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EXPOUSURE DEGREE AND VULNERABILITY TO FLOODS IN GALAȚI CITY

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Abstract. In the last few decades the rivers have drawn the attention more often trought negative events, these evnts are corellated more often to the climate changes. The urban areas are ones of the most exposed to natural risks, betwen theese risks urban flooding is considered to be among the most severe ones, since it acts on highly populated areas, with high density of socio-economic objectives. After presenting the general context of urban flooding and the specific meaning of exposure/vulnerability, the first part of this paper contextualizes the case study area: Galați city, the most important Romanian river port. The authors created a geographical information system for multilayer analysis based on simulations of potential flooding at different characteristic levels: defense, attention, flooding and danger. On this base, the main elements at risk were inventoried and interpreted according to their significance and in relation with the consequences of a real historical flooding (occurred in 2010).

Keywords: Danube, Galați city, flooding, exposure, vulnerability, GIS.

Introduction

Floods are one of the natural hazards which are affecting large and hightly populated areas of the Earth, causing significant damages, especially in low income contries and important economical losses in developed countries. The majority of global statistics have shown that floods are on the top of the natural hazards that happend during the last half century (number of events). Also this phenomenon has affected more than three billion people and caused economical losses of about 683 billion dollars. The consequences of urban floods can not be quantified exclusively statistic, theese refflecting on distructon of ecosystems, earnings decrease of some economical activities, damages on homes, schools, hospitals etc. Even though these hazards are caused by natural phenomena, they also represent some effects of the interactions between natural and anthropogenic factors (social, economical, political). More than this, the frequency and the severity of floods episodes in urban areas is in an uptrend and we have to notice that many times they are influenced by some factors such as: spatial distribution of rainfall variability, human pressure that reaches critical thresholds by

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overpopulation and discharge of sewage systems that lead to an intensification of the phenomenon. (Parker, 2000; Konrad, 2003; Moramarco et al.,2005; Hilden, 2005).

The floodplains are part of wetlands and they are defined as surfaces with low altitude which are flooded with water that flows from the rivers and lakes nearby (Junk and Wellcome, 1990). The Commission for Environmental Cooperation in 2006 defined floods such as coverage with water of a territory which usually works as a sub-aerian territory.

The European continent has not been spared from such hazards, important parts of the continent have been affected by major floods in the last decades especially on the Danube, one of the most important rivers, both the surface and the economic importance. On the base of global changes, in Romania and not only in Romania, occurred unusual weather phenomena with great intensity which generated calamities throughout the entire Danube river basin. These events were amplified by other factors such as: deforestation, poor management of water resources and not least the irresponsibility of human factor regarding the location of the buildings in insecure areas. Because of the huge impact of the floods on the affected areas, the scientists have always been interested to develop some tools to facilitate the quantitative evaluation of the phenomenon.

Defining risks requires understanding how a hazardous process or phenomenon could affect different exposed elements that are characterized by their specific vulnerability, usually adjustable through proactive and reactive measures. In terms of flood risk, this implies various combinations between the extreme hydrological events, characterized by inherent uncertainties related to frequency and intensity, the exposure of elements at risk, with a precisely defined spatial dimension, and the vulnerability of these elements, in terms of their capacity to anticipate, to prevent, to cope with and to recover from the impact of floods (cf. Wisner et al., 2004). The general context of climate changes explains somehow the increasing frequency and intensity of floods, but their impact must be contextualized from low-income countries to high-income countries, from highlands to coastal regions, from rural areas or small cities to great towns and megacities etc. (Mitchell, 2003).

Urban flooding is among the most devastating ones, since it acts on areas with high density of people, buildings and infrastructure with very high added value. In the last decades, this risk of urban flooding rapidly increased, but its profile varies greatly depending on the specific context: coastal flooding, river flooding or flash flooding. Regardless this context, the significant losses explain the general interest for urban floods and, consequently, the extensive researches, whether they focus on the impact of climate changes (Roger, 2003) or on the role of urbanization (Lambert and Catchen, 2013). Although there is an increasing number of papers that analyze the flooding events and their impact at catchment level, studies regarding the urban flooding in Romania are rather scarce, even they are diversified in terms of town size and drainage system features: Arghiuş (2007); Zaharia et al. (2008); Zaharia et al. (2011), Minea et al. (2011) Moroşanu (2012).

