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PhD Thesis

- Summary -

Geoinformatics Study Regarding the Hydrological Impact of the Damage to Water Supply Networks in Rural Areas. Application to Baia Mare Depression

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Key words: Geoinformatics, water supply networks, damage, hydric impact, rural area, the Baia Mare Depression

CHAPTER I. INTRODUCTION. AIM AND OBJECTIVES

More and more research is done on natural floods that occur in rural areas. Flood modelling difficulties for rural settlements occur primarily due to the large-scale work that requires the use of data sets that are often inaccessible without additional measurements. The situation becomes more complicated if, besides natural factors, there is a risk of damage to water supply pipes. This study aims to contribute to the solving of this problem. Evidently, the problem is not solved if one simply imagines that pipes are damaged. The amount of water required to saturate the soil and then to start the puddling phenomenon or the drainage process must be calculated.

The principle is new, as the specialised literature usually deals with the matter of damage to water supply networks from the viewpoint of water loss and its impact on the amount of water required by the industry or the local community.

The present research attempts to develop analysis patterns that would lead to: the simulation of drainage in the damaged network; the identification of areas and possible clients that might be affected by the damage; the development of calculation methodologies for the amount runoff in the case of broken network pipes; the developments of maps of areas prone to flooding in case of considerable damage; the estimation of the hydrological impact of damaged water networks.

CHAPTER II. STUDY AREA, PHYSICAL-GEOGRAPHICAL ELEMENTS WHICH ARE INVOLVED IN THE ASSESSMENT OF THE HYDROLOGICAL IMPACT OF DAMAGED WATER SUPPLY NETWORKS AND RURAL SETTLEMENTS IN THE BAIA MARE DEPRESSION

The Baia Mare Depression is, regionally speaking, a part of the geographic subunit of the Banat and Crişana Hills (specifically the Silvano-Someşene Hills), as it is a component of the western regions that are close to the Carpathians.

From an administrative point of view, the Baia Mare Depression includes the following towns and villages: Ulmeni, Mireșu Mare, Șomcuta Mare, Remetea Chioarului, Săcălășeni, Salsig, Satulung, Fărcașa, Ardusat, Recea, Groși, Dumbrăvița, Copalnic-Mănăștur, Baia Sprie, Baia Mare, Cicirlău, Tăuții-Măgherăuș.

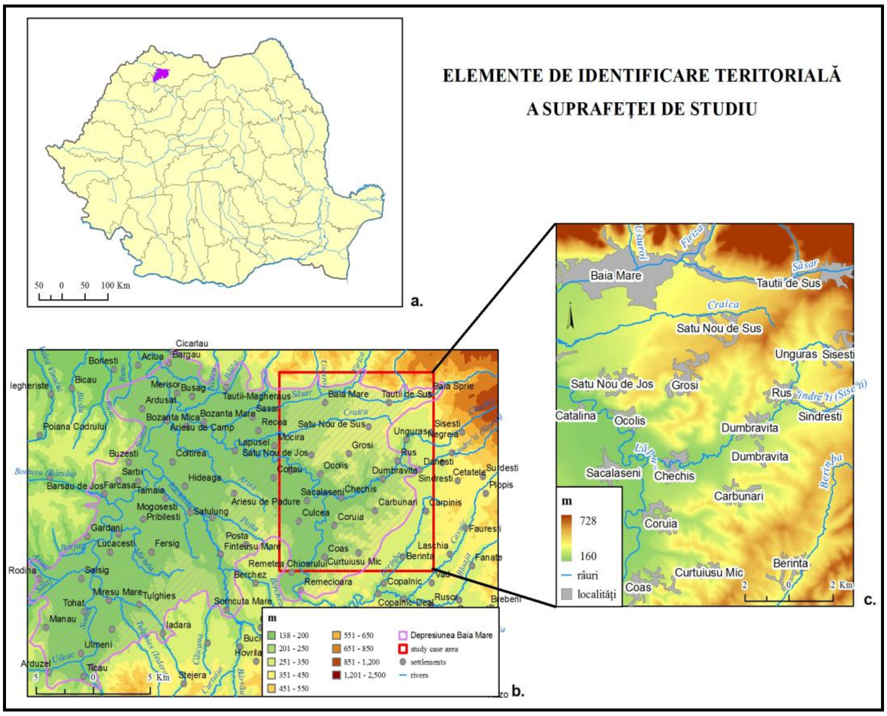


Fig. ***1*** *Elements of locating the study area: the location of the Baia Mare Depression in Romania (a); the location of the urban and rural settlements in the Baia Mare Depression (b); the location of the rural area involved in the case studies (c)*

The area selected for the analysis of the hydrological impact of damaged networks in the Baia Mare Depression (**Fig. 1**) overlaps with rural settlements south and southeast of Baia Mare, which have water supply systems directly linked to that of Baia Mare. These villages are generally located along certain river courses (Craica, Chechiş, Lăpuş, Berinţa) characterised by low altitudes and low slopes, which are favourable for maintaining a surplus of moisture in the soil.

These are the villages that cover the selected areas involved in the study: Tăuții de Sus, Satu Nou de Sus, Satu Nou de Jos, Unguraş, Sisești, Groși, Rus, Sindrești, Ocoliş, Dumbrăvița, Catalina, Săcălășeni, Chechiş, Culcea, Coruia, Cărbunari, Coaş, Curtuiușu Mic, Berința.

The Baia Mare Depression is characterised by a large number of inhabitants as it has over fifty settlements, mostly villages. Twenty Territorial Administrative Units (TAU) are situated in the Baia Mare Depression. These are: Baia Mare, Baia Sprie, Tăuții Măgherăuş, Cicârlău, Pomi, Ardusat, Recea, Groși, Dumbrăvița, Copalnic-Mănăștur, Săcălășeni, Remetea Chioarului, Șomcuta Mare, Satulung, Fărcașa, Ulmeni, Salsig, Ariniş, Asuaju de Sus, Mireşu Mare.

CHAPTER III. CURRENT STATE OF THE RESEARCH

At first, the general studies developed up to the present regarding the hydraulic modelling of water supply and distribution networks, as well as the system damage were taken into account (*Blitz E., Trofin P., 1971; Cioc D., 1967, 1983, 2001; Pislaraşu I., 1981; Trofin P., 1983*). The focus later shifted towards the research done on the utility/applicability of Geographic Information Systems (GIS) in the modelling of water networks, but also of hydraulic information systems.

CHAPTER IV. DATABASE

As regards the **rough cartographic database**, the following were used: topographic maps with level curves at a scale of 1:25.000, Gauss-Kruger projection; topographic plans 1:10.000; pedological maps 1:200.000; cadastral plans 1:5.000. **The primary GIS database** contains spatial information that refers to: the water supply network in the area of study; the level curves; the hydrographic network; the terrain usage; the inhabited space; the houses and homesteads; the branch points; the damage points.

