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APPLICATION OF HEC-RAS AND ArcGIS FOR FLOOD MAPPING SURFACES IN URBAN AREAS - CASE OF THE CITY OF GOSTIVAR

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ABSTRACT

Floods are natural disasters and often result in great material loss and even loss of human life. Their early prediction is necessary to provide protection from their harmful effects. In order to create accurate, realistic solutions, there is a need for concrete determination of the flood areas. In recent decades, various modern techniques have been used to map possible flood areas. One of them is the HEC-RAS software package.

The purpose of this paper is to map the flooded areas on part of the river Vardar in the city of Gostivar and to give the competent authorities a base for real solutions for flood protection in urban areas. Using the software package HEC-RAS in combination with ARC-GIS, a 1D model was made, which obtained the large waters, namely $Q_{20\%} = 22$ m^3/s, $Q_{10\%} = 39$ m^3/s, $Q_{4\%} = 68$ m^3/s, $Q_{2\%} = 95$ m^3/s and $Q_{1\%} = 124$ m^3/s.

The output data are displayed on the Orthophoto map. Then, using ArcGIS, the boundaries of the floodplains are displayed on Google Earth.

It was concluded that the HEC-RAS software package in combination with ARC-GIS is a useful tool, capable of mapping critical areas, which would serve as the basis on which various possible flood protection solutions can be provided in urban areas.

Keywords: HEC-RAS; Floods; Return Period; ARC-GIS; Urban Areas.

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1. INTRODUCTION

Urban floods usually occur during heavy rains and rainwater accumulates on the surface of urban areas. The reason for this accumulation is the poor drainage system, the failed infrastructure, the improper use of the land, the poor maintenance of the existing river regulations, etc. In case of heavy rains, the city is not ready to deal with the unexpected amount of water, due to rapid urbanization, the cities are already full of asphalt surfaces and buildings. As a result, rainwater cannot find a place to store it and this results in floods.

Urban flood control means efficient and fast transfer of water from urban areas. To that end, the first thing to do is to identify the urban areas most at risk of flooding. In practice, this is known as flood mapping. Flood mapping is the process of identifying these places on a map. Such places are called critical points. It provides a good basis for effective flood risk management and helps to set minimum flood standards by ensuring timely safety and resilience for flood protection.

The HEC-RAS Software (Hydrologic Engineering Center-River Analysis System) from the Center for Hydrological Engineering of the American Corps and MIKE11-DHI developed at the Danish Hydraulic Institute, Denmark (DHI), are widely used for dynamic simulation of 1D flowing in rivers [Ogras and Onen, 2020]. In addition, these programs are used to determine flood levels. In recent years, GIS (Geographic Information System) has become an essential tool for hydrological modeling primarily due to its ability to process large amounts of spatial data and attributes [Diedhiou et al., 2020]. The combination of the HEC-RAS model with the GIS environment make it possible to analyze and visualize the management of flooded areas [Sein and Myint, 2016]. This combination has great potential in simulating flood hazard maps.

The main goal of this study is to develop a fast and accurate method for analysis of floodplains in urban areas. For that purpose, first a hydrological study was performed in the catchment area of part of the river Vardar in the city of Gostivar, which obtained the relevant large waters, namely $Q_{20\%}$ = 22 m^3/s, $Q_{10\%}$= 39 m^3/s, $Q_{4\%}$ = 68 m^3/s, $Q_{2\%}$ = 95 m^3/s and $Q_{1\%}$ = 124 m^3/s. The hydraulic analysis was performed using the HEC-RAS and ARC-GIS software package. A 1D model of analysis of flood surfaces on the river Vardar in the area of the city of Gostivar has been developed and the output data are shown on the Orthofoto map. Then, using ARC-GIS, the boundaries of the floodplains are displayed on Google Earth. Based on the obtained results, concrete solutions are given for certain critical places for flood protection.

2. A REVIEW OF CURRENT STUDIES

2.1 HEC-RAC

There are several ways to map floods [Pasquier et al., 2018; Vojinovic and Tutulic, 2009; Mark et al., 2004; Liu, et al., 2014; Tuan et al., 2020; Ceribasi and Ceyhunlu, 2020], such is the application of HEC-RAS in flood analyses: By using HEC-RAS hydraulic analysis software Psomiadis et al., studied the dam breach, estimate the extent of floods and the flood wave propagation [Psomiadis et al., 2021], on a potentially affected area downstream of the existing Bramianos dam on southern Crete Island. The results show the seriousness of the dam break at Bramianos dam, so the authors emphasize that stricter measures should be taken for protection and resistance to the danger of natural disasters.

