

Vulnerability of urban floods in association with the sewage system and geographical features in the Giulești – Sârbi neighborhood, Bucharest, Romania

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Abstract: The study aims to analyze the vulnerability of floods and their impact in the Giulești-Sârbi area, the marginal northwestern neighborhood of Bucharest. The location of the accumulation lake has hydrological importance for the studied area. The anthropogenic dam is one of the susceptible sources of floods, but the most inefficiency of the sewage system is the actual principal cause, which frequently flows back when there are significant increases in rainfall. The motivation for choosing the study is represented by the vulnerability of the Giulești-Sârbi area and by the lack of a study on flood vulnerability and frequency in the area. A questionnaire was also applied locally, some of the results being presented in this paper. The main objectives of the study refer to the spatialization at the street level of the vulnerability of floods and their following impact. It also compares the vulnerability of floods after two key periods: before and after the construction of the dam, respectively 1980 and 2020 – for the comparison and evolution of terrain changes. The problem was also analyzed by the vulnerability related to the slope, land use and geological characteristics. The results show that the Giulești-Sârbi neighborhood is still susceptible to floods. The most affected streets are those from the southeastern part of the neighborhood and punctually to the NW. On the other hand, the application of the questionnaire shows that the southernmost street (Răsadniței Street) did not register problems as often as the current hazard maps from the *rowater.ro* source for which the highest vulnerability was expected to show. The areas indicating problems according to the questionnaires and Romanian Waters National Administration maps largely coincide with the results of the vulnerability maps resulting in this paper. The main solution that can reduce the effect of flood vulnerability is the modernization of the sewage system.

1. Introduction

Urban flooding events are much more found in the last century than in the past, being the highest reported climate hazard (Diaconu et al., 2021). Most modern cities experience small problems, but others are severely damaged. For example, cities in South and South-East Asia because of the lower drainage systems and heavier rainfall are most affected. In India (year 2000), almost 17 000 telephone lines failed to function

after a flood, where the depth of water reached 1.5 m and in Dhaka City a small amount of rain caused activities to paralyze and traffic jams (Ole, 2004).

Some of the cities found a way to solve the urban flooding problem by forming an organization called Urban Flooding Network that support them to identify, plan and implement projects. Urban Flooding Network is divided in two main parts: Connecting Delta Cities which is focused on flooding relevant to costal conditions and Cool Cities Network which support cities to adapt on Urban Heat impacts. In this project, the main cities are: Amsterdam, Accra, Cape Town, Copenhagen, London, Rio de Janeiro, Tel Aviv, Yokohama, Boston and other 26 cities (c40.org)

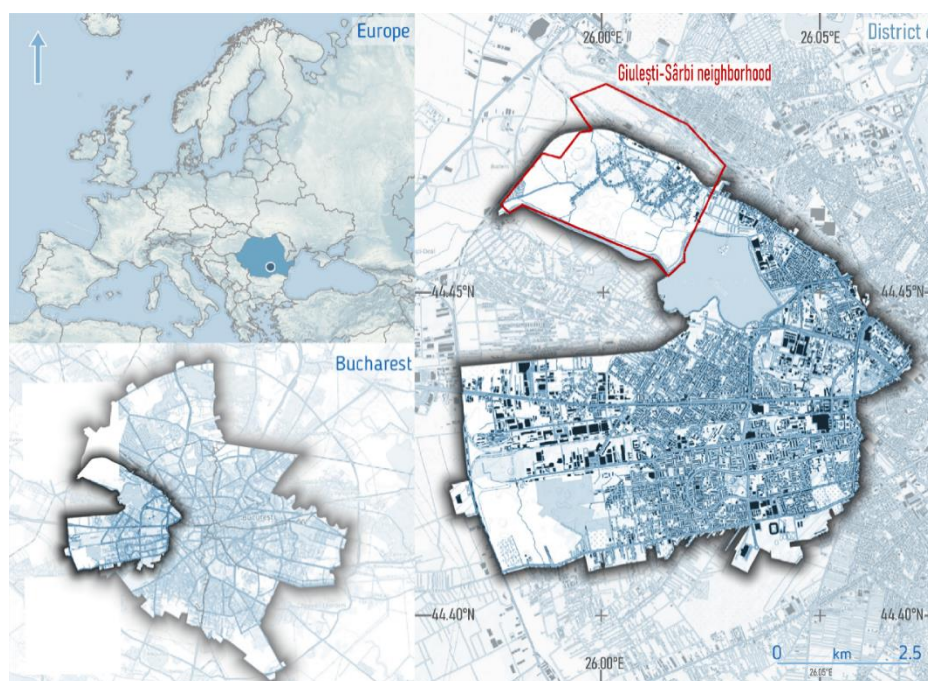


Figure 1: Localization of the study area

In Romania numerous severe flash floods developed in small basins or either in large areas as Siret, Prut, Mureș or Olt. In the past 5 years, historic flow rates were recorded on the main hydrographic arteries in Eastern Romania: Siret in 2005 (4,650 m³/s) (Romanescu, 2005, 2009), Suceava in 2008 (1,710 m³/s), Prut in 2008 (7,146 m³/s) (Romanescu et al., 2011b; Popa et al., 2020). In April 2005, heavy rains produced important floods in Banat: Oravița (226,4 mm), Reșița (205,3 mm), Lugoj (201,2 mm) and Caransebeș (200,6 mm) (Codea, 2013). Some researchers found a solution to map and monitor the flood evolution using EO (Earth Observing) data and in April 2005, the service was extended to whole country (Stâncălie, 2012).

The Giulești-Sârbi neighborhood had many problems with urban flooding in the past, but also in recent years. There are journalistic reports about the events of the floods in the area, but there is a lack of a recent scientific study. However, it has also been written about the vulnerable of floods in Bucharest (Posea, 1984; Zaharia et al., 2017; Calin et al., 2017) or other cities of interest (Marinică, 2007; Santato et al., 2018; Radu et al., 2017; GebreEgziabher, Demissie, 2020;) or Dâmbovița River (Popovici & Armaș, 2015; Zaharia et al., 2016; Armaș et al., 2018). There are also studies on Giulești-Sârbi but treated from a hydrotechnical point of view (Mihai et al., 2012, Gaitanaru et al., 2017).