The topographic numerical database was compiled by means of topographic measurements done in the study area. These measurements have verified the data obtained from the water supply network project. In addition, included in the category of numerical data is the **precipitation data** from the Baia Mare weather station (1961-2000) or the set of data from these pluviometric stations: Baia Sprie, Buciumi, Cavnic, Copalnic, Firiza, Lăpușel, Răzoare, Salsig, Suciu de Jos, Ulmeni (2006-2011).

CHAPTER V. THE WATER SUPPLY NETWORK IN THE BAIA MARE DEPRESSION AND CAUSES OF DAMAGE

The available vector database for water supply networks is located east of the Baia Mare Depression, specifically in the south and southeast of the city of Baia Mare. The water supply network of Groși is directly connected to that of Baia Mare, and this provides a link to the other supply networks of Chechiș, Săcălășeni, Dumbrăvița, Rus, Unguraș, Sindrești, Cărbunari, Berința (**Fig. 2**).

The water supply network consists of 2230 pipe sections, most of which being located in the city of Baia Mare.

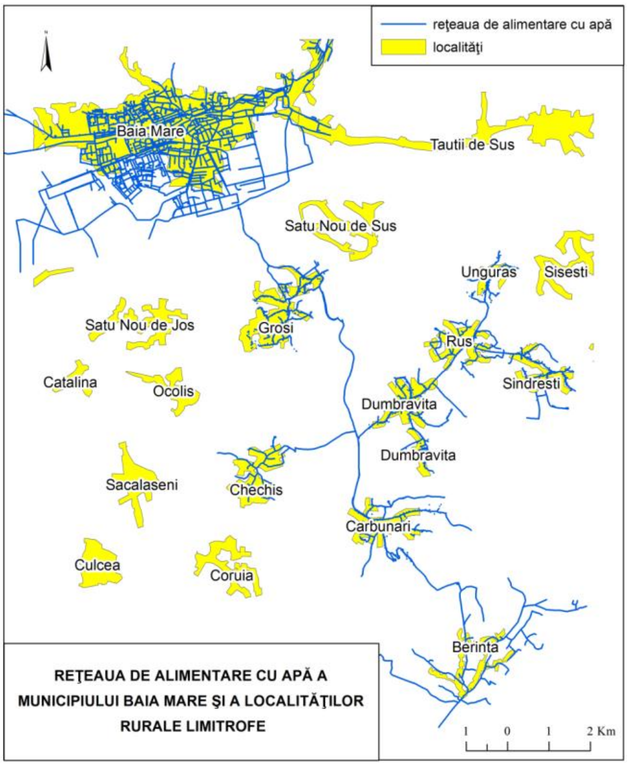


Fig. 2 *The configuration of the water supply network of Baia Mare and of the neighbouring rural areas*

The main towns get water from different sources. Baia Mare uses surface water, whereas Cavnic relies on surface water and—partially—groundwater. Sighetul Marmației, Vișeu de Sus, Tg. Lăpuș, Seini, Baia Sprie and Borsa are supplied with groundwater. The inhabited areas spread over circa 162.3 ha, and this means that most of the Baia Mare Depression population is thusly supplied.

As far as water loss is concerned, there exists within the S.C. VITAL S.A. Baia Mare (the local water supplier) a department of water loss that is divided into CC-TV inspections, detections – water loss identification and flowmetry. In the rural areas supplied by the Baia Mare water supply system there have been 40 such problems in 2011, most of them in Cărbunari (12), Dumbrăvița (11) and Chechiș (9).

CHAPTER VI. EVALUATION METHODOLOGY FOR HYDRIC RUNOFF CAUSED BY DAMAGE TO WATER SUPPLY NETWORKS

6.1. Classic methodology

Regardless of the method used to determine the amount of runoff onto the surface of the terrain because of damage to the network, it is necessary for one to know the water flow for that pipe. A possible solution in this respect is the installation of flowmeters that would enable a constant monitoring, taking into account the fact that the water flow in pipes varies during the day according to the customers' demands (which also vary throughout the day). There have been several campaigns of using flowmeters in the water supply network of Baia Mare.

Another stage in the study of the hydrological impact caused by damage to water networks consists in the assessment of runoff on the surface of the terrain. This chapter comprises the synthetic presentation of a few well-known methods of indirect evaluation of runoff, some of which have already been automatized in the shape of computerised hydrological models: Horton's equation, rational method, TR 55, methods of estimation of the runoff coefficients, TANK, Vidra, TOPMODEL. GEOTOP, STANFORD.

6.2. Geoinformatics methodology

Geoinformatics systems offer the possibility to introduce, maintain and especially analyse and interpret in a fast and efficient manner the data referring to water networks.

The functions of the EPANET program were used in order to simulate the runoff from damaged pipes.

The assessment of hydrogeological conditions is based on the Geoinformative representation of three hydrological indices: the API index, the Frevert index and the CN index (*Haidu I. et al., 2013*). A structure of the GIS model used for the spatial analysis of the hydrological conditions of the terrain is portrayed in **fig. 3.**

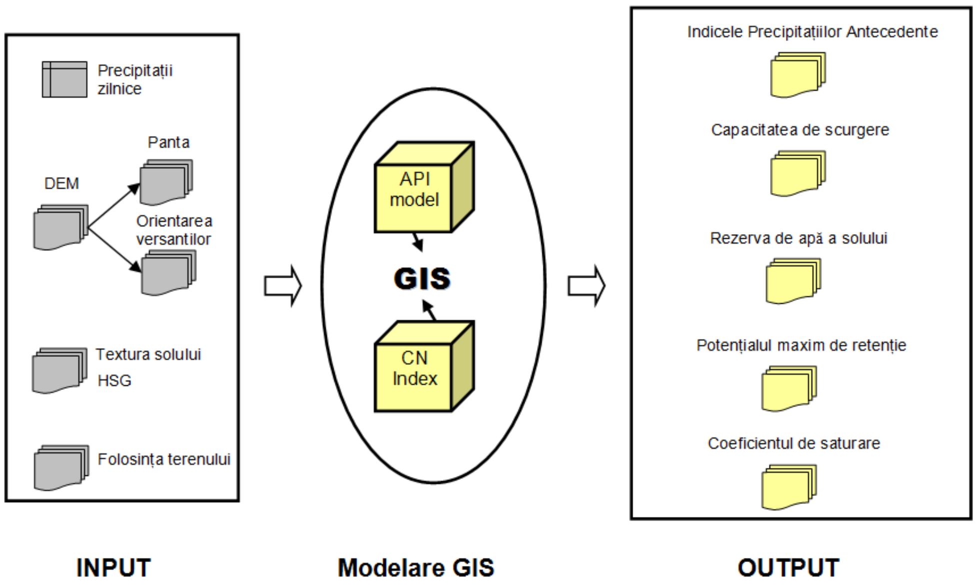


Fig. 3 *The entry data and the results obtained by means of GIS model used for analysing the hydrological conditions of the terrain*

Based on GIS models, thematic maps are obtained, and these are based on raster data regarding: *prior precipitation index, runoff capacity, soil moisture, highest retention potential (S), coefficient of water saturation of the terrain, infiltration capacity of the soil*.