Diedhiou and others performed hydraulic modeling of the Senegal River Basin downstream of the Diamond Dam using HEC-RAS software. The results given by the HEC-RAS simulations are variations in water level, maximum flow velocities and flood propagation time. These results suggest the use of HEC-RAS as a decision-making tool in flood management during a crisis [Diedhiou et al., 2020].

Khalfallah and Saidi presented spatio-temporal mapping and flood forecasting using HEC-RAS-GIS in the Meyerda River, Tunisia [Ben Khalfallah and Saidi, 2018]. The authors consider that obtaining information on floods in data-poor regions is a difficult and uncertain task, but it is very valuable for flood risk management in order to protect human civilization and the environment.

The study of Ogras and Onen [Ogras and Onen, 2020] provides flood analysis and a flood risk map between the Diyarbakir-Silvan highway and the historic Ten-Eyed Bridge. For the study, 1/1000 scale maps have been digitized using the AutoCAD Civil 3D program and cross-sections have been made by obtaining digital models of the region. The obtained cross-sections are defined in the HEC-RAS software and the hydraulic characteristics of the flood bed and water surface profiles for the return period Q25, Q50, Q100 and Q500 and one-dimensional analysis of the flooded Tigris rivers are determined.

In the Grand River, near the city of Painesville, Ohio, which has encountered frequent flooding, HEC-RAS is used to perform the hydraulic analysis to produce the flood depths [Ghimire and Sharma, 2021]. From the 1D and 2D HEC-RAS models and the topographic data flood damage assessment has been obtained.

2.2 HES-RAS and ArcGIS

No less numerous are the studies in which flood analysis and modeling were performed using HES-RAS in combination with ArcGIS: In Tetuan's urban areas, flood mapping and critical area detection have been done using the Hec-GeoRas and Hec-Ras hydraulic modeling tools integrated into the Arcgis information system. The results indicate that the use of aerial photography provides a good knowledge of the morphology and physical characteristics of the river, which will help decision - makers prevent flooding in the urban area of Tetuan. The obtained results locate the flood zones, speeds and water heights. These results are reliable and are consistent with the morphology of the field [Azouagh, et al., 2018].

Another study identified the application of flood frequency analysis, integrated with GIS and HECRAS models, to prepare a flood risk map with a return period in the Lower Mekong River in Cambodia [Kim, et al., 2020]. It is concluded that in general, HEC-RAS can assess the level of flood depth and is useful in providing information on the depth and characteristics of floods for river surfaces.

GIS and HEC_RAS model and HEC_GEO_RASextension are used by Hejazi and Geshlag, to study the areas potential to the flood occurrence from Varkesh-Chai River and to prepare floodplain maps a district in Tabriz city, Azerbaijan, during the return periods of 25 and 50 years [Hejazi and Geshlag, 2019].

The HEC-RAS method, together with the HEC-GeoRAS extension, in ArcGIS have been used to analyze the methodology for mapping flood-prone areas in the middle and lower sector of the Pluton river, which is a tributary of the Ozana river. The obtained results correlate with the field situation in a very high proportion, about 99% [Marina, et.al, 2013]. So, it is concluded that this model can predict the water level and flood - affected areas, for extreme hydrological events, with a high degree of precision and it is a useful tool for management during extreme flooding events.

In Akarcay Bolvadin Subbasin, ArcGIS and HEC are used to constitute flood inundation maps. The results of the hydraulic modeling, show the values of flood depth and velocity, with the help of which, areas at risk of flooding are determined [İcaga, Tas and Kilit, 2016].

Another application of ArcGIS, HEC-RAS is represented in the research work of El-Naqa and Jaber, for 1-D flood modeling of Purna River, near Navsari district. The results obtained from the HEC-RAS model identify the cross sections of the river where the flooding phenomenon is most likely to be expressed [El-Naqa and Jaber, 2018].

3. MATERIALS AND METHODS

3.1 Case study

The city of Gostivar is one of the largest cities in the Polog region in the R. N. Macedonia, Fig.1. From the aspect of water, it is known as the city where the river Vardar, the largest river in the country, starts its journey. The river Vardar is the longest and most important river in the Republic of Northern Macedonia. The total length of the river Vardar is 338 km, of which through the Polog Region it flows with 63.5 km, and through the urban scope of the city of Gostivar, it flows with 3.28 km. The riverbed of the river Vardat in the urban area is in the form of a double trapezoid, Fig.2. The dimensions of the minor riverbed are 19-20 m. The major trough with dimensions of 35.5 m is also regulated [Elem, 2016].

