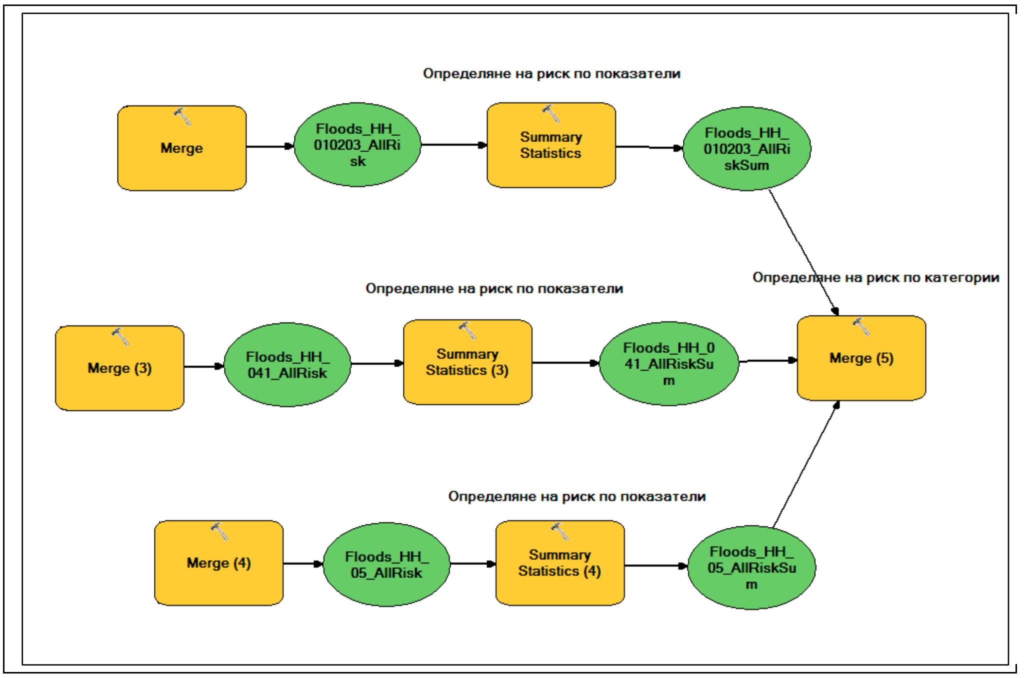

Fig. 3. Risk calculation for each category

Following this approach each category and the result is presented in 3 separated intermediate tables.

3) **Summarization of highest risk for each event in the category**

This step includes calculation of highest risk in a new field and assignment for the entire category.

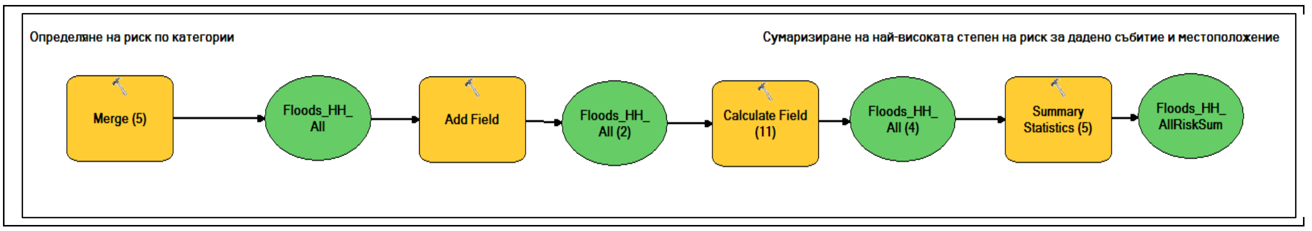

Fig. 5.Summarization of highest risk for each event in the category

4) **Merge of the risk factor for all categories.**

This step includes merging the highest risk of all categories into a separate intermediate table.

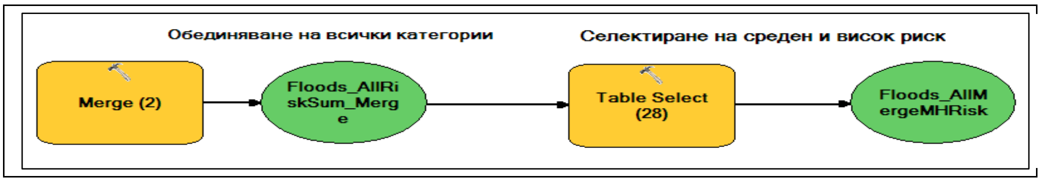

Fig. 6. Merge of the risk factor for all categories

The result is one final table with the highest risk for each category, which is the base for further estimation and spatial analysis.

