Urban Risk Assessment using Intelligent Geoinformation System

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1 ABSTRACT

Urban safety became one of the important components of a city government work in the whole world. It is connected with growth of megalopolises and agglomerations, globalization of terrorist and criminal structures, increase of number of natural and technological disasters. Therefore information system is necessary for management of urban areas that will allow to reduce resources spent on organization of situation monitoring in the cities and to increase overall performance of city services.

In the paper questions of development and implementation of urban safety information system on the basis of intelligent geoinformation technologies are considered.

2 INTRODUCTION

Hundreds of various catastrophes happen every day in the world. It is natural disasters (earthquakes, floods, tornado, snowfalls and others), technological disasters (fires, oil spill, dike burst, electric power system accidents), and transport accidents (shipwrecks, car accidents, air crash, railway accidents). Modern cities are complex, suballocated areas. Selection of megacities, agglomeration, coastal, dryaland, islands and high-altitude cities as places of residence make people particularly vulnerable in terms of their safety. As a consequence, urban population is less protected and urban areas are more vulnerable in case of catastrophe. All that leads to death of many people, heavy economic and environmental damage. In the past few decades the number and immensity of natural disasters increased approximately in 5 times, and their danger – in 9 times. Also it is important to note that in underdeveloped countries losses on natural disasters is significantly higher, than in economically developed regions (McGranahan G. et al., 2007).

Urban safety problem is one of the key problems considered in the most part of publications. The greatest contribution to the development of the concept of cities security is made by C. Moser (Moser C. et al., 2008) and G. McGranahan (McGranahan G. et al., 2007). Also the problem of risk assessment from natural and technological disasters is often discussed at CORP conferences. For example, the damage caused to large cities by floods is estimated in (Aubrecht, et al., 2009; Liao, et al., 2011).

Therefore development of effective system for risk of urban areas safety forecasting and assessment now is needed. Such system will allow:

- in some cases to prevent catastrophes;
- to provide recommendations to implement timely behavior in case of disasters;
- to estimate accident consequences.

In the paper one of the risk assessment methods for suballocated areas and variants of risk map creation using GIS-technologies is discussed.

3 RISKS' ASSESSMENT METHOD

The risk is understood as possibility of an event occurrence with negative implications. Risk assessment assumes calculation of a set of quantity characteristics, i.e. definition of possible implications of risks realization for different groups of population and infrastructure. Risk assessment includes following main aspects: estimation of damage from influence of one or several hazards, probability of disasters and others.

The risks assessment related to consequences of natural and technogenic disasters in a given region can be described as a set of features. So, the number of natural and technogenic disasters for the region has distribution density of this event time.

Risks assessment of natural and technological disasters consequence for a given region is proposed to be made using the method that includes the following steps:

(1) Dividing the entire set of possible natural and technological disasters variants into groups according to their parameters. Building groups is based on available statistics for these groups as well as on initial states

of infrastructure objects and population density for the given region. Groups are used in order to define matching probabilities of the events' occurrence.

(2) Defining based on statistics distribution density of event time (natural and technological disaster) taking into account disaster intensity (for example, earthquake magnitude, square of inundation area et al.). Event probability depending on time can be defined by the corresponding distribution density.

(3) Assessing risks for each variant of the natural and technological disaster with regards to infrastructure objects and population of the given region.

(4) Calculating the mean value of possible natural and technological disaster risks for these objects in a given time range taking into account uncertainty of event time.

Let us dwell upon the features of each step. Definition of density functions of i dangers occurrence time $f_i(t)$ can be carried out in advance and in future they are only improved. For recognition of natural and technological disasters current conditions on the basis of registered data analysis known methods (Ayvazyan S.A. et al., 1989) can be used.

For calculation of initial parameters of natural or technological disasters in some cases the known models and methods can also be applied (Stallings R.A., 2003). Each variant of initial condations leads to receiving $B_i(t)$ - parameters of i-th dangers in the given region using this models and methods. These parameters include the number of human losses, the number of earthquake induced failures, the square of ecological pollution et al.