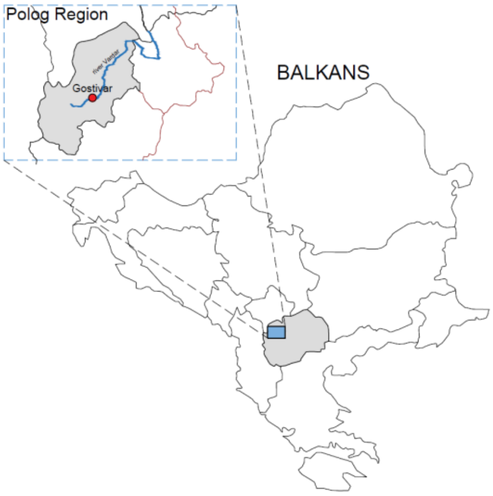

Fig.1. Location of the city of Gostivar

Fig. 2. The Vardar river in Gostivar

3.2 Methodology

The following substrates were used as input parameters in the formation of the model for detection of possible flood surfaces in the city of Gostivar: Topographic surfaces in digital form - with the help of the software package Arc MAP is generated Digital Terrain Model – DTM; - Hydrological analysis - in order to determine large waters with a different return period of repetition, as follows: Q5 year = 22 m3/s, Q10 year = 39 m3/s, Q25 year = 68 m3/s, Q50 year = 95 m3/s and Q100 year = 124 m3/ , data from the Elaborate were used to determine the boundaries of the regulated riverbed with a proposed coastal belt on part of the river Vardar [Elem, 2016]; Transverse profiles of the river Vardar obtained with a geodetic survey of the river - data from Elaborate were used to determine the capacity of the riverbed of the river Vardar on the stretch from HPP Raven to the Railway Bridge in Gostivar [Hidro-Consult DOOEL, 2019]; Longitudinal profile of the regulated riverbed, data from an excerpt from GUP, Gostivar, 2016 were used.

The procedure for obtaining maps for flooded areas consists of several steps which mainly consist of making DTM which obtains an area with isohypses which with the help of the software package CIVIL 3D is processed and the route of the river Vardar in the considered section and the transverse river profiles. They are needed to form the terrain model of the river, which simulates the flood wave. The HEC-RAS software package was used to form this model. For already defined reference waters and hydraulic analysis, the results are exported from HEC-RAS to CIVIL 3D and displayed on a high-quality topographic map (Orthophoto).

3.3 The HEC-RAS program

Its purpose is to make hydraulic modeling to simulate flow in streams, rivers, and canals [Diedhiou et al., 2020]. It is capable of modeling a number of hydraulic structures [Ogras and Onen, 2020] including determining the buoyancy of a part of a river. It is also used to visualize intersections and to determine the boundaries of floodplains which aims to describe the geometry of the terrain for sizing and determining protection [Diedhiou et al., 2020]. The input parameters of HEC-RAS models are river discharge, canal, flood geometry, and canal resistance [Sein and Myint, 2016].

The concept on which this software is based is one-dimensional, using the basic energy equation:

$$y_2 + z_2 + \frac{\alpha_2 V_2^2}{2g} = y_1 + z_1 + \frac{\alpha_1 V_1^2}{2g} + h_E$$

where:

y_1 and y_2 - water depths in two comparative sections,
z_1 and z_2 - height positions at the bottom in the same,
$\boldsymbol{\alpha_1}$ and $\boldsymbol{\alpha_2}$ - kinetic energy coefficients due to uneven gear schedule,
V_1 and V_2 - average velocities of the fluid in the respective cross sections,
g - acceleration by gravity and
he - energy loss

Energy loss is defined by dependence:

$$he = \overline{S_f}\,L + \mathbf{K}\left|\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right|$$

in which are:

$\overline{S_f}$ - average drop of the power line
L - distance between the comparative sections 1 - upstream and 2 -downstream,
K - coefficient of local losses.

For a known flow at Q = const., the calculations are performed in reverse, starting from section 1 in which all parameters are known (depth, speed, hydraulic gradient), and the parameters in section 2 are calculated [HEC-RAS, Use manual, 2016].

The software most often used in conjunction with HEC-RAS is ArcGIS. GIS works as an effective planning tool for transmitting results from HEC-RAS model data to flood management model, damage analysis, and flood warning systems [Sein and Myint, 2016].

