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Risk Flood Assessment for the Arachthos River using Analytic Hierarchy Process

Paraskevas Schismenos
Department of Informatics and Telecommunications
University of Ioannina
Arta, Greece
schismenos.p@kic.uoi.gr

Petros Karvelis
Department of Informatics and Telecommunications
University of Ioannina
Arta, Greece
pkarvelis@uoi.gr

Chrysostomos Stylios
Department of Informatics and Telecommunications
University of Ioannina
Arta, Greece
stylios@uoi.gr

***Abstract*— Floods are natural hazards with serious negative effects for the people, community, and economy. Advances in technology provide assessment and prediction of risk flooding, which is a complex problem dependent on many factors. Here, a risk flood assessment approach using the Analytic Hierarchy Process (AHP) for the Arachthos River, Greece is presented. It is based on real-time data deriving from various sources such as meteorological stations and water level sensors. The proposed risk flood assessment system is based on seven factors: the sum of one day and three-day rainfall, the elevation, the land use, the slope, the water level, and the differential river height. It considers the catchment area of the Arachthos River as a focus area and produces a hazard assessment map based on AHP method. The hazard maps are useful for civil protection and local authorities, they provide visualized warning on possible catastrophic events, identify areas with a high-risk flood likelihood and they include useful information and increase the knowledge of local authorities and relevant stakeholders.**

Keywords—Flood events, risk map, Analytic Hierarchy Process

I. Introduction

Risk analysis is the process of identifying and analyzing potential issues that could negatively impact key business initiatives. This process helps organizations to avoid or mitigate those risks [1]. After identifying and classifying the risks, usually one must proceed with their analysis to examine the potentiality and consequences of each risk factor and determine the corresponding risk level. The risk analysis determines the main risk factors that could potentially have the greatest impact and should, therefore, be carefully managed by the relevant stakeholders [2].

Floods affect more people worldwide than any other natural hazard [3]. Flood risk results from the interplay of several processes. Effective and efficient flood risk management requires understanding and quantifying the flood risk and its possible future occurrence [4]. One of the greatest challenges in flood risk analysis is the identification of the risk scenarios [5]. However, this is hard to estimate since the necessary volume and variety of data to validate the flood risk may not be available [6].

Estimating the probability of flood risk occurrence is based on all available evidence, using measurements and observations whenever possible, but also including theoretical knowledge, modelling, specific investigations, experience, or expert judgment. Thus, flood risk assessmentt are often associated with significant uncertainty [7].

Here, the area under study is the Arachthos River and the area around river [8]. It includes the section of the river downstream of the Pournari I Dam, about 11 km long. The Pournari I Dam, is operating since 1981 with the aim of producing hydroelectricity, flood protection, and irrigation [9] and the Pournari II Dam is operating since 1998. Arachthos river is the eighth largest river in Greece and flows from Pindos at an altitude of 1700 m [10].

The proposed methodology utilizes not only static data such as geographic data, but also dynamic (almost real-time) data such as the river level and the rainfall and other meteorological data. The usage of real-time meteorological data in combination with geospatial data make the proposed approach of Flood Risk Assessment innovative [11].

Section II presents the main environmental and climate conditions in the area of interest. Section III discusses the main methodologies that are used for Flood Risk Analysis. Section IV presents how AHP method is used and how the proposed methods combine the multidimensional and one-dimensional data in order to develop the risk map [12]. Section V presents the results of applying the proposed method and Section VI concludes the paper.

II. Climate Conditions

The climatic conditions at the area of interest are characterized as mild, Mediterranean type, consisting of dry and warm summers with humid and relatively not very cold winters. The mean temperature ranges from 16 °C to 18 °C. The wet masses that affect them, originate west of the Ionian Sea and land, east of Pindos. The altitude in the Arachthos basin ranges from 0 to 2,400 meters with an average altitude of 785 meters [13].

