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# DISASTER RISK MANAGEMENT OF URBAN SYSTEMS

BY
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Evaluating the risk of natural disasters is an intensely debated issue, both on national and international level. In the present paper, after a brief review of the international research in this field and an introduction in risk management, we insisted on risk analysis of an urban area, called urban system. More precisely, we investigated the evaluation of risk and the behavior of the pipelines infrastructure characteristic in an urban area during an earthquake.

By taking into account a certain region in Jassy city area, we present a methodology of evaluating seismic risk of the utilities network of the region. The method consists in establishing the necessary steps to be taken in such an evaluation. These steps are also graphically displayed for the gas pipelines of the area, and emphasizing the critical points existent in that sector (*e.g.* gas stations).

Using the cellular automata technique, inspired from the artificial intelligence and complex system fields, based on the GIS map of the analysed region, we obtained a map with the risk areas in case of an earthquake, taking into account the gas pipelines network and the existing critical points.

## 1. The International Context and National Strategies

### 1.1. International Strategy for the Prevention of Disasters

The general objective of the strategy is to enable all societies to overcome natural, industrial, and environmental disasters in a way that enables the reduction of environmental, human, economic, and social losses. Based on this remark, the following four objectives were identified [1]:

a) Increasing the awareness of the public to promote an understanding of risks, vulnerability, and prevention of disasters at international level.

b) The involvement of public authorities in the implementation of policy and actions in the area of disaster prevention.

c) The promotion of multi-disciplinary partnerships, including the extension of prevention networks.

d) The improvement of scientific knowledge in the area of disaster prevention. Thus, the scientific and academic sectors are directly involved.

To attain these objectives, a number of areas of general interest were defined: some of these concern the evaluation of vulnerability, some concern the management of eco-systems, land, town-planning sauvage, etc. and, finally, others concern legal instruments relating to disaster prevention.

### 1.2. Word Conference on Disaster Reduction

Another important stage in the fight against disasters was marked by World Conference on Disaster Reduction which was held in Kobe, Japan, in January 2005. At the end of this four-day conference, a final document, the Hyogo Framework for Action 2005-2015, was adopted, which provides a reference framework for the measures to be taken over the next decade. A Final Declaration was also adopted at the conference. The measures defined in the Framework for Action involve governments, international organizations, and civil society. They also incorporate all decision levels, *i.e.* local, regional, national, and international ones. The conference highlighted the urgent need to establish prevention and preparation programmes which are better coordinated at global level.

### 1.3. The European Level

The programmes of the majority of cooperation and development strategies, either those of the OECD's Development Cooperation Directive (DAC), the European Union, or national cooperation strategies, now include risk and disaster management.

At European Commission level, a humanitarian aid department (ECHO) was created in 1992 with the goal of providing aid to the victims of humanitarian crises outside the European Union. In view of the scope and repercussions that natural disasters can have in the most vulnerable countries, ECHO launched its disaster preparedness programme DIPECHO (Disaster Preparedness ECHO) in 1996. The basic objective of this programme is to reduce the vulnerability of populations to natural disasters and this is demonstrated, for example, in its support of projects targeting the integration of disaster preparedness measures in aid operations and in development programmes.

## 2. Introduction to Disaster Risk Management

Disaster risk management seeks to comprehensively reduce the disaster risk to which people are exposed in disaster-prone regions. The top priority is to reduce the population's vulnerability to earthquake, floods or storms, and prevent the emergence of new risks [2].

Risk management is a systematic management of the process exposures to achieve its objectives in a manner consistent with public interest, human safety, environmental factors, and the law. It consists of planning, organizing, leading, coordinating, and controlling activities undertaken with the intention of providing an efficient pre-loss plan to minimizes the adverse impact on risk regarding the organization's resources, earnings, and cash flows [1].

### 2.1. The Elements of Risk Management

Risk Management comprises two key elements: *Risk Assessment* and *Risk Control.*

*Risk Assessment* can take place at any time during the implementation of a project, though the sooner the better. However, *Risk Control* cannot be effective without a previous Risk Assessement. Similary, most people tend to thing that having performed a risk assessement, they have done all that is needed. Far too many projects spend a great deal of effort on Risk Assessement and then ignore Risk Control completely.