Overall, discussing about cities and river flood hazard (not risk!), there are two distinct situations: the city as acting factor (I) and the city as prevalently passive factor (II). In the first case (usually applied for flash floods), removing vegetation, covering soils and modifying the infiltrations rate, constructing drainage networks etc. increase the peak discharge, in terms of volume and frequency, both for heavy rains and snowmelt. In the second case, usually placed in very large hydrological system, the town cannot control the general features of flood hazard, but only its impact at local level through structural, technical and social adjustment. Thus, exposure and vulnerability become the most important elements of the risk equation (Stângă, 2006):

$$R = f(\alpha H, \beta E, \gamma V), \text{ where:}$$

H is the hazard; *E* is the exposure; *V* is the vulnerability of exposed elements; *α, β*, and *γ* are weighting coefficients, normally to be defined on a logarithmic scale (because of the cumulative effect of the acting factors).

On this background, the current approach provides a spatial perspective on vulnerability to floods in Galaţi, relating it to the physical exposure. This refers to the presence of the elements at risk in an area susceptible to be flooded at different levels of water, no matter the cause or the probability of water rise.

Case study area

Galaţi is one of the major towns of Romania (about 231,000 inhabitants in 2011) and the most important river port of the Romanian Danube, which influenced its development since the ancient times. The town site is related to the fluvial topography created between the confluences of the great river with Siret and Prut, its last two major tributaries. Three river terraces formed through accumulative and erosive processes: 5-7 meters; 20-30 meters; 35-55 meters relative altitude. The city is located mostly on these terraces that are protected from flooding due to their relative altitude. However, a considerable area of the eastern part developed on the alluvial plain and on a river levee along the Danube. This is the “Lower Town” with absolute altitudes that range from five to seven meters. On the river levee, there are located the harbor facilities and some industrial plants. Between this levee and Brateş Lake, the alluvial plain, with the Bădălan and Valea Orașului neighborhoods, was completely flooded under natural conditions. These areas and other lowlands of the city are still characterized by soil moisture excess and they are often flooded through infiltration, although defensive dams were built.

Climatically, Galaţi is characterized by annual mean temperatures of 10.6°C and mean rainfall of about 490 mm yearly. These data are however less important than the town position on the great river at about 135 km before it flows into the Black Sea (fig. 1).

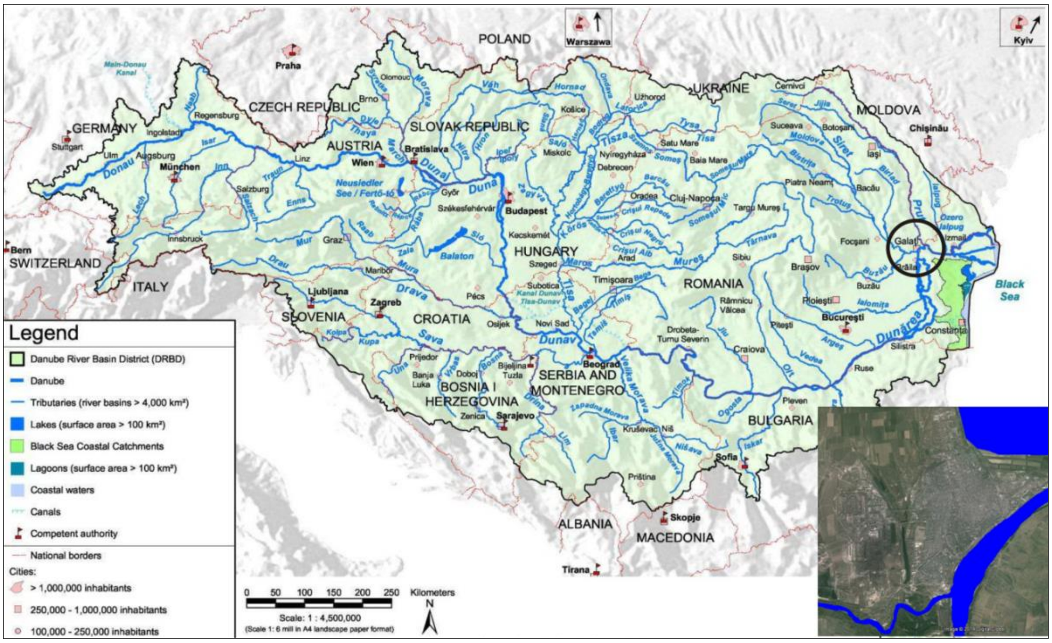

Fig. 1 The Danube River Basin and the location of the case study area
(Source: ICPDR, 2009, http://www.icpdr.org/)

In other words, the hydrological regime of Danube at Galaţi is influenced by the natural and human made conditions from almost the entire basin of 801,460 km^2. Thus, floods in Galaţi depend on discharge formation not only within the lower basin, but also within the upper and the middle basin, at least in some degree. Nevertheless, land use changes, successive damming, the Iron Gates accumulation and the alluvial plain features play an important role in flood propagation, emphasizing or mitigating the flood peak, accelerating or slowing the flood wave speed etc. Supplementary information regarding the Danube system and flood wave propagation along the river can be found in Gâştescu and Ţuchiu (2012), Mikhailova et al. (2012) etc.