Giulești-Sârbi is located on two layers of sand, Colentina and Mostiștea on the T1 terrace of Dâmbovița, with a relative altitude of 3-5 m. The absolute altitude of the relief at the terrace bridge is 88 m on Calea Giulești (Negru, 2011) and maybe more in the present. The hydrogeological characteristics in such a study are very important. In addition to those presented, the location of the piezometric level at low depths (Neagu,

2017) increased the vulnerability of flooding due to heavy rainfall. Two important rivers crosses the capital: Dâmbovița and Colentina. The first one crosses the study area. Upstream of Bucharest, the minor riverbed of Dâmbovița is in its natural state, but downstream, the riverbed was rectified until it flows in Argeș. (Cocoș, 2006). In Giulești-Sârbi neighborhood, Dâmbovița has its riverbed rectified but with the banks still made of ground, which leads to higher vulnerability to floods.

In this study, it will be analyzed the part of the neighborhood in district 6 (Figure 1), because it extends north into district 1 of Bucharest, the capital of Romania. The motivation to study this area is to demonstrate if the floods here are mostly urban or have a hydrological character, due to the proximity of the Dâmbovița river and Lake Morii (Watermillers Lake).

2. Materials and Methods

The data used in this study consist in questionnaires, satellite images from Google Earth Engine, as well as the military topographic plan from 1980 and an orthophotoplan from 2020, in order to make a comparison of the analyzed space for two representative periods (before the construction of Lake Morii and present).

The main method used in this study is the questionnaire. A series of key questions were applied to the inhabitants of the Giulești-Sârbi neighborhood on November 6, 2020. The authors applied the questionnaire to cover the entire area, choosing the most important streets in terms of flood vulnerability. The filled questionnaires are in number of 18. It is applied at the level of the residence and present the reality on the field because are located in representative points and distributed over the entire area of study. The questions of the questionnaire were related to the dating of the flood events and the damages caused by them, then to personal data that are reported in the results chapter. The results were represented in Excel charts and maps using GIS software.

For analyzing the land changes, it is used a DEM made from October 2008 satellite radar image with a 12.5 m resolution from the Alos Palsar satellite and SRTM corrections to show the elevation and the slope in the study area.

Also, were used the maps and the information about sewerage systems and hydrological characteristics from other authors.

3. Results

3.1. Main statistics of the applied questionnaires

The answers were given in the largest proportion by men (over 66%) over the age of 50 (over 60%) according to Figure 2, while the rate for those of 20 years and below is zero. This was an advantage because among them were the longest inhabitants who provided us with longer-term information. Some have even told us about the presence of floods in 1970, before the construction of the lake.

Of those who answered the questionnaires, over 80% told us that they had faced flood events in the past, and over 55% believe that they will be repeated as suggested in Figure 3. Those who answered that they do not know if the floods will be repeated believe that the system of defense and management of domestic water will not encounter problems as big as in the past and that if they continue to exist, they will be minor and not frequent. Or they raise the issue of a big flood only in the unlikely event of the dam around the lake will break.

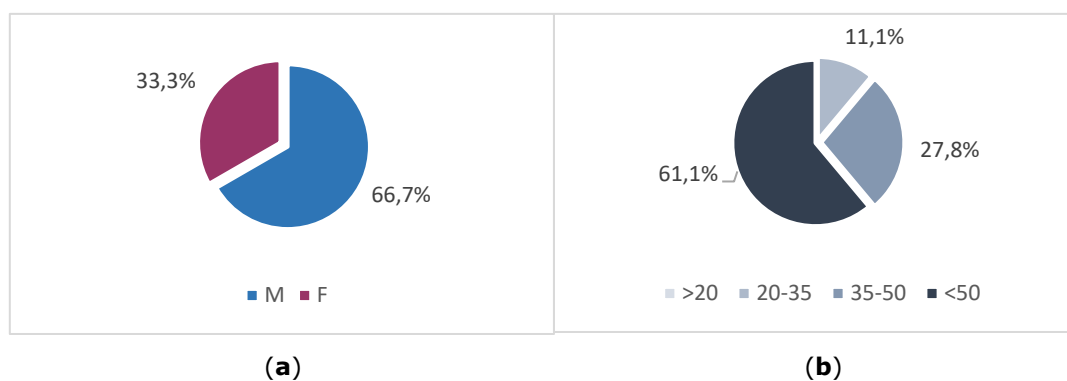


Figure 2: The sex ratio of the people answering the questionnaire (a); Age groups (b)

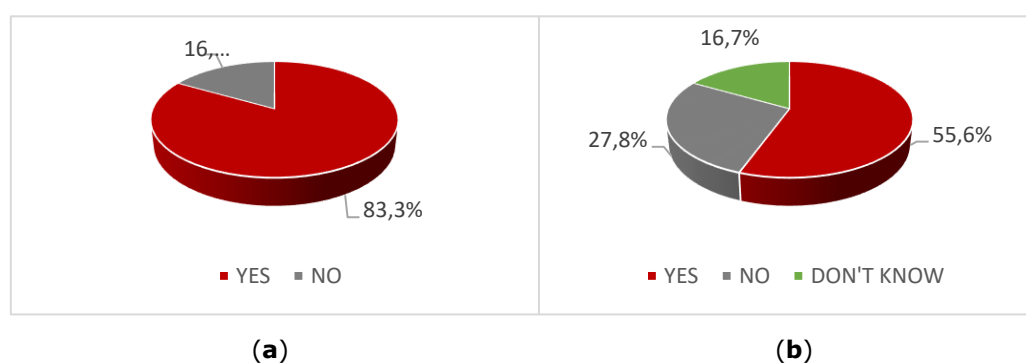


Figure 3: Previous incidence of floods (a); Expected future floods (b)