The methodological contributions of this thesis regarding the **analysis of susceptibility to** local **flooding** in case of damage consist of the development of GIS procedures of identification of areas susceptible to local flooding in case of damage to water supply pipes. The stages of these procedures are:

1. Compiling the GIS vector database with the parameters necessary for spatial analysis: water supply networks, levelling, soils, terrain usage, precipitation (if it is possible).

2. Generating, by means of spatial analysis, raster layers on physical-geographical parameters (Numerical Model of the Terrain, slope, slope orientation, precipitation) that are necessary for the evaluation of the hydrological conditions of the terrain.

3. Generating raster layers on the Frevert coefficient, API index, Antecedent Moisture Conditions (AMC), CN index and the highest retention potential S.

4. Generating raster layers on the water saturation coefficient of the soil based on results from the previous stage (API index and the highest retention potential S).

5. Extracting the areas that have a saturation coefficient ≥ 0.5 and then identifying the pipelines that overlap the areas with a saturation coefficient > 0.5, > 0.7 and > 0.9 for some of the villages from the study area.

The first result of the analysis is the map of areas susceptible to local flooding (which can be obtained at a daily scale), and then based on this layer, the map of the pipelines susceptible to produce flooding in case of damage has been generated.

Regarding the **evaluation of the surface runoff** caused by damage to water supply networks, this thesis contributes by perfecting and applying some GIS procedures by means of which the following questions can be answered:

'What are the values of the coefficient of water saturation of the soil and what is the storage capacity of the soil prior to the damage?'

'What is the length of the runoff course and what is the amount of water going through point "1, 2, 3 ... x" as a result of the damage that occurred in point "1"?'

The main stages that compile the GIS methodology used to calculate the runoff caused by damage to the pipelines are:

1. Compiling the GIS vector database with the parameters necessary for spatial analysis of the prior hydrological conditions of the soil: water supply networks, levelling, soils, terrain usage, precipitation.

2. Generating, by means of spatial analysis, raster layers on physical-geographical parameters that are necessary in the evaluation of the hydrological conditions of the terrain.

3. Generating raster layers on the following parameters: API, AMC, CN and S.

4. Generating raster layers on the water saturation coefficient of the soil based on results of the API index and the highest retention potential S.

5. Generating the Flow Direction raster layer and defining the flow path, originating from the damaged pipe.

6. Extracting the data on the highest capacity of retention and the saturation coefficient for each cell along the flow path.

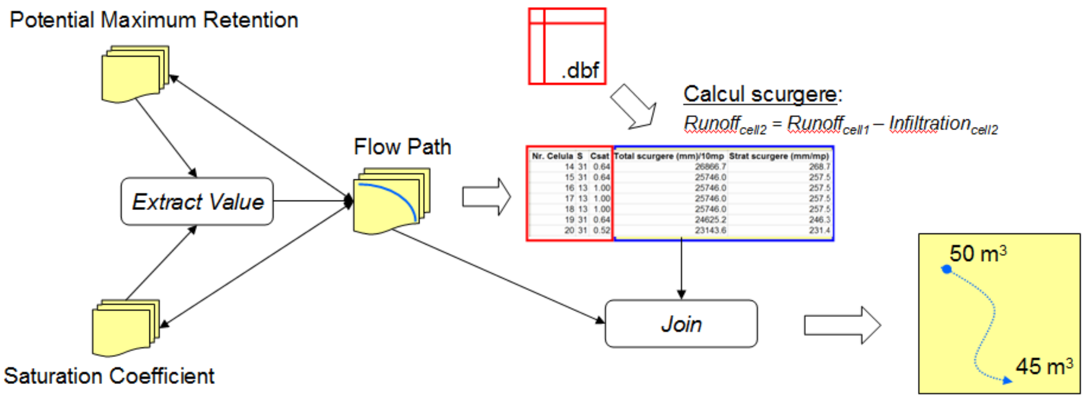


***Fig. 4** The algorithm and GIS layers required for the estimation of the runoff along the flow path*

The calculation of the runoff along the flow path is based on the following principle: the flow path is thought of as a string of "n" containers that begins from the cell corresponding to the spot where water joins a hydrographical course. Each cell that defines the flow path is considered a container that receives water from the container, which corresponds to the upstream cell and passes water on (after reaching its infiltration capacity by saturating the soil) to the downstream corresponding container. The image above **(fig. 4)** portrays the stages of the work process. It should be mentioned that the algorithm this thesis offers is new, as this approach has not been encountered in other studies from this field.

CHAPTER VII. CASE STUDIES AND RESULTS

Alongside the methodological contributions mentioned in the previous chapter, this thesis brings the following practical contributions: 1. Applications on the analysis of the hydrological conditions of the terrain aimed at either the entire Baia Mare Depression, or the territory of the villages connected to the water supply network; 2. Applications regarding the analysis of susceptibility to local flooding; 3. Applications regarding the calculation of the runoff caused by damage to the network, based on hypotheses and scenarios in Dumbrăvița and Chechiș.

7.1. Case studies and results regarding the analysis of the hydrological conditions of the terrain before the damage occurred

One of the applications was done in the first half of May. The amount of daily precipitation during this time was, in four days, over 10 mm/m^2, and on the 16th of May 2010, the recorded values were, in most of the depression, over 50 mm/ m^2.

Based on the precipitation maps and on the other layers concerning physical-geographical elements of the territory, maps that portray the hydrological conditions of the terrain for two villages—Dumbrăvița and Chechiș—were developed.

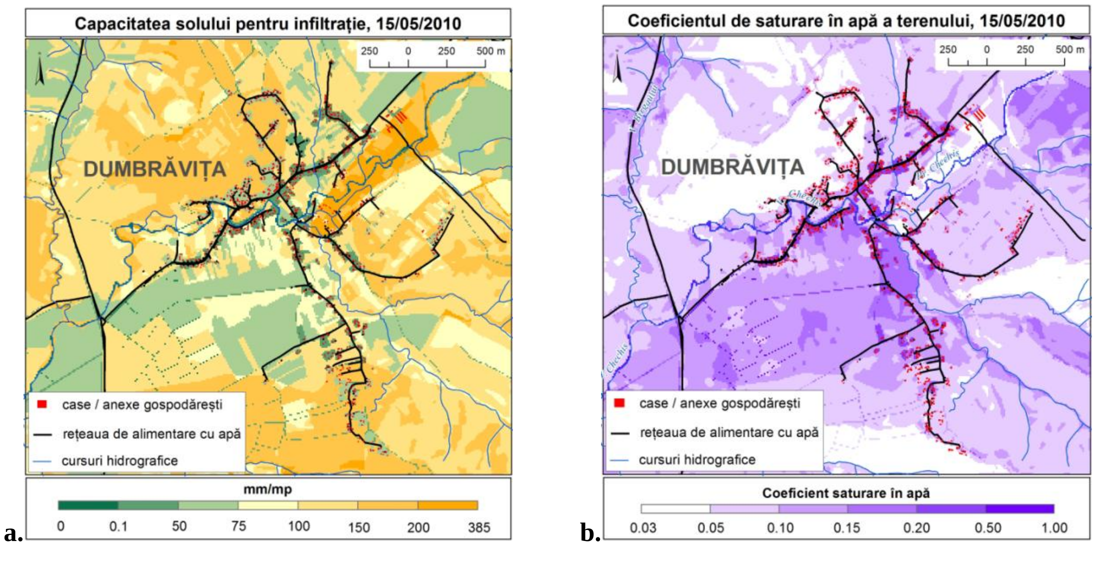


Fig. 5 *The hydrological conditions of the terrain that were analysed based on the infiltration capacity of the soil (a) and on the water saturation coefficient (b). Case study: Dumbrăvița, 15.05.2010*