Materials and Methods

The general systems theory, in the second half of the XX century, has lead to a fundamental change of analyzing natural phenomenon, in this moment it has moved from observation and description to measuring and quantifying (Rădoane el al., 2003).

There are many methods for assessing vulnerability to floods, especially based on the Geographic Information System and remote sensing techniques (Knebl et al., 2005; Büchele et al., 2006; Fedeski and Gwilliam, 2007; Fernandez and Lutz, 2010; Furdu et al., 2013). These provide a methodological framework suitable to obtain a very accurate precision in terms of spatial extent of elements at risk. By adding an adequate database including socio-economic indicators, the spatial statistics and the thematic mapping allow creating a more realistic pattern of vulnerability to floods, providing useful tools for risk management and mitigation. Analyzing urban flooding through a case study for a single town requires detailed data at street and building level in terms of physical data (technical details about buildings and other exposed objectives), social information (people in the exposed area, age structure etc.), economic indicators (both describing the people income/expenditure and the economic activity), technical urban facilities etc. Unfortunately, most often, in Romania, such data are difficult or even impossible to obtain and this affect the accuracy of results, especially in terms of real flooding costs.

In this study, a GIS has been created using input data from different sources, but mainly based on topographical plans (1:5000) and orthorectified aerial images (edition 2005, pixel size: 0.5 x 0.5 meters). Some information has been updated on the basis of the General Urban Plan (2012), as it appears on the local administration website. The digital elevation model has been created at a spatial resolution of 2.5 x 2.5 meters and all data have been made compatible for the stereographic projection (Stereo 70, Dealul Piscului). From the hydrological point of view, the maximum peak discharge (1897-2012) and the daily discharge (2000-2012) have been used in relation to the characteristic levels (attention, alarm, inundation and danger) to validate the suitability of flood simulations.

Table 1: Database and sources

Database	Sources
Topographical Plans 1:5000	Cadastre and Land Registration Agency Galaţi
Daily discharge of Danube (1955-2013)	River Administration of Lower Danube
General Urban Plan of Galati - 2012	www.primaria.galaţi.ro

According to the emergency system, the four reference levels at Galaţi are:

- 460 cm: *defense level*, which is, in fact, the dam height;
- 560 cm: *attention level*, which indicates that flooding could appear after a relatively short period of time;

- 600 cm: *flooding level*, which means that water begins flooding the first elements at risk;
- 700 cm: *danger level*, which requires special measures for emergency management: people and assets evacuation, restrictions on the use of bridges and roads etc.

Using the TNTmips 7.3 software facilities, successive simulations have been realized for the above-mentioned levels in order to count the flooded areas, buildings and roads. The flood return period as an element of hazard was not considered since the main question is not if these levels could be recorded, but what could happen if they really are. The elements at risk have been identified, extracted and very accurately updated using multiple sources (the orthorectified aerial images – 2009; the general urban plan – 2012; Google Earth satellite images – 2013). Additionally, the historical floods of 2010 provided the possibility to verify the validity of these simulations and for the calculation of statistical probabilities.

Results and discussion

Usually, the annual maximum discharge is lower than the flooding level, but what means usually? The pure statistics indicates a probability of about 1%, but only in the last ten years, the maximum discharge was higher twice:

- on April 26th, 2006, when the Danube reached 14,240 m^3/s (662 cm);
- on July 5th, 2010, when the Danube reached 16,300 m^3/s (680 cm).

Exceptional flow rates have been recorded in the past, but it is difficult to obtain precise data. Thus, while Antipa (1910) mentioned the level of 805 cm for Galaţi (1897), data concerning the maximum peak discharge vary from a source to another and do not refer explicitly to our area (more often they refer to Brăila and Ceatal Chilia). Any extrapolation or comparation between 1897 and 2010 should be done cautiously, especially because the relation between water level and liquid discharge was modified through damming works both along the entire floodplain and near Galaţi, through dredging actions (e.g. in the sandy banch naturally formed next to the Ţiglina neighborhood) etc.

