Comparison Between Two GIS Flood Models of the Magra River

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Abstract
Floods are frequent and widespread phenomena with a devastating impact on the environment, infrastructures, buildings, croplands and, in the worst cases, involving animal and human lives. The paper focuses on this issue in a specific area in Italy: for this reason, at first it is illustrated a detailed analysis of the territory at the estuary of the Magra river, in the Liguria region, an area affected by this problem for a while. Then it is introduced a GIS river flood model developed with the software ArcGIS, with the support of a hydraulic model provided by the HEC-RAS software, which can be used in ArcGIS thanks to the HEC-GeoRAS component. This model is then compared to another one, provided by the University of Genova, and realized with the GRASS software, also with the support of a hydraulic model provided by the HEC-RAS package. The results show a good level of agreement.
A further validation is also carried out with a comparison to the official expected flooding map provided by the Basin Authority and it shows to be quite satisfactory.

Keywords - *Floods, Magra River estuary, ArcGIS and GRASS Flood Models, Comparison, Validation*

I.INTRODUCTION

Floods are some of the most peculiar characters of hydrological instability and they occur when the water of a river cannot be contained by its levees and so it runs off in the surrounding zones, causing damages to buildings, industrial settlements, transport routes and rural areas. In the worst cases also animal and human lives are involved.

In Italy, frequent floods take place in hydrographic catchments of little dimensions, because of abundant and localized rainfalls which are difficult to be predicted. These catchments are mostly located in Calabria and Liguria and they are characterized by very fast times to develop rapid floods (of some hours) which then are extremely dangerous, a certain cause of casualties, environmental damages and can seriously compromise the economic development of the interested areas.

Floods are natural phenomena, anyway the high anthropization and the land sealing contribute to boost their frequency.

It is possible to decrease the risky consequences of floods both with structural interventions (like embankments, floodways, etc.) and with not structural ones (like the ones related to the territory and emergencies management). Anyway, an effective alert system is strongly recommended, which is based on forecast models connected with a monitoring network.

This work is focused on the analysis of this problem in the area of the inter-regional basin of the Magra river, in the Liguria region, mainly in its terminal reach. It has been developed with the use of GIS technologies which are nowadays recommended in risk assessment analyses [1].

II. THE TERRITORIAL LAYOUT

The source of the Magra River [https://it.wikipedia.org/wiki/Magra] is in Tuscany at 1200 m over the sea level and, after arriving in Liguria, it flows into the Vara river and then in the sea of Liguria with a wide estuary placed between the villages of Bocca di Magra and Fiumaretta, in the common of Ameglia. The city of Ameglia, in the province of La Spezia of the Liguria region, is located on the right bank of the Magra river, while the hamlets of Fiumaretta and Bocca di Magra are placed in areas adjacent to the estuary of the Magra River (Bocca di Magra on the right bank and Fiumaretta on the left). The territorial layout is illustrated in Figure 1.

The Magra River flows for 54 km and the Vara River for 65 km, before reaching their intersection, while nearly 16 km is the measure from this point to the estuary.

The catchment [http://www.adbmagra.it/Pdf/PGRA_UoM_Magra_rev_20151210.pdf] is nearly 1700 km^2 wide, with 960 km^2 in Tuscany and 750 km^2 in Liguria; it is the widest in Liguria, it is under the jurisdiction of the Inter-Regional Basin Authority of the Magra River [http://www.adbmagra.it] and it belongs to the Hydrographic District of the Northern Apennine [http://www.appenninosettentrionale.it/itc/].