Risk assessment of each natural or technological disaster at time instant T provides accounting its properties (for example, disaster intensity, damage by disaster et al.), as well as accounting the characteristics of the inflicted facilities. In the interests of such assessment taking into account natural or technological disaster event time uncertainty $\overline{B}_i(T)$ – mean values for parameters of i-th dangers at time instant T are calculated as:

$$\overline{B}_i(T) = \int_0^T B_i(T-t) f_i(t) dt \qquad (1)$$

It is suggested to calculate conditional risks $W_{ij}(\overline{B}_i(T))$ of i-th dangers at time instant T for specific j-th objects depending exactly on the parameters $\overline{B}_i(T)$. These especial conditional risks can be, for instance, determined by experts. They can be also received as a result of the processes' modeling based on advanced geoinformation technologies and special analytical problems' solutions. Among these problems are the assessment of area flood level, the environmental threats occurrence and other.

The resulting predicted risk from natural or technological disasters at time instant T taking into account previous conditions and probabilities P_i of i-th dangers occurrence are calculated using the following equation:

$$W_\Sigma(T) = \sum_{i=1}^{n} \sum_{j=1}^{m} W_{ij}(\overline{B}_i(T)) P_i \qquad (2)$$

where m – the number of analysed objects or regions.

Risk $W_\Sigma(T)$ according to (2) is a current risk. Risks' prediction for specified time intervals is possible using integral estimates derivation.

Unlike the known methods the proposed approach allows to predict the risks from natural or technological disasters in the current situation under a significant uncertainty of risk emerging time. The new method can be successfully implemented in modern geoinformation systems. However, the method application is associated with a number of features.

4 SOME FEATURES OF THE METHOD APPLICATION FOR GEOGRAPHIC INFORMATION SYSTEMS

Application of GIS-technologies for the solution of risks assessment problems of natural or technogenic disasters assumes application of effective methods of gathered geophysical data visualization, results of their modeling and forecasting.

Use of the risk assessment method allows operatively to reflect in geoinformation systems risk dynamics and to estimate damage values depending on type of a natural or technogenic disaster or their set. The spatial analisys performed by GIS tools allows:

- to represent the results of risk prediction as a series of thematic maps. On these risk maps taking into account spatial accessory to specific region zones that are defined by specific values $W_\Sigma(T)$ both separated objects and groups of objects can be displayed. Creation of the thematic maps assumes development of qualitative scale for $W_\Sigma(T)$ values that reveals the relation between risk level and level of destruction. On the basis of the developed dynamic maps the decisions aimed to decrease risks and to plan actions for coasts protection against disasters can be made.

- to classify regions by hazards level for each of disasters variants for specific infrastructure objects and for specific life environment.

- to carry out adoption of the rational and operational decisions directed on timely realization of actions complex, directed on reduction of risk, preservation of life and human health, decrease of damage from catastrophics.

Using intelligent GIS allows to imorove decision support on alarm, to predict possible consequences and to carry out offers on protection actions.

5 CASE STUDY

5.1 Study area

Let us consider a problem of a risk and safety assessment for Italy urban areas. The country is administratively divided into 20 regions (Table 1). The largest cities and towns of Italy are Rome, Milan, Naples, Turin, Palermo. It is known that the territory of Italy is the subject of such natural disasters, as earthquakes, floods, volcanic explosion and a tornado.

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The strongest earthquakes which occurred in Italy are: Sicily earthquakes 1693 (more than 60 000 of people deaths), the Great Neapolitan Earthquake (11 000 deaths), 1908 Messina and Reggio earthquake (100 000 deaths), 1915 Avezzano earthquake (killed more than 30 000 people), the 1980 Irpinia earthquake (2570 deaths). The last happened in April, 2009 L'Aquila earthquake.

Region	Capital	Area (km2)	Population
Abruzzo	L'Aquila	10763	1342177
Aosta Valley	Aosta	3263	128129
Apulia	Bari	19358	4090577
Basilicata	Potenza	9995	58768
Calabria	Catanzaro	1508	2011537
Campania	Naples	1359	5833131
Emilia-Romagn	Bologna	22446	4429766
Friuli-Venezia Giulia	Trieste	7858	1235761
Lazio	Rome	17236	5724365
Liguria	Genoa	5422	1616993
Lombardy	Milan	23844	9909348
Marche	Ancona	9366	1564866
Molise	Campobasso	4438	319834
Piedmont	Turin	25402	4456532
Sardinia	Cagliari	2409	1675286
Sicily	Palermo	25711	5050486
Tuscany	Florence	22993	3749074
Trentino-Alto Adige	Trento	13607	1036639
Umbria	Perugia	8456	906675
Veneto	Venice	18399	4936197

Table 1: Administrative divisions.