*The Assessment of Risk* has three elements:

a) *Identify Uncertainties* – explore the entire process plans and look for areas of uncertainty.

b) *Analyse Risks* – that specify how those areas of uncertainty can impact the performance of the project, either in duration, cost or users requirements.

c) *Priority Risks* – when it is established which of those risks should be eliminated completely, because of potential extreme impact, which should have regular management attention, and which are sufficiently minor to avoid detailed management attention.

*The Control of the Risk* comprises three elements:

a) *Mitigate Risks* – take whatever actions are possible in advance to reduce the effect of risk. It is better to spend money on mitigation than to include contingency in the plan.

b) *Plan for Emergencies* – for all those risks which are deemed to be significant, it exists an emergency plan in place before it happens.

c) *Measure and Control* – track the effects of the risks identified and damage them to a successful conclusion.

## 3. Urban System Exposure to Natural Disasters

### 3.1. Introduction

A city or an urban agglomeration can be easily considered as a system. To understand how this system works, we analyse the city using two main approaches. In the first approach one defines the urban components and the system's functioning, its representative indicators, their characteristics as urban resources, and their vulnerability. In the second approach, one analyses the elements of risk and their distribution in the urban components.

The urban system can be studied from several points of view. It can be seen as a place of heterogeneous groups of humans congregating, a place of living, a place of economic, cultural, and administrative activities, and a place of power and decision-making. It is a place that also provides a certain number of services and occupies a specific place within a given geographical and decision-making environment. It is a place where different systems converge, assuming specific shapes, and marking the urban identity and image, by radiating its influence.

### 3.2. The Operation of Urban System

Urban development and functioning depend on a numerous internal relations between its urban components. The damage caused by an earthquake to the same elements of risk in two different cities will not create the same disruptions and consequences for the whole system. The corresponding impact of the disaster will depend on internal and external relationships, and possible functional substitutions of damage elements. This means that the risk analysis must not only consider the vulnerability of elements at risk, but should also assess the failure and resistance chains due to interdependency of the main functions, activities, decision-making, and human behaviour in an urban system.

Thus, a city can be defined as an *open working system*, as it is the place of numerous social, economic, political, and physical exchanges. The urban system is not only dependent on inner flows, but also on its external environment and relationship at regional, national and international levels.

### 3.3. Risk Analysis for the Urban System

In analysing the risk for an Urban System, the following seven components are defined:

a) Populations: inhabitants, workers, tourists, transients, demographic distribution, demographic growth, etc. The inhabitants are the city's heart and a part of the city's vulnerability.

b) Urban space – natural environment, built-up environment (buildings, infrastructure, lifelines, etc.), and policy environment (spatial organization, land-use, urban fabric and natural features, natural resources).

c) Urban functional activities and services bear on the main urban services: housing, supply, sanitation, transportation, communication, social and emergency functions, presenting different levels of adaptation to seismic threat.

d) Urban activities, respectively economic, administrative and cultural activities that are variably vulnerable to earthquakes.

e) Urban government and actors: institutional, socio-economic, and political organizations, urban actors, urban policy, decision-marking process with special emphasis on emergency management.

f) Identity and culture: social cohesion, local culture and history (with special emphasis on the culture and memory of risk), symbolic images and representations, etc.

g) External radiance: symbolic features, external image and representations, regional position, etc.

Considering an analytical approach, the *Urban System* can be characterized by three groups of elements: material, human, and immaterial-groups of elements that are potentially exposed to natural risks.

A. *Material elements* represented by class of

a) *buildings*: housing, economic activity units, administrative activity units, cultural and sports activity units, urban-function units;

b) *main infrastructures and roads*: transportation terminals, civil engineering infrastructures, highways, roads, streets, bridges, etc.;

c) *lifelines and reservoirs*: energy systems (electricity, gas, oil, etc.), drinking-water system, sewage system, waste-disposal system, telecommunications system, radio system, etc.;

d) *patrimony*: natural resources as woods, waters, etc., historical buildings, other physical symbols;

e) *areas or geographic units*: identified as being homogeneous according to the urban frame.