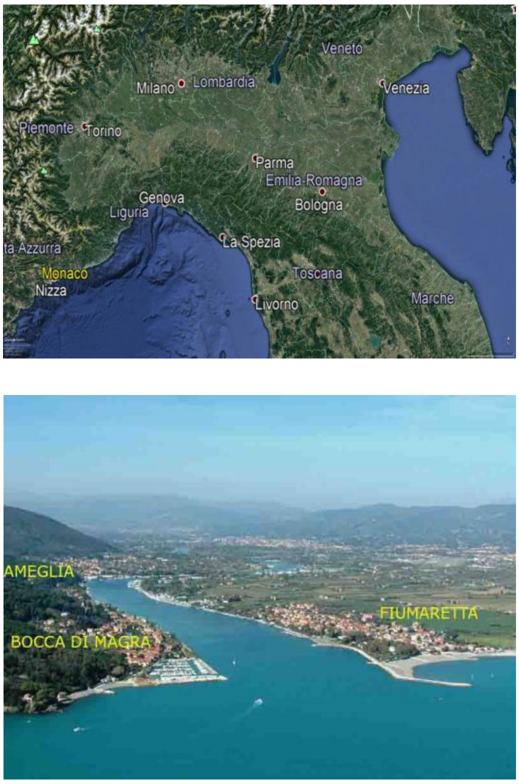

Figure 1: The territorial layout in Google Earth Pro [https://www.google.it/intl/it/earth/**] and an aerial image of the estuary of the Magra river [**http://www.risckit.eu/np4/45/**].**

A.The Magra terminal reach (the estuary): the problem

The terminal reach of the Magra River is placed in the common of Ameglia, mainly in its hamlets called Fiumaretta of Ameglia and Bocca di Magra. In time, this area has been characterized by many floods,

This has always been an area at risk and object of study [2]; besides, it has always been suggested to avoid constructions and perennial crops near the path of the river, so as to leave some areas free for the usual autumn floods.

In this paper, only the final 6 km of the river have been analysed since this is the most critical part, mainly due to dense population and extensive land use.

III. THE SOFTWARE PACKAGES EMPLOYED

In the work presented here, two different GIS software packages have been employed, so as to provide the two flood models which have been compared: ArcGIS, which is a commercial software package developed by Esri [http://www.esri.com], and GRASS (Geographic resource Analyst Support System), which is an open source free software [https://grass.osgeo.org/]. In this analysis, the ArcGIS Desktop release is 10.4, while the GRASS release is 6.x. It is also important to mention another software which has been employed as important support to the previous packages; HEC-RAS is a software developed by the USA engineering army corps at the Hydrologic Engineering Centre (HEC) [http://www.hec.usace.army.mil/software/HEC-RAS/]. HEC-RAS (River Analysis System) is now available in the 5.0.6 release and it is designed to perform one and two-dimensional hydraulic calculations for a full network of natural and constructed channels [3], [4]. Besides, it has been useful also HEC-GeoRAS which is a geographic river analysis system developed in ArcGIS Desktop and its extensions 3DAnalyst and Spatial Analyst [http://www.esri.com/library/fliers/pdfs/hec-georas-arcgis.pdf]. It is a GIS tool as support of HEC-RAS using ArcGIS, which means that it allows managing all the input and output transfers between ArcGIS and HEC-RAS.

IV. THE INPUT DATA FOR THE FLOOD MODEL DEVELOPMENT

In this work, a flood model has been developed in ArcGIS and HEC-RAS, with the aid of HEC-GeoRAS. This model has then been confronted with another one developed in GRASS and HEC-RAS and also validated with the official expected flooding maps, provided by the Basin Authority [http://www.adbmagra.it].

The data employed for the realization of this model are referred to the estuary area of the Magra River and they are listed hereafter; they have been provided by the Inter-Regional Basin Authority of the Magra River [http://www.adbmagra.it]:

- DSM with a 1x1 m resolution in the WGS84 reference system;
- 55 cross sections of the terminal reach of the Magra River in the WGS84/UTM Zone 32N reference system.

The 1x1 m resolution DSM is the product of an airborne LIDAR acquisition carried out for the Environmental Ministry.

V. THE ARCGIS AND HEC-RAS FLOOD MODEL

In this paragraph, it is presented a method for the creation of flood risk maps, based on the joint use of ArcGIS Desktop [http://www.esri.com], 10.4 release, a river modelling software HEC-RAS [http://www.hec.usace.army.mil/software/HEC-RAS/] and of its extension, for GIS environments (in this case for the ArcGIS software), named HEC-GeoRAS [http://www.esri.com/library/fliers/pdfs/hec-georas-arcgis.pdf], [http://www.hec.usace.army.mil/software/hec-georas/], [5].