5.2 Earthquake risk assessment for Italy region

On the basis of earthquakes data (Earthquakes, 2013) which have occurred in Italy since 1693 we will allocate nine categories of possible consequences from an earthquake (Table 2): I – instrumental to moderate; II – rather strong; III – strong; IV – very strong; V – destructive; VI – ruinous; VII – disastrous; VIII – very disastrous; IX – catastrophic.

Scale	Category	Magnitude	Estimate Number Each Year	Description
instrumental to moderate	I	<=4.3	900 000	No damage.
rather strong	II	4.4-4.8	30 000	Damage is negligeable. Small, unstable objects are displaced or upset; some dishes and glassware are broken.
strong	III	4.9-5.4	20 000	Damage is slight. Windows, dishes, glassware are broken. Weak plaster and masonry are cracked.
very strong	IV	5.5-6.1	500	Damage is moderate in well-built structures; considerable in poorly-built structures. Furniture and weak chimneys is broken. Masonry is damaged. Bricks, tiles, plaster and stones fall down.
destructive	V	6.2-6.5	100	Structural damage is considerable, particularly in poorly-built structures. Chimneys, monuments, towers, elevated tanks may fail. Frame houses are moved. Trees are damaged. Cracks appear in wet ground and steep slopes.
ruinous	VI	6.6-6.9	50	Structural damage is severe, some structural elements may collapse. General damage to foundations is caused. Reservoirs are seriously damaged. Underground pipes are broken. Conspicuous cracks are observed in ground; liquefaction.
disastrous	VII	7.0-7.3	10	Most masonry and frame structures foundations are destroyed. Some well-built wooden structures and bridges are destroyed. Serious damage is caused to dams, dikes. Sand and mud is shifting on beaches and flat land.
very disastrous	VIII	7.4-8.1	10	Few, if any (masonry) structures remain standing. Bridges are destroyed. Rails are bent greatly.
catastrophic	IX	>8.1	5-10	Damage total. Lines of sight and levels are distorted. Objects are thrown into the air.

Table 2: Categoty and number of possible earthquakes.

Fig. 1 displays histogram which demonstrate probabilities of earthquake events in each of Italy regions. Probabilities are defined on the basis of the statistical data received from http://earthquake.usgs.gov/earthquakes/map with use of statistical analysis methods. Generally, as it is seen from bar graph, Italy regions are subjects to earthquakes in a varying degree. It is possible to allocate two most dangerous regions: Sicily and Emilia-Romang. The calculations are also made for these regions.

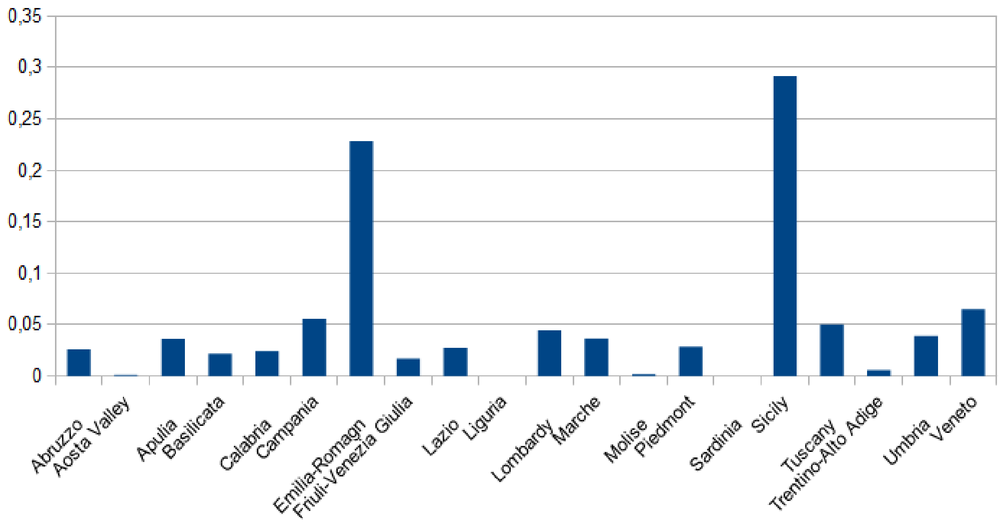

Fig 1: Probabilities of earthquake events in the Italy regions.