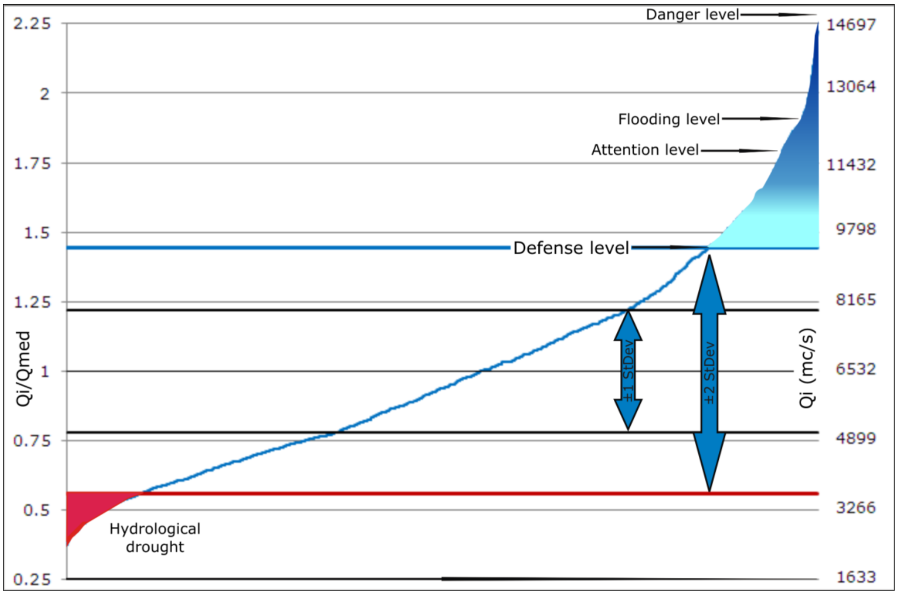

Fig. 2 Danube at Galaţi from drought to flood (daily data from 2000 to 2012)

Analyzing daily data between 1955 and 2013, we can easily notice the high variability of Danube discharge and the fact that the hydrological extremes are quite common. About 15% of time the water level is placed beyond the statistical threshold marked by the double of the standard deviation, whether it is negative deviation (hydrological drought risk) or positive deviation (flooding risk) (fig. 2).

The river maintained above the defense level more than 680 days (14.47% of days during twenty hydrological events), above the attention level more than 200 days (4.57% of days during seven hydrological events) and above the flooding level 89 days (1.87% of time during only one major event).

High river level is not only flooding, but also lateral seepage in dams, water table raising, sewage system repression, increasing of soil moisture and wetlands etc. All these may get worse during the rainy periods at Galaţi, because of the high infiltration rate within the loess of the upper terraces and the blockage of drainage to the lowlands near Danube and Prut.

Statistical processing of time series data allows however calculating long-term probabilities for maximum peak discharge and the hydrologic and hidraulic modelling allows predicting the short-term flood propagation along the river. From the perspective of flood risk management, the probabilistic studies substantiate structural measures and long-term planning, while the short-term modelling helps adopting emergency functional measures (see Draghia et al., 2012). All these measures are intended to protect the exposed elements, which are increasingly numerous and occupy more and more space, not always protected from floods.

The increasing vulnerability to flood is related to the demographic and spatial development of the town that caused normally a higher degree of exposure. At the beginning of the 19th century Galaţi had only a few thousand people (8600 inhabitants in 1831), but the population grew rapidly and surpassed the threshold of 100,000 people in 1930 and that of 200,000 people in the 70s of the past century (fig. 3).