This extension, as previously said, works as an interface between HEC-RAS and ArcGIS, allows extracting, from DTM/DSM models imported in ArcGIS, the planimetric and elevation information useful for the numeric modelling with HEC-RAS and also to import, in a second time form HEC-RAS to ArcGIS, the results of the simulations for the creation of flood maps and the definition of the areas at risk.

At first a thorough research has been conducted in literature with the aim to find other similar studies carried out with the software packages mentioned above.

Many applications have been found and taken into account [6] – [16].

To provide an ArcGIS model, describing the flood areas at the estuary of the Magra river, a DSM at 1 m resolution and 55 cross sections, provided by the Basin Authority [http://www.adbmagra.it], have been employed. The DSM choice has been made with the knowledge that the DSM would be richer in information than the DTM, since it describes the terrain with its natural and anthropic elements [https://3dmetrica.it/dtm-dsm-dem/]. This means that the buildings and other objects, which would interact with the flood event, should be considered important and for this reason accounted for, with the aim to provide a more realistic evaluation of the areas at risk.

For this analysis, 15 profiles have been derived, in HEC-RAS, starting from water discharges of 1000 m^3/s to 6400 m^3/s, with a step of 400 m^3/s.

The results, provided by ArcGIS with the aid of HEC-GeoRAS, in the WGS84/UTM Zone 32N reference system, are well illustrated in Figure 2, which shows the hydric level evolution for the established water discharges, and in Figure 3 illustrating the hydraulic hazard classes H2 and H3 which correspond, respectively, to the 200 and 30-year return periods flow rate (Q = 3600 m^3/s and Q = 6400 m^3/s).

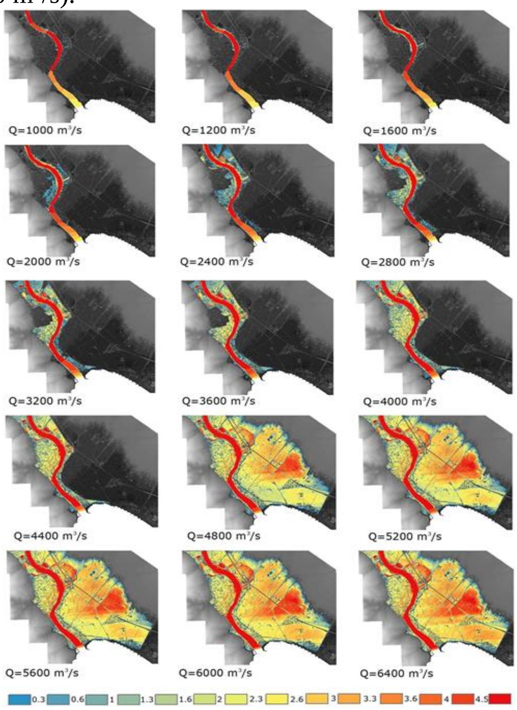

Figure 2: The hydric levels evolution in meters, from Q = 1000 m^3/s to Q = 6400 m3/s with a step of 400 m^3/s.

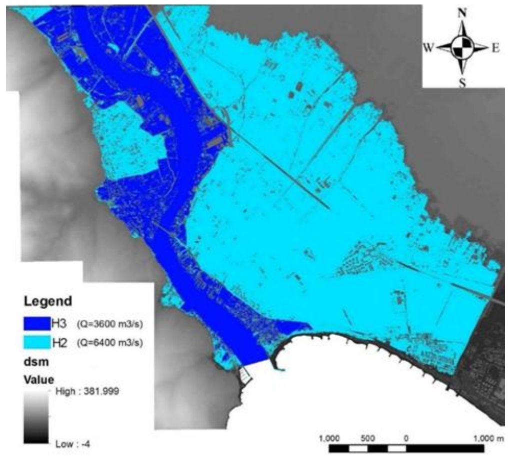

Figure 3: Maps for the Hydraulic Hazard H3 e H2, corresponding to the 30 and 200-year return periods, provided by the model developed in ArcGIS.

