

## Damages caused by floods and flash-floods upon critical infrastructures. Case study: Maramureş county (Romania)

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**Abstract.** Critical infrastructure is defined as a network including telecommunications, information services, energy transport (electrical lines, natural gas and oil pipes), water supply, goods and persons transportation, financial, banking and emergency response services. All these are so significant that a disequilibrium or interruption of their operation would have a disturbing effect upon the daily life. Estimating the damage done by natural hazards to certain critical infrastructure sectors is considered an important interest topic. The main purpose of this research is the estimation of the damages generated by floods and flash-floods on the critical infrastructure in Maramureş County during 2005-2010. The damages analysis is based mainly on observations and quantitative data, obtained after a thorough analysis of literature and reports from the Ministry of Environment and Forests and the Inspectorate for Emergency Situation of Maramureş County. The results of the study were alarming. The damages caused by floods during the period subjected to study reach approximately 32 million dollars, highlighting the need for an integrated management system for critical infrastructure protection.

**Key Words:** critical infrastructure, damages, floods, Maramureş.

**Rezumat.** Infrastructura critică este definită ca fiind o reţea ce include serviciile de telecomunicaţii, transport, energie (linii de curent electric, conducte de gaz natural sau petrol), alimentare cu apă, transportul persoanelor şi al mărfurilor, servicii financiare şi bancare şi de răspuns şi intervenţie în cazul producerii unei situaţii de urgenţă. Toate acestea sunt extrem de importante, astfel că un dezechilibru sau o întrerupere în funcţionarea lor are consecinţe semnificative asupra vieţii de zi cu zi. Estimarea pagubelor produse de dezastrelor naturale asupra sectoarelor de infrastructură critică este un subiect de mare interes. Principalul scop al acestei lucrări este estimarea pagubelor generate de inundaţii şi viituri asupra infrastructurii critice din judeţul Maramureş în perioada 2005 – 2010. Analiza pagubelor se bazează pe observaţii şi date cantitative, obţinute în urma unui studiu aprofundat al literaturii şi rapoartelor Ministerului Mediului şi Pădurilor şi ale Inspectoratului pentru Situaţii de Urgenţă al judeţului Maramureş. Pagubele produse de inundaţii în perioada studiată ating 32 milioane de dolari, subliniind necesitatea unui sistem integrat de management pentru protecţia infrastructurii critice.

**Cuvinte cheie:** infrastructură critică, pagube, inundaţii, Maramureş.

**Introduction.** Critical infrastructure is defined as a network including telecommunications, information services, energy transport (electrical lines, natural gas and oil pipes, heating network), water supply, goods and persons transportation, financial and banking services, governmental and emergency response services. All these are so significant that a disequilibrium or interruption of their operation would have a disturbing effect upon the daily life (Brugen 2008). A critical infrastructure is something that people depend on, either directly or indirectly, for their lives and well being, in any time frame (Cohen 2010).

Critical infrastructures play a significant role in providing operational safety of the economic, social, political, informational and military processes. They are considered critical due to:

- the one-of-a-kind nature within the infrastructures of a system or process;

- their vital significance, as a material or virtual support in the operation of systems and in development of the economic, social, political, informational and military processes;
- the irreplaceable role they have for the stability, reliability, safety, operation and especially security of the systems;
- enhanced vulnerability towards direct threats, as well as those connected to the systems they belong to;
- special sensitivity to the variation of the conditions and especially to sudden situation changes.

In Romania, there are many critical sites which lie across the country's borders, all of which could be potential points of failure of the critical infrastructure system. All these sites are simple elements of a complex system where the vulnerability of the whole is a function of the vulnerability of the weakest element (Bakir 2007). Electricity network, water supply system, chemical plants or roads network are all elements of this complex system. Protection of the critical infrastructure must be accompanied by a detailed and thorough research and analysis to correspond to the economic, social and political unique circumstances in each region (Ouyang et al 2009).

Floods represent a stage in the flow evolution of a river, being characterized by very fast rising levels and discharges.