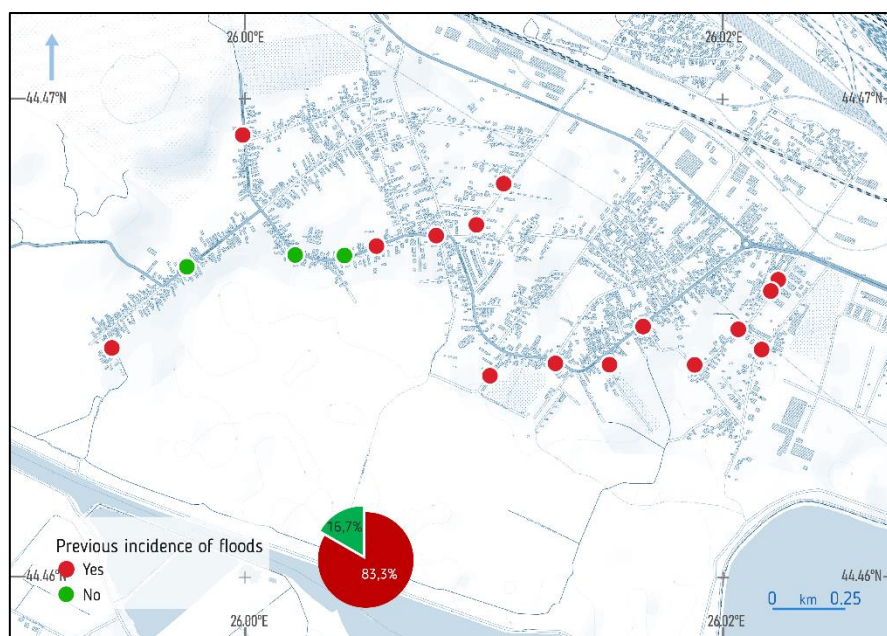


Figure 4: Spatialization of areas affected by floods in Giulești-Sârbi according to the questionnaires

According to the results from the questionnaires, resulted the spatialization of the flood vulnerability (Figure 4). It is noticed that there are problems in most of the space, except for the area represented by green dots. If the points where the questionnaires were applied are correlated with the terrain altitude, it will be noticed that the less affected areas are even higher. This means that the affected points if they are repre-

sented by lower elevations, collect water from precipitation that drains from higher points. These lower areas also favor the stagnation of water due to rainfall, and the sewerage system does not cope.

3.2. Actual sewerage system problems

The total length of the sewerage system in Bucharest is about 2470 km and the pipes are made either of concrete (73%) or PVC (20%). The collector is situated under Dâmbovița river and ends at Glina Wastewater Treatment Plant, outside the Bucharest (Pavel, 2021).

Using the longitudinal profiles made by Mihai et al. (2012) (Figures 5 and 6), two distinct moments of the state of the main collector system on Calea Giulești can be observed.

In the first scenario, the return period is 2 years with a duration of 37 minutes in which the system is not pressurized and the water does not reach the surface of the catchment.

In the second scenario, the return period increases to 20 years with a 37 minutes duration. At a time of maximum occurrence, the areas might get flooded during such an event (Figure 6).

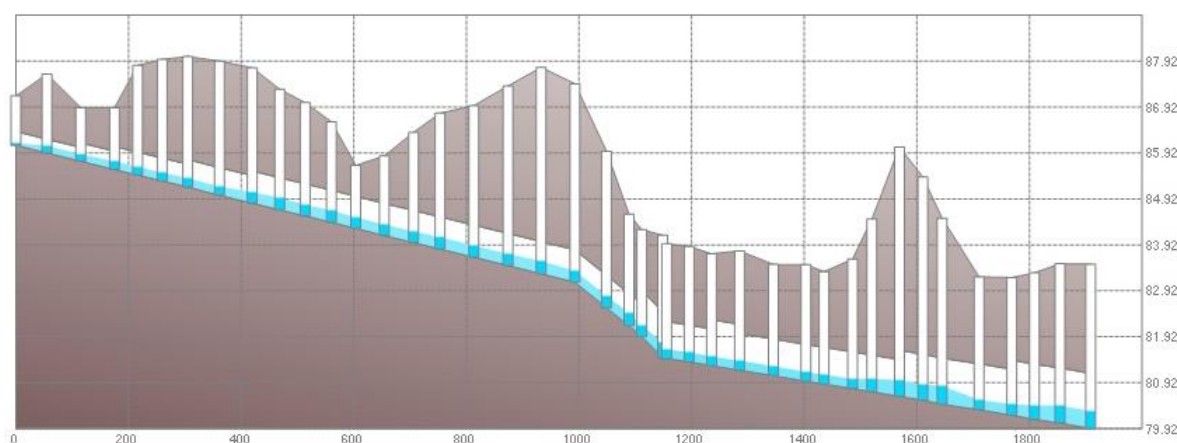


Figure 5: Longitudinal profile along with the main collector on Calea Giulesti after synthetic rainfall scenario with 2 years return (Mihai et al., 2012)

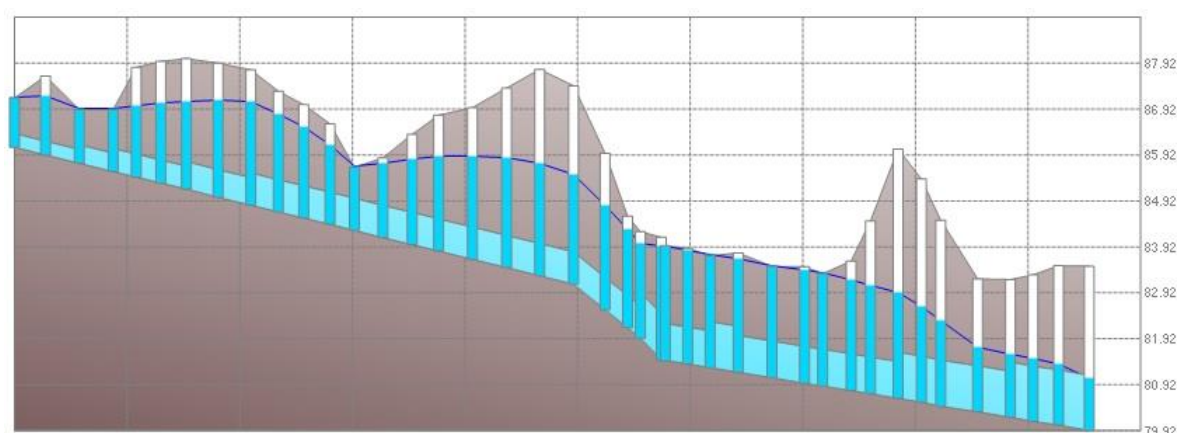


Figure 6: Longitudinal profile along the main collector on Calea Giulești after synthetic rainfall scenario with 20 years return period and a 37-minute duration (Mihai et al., 2012)

The same authors as before made the representation of a model of the hydraulic elements from the Giulești-Sârbi neighborhood (Figure 7). This model involves two types of sewerage systems (pluvial and combined), as it was in 2012 or earlier. The combined

system is associated with the apartments buildings area, and the rainwater system is associated with the area of the small house (generally with a single level). The evacuation, in the case of these two systems, is made by two pumping stations (R.1., Respectively R.2.1.).