In this figure it is possible to see that, because of the use of the DSM, many objects on the ground (mostly buildings) could be identified and removed from the prone to flood areas.

VI. THE GRASS AND HEC-RAS FLOOD MODEL

At the University of Genova, Laboratory of Geomatics DICCA [http://www.dicca.unige.it/geomatica/ricerca/], it has been developed a model for the evaluation of flood-prone areas. It is based on the employment of a GRASS [https://grass.osgeo.org/] command, called "r.inund.fluv" [17], [18]. The hydraulic profiles have been computed in the HEC-RAS [http://www.hec.usace.army.mil/software/HEC-RAS/] software knowing the flow rate and the river cross sections, assuming the flow as one-dimensional and stationary.It requires a high-resolution Digital Terrain Model (DTM).

The procedure has been applied successfully in many cases [19] - [21] and also to the terminal reach of the Magra river.

In this case, the input data, provided by the Inter-Regional Basin Authority of the Magra River [http://www.adbmagra.it] were:

- DTM with a 1x1 m resolution in the WGS84 reference system;
- 55 cross sections of the terminal reach of the Magra River in the WGS84/UTM Zone 32N reference system.

The 1x1 m resolution DTM is the product of an airborne LIDAR acquisition carried out for the Environmental Ministry.

The model has been testedwith the official expected flooding maps, supplied by the Basin Authority of the Magra River [http://www.adbmagra.it], with respect to the 200-year return period flow rate; the results attested the good quality of the procedure, with a Performance Index value [22],[23] of 72% [21].

VII. COMPARISON BETWEEN THE ARCGIS AND GRASS MODELS

By qualitatively comparing the perimeters of the flood areas provided with the ArcGIS and GRASS models, it is possible to observe an excellent correspondence for nearly all the area taken into account, with the exception of some little areas for the 30-year flood comparison (Q = 3600 m^3/s), illustrated in Figure 4, and also for the 200-year comparison (Q = 6400 m^3/s), illustrated in Figure 5.

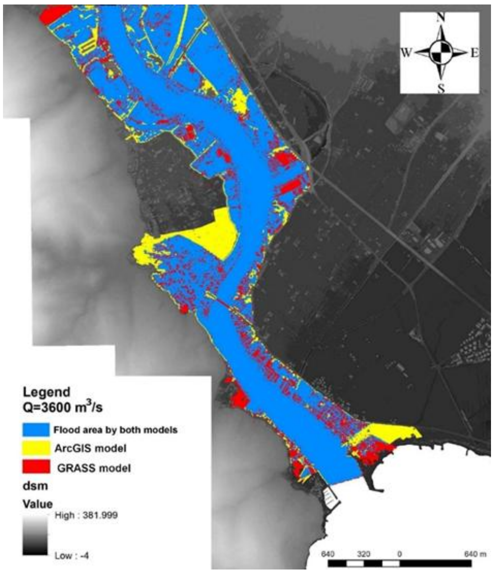

Figure 4: Comparison of the flood areas achieved in ArcGIS and GRASS, for a water discharge of Q = 3600 m^3/s, corresponding to the 30-year return period.

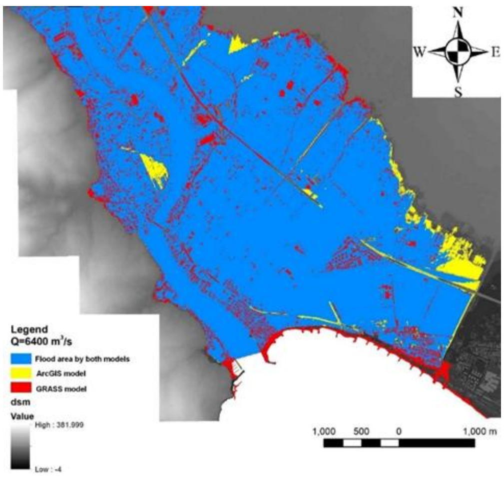

Figure 5: Comparison of the flood areas achieved in ArcGIS and GRASS, for a water discharge of Q = 6400 m^3/s, corresponding to the 200-year return period.