Fig. 1 displays a schematic representation of the flood events per each month, for the years 1981 to 2020 in combination with the average rainfall of each month for the respective years. It is easily observed that a significant number of folding events is occurred during the months e.g., January, February, March, October, November, and December. In particular, November and December have the highest frequency of floods events, with the month of December being the month with the highest occurrence of flooding events. On the other hand, for the same time period, the highest value for the average precipitation is reported during November.

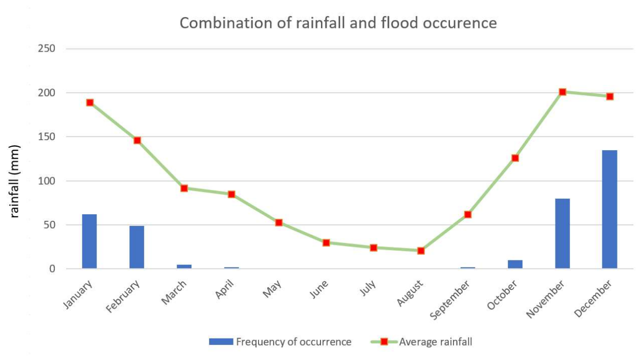

Fig. 1. Flood occurrence per month and average rainfall per month for the years 1981 to 2020

III. Risk Analysis Methodologies

Many studies have been reported in the literature for flood susceptibility mapping and flood analysis through Geographical Information Systems (GIS) [14]. Multi-criteria decision analysis (MCDA) has been recognized as an important method for analysing complex decision problems, which often involve incommensurable data or criteria [15]. MCDA methods are employed in order to integrate technical, environmental and socio-economic objectives to achieve an optimal decision [16]. The GIS-based decision support system for flood prevention in Quanzhou, China is based on real-time hydrological information systems, such as rain and flow control, flood management control, flood forecasting and simulation and flood propagation information [17].

Coupled MCDA-GIS approaches have been employed in spatial modelling and natural hazards analysis [18]. Different studies have demonstrated that these techniques can be used for generating hazard maps [19]. AHP method [20] is successfully applied in many fields, such as regional studies [21]. The efficiency of GIS and MCDA has been assessed by Fernandez and Lutz to map the flood-susceptible areas in Tucuman Province, Argentina, where they indicated that the Analytic Hierarchy Process (AHP) [22] using a GIS environment is a powerful method to generate flood hazard maps with a good degree of accuracy.

IV. Method

The Analytic Hierarchy Process (AHP) [24] has become widely accepted as a method [25] for supporting decisions considering conflicting goals and multiple criteria. The comparative advantage of the AHP method is the usage of hierarchical approach that are like the mental processes that a human follows when he makes decisions. AHP is able to manage quality and quantitative criteria [26] and it has been applied to many complex decision-making problems [27] and problems with uncertainty [28].

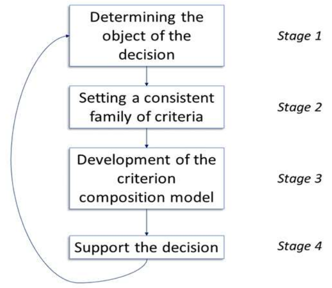

Fig. 2. Problem Solving and Decision-Making Process

The process of analysing the decision-making problem within the framework of the multi-criteria approach involves four stages as described in the Fig. 2.

- Stage 1: The person in charge of the decision-making process should constantly or regularly monitor the environment to identify problems. When a problem is identified, special care should be undertaken. For that purpose, the problem should be precisely defined to not include irrelevant aspects of it.
- Stage 2: Alternative action plans are created and analysed to solve the problem. The applied models are based on principals of mathematics. Data analysis methods and techniques are applied to investigate the effect and degree of influence of any possible factor on the problem.
- Stage 3: In this step, all the alternative solutions of the problem are examined and evaluated. The separation of Stage 2 and Stage 3 is often not so visible. This is because sometimes it is necessary to revise a model or decision criterion, which has been defined in Stage 2, while Stage 3 with the selection phase has already begun.
- Stage 4: The decision maker understands the results and the model composition of the criteria chosen in previous stage. Here, the role of the analyst is very crucial, he must identify and organize the elements of the answers to specific questions. Thus, the decision maker will be able to successfully implement the results of the analysis.