Floods are generated by both natural and anthropogenic factors. Most river floods are generated directly or indirectly by atmospheric events, such as heavy or prolonged rainfalls. Snowmelts and ice melts are causes specific to the cold periods, when the snow accumulates and melts rapidly in spring. Anthropogenic causes include deforestation, failure of dams and embankments.

Flood damages encompass a wide range of harmful effects on humans, their health and their belongings, on public infrastructure, cultural heritage, ecological systems, industrial production and the competitive strength of the affected economy (Messner & Meyer 2006). Absolute protection is both unachievable and unsustainable, because of high costs and inherent uncertainties (Schanze 2006). Therefore, an adequate and efficient flood risk management is more appropriate.

In Romania, the most important disasters triggered by floods took place in 1926, 1970, 1975, 1991, 2005 and 2010. Taking into account the number of deaths in 1926 (1,000 deaths) it can be said that flooding represents the second disaster in the recent history of Romania after the earthquake in 1977 when there were registered 1,641 deaths. The recent floods in 2005 together with the earthquake in 1977 represent the most representative natural disasters in the Romanian history in what concerns the material damages, which were calculated at approximately 2 billion dollars for each event. In the last decade, the damages exceeded 5 billion dollars, meaning a medium annual loss of 483 million dollars. Almost half of them were generated by the 2005 flooding. The number of casualties in that period is 208 (Senzaconi et al 2010).

## Material and Method

***Methodology for estimating the damages generated by floods and flash-floods on critical infrastructure.*** The term "damages" associated to floods includes the entire range of potential losses generated by floods: negative impacts on human life, health, public infrastructures, cultural heritage, industry and ecosystems.

The estimation of the damages generated by floods and flash-floods on the critical infrastructure in Maramureş County was based mainly on observations and quantitative data, obtained after a thorough analysis of literature and reports from the Ministry of Environment and Forests and Inspectorate for Emergency Situation of Maramureş County. The analysis highlighted the direct, tangible consequences of floods on several infrastructure elements, such as: roads, bridges, electrical lines or gas network. In order to obtain a clear view of the impact these disruptions had on the everyday life and human society, the damages were measured in monetary values or in units, without taking into account any associated/supplementary indirect costs. Damages values were

estimated in American dollars, using the leu-dollar reports in the flood periods (Arghiuş et al 2010).

This paper calculates the damages generated by floods in the towns and communes in Maramureş County, over a representative time period of almost 6 years (2005 - September 2010).

**Study area.** Maramureş county is located in the North of Romania, at the border with Ukraine, between 47°20'00''–48°00'15'' latitudes and 22°52'30''–25°07'30'' longitudes. The surface of the county totals 6,215 km<sup>2</sup>, 2.6 % of the entire country.

This represents one of the most interesting geographical areas in Romania. The geological-morphological evolution shaped a few distinct relief units within the county: mountain area (2,655 km<sup>2</sup>, representing 43 % of the county territory); hills, plateaus and piedmonts area (1,873 km<sup>2</sup> - 30%); depressions with meadows and terraces (1,687 km<sup>2</sup> - 27%).

The county includes 76 localities, totaling 510,109 inhabitants (137,921 in the city of Baia Mare), of which: 2 cities, 11 towns and 63 communes with 234 villages. The demographic density is 85.7 inhabitants/km<sup>2</sup>, lower than the country average. Of all the inhabitants, 241,832 live in the rural areas and 268,277 in urban areas.

The climate is temperate - continental, with moderate influences. The Eastern part is influenced by polar air masses, while the Western part of the county is dominated by a moderate continental climate with oceanic influences. The prevailing winds blow from East and North-East.

The hydrographical network has a total length of 3,100 km, being tributary directly or indirectly to Tisa river (Figure 1).