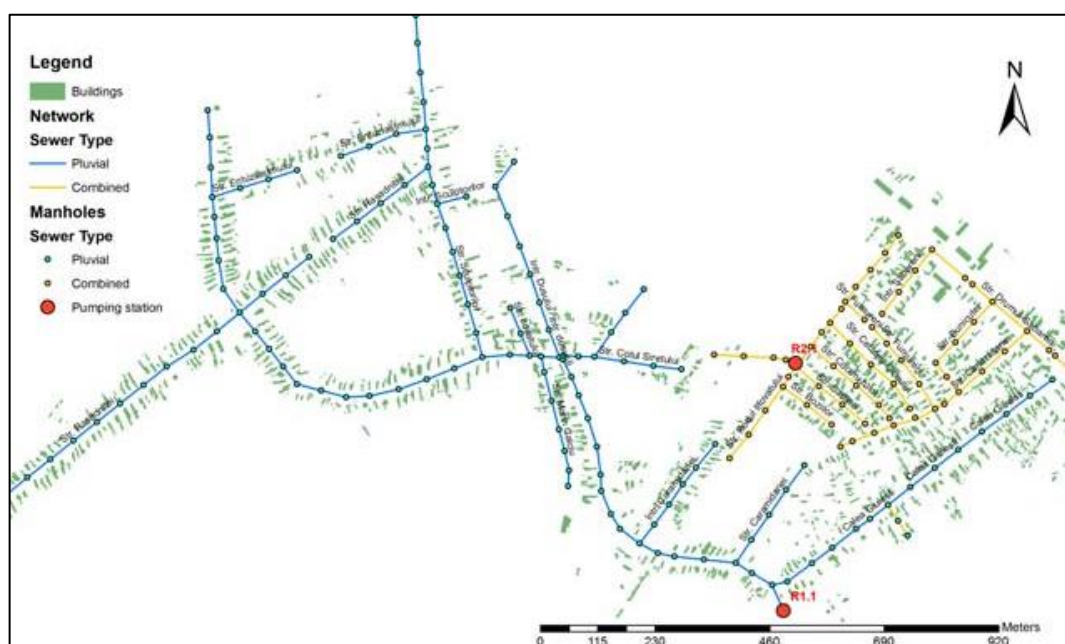


Figure 7: Representation of the hydraulic elements of the sewer model Giulești - Sârbi (Mihai et al., 2012)

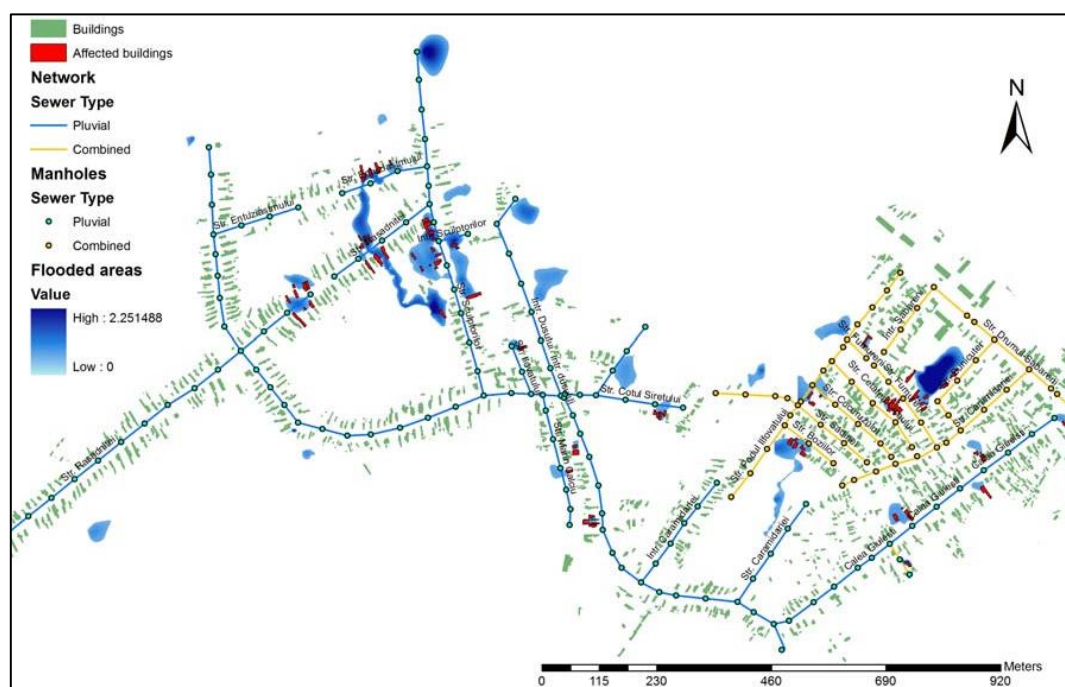


Figure 8: Flooded areas and possible affected buildings from a precipitation event with a 100-year return period and 37-minute duration (Mihai et al., 2012)

For the vulnerable buildings during precipitation with 50 years return period (Figure 8) is observed that the most affected areas are located in the northern part of the area, where the congestion of streets and buildings is greater.

Nevertheless, the spatial distribution of flood vulnerability in this model does not continue to be a reality. The sewerage system has changed from 2012 on some streets. For this reason, the sewer system has become combined for most of the area. According to the questionnaires, the modernizations in the sewerage system are still insufficient in case of heavy rain.

However, the problems still exist, because, as the inhabitants support, the sewer system does not always cope with the large amounts of water from pluvial and used water, and it still needs modernization.