The AHP method requires the determination of an initial comparison for the different criteria. All these values are based on the user's judgment. Table 1 provides useful information to the user how to choose the right value for the importance of each criterion [24]. This approach is mathematically derived from Weber-Fechner's law [29].

TABLE I. The Scale of the Analytic Hierarchy

Importance	Reciprocal Scalar value	Definition
1	1	Equally important
2	1/2	Weakly or slightly important
3	1/3	Moderately more important
4	1/4	Moderately plus more important
5	1/5	Strongly more important
6	1/6	Strongly plus more important
7	1/7	Very strongly more important
8	1/8	Very, very strongly more important
9	1/9	Extremely more important

The flood risk assessment AHP method is based on seven criteria that are formulated in a hierarchical structure and are presented in Fig. 3.

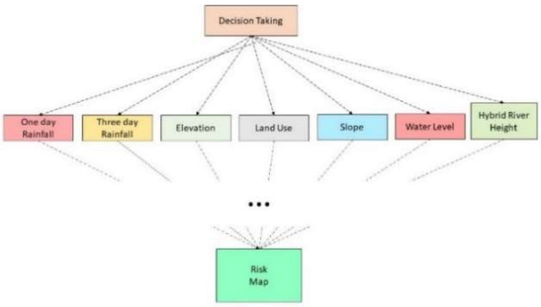

Fig. 3. The conceptual framework for flood risk assessment

The seven criteria are the following:

- C_1 : One day Rainfall, which is the accumulated rain for 24 hours.
- C_2 : Three Day Rainfall, which is the accumulated rain for 72 hours.
- C_3 : The Elevation which is the height above sea level on a digital elevation model.
- C_4 : Land Use, which is a set of regulations that guide how property is used and developed.
- C_5 : Slope, which is the Terrain Slope and is calculated on the direction of steepest descent or ascent at a specific point.
- C_6 : Water Level at the river.
- C_7 : Differential River Height, for the area of interest we calculate the difference in height from the closest river point.

The criteria utilize data, which are collected from the following sources:

- Five meteorological stations provide the one day and three-day rainfall [11].
- Data from terrestrial observation satellites is used to provide the elevation, the slope, the land use and the differential river height [23].
- Two Water Level sensors have been installed in two different locations and provide the water level [11].

The AHP method uses a fundamental scale of absolute numbers to calculate the individual preferences. Pairwise judgments are made [30] based on the best information available and the decision maker's knowledge and experience.

The AHP also provides mathematical measures to determine the inconsistency of judgments mathematically. Based on the properties of reciprocal matrices, the consistency ratio (CR) is calculated through Eq. 2. In a reciprocal matrix, the largest eigenvalue (λ_{max}) is always greater or equal to the number of rows or columns (n). When a pairwise comparison does not include any inconsistencies then $\lambda_{max}=n$. The more consistent the comparisons are, the closer the value of computed λ_{max} to n. A consistency index (CI) that measures the inconsistencies of pair-wise comparisons is calculated using Eq 1:

$$CI = \frac{\lambda_{max}-n}{n-1}, \quad (1)$$

After completing the computation of the consistency index CI, then the consistency ratio CR is computed. The CR is calculated using Eq. 2:

$$CR = \frac{CI}{RI}, \quad (2)$$

where, RI is the random index (Table II). Eventually, the calculated consistency ratio is 0.097 which is lower than the predefined threshold 0.1. Thus, the weight's consistency is affirmed.