7.2. Case studies and results regarding the analysis of susceptibility to local flooding

The result of this analysis is, at first, the map of the areas prone to local flooding (which can be obtained at a daily scale). F**ig. 6a** and **6b** give an example of such a result that was obtained by extracting the areas that have a water saturation coefficient of ≥ 0.5. Based on this layer, the map of pipelines prone to flooding in case of damage was developed. **Fig**. **6c** shows the pipelines that have different degrees of susceptibility in relation to the water saturation coefficient for Chechiş, Dumbrăviţa and Cărbunari.

The highest degree of susceptibility to flooding in case of damage to networks is in areas where the water saturation coefficients are of ≥ 0.9. These areas consist of the following towns and villages: Ulmeni, Salsig, Mireșu Mare, Lucacești, Gârdani, Pribilești, Tamaia, Chechiş, Dumbrăvița, Cărbunari, Coaş, Tăuții de Sus.

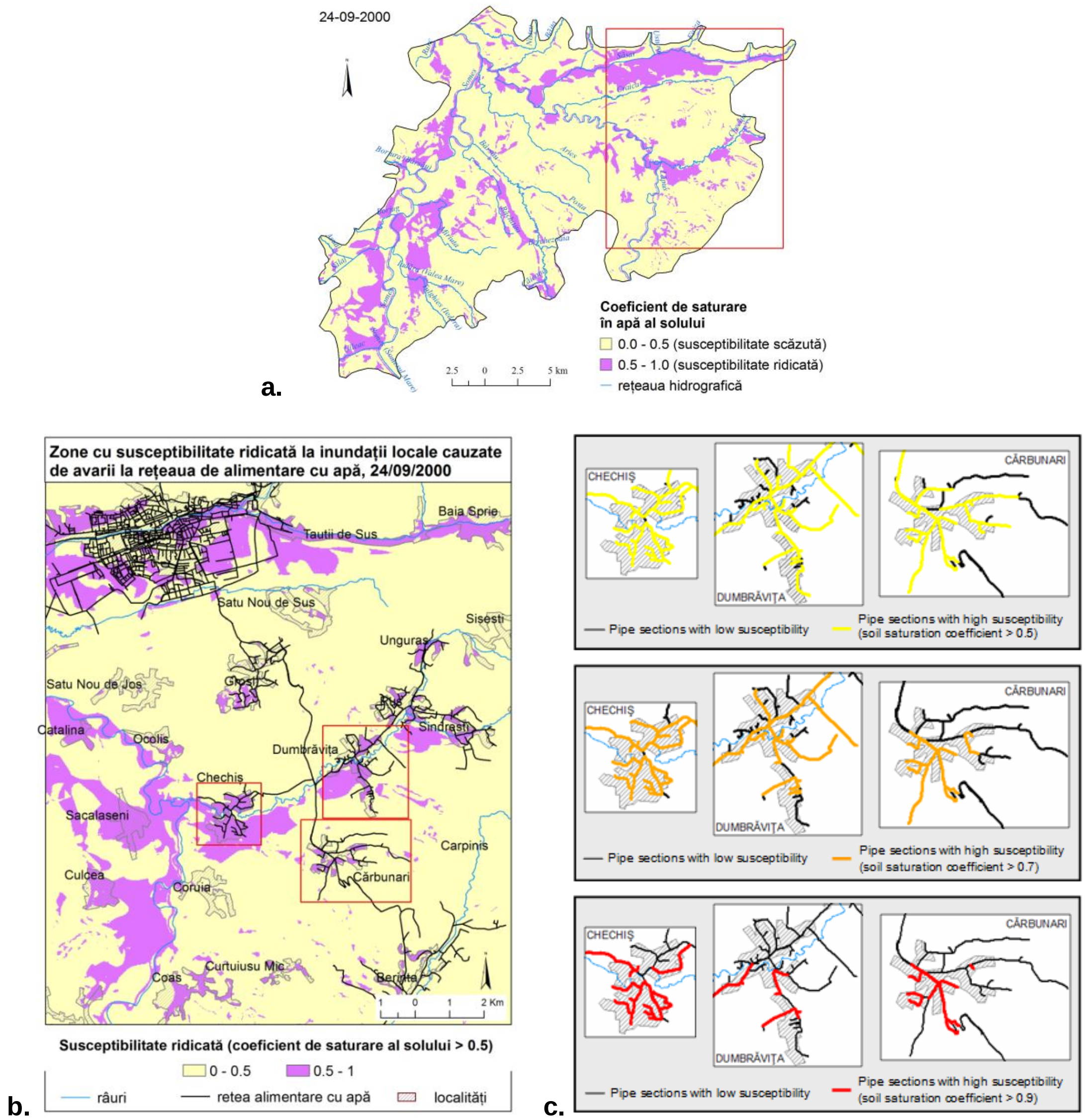


Fig. 6 *Maps of susceptibility to local flooding caused by damage to the water supply network (Haidu et al., 2013):* **a.** *susceptible areas in the Baia Mare Depression,* **b.** *susceptible areas in the area covered by the*

water supply network, **c.** *pipelines susceptible to cause flooding in case of damage in Chechiș, Dumbrăvița and Cărbunari*

Without a doubt, in order to complete the analysis of susceptibility to hydric risk phenomena caused by damage to networks, the deterioration of the distribution and supply pipes should be taken into consideration (degradation rate).

7.3. Case studies and results regarding the calculation of the runoff along the flow path from the damage point

The applications were in fact simulations of damage and assessment of runoff along the flow path on three water pipes located in Dumbrăviţa and two others located in Chechiș.

Information on real cases was unavailable. Therefore, several hypotheses were considered:

Hypothesis 1: the damage leads to water loss of 50 % of the average volume of water conveyed through the pipe.

Hypothesis 2: the damage is complete (for example if the pipe explodes) and this leads to water loss of 100% of the average volume of water conveyed through the pipe.

For each of the two hypotheses, the calculations were done following three scenarios:

1) damage duration 2 h; 2) damage duration 5 h; 3) damage duration 10 h

The average flow of water loss (**24 m^3/h** in the case of damage of 100%; **12 m^3/h** in the case of damage of 50%) was based on measurements done with flowmeters at the Mihai Eminescu pumping station during 27.02.2012, 10:37 – 29.02.2012, 05:27, with a temporal resolution of 10 minutes.