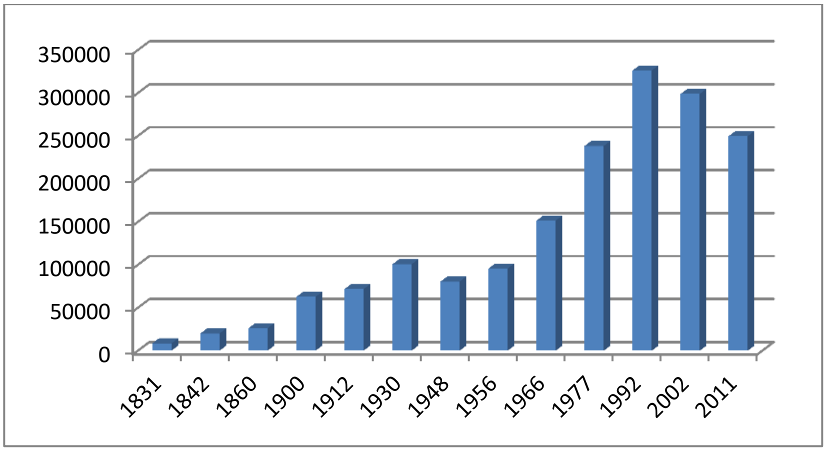

Fig. 3 Dynamics of Galaţi population in the last two centuries

This upward evolution of the population is closely related to the economic development of the town in the last two centuries and it was accompanied by an inherent territorial development, especially after 1837 when Galaţi is declared a free port by the prince Mihail Sturza. Initially placed on the first fluvial terrace, the town evolved until the mid-nineteenth century mainly northward, on the second fluvial terrace, and to a lesser extent along the Danube (Munteanu-Bârlad, 1927). Extended into the riverbed since the second part of the 18th century, the town slowly began developing along the river during 19th century, together with improving port facilities, port organizing and the damming actions (Fig. 4). Also, the port moved progressively towards the east, with the digging of the docks basin between 1885 and 1890 (Ungureanu, 1980).

Overall, it is suggestive to mention that the town area had only 180 hectares in 1829 and more than 1,400 hectares in 1914 (Paltanea, 1995). Nowadays, according to the General Urban Plan, the urban territory occupies 5,856 hectares, but the total administrative area has about 24,150 hectares, completely covering the left bank of Danube between Siret and Brateş Lake, including areas at flooding risk (Bădălan, Valea Oraşului, Port Zone).

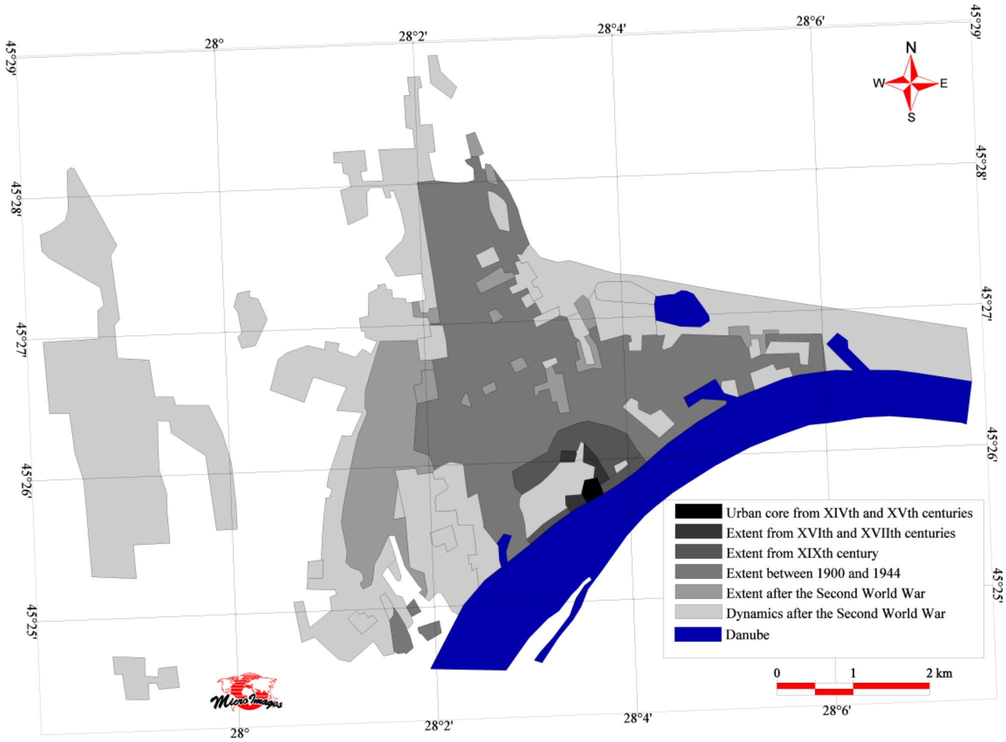

Fig. 4 Spatial evolution of Galaţi City (cf. Ungureanu, 1980)

Using the GIS software facilities for data processing and analysis, the flooded areas were clearly delineated as well as the roads and the buildings. Comparing to the average level of about three meters (300 cm), more than 400 hectares would be covered by water at the flooding and danger levels (fig. 6).