TABLE II. RANDOM INDEX (RI)

n	1	2	3	4	5	6	7	8	9	10
Random index	0	0	0.55	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Using the digital terrain model, we are able to use the Hydrologic Engineering Centers River Analysis System (HEC RAS, [31]), which is a software program for simulating one-dimensional analysis of open pipelines and river systems. So, we calculate and simulate the river flood accordingly with its flow.

Using QGIS [32], which is a complete collection of software products for Geographic Information Systems, we process all geographic data and we create the visualization of the model [33].

TABLE III. PAIRWISE COMPARISON OF THE PARAMETERS USED:

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7
C_1	**1.00**	0.5	4.00	4.00	4.00	5.00	4.00
C_2	2.00	**1.00**	6.00	5.00	5.00	7.00	6.00
C_3	0.25	0.17	**1.00**	0.33	0.33	0.50	0.50
C_4	0.25	0.20	3.00	**1.00**	0.33	0.50	3.00
C_5	0.25	0.20	3.00	3.00	**1.00**	3.00	3.00
C_6	0.20	0.14	2.00	3.00	0.33	**1.00**	4.00
C_7	0.25	0.17	2.00	0.33	0.33	0.25	**1.00**

In order to apply AHP, it is necessary to study the relative importance of all factors so that to produce the pairwise comparison. Once all criteria are sorted in a hierarchical manner, a pairwise- comparison matrix for each criterion is created to enable a significance comparison. The relative importance score is set from 1 to 9, starting in an ascending order from the least important to much more important factors (Table I). The pairwise comparison table is presented in Table III, using a 7×7 matrix, where the diagonal elements are equal to 1.

The values of each row are compared with each column to determine the relative importance. For example, one-day rainfall is significantly more important than land use and therefore the value 6 has been assigned to one-day rainfall.

Row describes the importance of land use. Three days rainfall has been considered the most important parameter in the relevant study. The second most important parameter is the daily rainfall. Altitude and Land Use are the third most important with the altitude being slightly higher on the methodology scale, because the study area is a small basin, which is mainly an urban area [34].

TABLE IV. CLASSES OF THE PARAMETERS

Parameters	Class	Average rating (R)	Weight (W)	Effectiveness
1 day Rainfall	>100mm	90		21,6
	100mm – 110mm	80		19,2
	80mm – 100mm	70		16,8
	70mm – 80mm	60		14,4
	50mm – 70mm	50	24%	12
	30mm – 50mm	40		9,6
	20mm – 30mm	30		7,2
	5mm – 20mm	20		4,8
	<5mm	10		2,4
3 day Rainfall	>220mm	90		33,3
	175mm – 220mm	80		29,6
	150mm – 175mm	70		25,9
	125mm – 150mm	60		22,2
	75mm – 125mm	50		18,5
	50mm – 75mm	40	37%	14,8
	25mm – 50mm	30		11,1
	10mm – 25mm	20		7,4
	<10mm	10		3,7
Slope	<2	90		7,2
	2 -5	70		5,6
	5-15	50	8%	4
	15. – 35	30		2,4
	> 35	10		0,8
Land Use	Urban fabric	90		8,1
	Mineral extraction sites	70		6,3
	Irrigated land	50	9%	4,5
	Agriculture land	30		2,7
	Non-irrigated land	20		1,8
	Pastures, Beaches	10		0,9
Elevation	<6	90		10,8
	6m - 12m	80		9,6
	12m -18m	70		8,4
	18m - 24m	60		7,2
	24m - 28m	50	12%	6
	28m - 36m	40		4,8
	36m – 48m	30		3,6
	48m – 60m	20		2,4
Water Level	<4m	90	4%	3,6
	3m-4m	60		2,4
	2m-3m	40		1,6
	>2m	10		0,4
Differential River Height	< -10	90		4,5
	-10 to -5	70		3,5
	-5 to -3	60	5%	3
	-3 to 0	50		2,5
	0 to 2	30		1,5
	>2	10		0,5

The distance from the river is the next important element of our methodology followed by the level of water of the river. The slope of the ground is somehow considered in the elevation parameter, explaining its lesser importance.