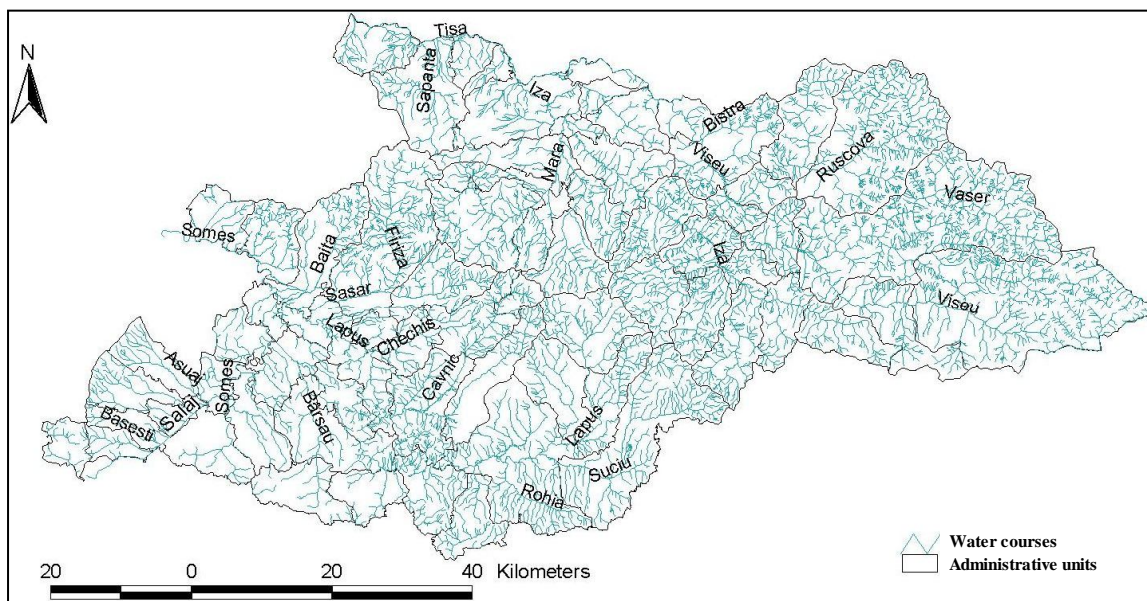


Figure 1. The hydrographical network in Maramureş County

The most important component of critical infrastructure is the road network, which includes 309.1 km of national roads, 895.8 km of county roads and 370.4 km of village roads. Besides those mentioned above, there are several hundreds km forestry roads (Figure 2).