In these figures different colours have been chosen:

- blue for the flood area provided by both models;
- yellow for the flood area provided only by the ArcGIS model;
- red for the area provided only by the GRASS model.

It is possible to observe that the two models provide flood maps quite similar and, to quantify the correspondence between the two flood areas provided, it has been set a Performance Index [22], [23]:

$$PI = \frac{A_{GRASS} \;\; \text{AND} \;\; A_{ArcGIS}}{A_{GRASS} \;\; \text{OR} \;\; A_{ArcGIS}}$$

where:

A_{GRASS} is the flood area with the GRASS model;
A_{ArcGIS} is the flood area with the ArcGIS model.

The two areas have been generated with the AND and OR logic operators, to provide the ratio between the flood area accounted by both models and the total flood area.

The results provided for the comparison are:

PI30 = 77% for the 30-year water flow;
PI200 = 87% for the two 200-year water flow.

These values seem to provide worse results than the ones expected, but this can be easily explained. In fact, in ArcGIS, the model has been developed starting from a DSM model; on the other side, the GRASS model has employed a DTM which provides the terrain height without taking into account all the objects on it.

For this reason, to provide a best fitting evaluation of the performance index, it is important that the gaps, occupied by the buildings and objects taken into account in the ArcGIS model, should be deleted with the aid of a topology rule (must not have gaps) and then added to the other ones, so as to allow a more significant comparison. The final results, after this correction, are:

PI30 = 85% for the 30-year water flow;
PI200 = 92% for the 200-year water flow.

These results definitely confirm the good quality and the satisfying results achieved in this comparison analysis between the flood models created in GRASS and ArcGIS.

VIII. VALIDATION OF THE MODEL DEVELOPED IN ARCGIS WITH THE OFFICIAL EXPECTED FLOODING MAP

A validation of the achieved results, provided by the ArcGIS model, has been performed by taking into account the official expected flooding map, supplied by the Basin Authority [http://www.adbmagra.it], adopted by PAI (Hydro Geologic Safety Plan) [24]; this map, illustrated in Figure 6, defines the Magra River areas of fluvial pertinence [25] for the 30 and 200-year flood return periods, mapping the Hydraulic Hazard levels H3 e H2, corresponding to the just mentioned return periods. This study of the river behaviour [http://www.adbmagra.it/Pdf/Relazione_generale_variante_20160629.pdf], for different flood conditions, has been accomplished with a two-dimensional numeric model, in unsteady flow, developed with MIKE 21 from DHI (Danish Hydraulic Institute) [https://www.mikepoweredbydhi.com/products/mike-21].

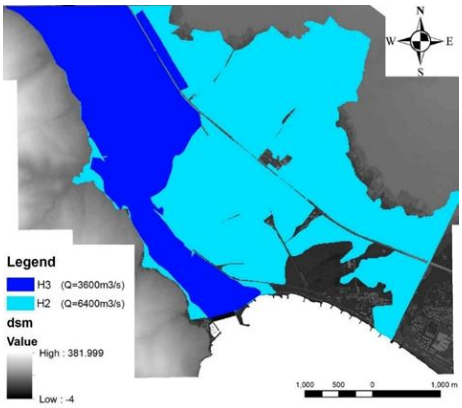

Figure 6: The official river area of fluvial pertinence, for the 30 and 200-year return periods (Hydraulic Hazard levels H3 an H2), provided by the Basin Authority [http://www.adbmagra.it].

Making a comparison between the perimeters of the flood areas provided by the ArcGIS model and the official expected flooding map [http://www.adbmagra.it], it is possible to see a good agreement, with the exception of some little areas both for the 30-year flood comparison (Q = 3600 m^3/s), illustrated in Figure 7, and for the 200-year flood comparison (Q= 6400 m^3/s), illustrated in Figure 8.