B. *Human elements*:

a) *city users*: citizens, visitors, workers, etc.;

b) *urban actors*: institutional and socio-economic managers, political and economic actors, decision-makers, public-service representatives, health and crisis-management specialists, etc.;

c) *outstanding personalities*: key political figures, captains of industry, well-know artists, etc. Such persons can play determinant roles in city life, either directly such as the mayor, or indirectly such as captains of industry.

C. *Immaterial elements*, that correspond to certain symbols or representations of the city, related to inhabitants, its image, its culture, or to its social fabric or history. One place will be considered as particularly young and dynamic, whereas another will be known for its calm and good life. Such immaterial and subjective-though quite real-elements share in a city's development and its position in relation to the outside world. Just like the other elements, they are vulnerable to a major disaster such as an earthquake:

a) *identity*: culture, history, social cohesion, preparedness;

b) *radiance of the system*: projected image, external relationship.

To evaluate the consequence of a disaster such as an earthquake, the method aims at identifying the essential elements for the functioning and development of an urban system. This refers to the elements of "significant value", in terms of social or utility value for city operations. This ranking is necessary for fine-tuning the vulnerability analyses, by subjecting the main issues to in-depth analysis and limiting the secondary use to a rapid evaluation [3].

The aim of the Urban System Exposure approach is to evaluate the role of these elements with risk in the urban system's functioning. In order to do it, it's necessary to use some adapted tools.

## 4. Risk Assessment of Lifelines Systems

### 4.1. Introduction

As we have seen before, the first step of the Project Risk Management is Risk

Assessment and the next one is Risk Control.

Risk Assessment implies the inventory of all risk elements encountered in the area in question, their analysis as well as establishing an indicator for each of them, according to its importance in case of a natural disaster of an earthquake. Naturally, according to this indicator, a hierarchy of all these risk elements shall be settled. As seen, an urban system is characterized by three elements exposed to risk: material elements, human elements, immaterial elements.

A high risk within an urban system appears in the lifelines systems (material elements), whose efficiency is reflected in the development and evolution levels of the society in question. These systems represent a complex set of components and subsystems essential in sustaining and developing the life of the community.

The modern society is totally dependent on an installation infrastructure which is a subsystem of the lifelines system made of numerous different networks. The common factor is to provide utilities without which the society could not exist: water supply, sewage, gas distribution, power supply, telecommunications network, etc.

The risk assessment of lifelines, infrastructures and essential facilities follows the general equation, used also in [4]

$$(1) \qquad \{\text{Seismic risk}\} = [\text{seismic hazard}] \times [\text{vulnerability}] \times [\text{elements at risk}].$$

The complexity of risk elements of this subsystem varies from an area to another, from a community to another and the impact on the society of the losses due to any disfunctionality after an earthquake depends on the vulnerability of each component and of the entire network as a whole.

The research performed lately around the world lead to significant advance in discovering new data, useful in preparing the community for the direct and indirect loss derived from the damage provoked by an eventual earthquake [4]. The implementation of a new methodology for risk assessment leads to the minimization of the damage. The risk, once established, may help to determine the priorities in risk management in order to evaluate and compare the risk level to the specific standard one.

#### 4.2. Risk Assessment of Installation Infrastructure after an Earthquake

A. *The socio-economic impact on the society of the malfunction of the installation infrastructure*

The functioning of the installation infrastructure *during* and *after* a destructive earthquake is of vital importance for the society and contributes to the rescue and emergency operations, as well as to weighing the anchor. The malfunctioning or the nonfunctioning of certain systems within the infrastructure leads, in the best case, to a scenario concerning the breaking of a branch of the network in question, this fact leading to losses on a certain area more or less important in the urban system. That is why, within a settlement, when assessing the risks it is necessary the division of the area in question in certain sectors of importance, assigning an indicator for all the sectors with the same degree of relevance: maximum, medium and low. Establishing this indicator is based on an evaluation of the losses induced by a natural disaster: direct and indirect economic loss, human, material and immaterial losses as well as on a precise evaluation of all prejudices [5].

The development of IIS and, respectively, GIS ensures an excellent platform for the efficient implementation of the risk analysis methodology in an urban area.