At the flooding level (600 cm), the exposed area covers a narrow band of a few tens of meters along the river cliff and greatly extends to east, starting on the Port Street, near SC ICEPRONAV. Further, it is conventionally “bounded” by Dogăriei Street until the Galaţi Railway Station and Galaţi-Brateș. Thus, Valea Orașului neighborhood, with more than 15,000 inhabitants, is highly exposed to river flood, but it is also frequently affected by flash flooding caused by heavy rains. Comparing to the entire town, Valea Orașului is characterized by the most deficient technical urban facilities (including sewerage network) and concentrates the population with the lowest income. Although it is unitary, there are still secondary roads without appropriate sewerage and sectors where the sewerage network was not modernized for more than 50 years. There important is the fact that the collectors from the low lands of this neighborhood are placed bellow the Danube level, causing big problems during floods.

Table 2 synthesizes statistically the areas, the roads and the buildings that would be flooded at different water levels. Obviously, the most extended area covers the Port area, with the River Station and the port facilities. The highest losses in this case are related to the stopping or limiting the activity of different transporters or industrial operators.

Table 2 Flooded areas at the reference levels of Danube at Galaţi

Water level (cm)	**Flooded area (hectares)**				**Roads (km)**	**Buildings**	
	Along the river cliff	**Residential area**	**Port area**	**Total**		**Number**	**Hectares**
460	12.57	20.76	412.51	445.84	35.73	595	55.5140
560	18.25	50.62	453.95	522.82	42.31	1041	67.6110
600	29.92	53.09	471.11	554.12	44.20	1092	70.5913
700	46.7	56.25	492.77	595.72	46.69	1199	77.3739

The flooded roads trigger various failures in the urban traffic (private or utility transport, public transport), with distinct impact depending on the road rank, from main roads (e.g. Portului, Ana Ipătescu, Griviței, Dogăriei streets) to secondary roads (e.g. those of access to the individual houses from Valea Orașului neighborhood).

Complementary and supplementary, the population flood vulnerability, and as well as the social economical objectives to floods implies a economical quantification of the losses generated at different flow rates of the Danube. But, such quantification is almost impossible because of the lack of data about population density in exposed areas and their value. For this reason we choose to calculate a probabilistic density of the buildings in the exposed area, density weighted with the surface of the buildings. On this purpose, the buildings in the exposed areas were drawn as polygons and then converted to points. To the points have been attached an attribute table which contains the real surface of the buildings. On this base the Kernel Density have been generated with the help of the open source soft SAGA GIS (fig. 5).

The most heterogeneous situation appears when discussing about flooded buildings, due to their high typology, features and functionality: individual single-level houses, apartment blocks, hospitals, educational and administrative institutions, economic units etc.

There is a great difference between the residential buildings. On the one hand, the single-level houses have a lower unitary value in terms of money, they have fewer people in the exposed area, but they are usually strongly affected because of their construction details (foundation walls, structural frame). On the other hand, the apartment blocks concentrate a higher number of people in the exposed area, but the buildings themselves have better foundation and structural frame; equally, not all people within such buildings are equally affected (depending on the floor).

Among the potentially flooded non-residential constructions, there are some that belong to the local heritage, being ranked as “B” monuments: The Palace of Navigation (built in 1912), the State Fisheries and the Grain Elevator (projected by Anghel Saligny at the end of 19^{th} century). Besides, there are other buildings with various destinations: the Clinical Hospital CFR, the County School Inspectorate the Trade Register building etc.