Two of the damage cases (*Damage 1* and *Damage 2*) that were taken into account in Dumbrăvița, whose results are shown in **fig. 7,** were studied by means of analysing and considering the hydrological situation of the terrain prior to 15.05.2010.

By analysing the most pessimistic hypotheses that correspond to the total destruction of the pipe in that precise spot (the damage leads to 100% water loss), it becomes evident in the case of Damage 1 that the flow path extends to over 50 m if the damage persists for 2 h; approximately 100 m, if the damage persists for 5 h; and > 230 m, if the damage persists for 10 h.

Here is another application, this time concerning Chechiș. In this case, as well, two possible damage points were identified, and based on the GIS methodology presented in the previous subchapters, the surface runoff from the damaged pipe was assessed.

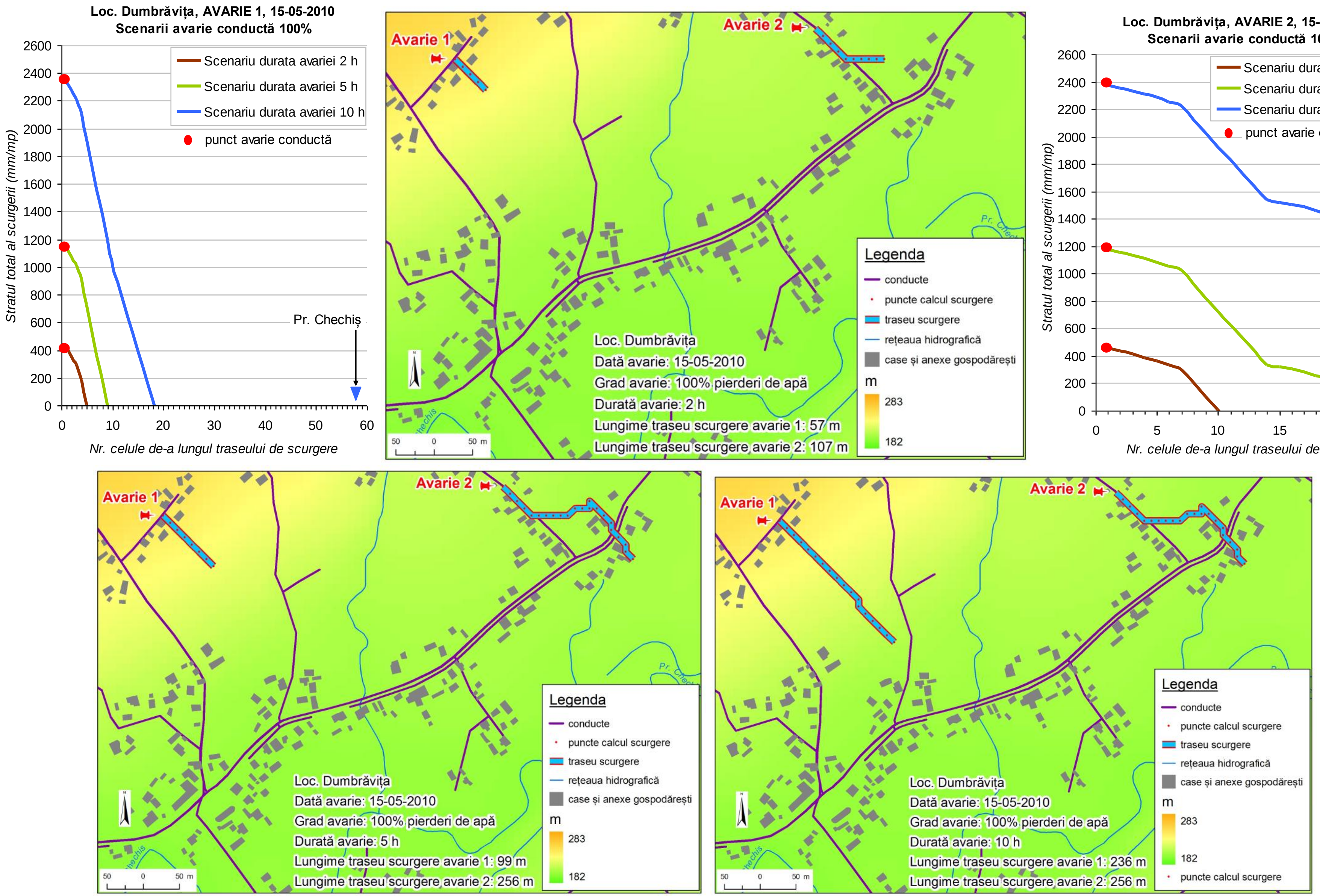


Fig. 7 *Results regarding the surface runoff along the flow path according to* ***hypothesis 2*** *(the damage is complete and it leads to water loss of 100% of the average volume of water conveyed through the pipe) following different scenarios that refer to the duration of the damage*

CHAPTER VIII. THE HYDROLOGICAL IMPACT OF DAMAGED WATER SUPPLY NETWORKS IN RURAL AREAS

This chapter first provides the cartographic identification of terrain susceptible to flooding or excess moisture taking into account the damage scenarios for Dumbrăvița and Chechiș, and after that it gives a quantitative assessment of the hydrological impact of the damage in the rural community and on the terrain that have different uses: *impact on homesteads, impact on means of communication, impact on crops*.

The main hydric risk phenomena caused by damage to water supply networks are the flooding of the analysed rural area and excess moisture.

Serious damage to water supply networks can have a significant impact on the following: settlements and their infrastructure, population, economic activities. Rural settlements that have such problems with their water supply network that lead to flooding or excess moisture, undergo hardship according to the location of the damage (and therefore, the degree of exposure to the hydric risk phenomenon), but also according to the sensitivity of the affected area as regards these aspects:

1. How the hearth of the settlement is affected because of the deterioration of the houses, homesteads.
2. How the population that lives or works around the range of the damaged area is at risk.
3. How the infrastructure elements from within the hearth or from areas where the population works are affected (”țarina” [“earth”], ”moșia” [“land”]). It regards the manner in which the following are affected: the electrical and telephone lines in such situations when the poles are damaged (as a result of surface runoff or infiltrations); the gas pipelines; the water supply network (as a result of surface runoff or infiltrations), thus creating the perfect conditions for pipe deterioration and occurrence of other flaws in the network.
4. Ecological effects: soil degradation (by erosion due to surface runoff), affecting and even destroying the flora, especially the vegetation near the damage site (as a result of the mechanical action of runoff or of the thermic action when the affected pipe conveys hot water).