These calculation results are used for risk level assessment in relation to concrete components of environment or infrastructure connected with human life. The risk assessment from impact of a possible earthquake was estimated taking into account danger and damage to people health, danger and negative influence on environment for two regions: Sicily and Emilia-Romang.

Overall risks summary is made taking into account weight coefficients which have been set by an expert for each of allocated territories. In Fig. 2 the predicted risk from natural disaster at time instant , probabilities of -th dangers occurrence and earthquake magnitude for two most dangerous Italy regions: Sicily and Emilia-Romang is given.

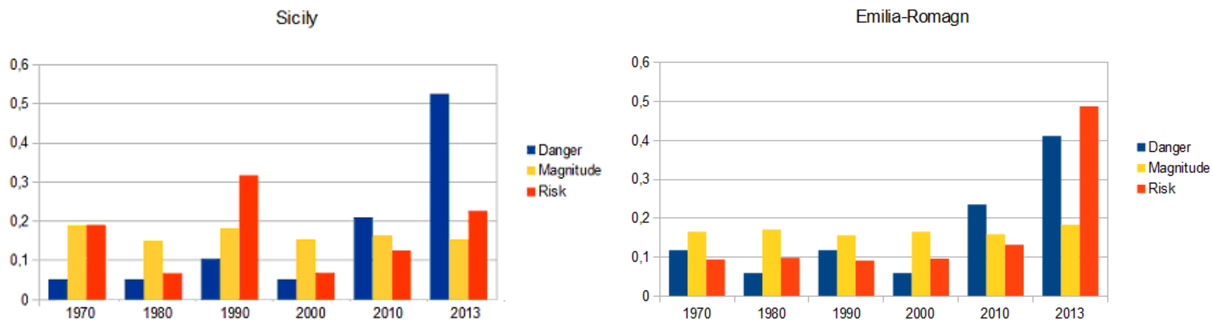

Fig 2: Results of risk assessment for Sicily and Emilia-Romang regions.

The obtained results indicate first of all that some territories become eventually more and more steady against certain types of disasters while others on the conversely, they only start meeting certain difficulties. As can be seen from Fig. 2, in recent years the earthquakes magnitude on Sicily decreases, and in Emilia-Romagn increases.

While the earthquakes magnitude on Sicily decreases, disaster hazards are preserved to be high. All this is first of all due to that over the past ten years Italians have become more prepared for possible earthquakes and eruptions of volcanoes. The researches concerning the reasons of these phenomena are continuously conducted, early warning systems are improved, and danger of underground fluctuations when constructing roads, houses and office buildings is considered.

Let's create a qualitative scale for the resulting predicted risk, using nine point grading scale of earthquakes (Table 2). This scale connects risk levels with nature of destroying influences, danger and damage to health of people. The qualitative scale for risk values is given in Fig. 3.

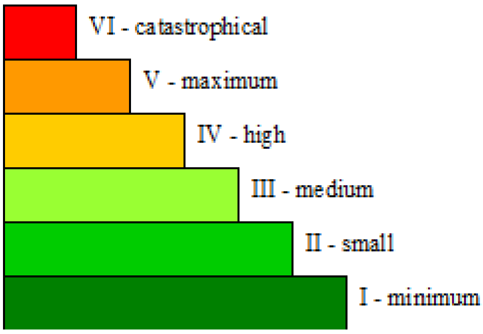

Fig 3: Qualitative scale for $W_{\Sigma}(T)$ values

Risk level	Risk value
VI – catastrophical	0.186-0.833
V – maximum	0.127-0.186
IV – high	0.103-0.127
III – medium	0.07-0.103
II – small	0.005-0.07
I – minimum	0-0.005

Table 3: Results of risk assessment

Negative influence degree (risk level) is estimated with a qualitative scale for the resulting predicted risks taking into account their weight coefficients. Weight coefficients are defined by experts such as city managers or other experts.

The results of risk assessment for Italy region is given in Table 4. Fig.4. illustrates a risk map. On the basis of the received risk maps further actions for region protection from the subsequent disasters are planned.