In the future, each city exposed to a certain seismic risk has to benefit from a real warning system. The emergency services predict the intensity of the damage and the spatial distribution for the future events, estimate the losses for each material and immaterial risk elements and the strategies to reduce them, founding the implementation of certain intervention strategies in case of a seismic event.

B. *Basic characteristics of building services infrastructure*

The installation infrastructure is composed of several systems and pipe networks, essential and singular, each system having its own distinct characteristics: the transported agent, the served area and implicitly the corresponding number of consumer, the indicator of the served area, etc.

These networks are made of lines and joints with different typologies. Being familiar with these typologies is an important step in risk assessment. The malfunction of some of these networks represents a higher risk according to, for example, the importance of the served buildings: hospitals, kindergartens, firemen stations, governmental buildings, etc.

In conclusion, the basic characteristics of the installation infrastructure are:

a) spatial distribution in the serviced urban areas;

b) different typologies for each system;

c) each system is given by own intrinsic features as the name of the network and its functionality;

d) the interactions and the synergies between various systems.

C. *Methodology of evaluating seismic risk of the utilities network*

The following essential steps for assessing seismic risk cause must be identified:

a) *The establishment inventory data*: comprises the identification and the classification of all subsystems according to their typology, with geometric, functional and structural characteristics. The attributes of each location, the geometry, the material properties, the wear and tear degree, the level of seismic projection are considered starting point data in establishing the seismic risk.

This information is gathered distinctly for a certain utilities net; for example for a water supply, the inventory comprises:

$\alpha$) *General information*

The geographic location-coordinates, the coordinates of the location of the pressure valves, the exact locations of connections, the locations of the shafts, the flap doors, etc., the location of the isolation valves. In case of their absence – the isolated pipe segments – spreading area, served consumers.

$\beta$) *Geometrical and constructive details*

Length, [m], type, fragile, ductile, diameter, [mm], width, [mm], apparent or buried, material, tensions, type of connection, tolerance to rotation, height, type of cover, type of material protection, operational-characteristics – free, under pressure, working pressure, transported agent, year of construction, corrosion (yes, no, possibly, I don't know), the executed repairs, method of repair.

$\gamma$) *Urban and economic characteristics*

Type of served consumers – important, regular, connection to critical facilities – hospital, police department, direction options, pipe segment evacuation time, economic costs of construction, cost of reconstruction after an earthquake.

b) *The establishing of the "global value"*: the global value of each risk element does not depend directly on the human or physical value, but also on the material – immaterial value represented by the utility and the purpose of the urban system in a certain moment. The indirect value can be different according to the situation and time circumstances. That is why the assessment is performed during three stages: *normal*, *crisis* and *restoration*. The global value for each element depends on each operational attribute, soil, influence on the population, human losses, socio-economic impact during the three stages. Thus, the qualitative and quantitative indicators are defined based on a certain period. For example the indicators and the measurement sizes may be proposed for each system.

In general, the steps are:

1° defining the adequate criteria for estimating the global value for each risk element;

2° collecting all data requested for evaluating the global value;

3° collecting of all necessary data required for the evaluation of the global value;

4° establishing a relative value ranged between 0...1 for each risk element and for each stage;

5° establishing the main result, important and secondary, for each stage.

A typical example of the selected indicators for gas pipes is given in Table 1. The method has been applied for the gas and other utility and transportation systems in urban system. Risk management priorities in terms of post-seismic restoration strategies, pre-seismic retrofitting decisions and co-seismic rescue are influenced by this description of global value.

**Table 1**

*Indicators and Value Scale for Gas Pipelines*

| Indicator | Measuring Unit | Relative value | Period N | Period C | Period R |
|---|---|---|---|---|---|
| Function (supply-diameter) | $D \geq 200$ mm | 1.00 | + | + | + |
| | $D \in (200, 150]$ mm | 0.75 | | | |
| | $D \in (150, 100]$ mm | 0.50 | | | |
| | $D < 100$ mm | 0.25 | | | |
| Emergency | Yes | 1.00 | – | + | – |
| | No | 0.00 | | | |
| Radiance | Subtransmission pipes | 1.00 | + | – | + |
| | Transmission pipes | 0.50 | | | |
| | Distribution pipes | 0.25 | | | |