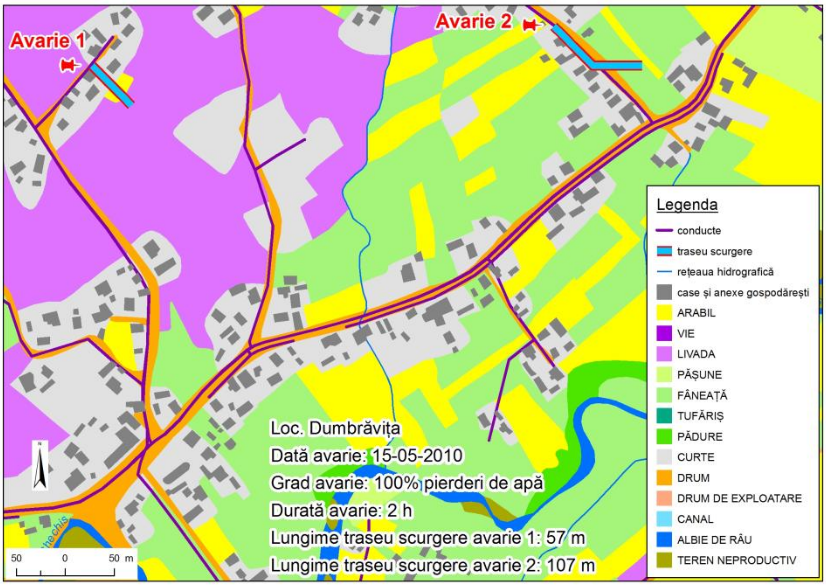
Evidently, when the runoff from damage to a network overlaps with a natural flood, the hydrological impact is much greater, having an enormous destructive potential that might even lead to loss of human lives. It is obvious that natural floods offer enough circumstances for the water released from the damaged pipe to follow its course according to the topographic configuration of the impermeable terrain.

When analysing the map of areas with high degrees of susceptibility to local flooding caused by damage to water supply networks according to the permeability/impermeability of the terrain in the Baia Mare Depression or in the rural areas south of Baia Mare, the following group of villages and towns can be observed as having the greatest exposure: Chechiș, Dumbrăvița, Cărbunari, Coaș, Tăuții de Sus, Ulmeni, Salsig, Mireșu Mare, Lucacești, Gârdani, Pribilești, Tamaia. Baia Mare runs a high risk of vulnerability as hydrological phenomena are concerned in the case of damaged networks in some areas on the outskirts of the city: the Vlad Țepeș neighbourhood, the Vasile Alecsandri neighbourhood, the industrial area (the west part), the southeast and east extremity (the exit towards Tăuții de Sus).

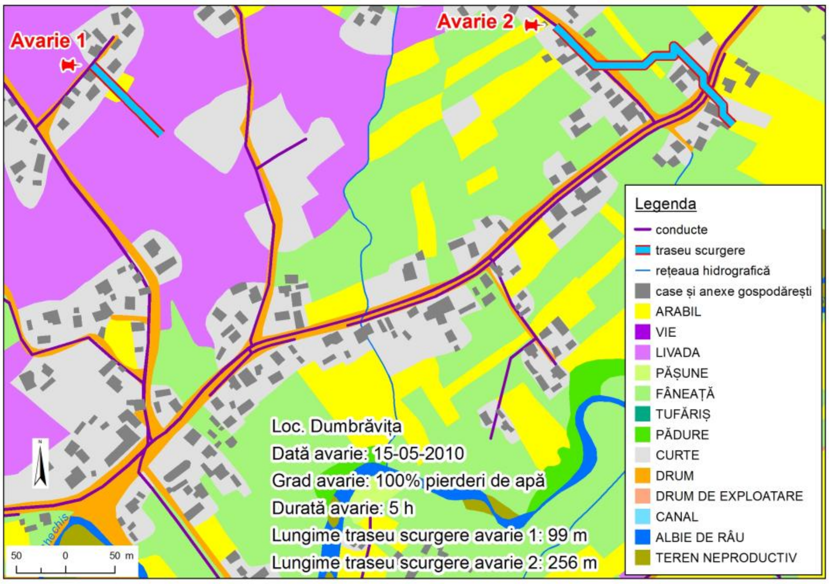
As regards the hydrological impact of the damage to water supply networks on the infrastructure, the following roads that cross or connect the areas prone to flooding in case of damage should be mentioned:

- DJ128B (in Săcălășeni; in an area of approximately 2 km between the intersection with DJ184A and the intersection with DJ182C; in Catalina).
- DJ184A (north of Coruia; in Chechiș; in some parts of Dumbrăvița, Rus, Sândrești).
- DJ182C (in Coaș).
- DN18 (in Baia Sprie and Tăuții de Sus, but also in a 1-2 km area as one enters Baia Mare).
- DN18B (in some areas in Berința and Cărbunari).
- DC79 (in Chechiș; in some areas in Ocoliș).
- DC107 (in some areas in Cărbunari)
- DC26 (in some areas in Rus and Unguraș)

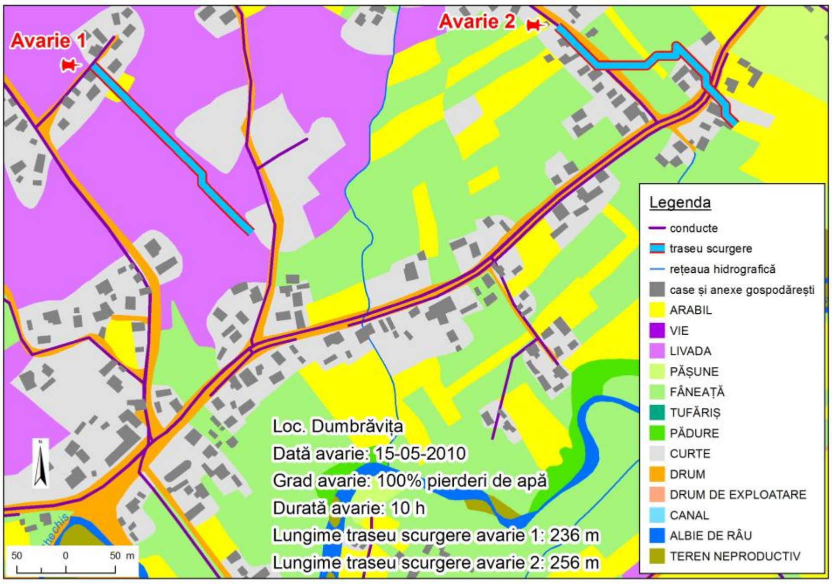
The categories of terrain prone to flooding or excess moisture can be observed in **fig. 8** for one of the scenarios for Dumbrăvița.



Damage duration 2 h



Damage duration 5 h



Damage duration 10 h

Fig. 8 *Categories of terrain prone to flooding or excess moisture in the case of damage of 100%. Case study: Dumbrăvița*

As in the case of homesteads, a synthesis has been done in reference to the number of roads affected in case of damage in the two analysed villages (the **tables 8.3** and **8.4** found in the thesis).

Water loss caused by damage to supply networks can also affect arable terrain, primarily because of excess moisture.

The **tables 8.5** and **8.6** from the thesis present a synthesis that refers to the number of cultivated parcels and their use, which would be affected in case of runoff in the two selected points.