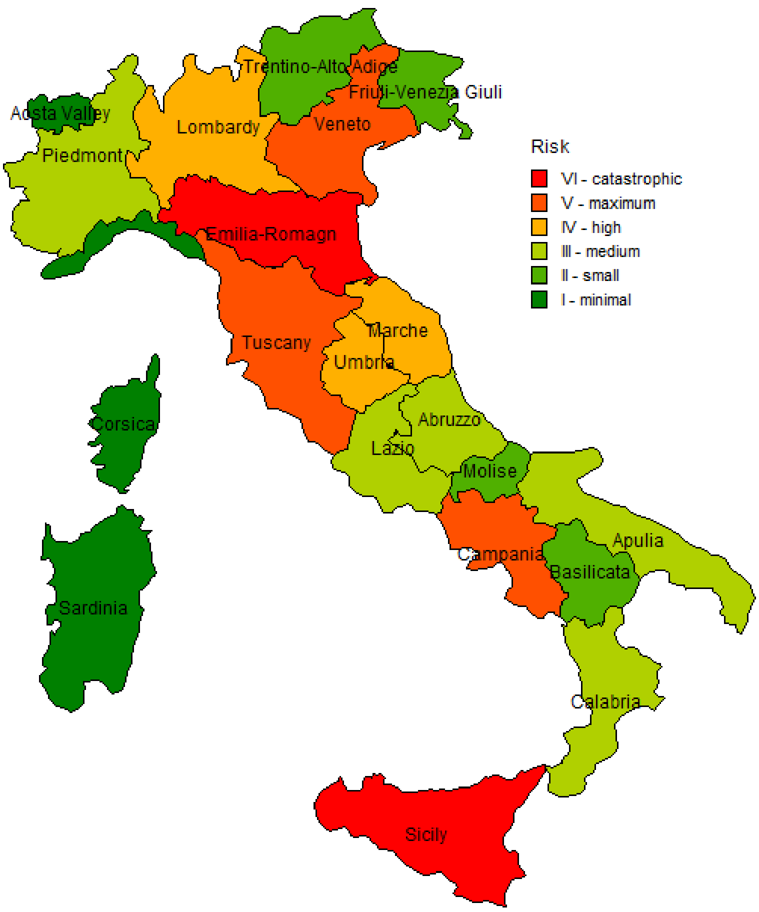

Fig 4: Risk map for Italy region.

6 CONCLUSION

The paper proposes a new approach to a risks assessment from natural or technogenic disasters taking into account specific features of regions. In future work it is supposed for risk assessment to consider not only such factors as damage to health of the person, danger and negative influence on environment, the built-up territories hazards but also social and economic risks. Also possibility of animation and 3D maps development can be discussed.

7 REFERENCES

AUBRECHT, C., KOSTL, M., KNOFLACHER, M., STEINNOCHER, K. The importance of active public communication – Settlement systems and land use patterns seen from a disaster perspective. In: Proceedings of 14th International Conference on Urban Planning, Regional Development and Information Society, pp. 895-900. Catalonia, Spain, 22-25 April, 2009.

LIAO, C.-H., CHANG H.-S. Explore Urban Flood Vulnerability based on Spatial Pattern in Taiwan Ecological City Viewpoint. In: Proceedings of 14th International Conference on Urban Planning, Regional Development and Information Society, pp. 309-314. Essen, Germany, 18-22 May, 2011.

World Bank. Building Safer Cities: The Future of Disaster Risk. Washington, DC: World bank, 2003.

McGRANAHAN, G., BALK, D., ANDERSON, B. The Rising Tide: Assessing the Risk of Climate Change and Human Settlements in Low Elevation Coastal Zones. J Environment and Urbanization, 19(1): 17-37, 2007.

MOSER, C., SATTERHWAITE, D., et al. Pro-Poor Climate Change Adaptation in the Urban Centers of Low- and Middle-Income Countries. In: Background paper for the “Social Dimensions of Climate Change” workshop, Washington, DC, 5-6 March, 2008.

AYVAZYAN, S.A., BUKHSTABER, V.M., ENYUKOV, I.S., MESHALKIN, D.D. Practical statistics. Classification and decrease in dimension. Moscow, Financy and statistics, 1989. (in Russian)

STALLINGS, R.A. Methods of disaster research. Xlibris Corporation, 2003.

EARTHQUAKERS, http://earthquake.usgs.gov/earthquakes/?source=sitenav, accept on 01.02.2013