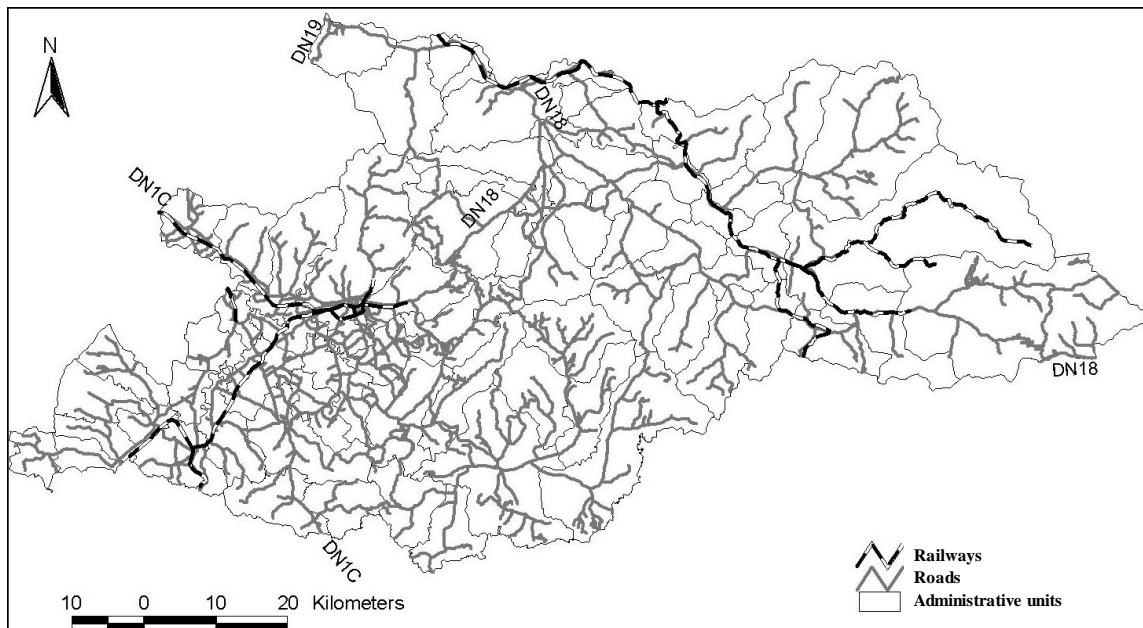


Figure 2. The road and rail-road network in Maramureș County

**Results and Discussion.** As a result of detailed interpretation of reports elaborated by the Ministry of Environment, by the Romanian Waters and by the Inspectorate for Emergency Situations of Maramureș County, there was concluded that since the floods and flash-floods in 2005 to present times, a series of critical infrastructure elements were damaged, thus disturbing the daily life, the health of the population and the efficient functioning of several socio-economic units (e.g. schools, tourist motels, furniture factories etc). The main elements of damaged critical infrastructure were the streets, bridges and village roads, and, to a smaller extent, the national and county roads, water supply networks, water storage systems, electric networks and communication networks.

The total value of the damages is 32 million dollars, distributed yearly according to the graphic below.

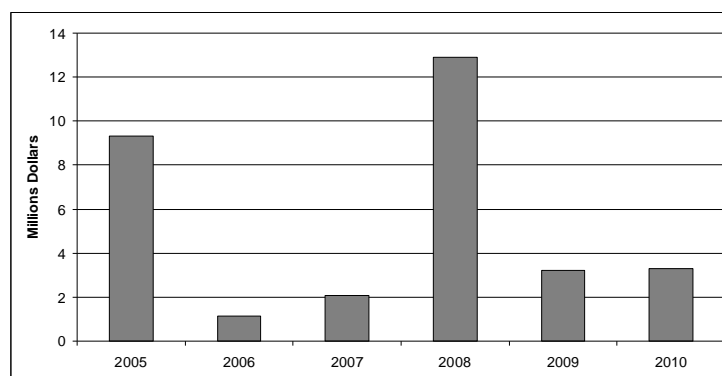


Figure 3. Value of damages caused by floods and flash-floods upon the elements of critical infrastructure in the Maramureș County (2005 - present)

The highest value of the damages inflicted upon the critical infrastructure elements was reached in the year 2008. The significant negative consequences of 2008 are caused by the floods occurred on Tisa, Vișeu and Iza rivers, during 24 and 27 July 2008. During this period of time, the Northern Romania was under meteorological and hydrologic warnings, of yellow, orange and red levels.

Of total losses, approximately 21 million dollars (65%) represent the value of traffic infrastructure damages. Very high losses associated to the damage of these infrastructure elements are due to the local topography, from the mountain and hilly regions of the county, which forces the network of national, county, village and forestry

roads to accompany the watercourses in their immediate neighborhood. Also, one should not forget the high specific cost of the road infrastructure works, especially in a fragmented region such as the studied one.

In Maramureş county, during the study period, no less than 6.7 km of national roads, 26.03 km of county roads and 442 km of village roads were damaged by floods and flash-floods. The significant damages associated to county roads are generated by the low building and design standards, lower than those for national roads. Therefore, taking into consideration the lower importance of these roads, their level is only a little higher than the average level of the neighboring river waters, which leads to their flooding even in case of floods with high exceedence probability. On the other hand, the lack of protection associated to asphalt covers must be mentioned, given the fact that almost all the commune roads are unmetalled, thus being more exposed to torrent flooding.

Based on the analysis of the results, it can be observed that the county roads have been affected over a total length of 442 km, which exceeds the total length of the roads network in the county 370.4 km. This situation is explained by the fact that some road sectors, having significant lengths, have been affected several times in the mentioned time period.

Another 195.8 km of damaged town streets are added, totaling approximately 670 km of damaged traffic infrastructure. The level of damaged roads (affected km) due to floods is illustrated in Figure 4.