Figure 9: Pipes unearthed from the old sewerage system on Calea Giulești (6 Nov 2020)

During the application of the questionnaires, it was possible to observe more closely the land for some homes that inhabitants say are among those most affected by floods. Thus, it was observed that urban floods, due to the inefficiency of the sewerage system, were frequent and they occurred also in 2019 year. Figure 5 shows pipes from the sewer system that crosses the courtyards of two houses. The two houses are located on the main street of the neighborhood, Calea Giulești. These unearthed pipe segments come from the old sewer system which was largely made up of ditches. The actual sewerage system was implemented in the neighborhood around the 2000s, and these segments remained incorporated into the new system, without undergoing modernization changes.



Figure 10: Watermark on a storeroom door on Calea Giulești (same yard like in A. from Fig. 9) (6 Nov 2020)

As can be seen, the two segments pass through vegetable gardens that become inedible when, in addition to wastewater, heavy rainfalls occurred, and the system was no longer able to cope with the high flows from the two sources: gray and green water.

At least for these two cases, people have told us that the spills occur in any heavy rain, and only in 2020, there were 2-3 such events between June and September, when predominant was convective rain system. The marks left by the floods on the houses in the area are observable (Figure 10).

According to the inhabitants, the sewerage system was built according to an old urban plan in which the built-up area appeared in a smaller area. For this reason, at heavy rainfall, the sewer ends up flowing through the sewer holes and these pipe segments that are not buried in the ground.

Currently, the water evacuation in the area of houses is made through a canal (Figure 11 - **a**) that crosses the southern part of the studied area, reaching a station located near the Dâmbovița riverbed (Figure 11 - **b**), the riverbed, and the pumping station is separated by an earth dam that is only a few meters wide. With the help of 4 pumps, the water is directed to the riverbed (Figure 12).



Figure 11: Wastewater channeled **(a)**; Wastewater pumping station **(b)** (6 Nov 2020)



Figure 12: The place where wastewater flows into the river (6 Nov 2020)

3.3. Land changes

According to the observation on the field and based on what inhabitants say, the elevation points on the maps no longer correspond to reality. At least in the case of old topographic maps (Figure 13), probably most of the highlighted altitude points no longer correspond to reality because at certain points the land has been covered with a surplus of land several times. In Figure 14, two such areas can be observed where positive terrain changes have been made and which can be observed with the help of satellite images. Figure 15 shows the evolution of these changes between 1985 and 2020. Images were extracted from representative years. The Google Earth Engine satellite imagery collection contains captures from 1984 to 2018. The oldest ones have the lowest resolution; therefore, the analysis starts with 1985, which is important as Lake Morii (the Watermill Lake) was not yet completed.

The two polders with excess land are still functional landfills in which people throw uncontrolled household waste. In both cases, the two are sectioned by a canal, probably a former irrigation canal that served the irrigation of agricultural land, which no longer exists today.

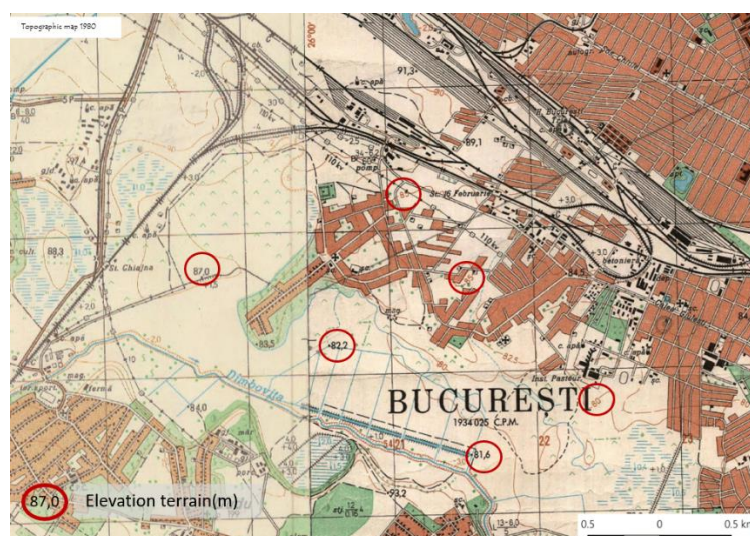


Figure 13: 1980 Topographic map (source: geomil)

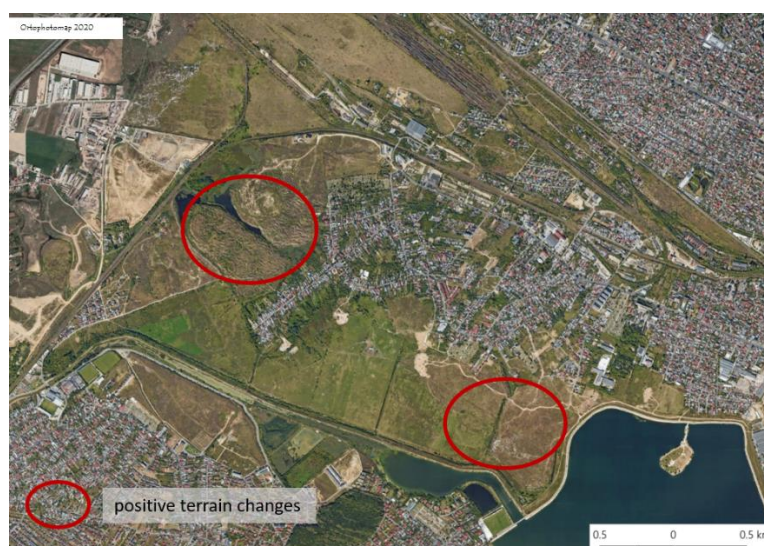


Figure 14: 2020 Highlighting positive terrain changes on 2020 orthophoto map (source: geomil)

The two polders with excess land are still functional landfills in which people throw uncontrolled household waste. In both cases, the two are sectioned by a canal, probably a former irrigation canal that served the irrigation of agricultural land, which no longer exists today.

The modification of the land is important because of the hydrological vulnerability, because this changes the depth of the piezometric level and the degree of floodability, especially if the flood is hydrological, but not urban.