Table IV presents the values of the seven criteria (One day Rainfall, Three Day Rainfall, The Elevation, Land Use, Slope, Water Level, Differential River Height). The values of each parameter are classified into five classes, based on the weighted spatial probability modelling with equal intervals.

Besides the fact that all maps use the same classification, they don't contribute to the same extent. The effectiveness (last column of Table IV) of each factor-parameter is calculated by multiplying its weight by the rate [35].

V. RESULTS

To investigate the effectiveness of the proposed method, three scenarios were created, that we run based on historical data. The dynamic data are: the One day Rainfall, Three Day Rainfall, and the Water Level of the river Arachthos. The static data are: the Elevation, the Land Use, the Slope, and the Differential River Height.

A. *Scenario 1*

Scenario 1 is based on data originating from the area under study that refer to the specific time-period of the catastrophic flood in 2015. We applied the proposed method for the specific data. The three-day rainfall values were very high between 120mm to 130mm, and the rainfall values of one day were very high between 70mm-90mm. The river water level was very high at 3.1 meters. After running the first scenario, we observe that the affected areas are mainly the settlements which are located in the southern part of the area of interest. As it can be seen in Fig. 4, the areas with a Risk Rating 5, are exactly the same areas that were most affected at the flood of 2015.

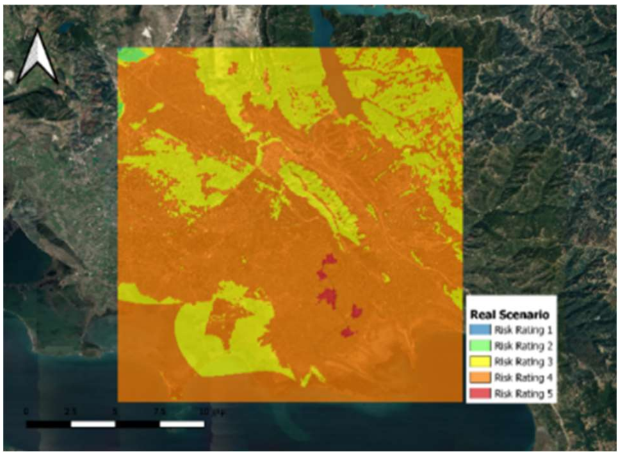

Fig. 4. Flood Risk Map for the first scenario (based on values of past flood).

B. *Scenario 2*

For the second scenario, we set high rainfall values for the last three days (between 80mm to 100mm), and the value of one day rainfall (between 30mm to 45mm); and we add a sudden rain in the southwest area. The water level at the river will not rise dramatically, it is just above normal levels, at about 1.7 meters. The sudden rain will mainly affect the southeast of the area. As it can be seen, in Fig. 55, most of the area has a Risk Rating 3 and it is observed that a few villages located in southeast area are at Risk Rating 4.

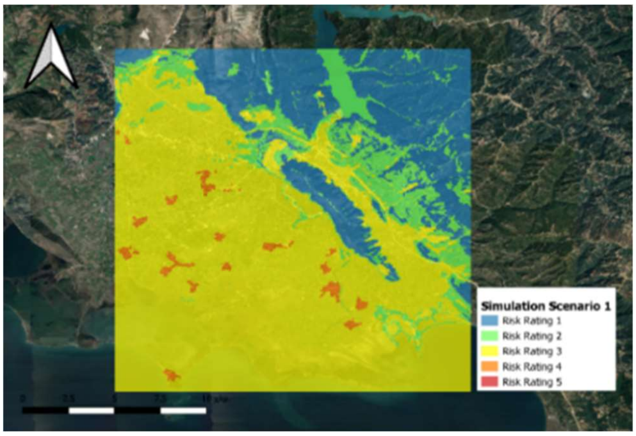

Fig. 5. Flood Risk Map for the second (simulation) scenario.