CHAPTER IX. CONCLUSION

The results that refer to surface runoff in the area of affected pipes, obtained by means of GIS procedures, which were previously mentioned in the methodological part of the thesis, emphasise a dependence of the runoff values on the degree of water saturation of the terrain.

The map of the coefficient of water saturation of the soil highlights an increase in the values starting from wooded areas located on abrupt sunny slopes to urban or rural areas located on not as abrupt shady slopes. At the same time, high saturation coefficients are noticed in the area of the riverbeds of the main hydrographic courses that drain the study area (Craica, Chechiş, Berinţa, Săsar, Lăpuş).

When analysing the map of areas with high degrees of susceptibility to local flooding caused by damage to water supply networks according to the permeability/impermeability of the terrain, in the Baia Mare Depression or in the rural areas south of Baia Mare, the following group of villages and towns can be observed as having the greatest exposure: Chechiș, Dumbrăvița, Cărbunari, Coaș, Tăuții de Sus, Ulmeni, Salsig, Mireșu Mare, Lucacești, Gârdani, Pribilești, Tamaia.

Table 1 presents a synthesis regarding the runoff generated by damage and the terrain affected in Dumbrăvița for different periods of the damage under the same pluviometric conditions (15.05.2010).

As regards the usefulness of the Geoinformatics systems used in this field, the following benefits this system provides should be mentioned: the compilation and managements of the necessary spatial databases; the spatial modelling of the hydrological conditions of the terrain before to the damage occurred; the hydraulic modelling of water supply networks by means of simulating the water flow inside the damaged pipes; the spatial modelling of the surface runoff caused by water loss in the network due to damage.

Table 1. *Synthesis regarding the runoff generated by damage and the terrain affected for different periods of the damage under the same pluviometric conditions (15.05.2010) in case of pipe explosion.*
Case study: Dumbrăvița

Damage	**Scenario duration damage**	**Runoff length**	**Total layer of runoff (mm/ m^2) at the "x" distance from the damage point**				
			20 m	***40 m***	***60 m***	***80 m***	***100 m***
Damage 1	2 h	57 m	354	187	0	0	0
	Affected Terrain		homesteads, yards	Homesteads, yards, arable	arable, orchard	-	-
	5 h	99 m	1074	907	541	175	0
	Affected Terrain		homesteads, yards	Homesteads, yards, arable	arable, orchard	orchard	orchard
	10 h	236 m	2274	2107	1741	1375	1010
	Affected Terrain		homesteads, yards	Homesteads, yards, arable	arable, orchard	Homesteads, yards, arable	arable, orchard
Damage 2	2 h	107 m	434	389	333	203	6
	Affected Terrain		Homesteads, yards, road	Homesteads, yards, road	Homesteads, yards, road	road, meadow	meadow arable
	5 h	256 m	1154	1109	1053	923	726
	Affected Terrain		Homesteads, yards, road	Homesteads, yards, road	Homesteads, yards, road	road, meadow	meadow arable
	10 h	256 m	2377	2331	2286	2221	2024
	Affected Terrain		Homesteads, yards, road	Homesteads, yards, road	Homesteads, yards, road	road, meadow	meadow arable

This research can be developed and analyses that are more complex can be done in order to define the areas prone to flooding in case of damage to water supply networks, by means of studying the hydric risk that these events imply and assessing the disastrous effects they might have.

SELECTIVE REFERENCE LIST

1. Aburawe M. S., Mahmud R. A., (2011), *Water loss control and real-time runoff detection using GIS technology*, Proceeding of Geomatics Technologies in the City, Jeddah, Arabia Saudită.
2. Amaguchi H., Kawamura A., Olsson J., Takasaki T., (2012), *Development ant testing of a distributed urban storm runoff event model with a vector-based catchment delineation,* Journal of Hydrology 420-421, pag. 505-215.

3. Andreou, S., Marks, D.H. and Clark, R.M. (1987a). *A New Methodology for modelling Break failure Patterns in Deteriorating Water Distribution Systems*: Theory. Journal of Advanced Water Resources, **10**, March, pp. 2-10.
4. Baba H., Mano A., (2007), Inundation analysis on road-oriented mesh with digital city and sewerage maps, Advances in Geosciences, vol. 11: Hydrological Science, World Scientific Publishing Company, pp. 299-312.
5. Bhave P., (1991), *Analysis of flow in water distribution networks*, Technomic Publishing, Lancaster, PA, 641 pag.
6. Bilaşco, St., Haidu, I., (2006), *The valuation of maximum runoff on interbasinal areas, assited by G.I.S*, „Geographia Technica, no.2, ISSN 1842-5135, p.1-7, Cluj-Napoca.
7. Blažević M., Samardžic I., Kolumnić Z., (2005), *Leak detection in underground pipelines of municipal water distribution*, 4th DAAAM International Conference on Advansed Technologies for Developing Countries, Slavonski Brod, Croatia.
8. Butler D., (2009), *Runoff detection and management. Acomprehensive guide to technology and practice in the water supply industry*, Edit. Palmer Environmental, ISBN 0-9538014-0-3.
9. Chevallier Pierre, (1983), *L'indice des precipitation anterieures. Evaluation de l'humectation des sols des bassins versants representatifs*, Cah. ORSTOM, vol. XX.
10. Chow te Ven, (1964), *Handbook of applied hydrology. A compendium of water-resources technology*, McGRAW-HILL Book Company, New York, ISBN 07-010774-2.
11. Covas D., Ramos H., Graham N., Maksimovic C., (2004), *Application of hydraulic transients for leak detection in water supply systems*, Water Science and Technology: Water Supply, vol. 4, no. 5-6, pp. 365-374.
12. Crăciun A. I., (2009), *G.I.S algorithm for spatial representation of areas vulnerable to high flood depending on soil water reserve. Application: Hydrographic Basin of Posaga*, Geografia în contextual dezvoltării contemporane. Strategii de dezvoltare teritorială, p. 224 -231, Edit. Presa Universitară Clujeană, ISSN: 1843-2158.
13. Dong X., Shinozuka M., (2004), *GIS-based seismic damage localization for water supply systems*, 13th World Conference of Earthquake Engineering, Vancouver, Canada.
14. Gebremeskel S., Yong Bo Liu, De Smedt F., Pfister L., (2002), *GIS based distributed modeling for flood estimation*, Proceedings of the Twenty-Second Annual American Geophysical Union Hydrology.