Besides the evolution of these polders, the evolution of constructions is also observed. The geometry of the streets is the same, if you don't look closely, you would say that the density of the buildings has not changed. The truth is that people used to have bigger yards and gardens, and after 1990 and especially after 2010, the land was parceled out and sold. Then the built-up area visibly thickened and also expanded vertically. This was the main reason for the inability of the sewerage system: a higher consumption and flow of wastewater.

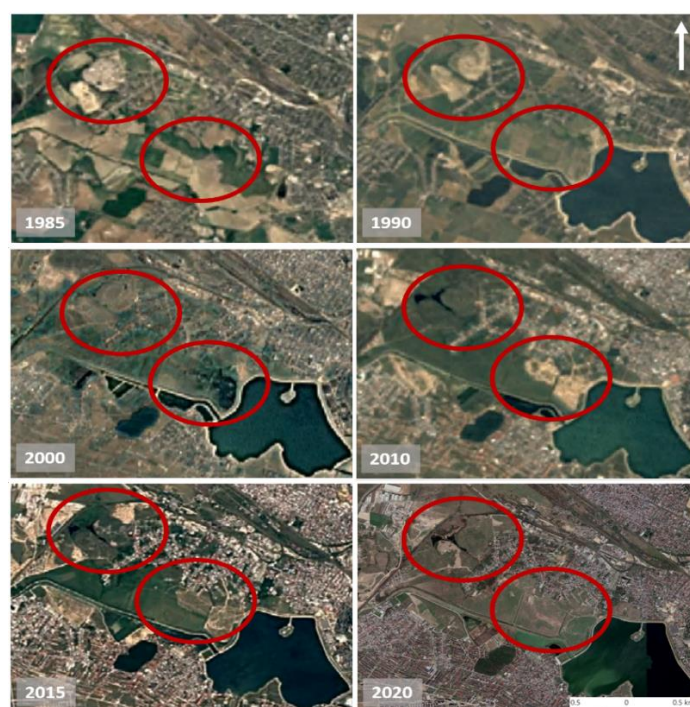


Figure 15: Terrain and construction density evolution between 1985-2020 from satellite images (source: google earth engine)

3.4. Floods and Vulnerability

For a clearer perspective, maps were made in the QGis software. In the case of the altitude map (Figure 16) and slope one (Figure 17 A), the presence of the landfill in the NW of the area is observed.

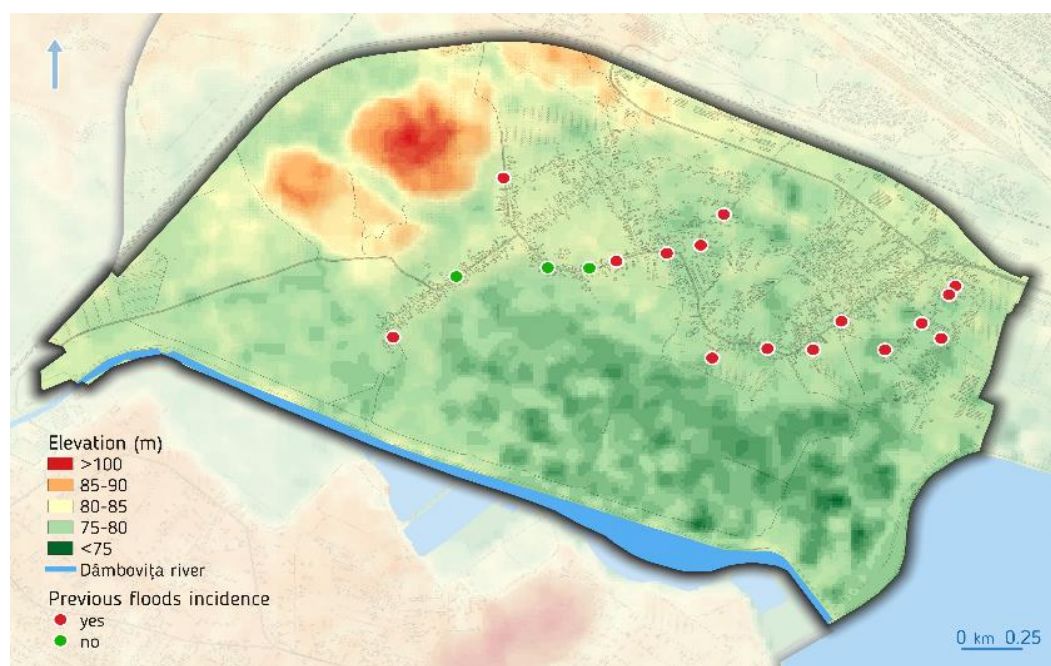


Figure 16: Elevation map in Giulești-Sârbi area (altimetric data from Alos Palsar satellite from Oct 09, 2008, with 12.5 m resolution and SRTM corrections; land use data from Copernicus CLC 2018, geology)