For the analysis of the riverbed of the river Vardar in the city of Gostivar, a hydraulic model was made with the help of the software package HEC-RAS. The total length of the analyzed section is 4388 meters starting at the section of 500 meters downstream railway bridge along the river. Nineteen basic transverse profiles were analyzed and transverse profiles were interpolated every 20 meters along the entire section in order to obtain a better water line and better flood zones.

In addition to the information on the geometric characteristics of the riverbed, the initial boundary conditions of the downstream and downstream flow are defined, respectively. Thus, on the borders of the modeled section are given the slopes of the river bottom in the lowest profile S0 = 1.0% and in the most upward profile S0 = 2.0%. The basic assumption is that in these profiles, the flow can be treated as stationary. A situation with a representation of the cross - sections modeled in order to simulate the flow of water in the river Vardar is shown in Fig. 3.

Fig 3. Situation of modeled cross sections

The roughness coefficient of the modeled section is adopted based on the characteristics of the riverbed lining. For the entire section of the river Vardar through the city of Gostivar, the riverbed is regulated with a stone cladding in cement mortar in relatively good condition and a Manning coefficient of n = 0.028 has been adopted. The incubations are relatively clean, in some places overgrown with low vegetation, and therefore a ratio of incubation for incubations n = 0.040 was obtained.

4. RESULTS AND DISCUSSIONS

Using a hydraulic model formed in the HEC-RAS software package, version 5.0.7, a 1D model of floating surface analysis was developed for various relevant leaks, and the output data were displayed on a map. The simulation of the flood wave through the riverbed is for the river Vardar in the area of the city of Gostivar, in conditions of a stationary uneven flow. According to the analysis, the relevant large waters with a period of five and ten years return period, Q5year = 22 m3/s and Q10 year = 39 m3/s appear in the regular part of the riverbed, in the minor riverbed and no water outflow is registered, Fig. 4 and Fig.5.

The first outflows of water from the minor riverbed start with leaks greater than Q = 50 m3/s. In the urban area, the relevant leaks Q25year = 68 m3/s, Q50year = 95 m3/s and Q100year =124 m3/s overflow from the minor riverbed and flow through the major riverbed, but there is no danger of overflow from the major riverbed (Fig.6- 8).

During Q25year = 68 m3/s, Q50year = 95 m3/s and Q100year =124 m3/s leaks, there is an outflow from the minor riverbed and the appearance of the flood zones in the downstream profiles of the analyzed section, in a length of about 4.4 km. In this part, the riverbed has partial regulation of the minister riverbed, but due to the filling with sediment and waste of the riverbed, and overgrown vegetation, the water overflows.

It can be said that in general the river Vardar along its entire bed, in the urban area has received appropriate treatment.