A relation for estimating the global value is the one presented below (after [4]):

$$\text{Global value} = \sum(\text{Relative values selected for each period}). \tag{2}$$

At the end of the evaluation, each element considered in the analysis is characterized by one or several relative values and three global values: one for the development period, one for the critical period and the last for the recovery period. Thus, this evaluation method allows a comparison between two elements in terms of importance for the city, even if they are not evaluated according to the same indicators.

c) *The establishing of the interactions*, which represents the high interdependency between different systems, is a very important aspect in the study of the seismic risk. Thus, the interactions may be very important, leading to direct consequences. Subsequent to the establishing of the inventory data, the interactions between the systems may be identified, as belonging to three different categories:

1° the physical interaction represents the physical propagation of the damage, as the damage of some pipe networks caused by the coming down of a bridge, etc.;

2° the functional interaction represents the functional propagation of the damage, that is the fall out of certain components of a network, leading to the seizure of the entire system;

3° the imposed interaction represents the closure of a system for a limited period of time in order to execute certain repairs.

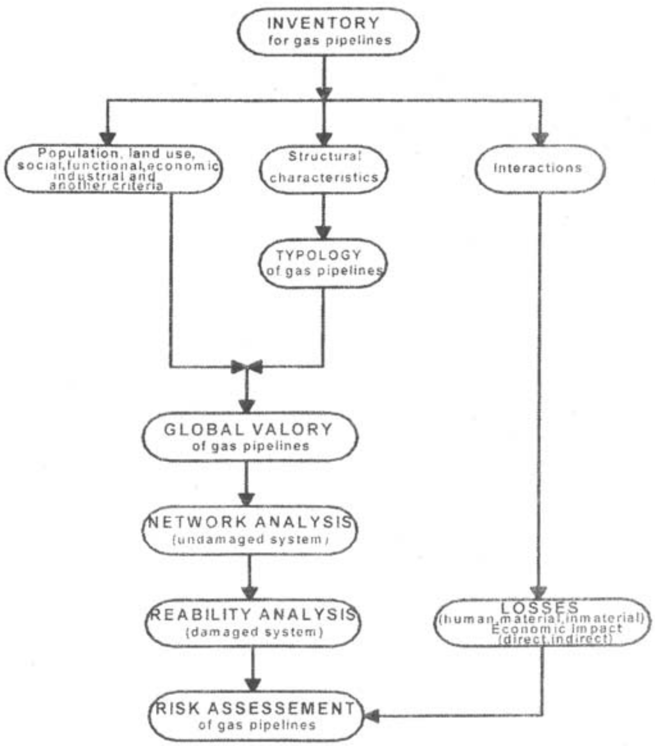


Fig. 1.- Flowchart of risk assessement methodology of gas pipelines (adapted after [4]).

Subsequent to establishing this data, one can assess the risk in case of a seism to which an installation infrastructure from a certain urban background is exposed. Thus, we can move forward to the steps to be followed within the project *Risk Control*, with its three elements: *risk mitigation, plan for emergencies, measure and control.*

Fig. 1 describes the main steps of proposed methodology for risk assessment in case of gas pipelines supply.

## 5. Case Study

Following our objective of preventing the disasters effects on people safety from a dense populated urban area we choose from the digit map of an area of Jassy city presented in Fig. 2 an urban generic sample which includes the gas station and gas pipelines afferent the zone.