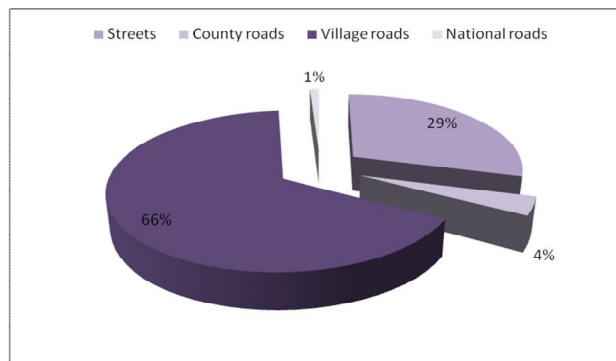


Figure 4. Damages (in percentage) inflicted upon various types of traffic infrastructure due to floods and flash-floods in Maramureş county, during the 2005-2010 period.

A special situation occurred in 2005 when 24.05 km of road in the town of Seini and 10.4 km of road in the city of Baia Mare were damaged by floods and flash-floods. These losses have reached a total amount of 3.1 million dollars from a total of 3.3 million dollars representing the entire value of losses caused by the damage of streets in the year 2005.

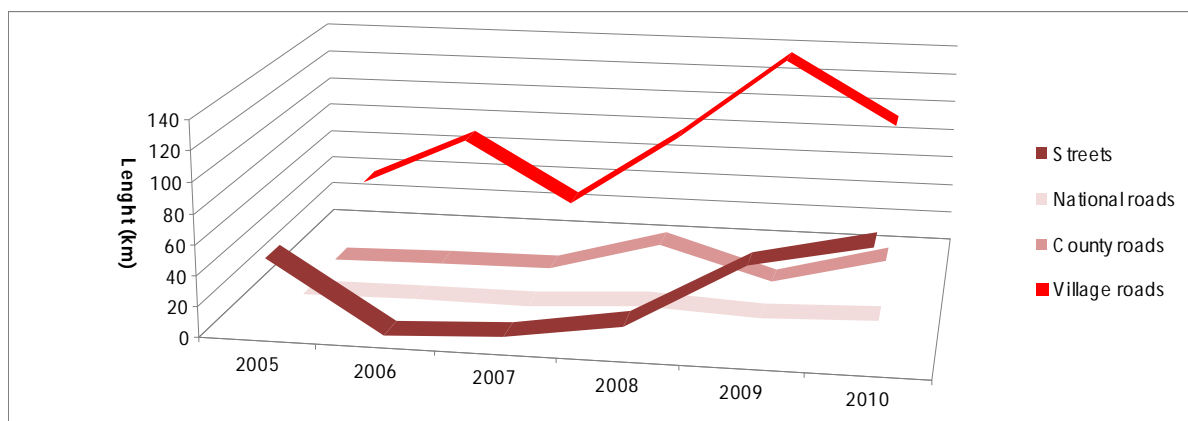


Figure 5. Length of damaged critical traffic infrastructure related to the type of infrastructure and the period of study.

One should also mention that the most significant damages were inflicted upon the traffic infrastructure in the year 2010, exceeding the values reached in previous years. During the current year, approximately 190 km of road were destroyed by floods within the surface of Maramureş county (Figure 5). Moreover, the fact that of this total of 73 km from the damaged traffic infrastructure is represented by streets in towns and cities is an alarm signal for the need of an integrated management system for the critical infrastructure protection.

Therefore, the development of flood control works of the valleys crossing the localities is absolutely necessary in view of the protection of streets in towns and cities. Moreover, in order to decrease the losses caused by floods and flash-floods to the traffic infrastructure, risk maps should be elaborated to illustrate the real state of the national, county and village roads in the neighborhood of the water courses.

Another negative consequences caused by floods and flash-floods to critical infrastructure is the damage of bridges. A number of 116 important bridges (Figure 6) and more than 300 bridges in villages and communes were damaged or destroyed by flood (Figure7).