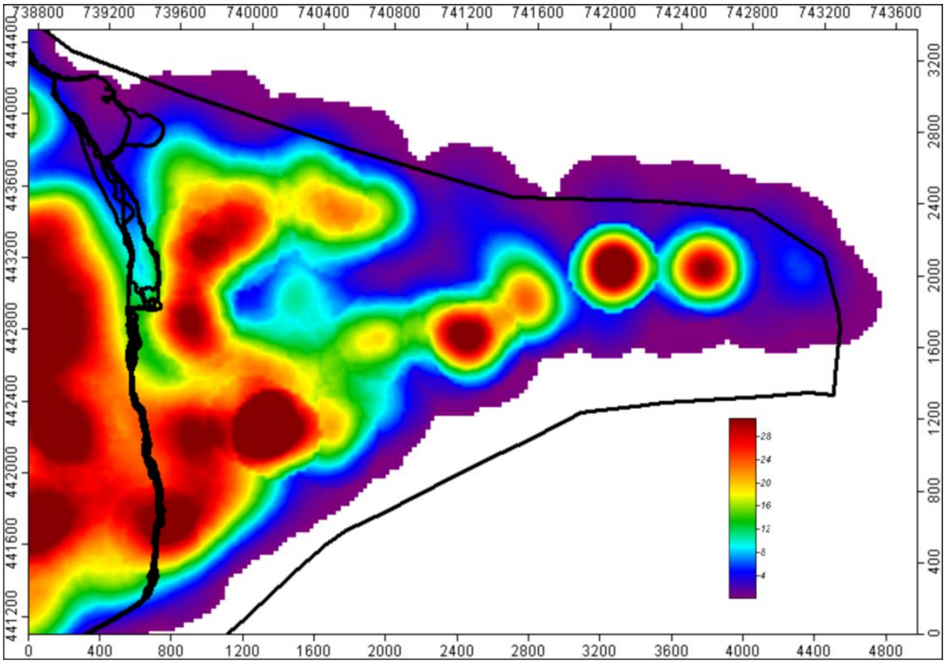

Fig. 5 Kernel Density in the exposed areas
(Valea Orașului, Bădălan and Port neiborghoods)

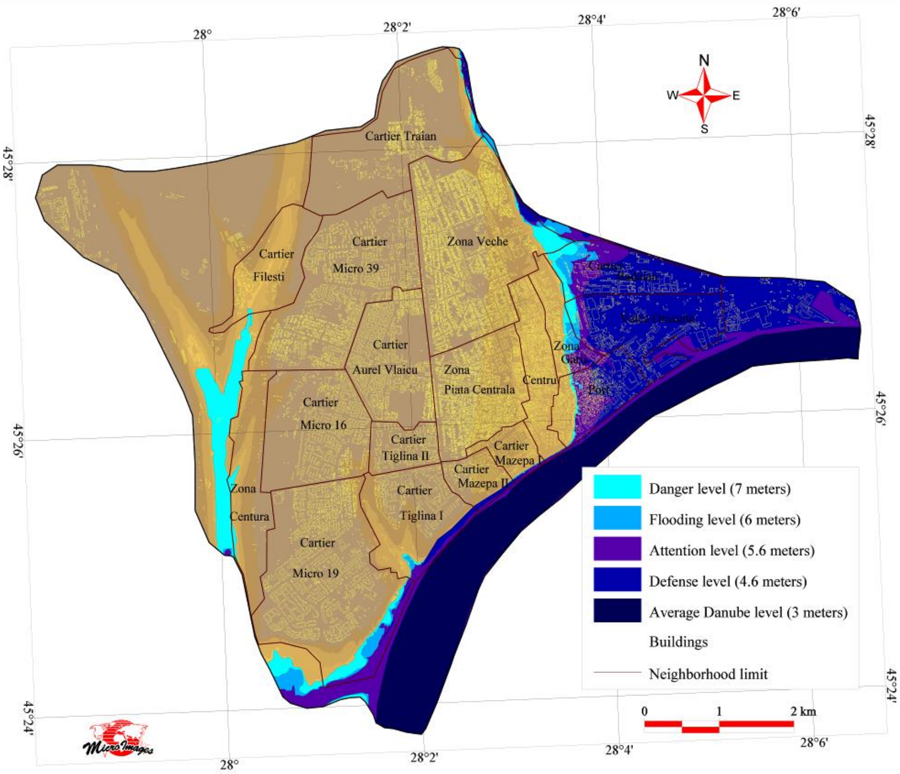

Fig. 6 Flooded areas at different characteristic levels

Fig. 7 Valea Orasului and the port area within the flooding level (Google Earth extract)

The highest frequency and the biggest probability to be exceeded corresponds to defense level of 460 cm (Table 3), this reference level is reached most often when the Danube flow increases. The attention level and the flooding level have lowest frequencies, but highlight very well the periods when the Danube had a very high discharge and jeopardized many socio-economical objectives of the city.

Table 3 : *The frequency and probability of reference levels to be exceeded*

Reference levels (cm)		**Discharge (m^3/s)**	**Exceeded frequency (%)**	**Calculated probability (%)**
Reference	Level(cm)			
Defese Level	460	9722	10,94	11,94
Attention level	560	11602	1,89	4,5
Flooding level	600	12536	0,39	0,26
Danger level	700	15024	0	0

During the historical floods from 2005, 2006 and 2010 the attention and flooding levels were often exceeded. In 2006 and 2010 the discharges recorded at Galați were very colse to the historical ones, which have a probability to be recorded once every 100 years, even thought în the two cases the hydrologycal conditions were differnt (Draghina et al., 2012).