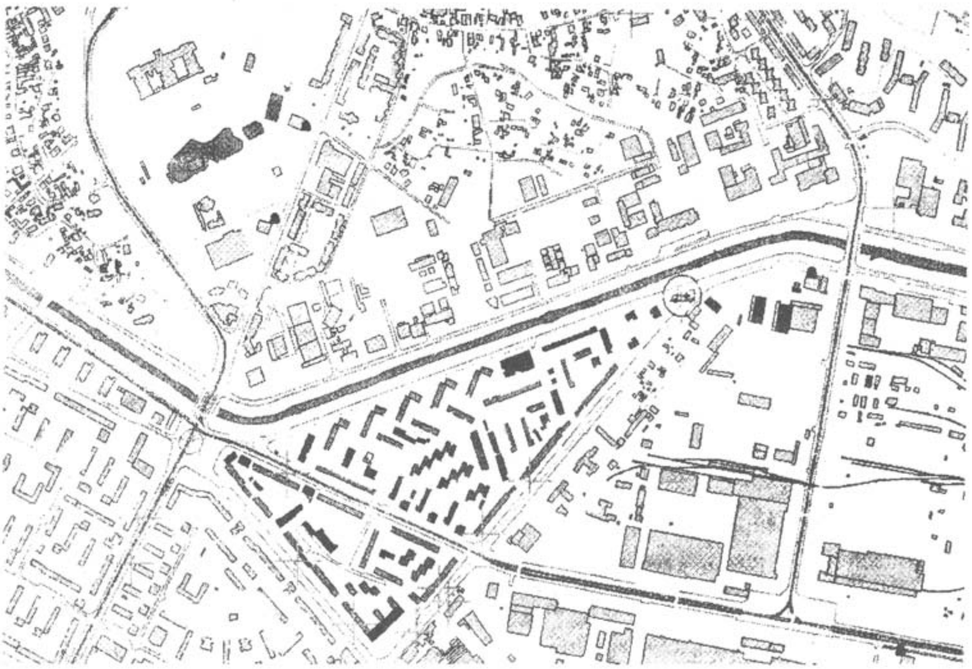

Fig. 2.- GIS map of the analysed urban sample of Jassy city, Romania.

We take into account the gas stations and gas pipelines in the map under analysis in order to characterize the seismic risk of a region. We try to analyse the risk of this region by using the technique of cellular automata, originating from the field of complex systems/artificial life. We divide the previous GIS map into a grid of small (pixel-sized) cells. Each cell can have one of three values:

0 – no risk (green);

1 – moderate risk (yellow);

2 – major risk (red).

Each cell is assigned a value according to one of the following rules:

a) if a cell is at a distance less than 5 cells from a gas pipelines, than mark it as a major risk cell;

b) if a cell is at a distance less than 15 cells from a gas station, than mark it as a major risk cell;

c) if a cell is at a distance less than 15 cells from a major risk cell, than mark it as a moderate risk cell;

d) otherwise, if none of the above rules apply, then mark the cell as a no risk cell.

Fig. 3 displays the risk map of the area.

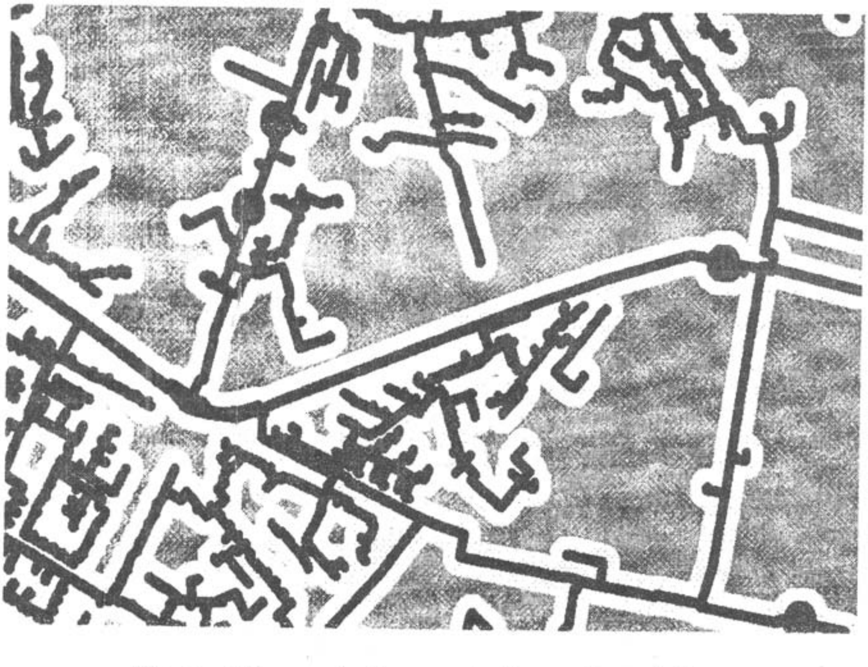

Fig. 3.– Risk map for the gas pipelines and gas stations.