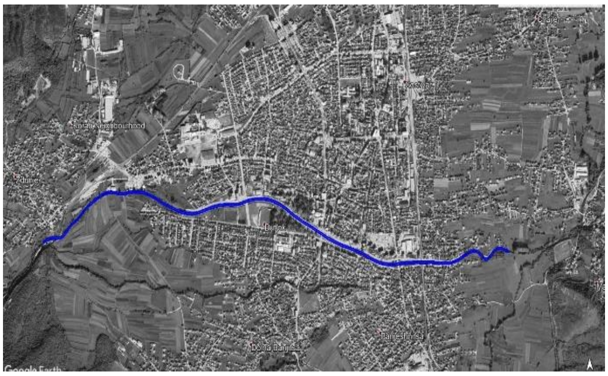

Fig. 4. Water level at $Q_{5\ year}$ = 22 m^3/s

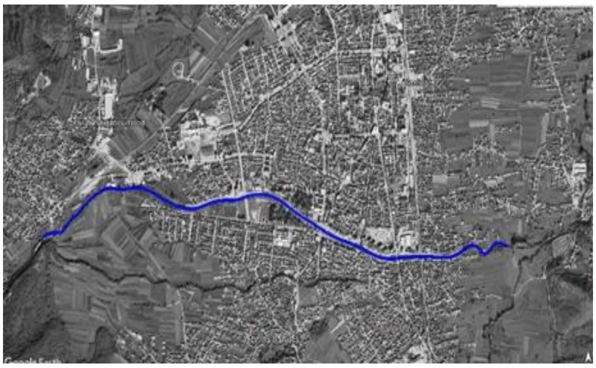

Fig. 5. Water level at Q_{10year} = 39 m^3/s

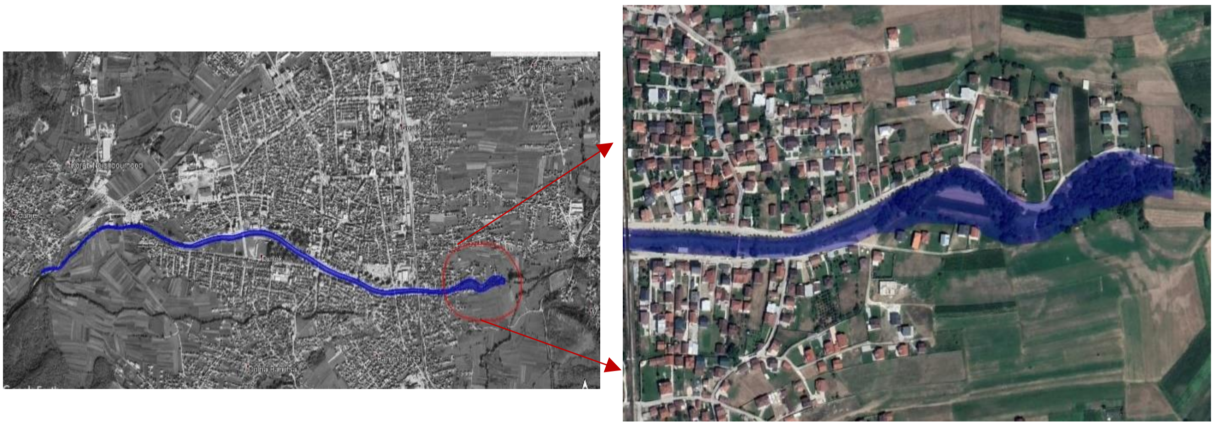

Fig. 6. Water level at Q_{25year} = 68 m^3/s

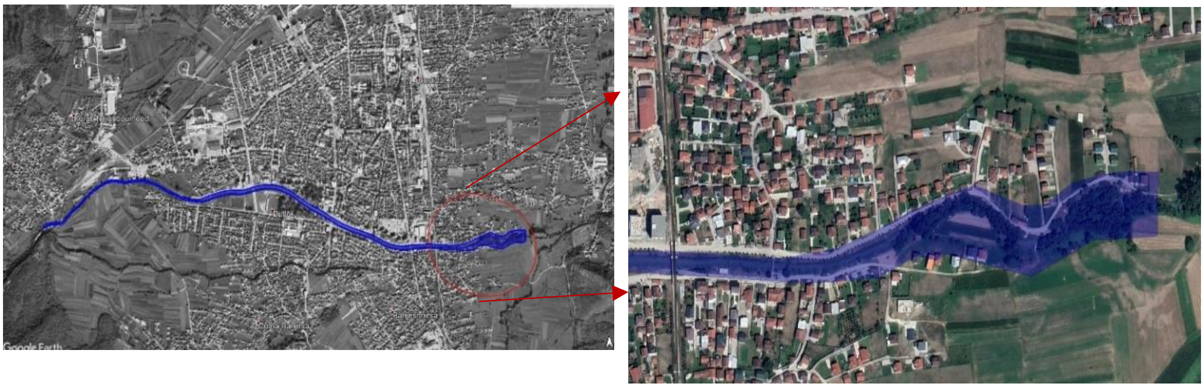

Fig. 7. Water level at $Q_{50\ year}$= 95 m^3/s

Fig. 8. Water level at $Q_{100year}$ = 124 m^3/s

5. CONCLUSION

Accurate flood prediction is almost impossible. However, the application of modern techniques and software, such as HEC-RAS, makes a great contribution in this direction. With its application, in this paper a 1D model for possible buoyant surfaces is obtained, for relevant large waters, namely Q_{5years} = 22 m 3/s, $Q_{10\ years}$ = 39 m 3/s, Q_{25year} = 68 m^3/s, Q_{50year} = 95 m^3/s and $Q_{100year}$ =124 m^3/s, for part of the river Vardar that passes through the city of Gostivar. The resulting data is transferred to ArcGIS, which prepares the orthophoto map, and then the results are displayed on Google Earth.

The results of the research presented in this paper can serve as a starting point for further studies on floods in the city of Gostivar and provide specific solutions for flood protection. And the results of the research in this paper indicate that the main problem is not the river Vardar, so the focus of future research should be emphasis on other possible sources of the problem.

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