C. Scenario 3

In the third scenario, we set the three-day rainfall values very high, and the rainfall values of one day was selected to be relatively low between 40mm-70mm. We also set the river water level very high (3.1 meters). As it can be seen in Fig. 6 the whole area has a Risk Rating 3, and the riparian areas of the river Arachthos river, have a Risk Rating 4. It seems reasonable because at this point the river has a sharp change of the direction and the elevation in the riparian areas are very low.

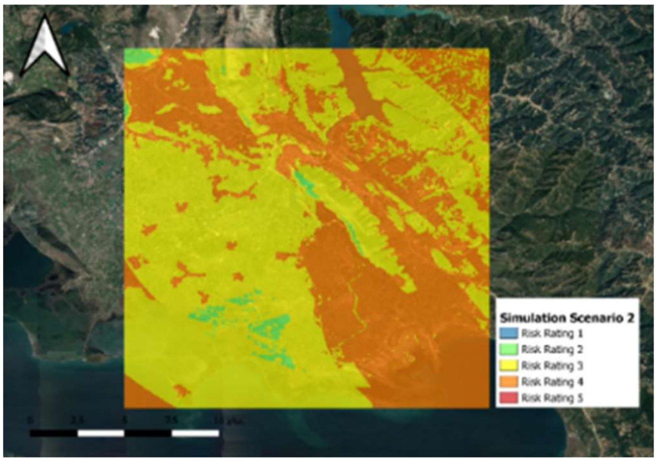

Fig. 6. Flood Risk Map for the third (simulation) scenario.

D. Scenario 4

In the fourth scenario, we set the one-day rainfall data high between 40mm and 60mm, but the rainfall data of the three day was relatively low between 30mm and 50mm. We also set the river water level very high (1.3 meters). As it can be seen in Fig. 7 most of the areas are in Risk Rating 1 and 2, with the exception of some village areas at the East side which has Risk Rating 3.

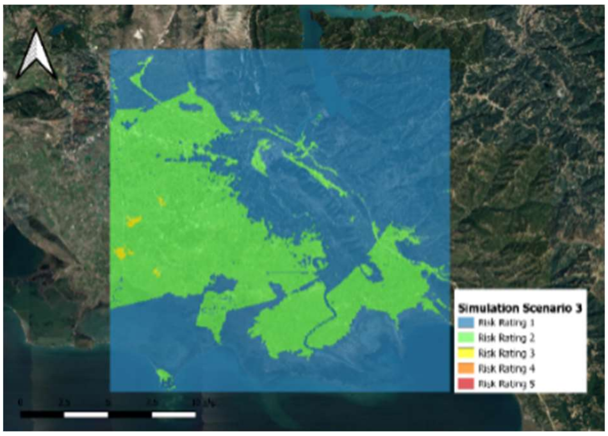

Fig. 7. Risk Map for the fourth (simulation) scenario.

VI. Conclusions

For the study area, it has been proven that the three most important factors for provoking floods in the specific area are the one- and three-day rainfall. In addition to this, a substantial percentage of the residential areas downstream of the city of Arta are in vulnerable zones, since most of the villages located in the area with very low altitude south of Arta.

The proposed and developed AHP model can successfully predict the occurrence of flood phenomena, as scenario 1 proved, which correspond to the case of the flood of 2015. Satellite and meteorological data are inputs to AHP model and are used to produce the Flood Risk Maps that are extremely useful to civil protection and other organisations. The proposed method for flood risk assessment was verified with the most recent significant flood events in the area of interest.

In future work, in the identified high-risk areas, we will add extra weather stations to have a more detailed mapping and to improve the AHP model; and we will instal flowmeter for estimating the volume of water transported per time unit. We are also planning to investigate and apply other state of the art modelling methodologies such as FuzzyAHP, TOPSIS, DEMATEL, and others. We are also planning to further examine the visual conception of the problem by applying 3D reconstruction in the area.

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