In order to more clearly show the risk areas on the original GIS map, we can superimpose the risk map based on cellular automata on the GIS map (Fig. 4). The gas pipelines and gas stations are marked as dark gray, and the risk areas are marked using a transparency effect.

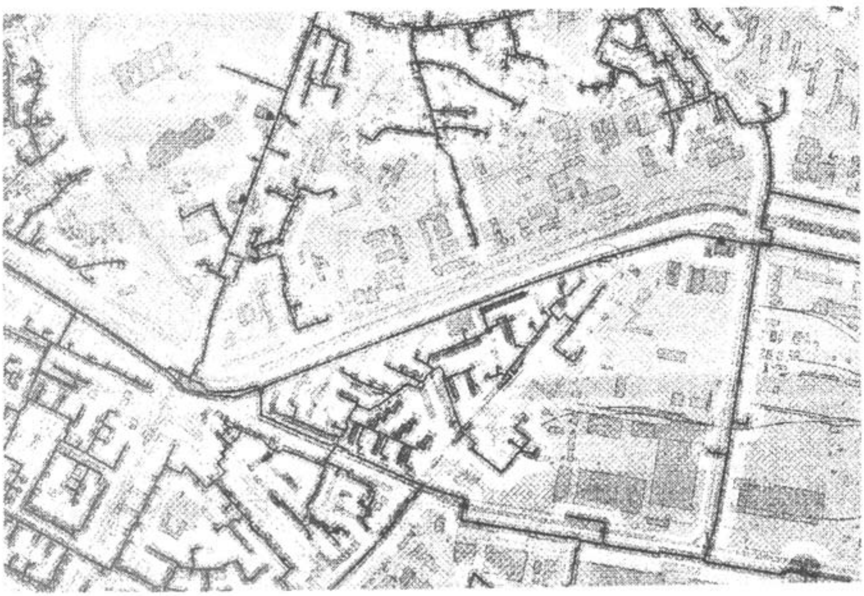

Fig. 4.– Risk areas on the GIS map.

## 6. Conclusions

An important stage in project risk management is risk assessment. Within an urban settlement the risk elements are numerous and of high importance, depending on the study of the phenomena implying the risk in question: earthquake, fire, etc.

In case of an installation infrastructure, for a risk assessment all inventory elements must be known, in terms of systems interaction. Only an in depth knowledge of all the elements leads to a correct risk assessment of the analysed and studied phenomena.

Most certainly, the problematic is very generous, project risk management being a broad theme, which can only be solved by structuring the project into subchapters, with a clearly defined project theme each (for instance, risk management in case of a flooded urban seettlement).

This paper referred to one risk element (the installation infrastructure of an urban settlement) in case of a seismic event, which represents a small part of the project on risk management.

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## MANAGEMENTUL RISCULUI LA DEZASTRE ÎN CAZUL SISTEMELOR URBANE

(Rezumat)


Evaluarea riscului la dezastre naturale este o problemă intens dezbătută atât pe plan naţional cât şi internaţional.

După o scurtă prezentare a stadiului cercetării internaţionale în acest domeniu şi o introducere în managementul riscului se insistă asupra analizei riscului în cazul unei aşezări urbane, denumită sistem urban, mai exact, asupra evaluării riscului din punct de vedere al comportării infrastructurii de instalaţii caracteristică unei anumite zone urbane, în cazul unui seism.

Considerand o anumită zonă componentă unei aşezări urbane (oraşul Iaşi), se prezintă o metodologie de evaluare a riscului seismic în cazul reţelelor de utilităţi existente în zonă. Metodologia constă în stabilirea etapelor necesare a fi parcurse într-o astfel de evaluare, aceste etape prezentându-se şi schematic pentru reţeaua de gaze naturale aferente zonei, luându-se în considerare punctele critice existente în sectorul respectiv (ex.: benzinării).

Prin tehnica automatelor celulare inspirată din domeniul inteligenţei artificiale şi al sistemelor complexe, avand la bază harta GIS a zonei considerate, s-a obţinut o hartă a zonelor de risc pe sectorul considerat în cazul unui seism, luând în calcul reţeaua de gaze naturale şi punctele critice existente.