For each calculated probability (Table 4) were centralized the characteristic discharges and levels, and was followed the frequency exceeding in the studied period. It can be noticed that the frequencies in the reference period are close but biggest than the calculated probabilities (1%, 5%, 10%). Table 3 shows that the equivalent discharges for the 0,1% and 0,01% probabilities were never recorded at Galați, but the probability of 0,1% have a very close value to danger level. The biggest exceeding frequency (11,91%) corresponds to 10% probability which is very close to mean discharges.

***Table 4**: Exceeding frequency for calculated discharges for different probabilities*

Probability (%)	**Level(cm)**	**Discharge ($m^{3/}s$)**	**Exceeding frequency (%)**
0,01	905	18.833	0
0,1	733	16.089	0
1	629	13.088	0,26
5	203	10.743	4,5
10	461	9594	11,91

In July 2010, historical discharges have been recorded at Galaţi due to a context that combines successive events occurred in the entire Danube system. During May, large parts of the upper and middle basin were flooded and the wave propagated gradually downstream. On June 7th, the attention level (560 cm) was reached at Galaţi and the liquid discharge continued rising with the rain that fell on large areas of Siret and Prut basins and culminated with three torrential phases between June 20th and July 1st. On this background, Danube exceeded the flooding level (600 cm) on June 22th and reached the maximum (680 cm) on July 5th. Only 20 cm missed until the danger level and, since the exposed area was quite extent, the difference between safety and disaster was made by the emergency management. Several measures have been realized by County Committee for Emergency Situations, especially consisting in: consolidating the weakened sectors of levees; heightening the defense levee along the river with about 1.3-1.5 meters; constructing a temporary levee of 4.5 km to protect the Valea Orașului and Bădălan neighborhoods etc.

Overall, according to the CCES Galați (2010), the losses totaled more than 8.7 mil. € being mainly caused by: seepage and complex dams degradation (about 5.9 mil. €); the Danube water raising over the unequipped area (about 2.3 mil. €); the repression of sewage water within the industrial area (about 0.31 mil. €); the groundwater raising (about 0.22 mil. €) etc. Also, the effective costs of emergency actions and the recovery costs are an integral part of the floods price. For example, only rehabilitating and strengthening the Bădălan dam was evaluated to about two million euros. Being a strategic objective, this is to be done at community level, with the support of local, regional and central authorities, but there are many small pieces of a giant. As a single example, the residential pattern of Valea Orașului is composed mostly by individual dwellings and households and there is no information about the recovery expenses of each private person.

Furthermore, the real cost of floods is obviously higher since it is influenced not only the direct costs, but also the indirect ones. The indirect costs are more difficult to count, because they are not immediately felt or settled. Within the theoretically flooded area operates many economic entities that would suffer considerable losses by limiting or suspending their activity (more than ten thousand people work within this area). During the 2010 floods, the local authorities estimated unofficially that only by closing the customs activity, the losses would have been of nearly 18.5 million euros per day. Since there are numerous transporters and distribution companies, the fluctuation of their activity generates cascading effects far away from Galați flooded area.

Conclusions

Analyzing exposure and vulnerability is an important component of risk assessment and mitigation, especially in the case of extreme natural events. The society has often little to do in terms of hazard itself: when a large amount of water accumulates in smaller or larger catchment, it is a matter of physics that it will drain to the alluvial plains and the lowlands. Despite this, floods can be anticipated through meteorological and hydrological forecasts can be prevented through (hydro) technical and structural measures or, if not, their effects can be mitigated through adequate emergency management. In the highly exposed urban areas, as Galați is, the precise identification of elements at risk is a mandatory step for risk assessment and mitigation, due to their high density and diversity that require special attention in further analysis. Classifying the different degrees of exposure according to the four characteristic levels of Danube (other criteria could be also used) creates a preliminary ranking of priorities, both in research and in action. Normally, this is modified by integrating the intrinsic vulnerability of elements at risk, no matter which component induces the most prominent aspect of vulnerability: physical, economic, social or structural vulnerability. Unfortunately, the lack of data forces us to make general remarks based on discontinuous or incomplete information that does not allow a precise quantitative assessment. Such approach is more than necessary for the low town of Galați, with more than twenty thousand people in the exposed area and important economic activities that influence especially the trade dynamics and balance.

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