15. Grise S., Idolyantes E., Brinton E., Booth B., Zeiler M., (2001), *Water utilities. ArcGIS data models*, ESRI SUA, 126 pag.
16. Haidu, I., Bilaşco, Şt., (2007), *Serious „flash flood" risks in rural area, Rural Space and Local Development*, Presa Universitară Clujeană, Cluj-Napoca.
17. Haidu I., Crăciun I. A., Marian R. A., (2013), *Mapping the pipe sections located in areas of high susceptibility to flooding.* Water Science and Technology: Water Supply (depusă pentru publicare).
18. Haidu, I., Imbroane, A., M., (1994), *The indirect computing of maximum runoff of small rivers*, Studia Universităţii „Babeş-Bolyai", Seria Geographya, Cluj-Napoca.
19. Haidu, I., Lazăr, I., Lenart, C., Imbroane, Al., (1990), *Modeling of Natural Hyrodenergetical Organization of the Smal Basins*, 1-st World Renewable Energy Congres, Reading-UK, in Energy and the Environment, Pergamon.
20. Haidu, I., Sorocovschi, V., Imecs Z., (2003), *Utilizarea SIG pentru estimarea riscului de producere a evenimentelor extreme: excesul de umiditate si seceta din Campia Transilvaniei*, vol. „Riscuri si catastrofe" (pag. 287-303), Edit. „Casa Cartii de Stiinta", Cluj-Napoca.
21. Halfawy M. R., Hunaidi O., (2008), *GIS-based water balance system for integrated sustainability management of water distribution assets*, NRCC-50807, 60th Annual Western Canada Water and Wastewater Association Conference, Regina, Saskatchewan, pp. 1-16.
22. Henry J. B., (2004), *Systemes d'Informations Spatiaux pour la gestion du risque d'inondation du plaine*, Thèse presentée pour obtenir le grade de Docteur, Université Louis Pasteur, Strasbourg.
23. Hickey E. H., (2008), *Water supply systems and evaluation methods. Volume II: Water supply methods*, U.S. Fire Administration, FEMA, 187 pag.
24. Keller E. I., Bilaşco Ş., Haidu I., Văduva B., (2009), *Using GIS to determine the flooded areas and risk assessment in the water supply system*, RevCAD – Journal of Geodesy and Cadastre, Alba Iulia.
25. Keller E., (2008), *Evaluarea şi simularea fluxului de apă în situaţii de risc cu ajutorul S.I.G. : aplicaţie la municipiul Baia Mare,* teza de doctorat, UBB Cluj.
26. Keller I. E., Bilașco Ș., Haidu I., Văduva B., (2010), *Using GIS to determine the flooded areas and risk assessment in the water supply system*, RevCAD – Journal of Geodesy and Cadastre, Alba Iulia nr. 10, pp. 239-248.

27. Li W., Ling W., Liu S., Zhao J., Liu R., (2011), *Development of systems for detection, early warning, and control of pipeline runoff in drinking water ditribution: A case study*, Journal of Environmental Sciences, 23(11), pp. 1816-1822.
28. Magyari-Saska Zs., (2008), *Dezvoltarea algoritmilor S.I.G pentru calculul riscurilor geografice naturale: aplicaţie la Bazinul Superior al Mureşului*, Teză de doctorat, UBB, Cluj-Napoca.
29. Marian R. A., Haidu I., Văduva B., (2008), *Realizarea retelei de sprijin pentru masuratori GPS RTK - Aplicaţie la depresiunea Baia Mare*, Simpozion International de Geografie Tehnica, Cluj-Napoca.
30. Marian R. A., Haidu I., Văduva B., (2008), *Proiectare bazei de date, definirea unui protocol de numerotare al nodurilor retelelor de apa*, SIG in evaluarea potentialului ecologic, managementul teritoriului si al resurselor umane – Confernce, Iasi
31. Marian R. A., Haidu I., Crăciun A. I., Văduva B., (2012), *GIS utility for hydrological impact evaluation caused by damages of water supply network in rural areas. Applications in Baia Mare Depression*, Geographia Napocensis, anul VI, nr. 2, pp. 103 – 109.
32. Marian R. A., Haidu I., Crăciun A. I., Văduva B., (2012), *Quantitative Study Of The Parameters Required To Identify The Zones With Susceptibility To Local Flood Caused By Damages Of Water Supply Network.* Water resources and wetlands-Conference, Tulcea
33. Marian R. A., Haidu I., Crăciun A. I. (2012), *GIS Techniques for Hydrological Flow Assessment Caused by Damages of Water Supply Network in Rural Environmental Application in Baia Mare Depression*, Air and Water components of the environment – Conference, Cluj-Napoca.
34. Marian R. A., Haidu I., Crăciun A. I., Văduva B., (2012), *Development of GIS portal for management in rural and urban space of Romania,* Rural Space and Local Development – Conference, Sighetul Marmatiei.
35. Olsen B. R. N., (2007), *Numerical modeling and hydraulics*, Department of Hydraulic and Environmental Engineerin, The Norvegian University of Science and Technoloy, ISNB 82-7598-074-7, 147 pag.
36. Pal M., Dixon N., Flint J., (2010), *Detecting & locating leaks in water distribution polyethylene pipes*, Proceedings of the World Congress on Engineering, London, vol. II, ISBN 978-988-18210-7-2.

37. Pratheeba P., Ambujam K. N., (2011), *Failure analysis and simulation based performance evaluation of water distribution system*, European Journal of Scientific Research, vol. 53, nr.3, pp. 369-384.
38. Ramesh H., Santhosh L., Jagadeesh J., (2012), *Simulation of hydraulic parameters in water distribution network using EPANET and GIS*, International Confecence on Ecological, Dubai, pp. 350-353.
39. Sandik D., (2009), *Handbook for reducing basement flooding*, Published by Institute of Catastrophic Loss Reduction, Toronto, Canada.
40. Sandik D., (2011), *Involving Homeowners in Urban Flood Risk Reduction. A study case of Sherwood Forest Neighbourhood, London, Ontario*, Published by Institute of Catastrophic Loss Reduction, Toronto, Canada.
41. Trépanier M., Gauthier V., Besner M. C., Prévost M., (2006), *A GIS-based tool for distribution system data integration and analysis*, Journal of Hydroinformatics, 08.1, pp. 13-24.
42. Văduva B., Marian R. A., Haidu I., (2007), *The use of geotools library in developing WEB GIS dashboards for pressure sensors*, Geographia Technica, no. 2, p. 77-84.
43. Văduva B., Marian R. A., Keller I. E., (2009), *Integrate GPS surveys and PDA to gather the necessay data for a hydraulic model of water management systems*, Buletinul Institutului Politehnic din Iași, Secția Hidrotehnică, tomul LV (LIX), Fasc. 1, pp. 47-54.
44. Wagner G. E., Lanoix N. J., (1959), *Water supply for rural areas and small comunities*, World Health Organization, Palais des Nations, Geneva.
45. Wu Y. Z., (2008), *Innovative optimization model for water distribution runoff detection*, Haestad Methods Solution Center, Benthey Systems, USA.
46. Zaharia C. S., (2012), I*dentificarea şi analiza hazardelor geomorfice, climatice şi hidrice din municipiul Baia Mare*, Teză de doctorat, UBB Cluj-Napoca, 293 pag.
47. Zaharia S., Chendeş V., Driga B., (2011), *Flooding occurence within the buit-up areas of Baia Mare*, Riscuri şi catastrofe, nr. X, vol. 9, nr. 1/2011, p. 175-184.
48. Zeiler M., (1999), *Modeling our world. The ESRI guide to geodatabase design*, Published by Environmental System Research Institute, California, 202 pag.