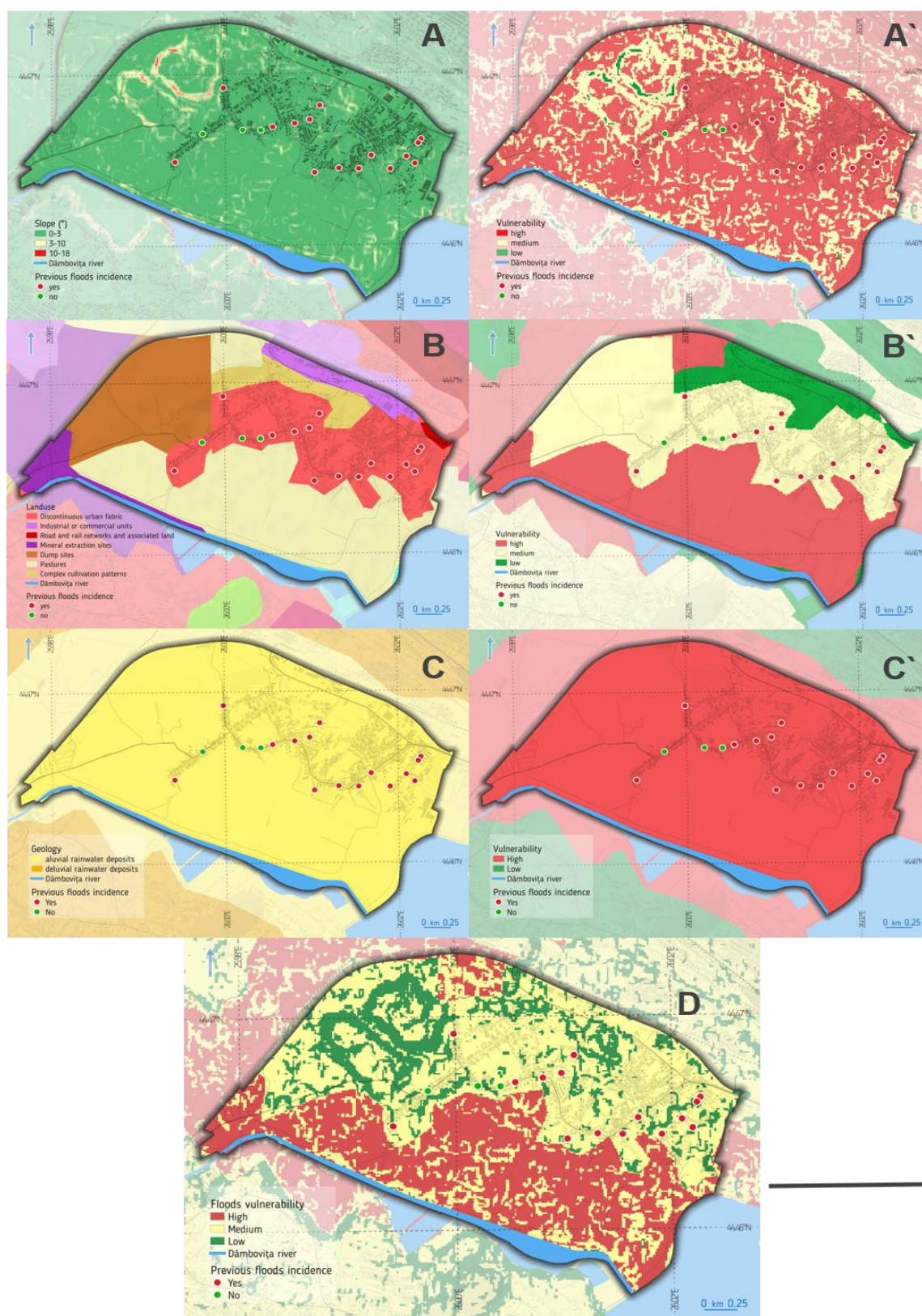


Figure 17: Floods vulnerability (D) depending on the slope (A, A'), land use (B, B') and geology (C, C'); A, B and C are for the base elements and A', B' and C' for their vulnerability association

Once again, it is confirmed that this point, which has been changed numerous times, significantly changes the vulnerability to floods.

In the case of altitude distribution, it is expected that in the smallest areas the water will stagnate for a longer time, increasing at the same time the vulnerability to floods

(Figure 17 A'). Instead, where the slopes are larger, the water will flow faster and the vulnerability will decrease. However, these factors will be taken into account only if there is no sewerage system, in whatever state it may be, and the hydrogeological characteristics and the amounts of precipitation have a uniform character. Therefore, the distribution of vulnerability is not uniform, representing a combination of factors that influences land use and geology (Figure 17 B, C). Figure 17 D shows the general vulnerability risk for these principal 3 characteristics.

4. Discussion

Although there were other projects for the modernization of the sewerage system, people still raise the issue of the sewerage because the authorities were not carried out on the whole area, but only on certain sections. It is difficult for the whole neighborhood to become a construction site and the whole system to be changed, not just modified. As a result of such an action, the neighborhood would be blocked, which cannot be allowed. Therefore, the works must continue to be isolated.

An idealistic solution could refer to rethinking the entire sewerage system, as it is associated with smart cities. More precisely, the system is a dual one in which there is two separate collection system for rainwater and domestic water. Advantages and disadvantages intervene in this concept. The main advantage of the separate sewerage system is the capacity of the water treatment plant will be smaller since only domestic sewage alone is to be treated. The disadvantage of the separate sewerage system refers to stormwater that may always find its way into the domestic sewerage system.

In another way, for more expansive study should exist actual topographic map that includes terrain modification by the evolution of the build and landfills area.

The need for measurements is a first step in making vulnerability and risk actual maps. Rowater.ro has available maps with floodplains (Figure 18), but they show just the hydrological floods risk, the urban floods risk are missing.

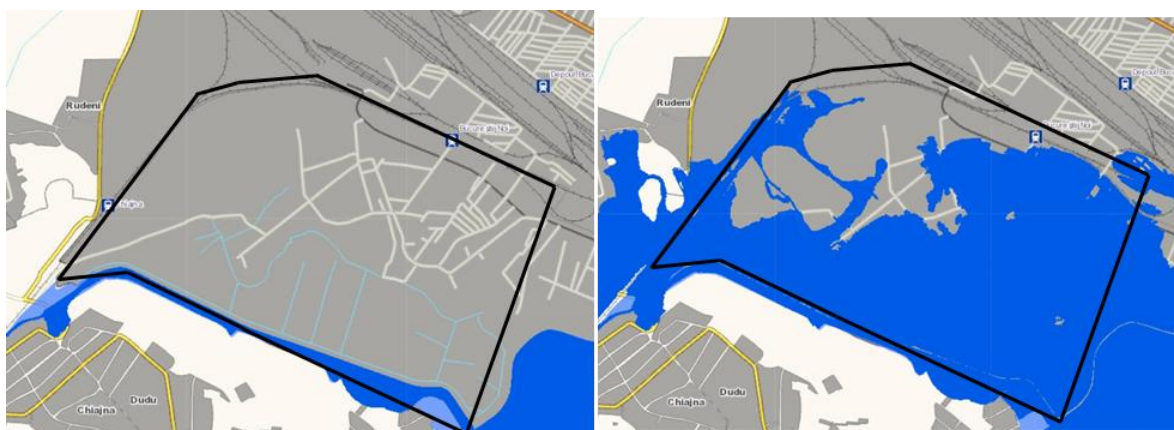


Figure 18: Flooded areas at 1% (left) and 0.1% (right) in Giulești-Sârbi neighborhood; source: *rowater.ro*

5. Conclusions

Vulnerability is defined by a multitude of characteristics of an area. Among the most important are those presented in this study. In order of their importance in urban areas are: sewerage system, land changes, hydrological characteristics.