5) **Estimation and risk calculation by location**

The location risk is determined as a combination of the risk determined per categories while observing the following principles:

- If a high risk is determined for each basin management region for any of the categories, the location remains in high risk;
- If the risk is medium in three of the categories, the location is in high risk;
- If the risk is medium in two of the categories, the location is in medium risk;
- If the risk is medium in two of the categories when these categories are human health and economic activity, the location is in high risk;
- If the risk is medium in one of the categories, and if the risk in the remaining categories is low, the location is in low risk, save in the cases where the determined medium risks as per the human health category.

This estimation is done manually, based on the model result. The final table is joined in GIS environment with point, line and polygon flood events, resulting in classified events with low, moderate and high risk.

Final result of the model and follow up post processing procedures is presented in the form of modified polygons, based on the catchments areas boundaries.

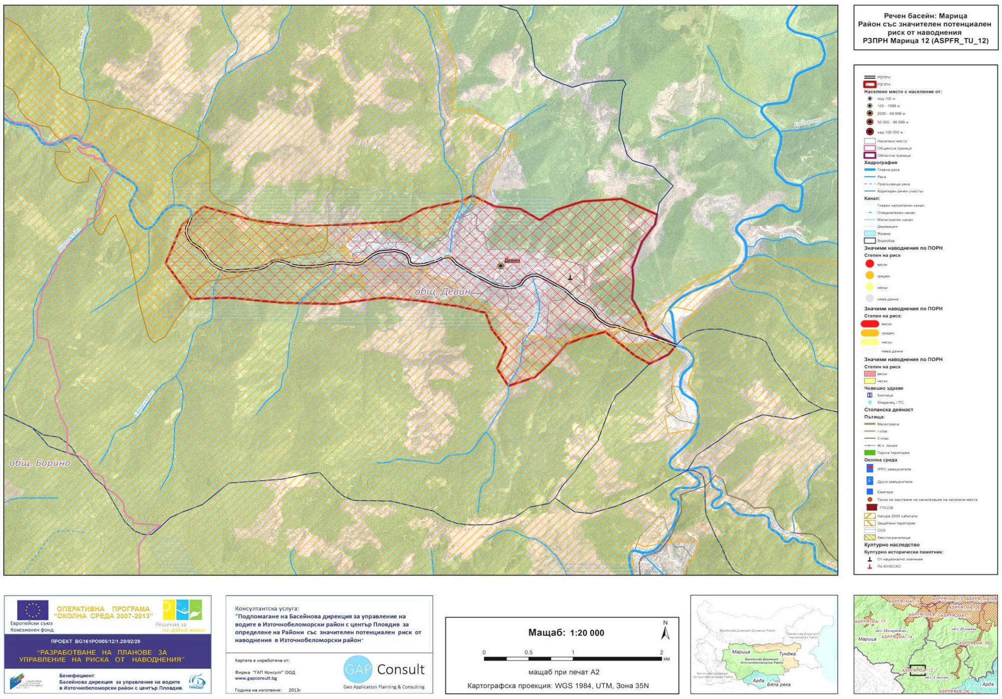

Fig.7. Final map of areas with significant potential of flood risk

5. Conclusions

The correct determination of APSFRs is of great significance since only the territory within their scope shall be subject to the second stage under the Directive, namely, preparation of flood hazard maps and detailed flood risk maps. In this paper we tried to illustrate the advantages of GIS for the automation of some steps in the methodology for determination of APSFRs. The automated model reduces the possibilities for errors and makes the process of determination of the flood risk areas faster and easier. The same model can be applied for any other territory in Bulgaria without geographic limitations, as long as it follows the officially accepted methodology of Ministry of Environment and Waters. GIS possibilities for manipulation, analysis, and the graphic presentation of the risk and hazard data are well known and explored, but we consider this model a good example and powerful tool for risk assessment.

Further research can be done in regards to the usage of collaborative GIS platforms (e.g. Ushahidi) for data collection, taking into consideration the local knowledge, possibilities for data sharing and dissemination to as wider audience as possible.

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