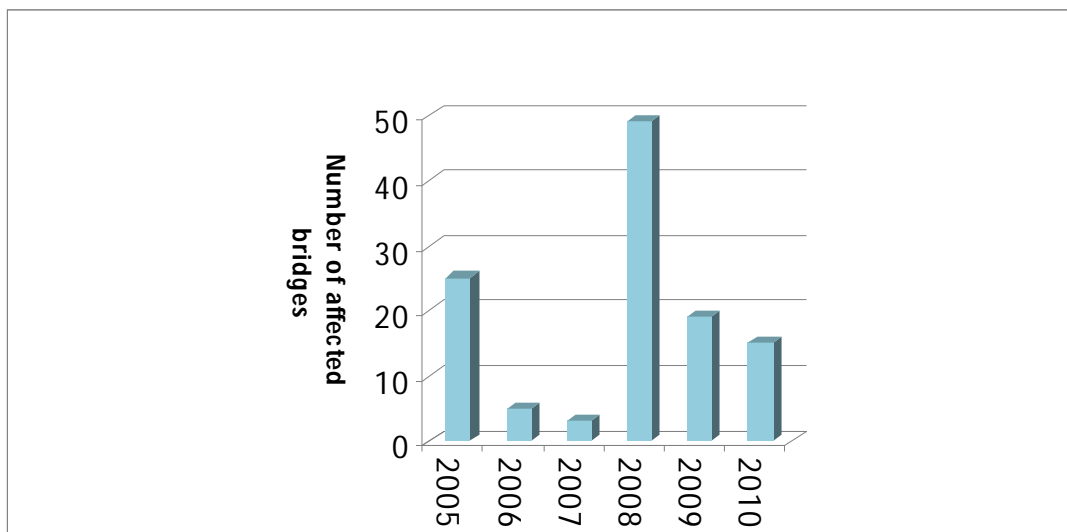


Figure 6. The number of bridges damaged during the 2005-2010 period by floods and flash-floods in Maramureş county.

Special problems occurred in 2008 in Borşa Maramureş where 20 bridges and 49 footbridges were destroyed or damaged by floods. The value of these damages reached approximately 2 million dollars.



Figure 7. Bridges affected by flood in Vişeu de Sus town, July 2008.

Bridges have a major importance during emergency situations, especially where some settlements can remain isolated following the disaster. The cases of temporary partial isolation of groups of persons were quite frequent. In such conditions, the access of

people to shops, pharmacies, schools, and other services necessary for the daily life was much restricted.

The roads and bridges were not the only types of critical infrastructure damaged by floods within the limits of the Maramureş County. Flood control works such as the canalization works along several rivers in the county were much damaged by the floods. Moreover, the urban public works (water supply, sewage system, communication networks, electrical and gas supply networks) were also damaged by the large floods. Both in the year 2006 and in 2007 the water storage basin used for the needs of the Dumbravita locality was seriously damaged. In the year 2008, 8.7 km of drinking water supply network from various localities of the county were damaged, creating discomfort to the population and in some cases, even threatening their health. A special case occurred in Borşa where 4.7 km of water supply network totaling 600,000 dollars were destroyed by flash-floods. In 2008, another 5 km of phone line network and 16.4 km of electrical network were destroyed. The intensive erosion processes occurred during the flash-floods favored the collapse of a series of the cables support poles through the sinking phenomena, causing the isolation of several households in Leordina, Moisei and Rozavlea, from the electrical and communication networks.

**Conclusions.** The present study was performed during a period of 6 years (2005-2010) with the specific objective of assessing the damages caused by floods and flash-floods upon critical infrastructure, which are the most frequent natural hazards in Maramureş County.

The results of the study were alarming. The damages caused by floods during the period subjected to study reach approximately 32 million dollars. 670 km of traffic infrastructure, 116 important bridges, 16.4 km of electrical network, 8.7 km of water supply and 5 km of phone lines network were destroyed or damaged. Most of the damages are associated to traffic infrastructure, major damages being recorded especially in the hills and mountains regions, with high population density (e.g. Maramureş Depression), where floods have greater speeds and strengths and the roads neighbor the water courses. All these damages, besides the fact that they represent significant material losses, lead to threats upon the safety and wellbeing of population.

The efficient solution for the removal of these shortcomings is the implementation of an integrated protection system of critical infrastructure. This is a concept management system, based on the disaster management. Such a system is composed of a series of stages which include an ensemble of rules and procedures necessary for the protection of critical infrastructure from the natural disasters. The implementation of such a system is a voluntary system and the improvement of critical infrastructure protection should be seen as a high-interest issue in Romania.

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