According to the questionnaire results, Giulești-Sârbi still presents a vulnerability of flooding in most of the neighborhood excepting the NW part. The main reason is a deep-rural character with many sewerage problems, the absence of modern infrastructure, and disregard for the authorities.

The evolution of the vulnerability of floods between 1980/1985 and 2020 isn't mostly related to the subsequent changes of the Dâmbovită river course and

hydrotechnical arrangements, but more to the evolution of the terrain elevation and built area. The houses were densely populated and expanded horizontally and vertically, which means the sewer system is under higher pressure. This evolution does not have a uniform sign on the entire surface of the analyzed area and the vulnerability has remained the same in areas where there are still old sewers. It is not known exactly whether the vulnerability has decreased in the vicinity of areas covered with surplus land (landfills), but it is expected to be.

The same importance is shown by the hydrogeological characteristics because where the piezometric level is at a lower depth, more water can rise to the surface in case of heavy rains and create floods.

The impact of floods is reflected in the streets, courtyards, and gardens, which sometimes reach a level of 1/2 m as in Figure 10, thus small crops, housing and annexes are affected.

The new sewer system should follow the model of smart cities that used two separate sewer systems for grey and green water.

For a valid comparison of changing the terrain altitude measurements are required that can be performed using drone flights or GPS point mapping. These current measurements are needed to create flood and vulnerability risk maps in the Giulești-Sârbi neighborhood.

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References

1. Armaș, I.; Necea, D.; Miclăuș, C. (2019) Fluvial terrace formation and controls in the Lower River Danube, SE Romania. *Quaternary International*. Elsevier, 504: 5–23. <https://doi.org/10.1016/j.quaint.2018.03.031>
2. Calin, N.; Radu, C.; Bica, I. (2017) Dewatering system of a deep of excavation in urban area – Bucharest case study. *Procedia Engineering*. Elsevier B.V., 209: 210–215. <https://doi.org/10.1016/j.proeng.2017.11.149>.
3. Codea, D.M. (2013). Timiș River Flooding in Banat (Romania) in 2005. *Transylvanian Review of Systematical and Ecological Research*. 15:3. doi:10.2478/trser-2013-0029
4. Diaconu, D.C.; Costache, R.; Popa, M.C. (2021) An Overview of Flood Risk Analysis Methods. *Water*, 13, 474. <https://doi.org/10.3390/w13040474>
5. GebreEgziabher, M.; Demissie, Y. (2020) Modeling urban flood inundation and recession impacted by manholes. *Water (Switzerland)*, 12(4): 15–20. <https://doi.org/10.3390/W12041160>.
6. Marinică, I. (2007) The abundant rainfalls from Oltenia between the 18 th and the 23 rd of September 2005., 10(September 2005): 29–37. <http://cis01.central.ucv.ro/geography>
7. Mihai, A.F.; Maksimović, C.; Drobot, R. (2012) Flood delineation in Giulești-Sârbi area using dual drainage modelling. *Scientific Journal of the Technical University of Civil Engineering, Mathematical Modeling in Civil Engineering*, No. 1 – March – 2012. https://mcee.utcb.ro/images/doc/2012/modelling_nr1_2012.pdf
8. Neagu, D. (2017) Managementul sistemului acvifer de mică și medie adâncime din zona Municipiului București, Rezumatul Tezei de Doctorat, Universitatea București, Facultatea de Geologie și Geofizică. <http://gg.unibuc.ro/wpcontent/uploads/2018/05/NEAGU-Dumitru.pdf>
9. Ole, M. et al. (2004) Potential and limitations of 1D modelling of urban flooding. *Journal of Hydrology*. Elsevier. 299: 284 – 299. <https://doi.org/10.1016/j.jhydrol.2004.08.014>
10. Popa, M.C., Simion, A.G., Peptenatu, D., Dima, C., Drăghici, C.C., Florescu, M.S., Dobrea, R.C., Diaconu, D.C. (2020) Spatial assessment of flash-flood vulnerability in the Moldova river catchment (N Romania) using the FFPI. *J Flood Risk Management*.; e12624. <https://doi.org/10.1111/jfr3.1262410>
11. Popovici, D.; Armaș, I. (2015) Geomorphological changes in Bucharest city over the last 150 geomorphological changes in Bucharest city over., (December). <https://doi.org/10.29081/jesr.v21i2.29>.

12. Posea, G.; Ștefăvnescu, I. (1984) Municipiul București cu Sectorul Agricol Ilfov. Ed. Academiei Rep. Soc. Romania.
13. Radu, C.; Gaitanaru, D.; Amine, M. (2017) Urban hydrogeology studies in Bucharest City, Romania. *Procedia Engineering*. Elsevier B.V., 209: 135–142. <https://doi.org/10.1016/j.proeng.2017.11.139>.
14. Romanescu, Gh.; Stoleriu, C. (2013) Causes and effects of the catastrophic flooding on the Siret River (Romania) in July–August 2008. *Natural Hazards*. 69: 1351 – 1367. <https://doi.org/10.1007/s11069-012-0525-6>
15. Rowater. Available online: <https://rowater.ro/despre-noi/descrierea-activitatii/managementul-situatiilor-de-urgenta/directiva-inundatii-2007-60-ce/harti-de-hazard-si-risc-la-inundatii/> (accessed on 2 November 2020)
16. Santato, S.; Bender, S.; Schaller, M. et al. (2018) Urban pluvial flood modelling: current theory and practice. Review document related to Work Package 3 – Action 13. *Journal of Hydrology*, 13(2): 1–15. http://www.raingain.eu/sites/default/files/wp3_review_document.pdf
17. Stâncălie, Gh.; Crăciunescu, V.; Nerțan, A.; Mihăilescu, D. (2012) Contribution of satellite data to flood risk mapping in Romania. 2012 IEEE International Geoscience and Remote Sensing Symposium. <https://doi.org/10.1109/IGARSS.2012.6351413>
18. Zaharia, L.; Toroimac, I.; Cocoș, O.; Adrian, F.; Mailat, E. (2017) Urbanization effects on the river systems in the Bucharest city region (Romania). 4129. <https://doi.org/10.1002/ehs2.1247>.



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