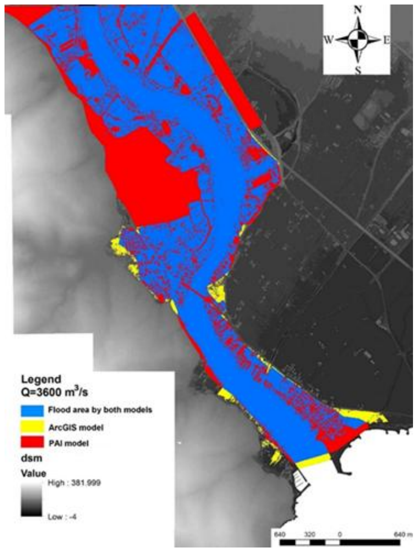

Figure 7: Comparison between the perimeters of the flood areas achieved in ArcGIS and the official expected flooding map [http://www.adbmagra.it], for a water discharge Q = 3600 m^3/s, corresponding to 30-year return period.

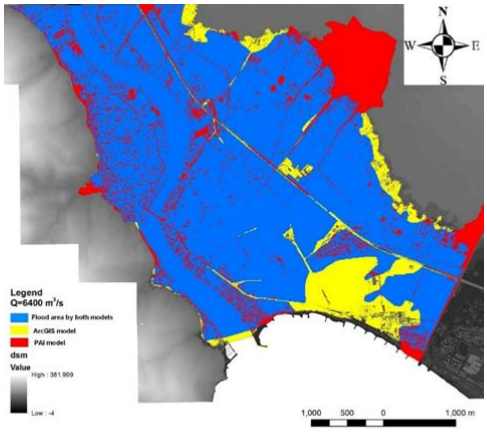

Figure 8: Comparison between the perimeters of the flood areas achieved in ArcGIS and the official expected flooding map [http://www.adbmagra.it], for a water discharge of Q = 6400 m^3/s, corresponding to the 200-year return period.

In these figures the blue area is the flood area taken into account by both models, in yellow only the area for the ArcGIS model and in red the flood area provided by the Basin Authority [http://www.adbmagra.it].

For this reason, to quantify the correspondence of the flood areas illustrated above, it has been adopted the Performance Index [22], [23]:

$$PI = \frac{A_{PAI} \text{ AND } A_{ArcGIS}}{A_{PAI} \text{ OR } A_{ArcGIS}}$$

where:

A_{PAI} is the flood area for the PAI area of fluvial pertinence;
A_{ArcGIS} is the flood area with the ArcGIS model.

For the 30-year water flow the result is PI30 = 65%, while for the 200-yaer water flow it is PI200 = 75%.

The PI values are worse than the ones expected by simply looking at the two maps. This is due to the fact that for the ArcGIS model it has been employed a DSM, while the PAI model has been derived form a DTM model. With the same procedure adopted to make the comparison between the ArcGIS and GRASS models, it has been decided to delete the gaps in the polygon shapefile describing the flood area in ArcGIS.

The new recalculated PI values are:
PI30 = 74%, and PI200 = 80%.

These values testify the effectiveness and validity of the ArcGIS model.

IX. CONCLUSIONS

The subject of the project, illustrated in this paper, has been the analysis and study of possible floods at the estuary of the Magra river. For this purpose, a flood model has been developed with ArcGIS [http://www.esri.com] and then compared with another one, developed with GRASS [https://grass.osgeo.org/], provided by the University of Genova [http://www.dicca.unige.it/geomatica/ricerca/], and both supported by HEC-RAS [http://www.hec.usace.army.mil/software/HEC-RAS/]. The results showed a high similarity and correspondence between the two models, reaching high values for a defined Performance Index [22], [23], which means 85% for the 30-year return period and 92% for the 200-year one. A final evaluation and validation of the model developed in ArcGIS has been carried out with the official expected flooding map, provided by the Basin Authority [http://www.adbmagra.it], with values of the performance index of 74% and 80% for the 30 and the 200-year return periods. This way, according to the achieved results, it is possible to say that the model developed in ArcGIS is quite effective and satisfactory. It is also important to explain that the DSM choice, would provide results useful to detect all the objects which could be hit by a possible flood and make structural evaluations.

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