THE VULNERABILITY OF THE BAIA MARE URBAN SYSTEM (ROMANIA) TO EXTREME CLIMATE PHENOMENA DURING THE WARM SEMESTER OF THE YEAR

DRAGOTĂ CARMEN [1]**, *GRIGORESCU INES*** [1]**, *MIHAELA SIMA*** [1]**,**
KUCSICSA GH. [1]**, *MIHALACHE S.*** [1]

Abstract - The vulnerability of the Baia Mare urban system (Romania) to extreme climate phenomena during the warm semester of the year. The geographical position of the Baia Mare Urban System (intra-hilly depression) favours the occurrence of a wide range of extreme climate phenomena which, coupled with the industrial profile of the city (non-ferrous mining and metallurgical industry) triggering typical emissions (CO_2, SO_X, particulate matters and Pb), might pose a significant threat to human health. The article is aiming to assess the occurrence, frequency and amplitude of these extreme climate phenomena based on monthly and daily extreme climatic values from Baia Mare weather station in order to identify the areas more exposed. A GIS-based qualitative-heuristic method was used, each extreme climatic hazard being evaluated on a 1 to 3 scale according to its significance/impact in the study area and assigned with a *weight (w)* and a *rank (r),* resulting the climate hazard map for the warm semester of the year. The authors further relate the areas exposed to the selected extreme climatic events to socio-economic aspects: *demographic* and *economic* in order to delineate the spatial distribution of the environmental vulnerability in the Baia Mare Urban System.

Key-words: Baia Mare Urban System, socio-economic vulnerability, extreme climate phenomena, warm semester of the year, natural and technological hazards, Romania.

1. INTRODUCTION

Natural hazards have a strong influence on future spatial development, thus displaying spatial patterns on a regional level, including possible impacts of climate change on hydro-meteorological hazards (Schmidt-Thomé, 2006). Under the given circumstances, the vulnerability assessment is designed to put together a complex analysis of the conditions and the characteristics of a system that is exposed to a certain type of natural hazard (Bălteanu, Costache, 2006; Tanislav et al., 2009). In view of that, it is well recognised that climate change is a global problem and the associated impacts that have been experienced so far stress upon the magnitude of change likely to be experienced over the next decades (Kingston, 2011b). Moreover, the academic community has constantly drawn attention on the

[1]Romanian Academy, Institute of Geography, 023993 Bucharest, Romania, e-mail: dragotacarmen@yahoo.co.uk; cmarculet@yahoo.com;

increasing frequency and intensity of extreme whether events and the related environmental impacts on regional and local level affecting human systems (Smit and Wandel, 2006; Parry et al., 2007).

When discussing the vulnerability of a system there are several driving forces to be considered (physical, social, cultural, economic and political), working together in a complex manner in direct connection to the particular features of each system at stake (Costache et al., 2005; Tanislav et al., 2009).

Generally, vulnerability refers to the "characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard" (UNSDR, 2009). Moreover, it deals with the distinctive susceptibility of both social and biophysical systems (social or biophysical vulnerability), thus representing the extent to which a certain system might be affected by a disturbing phenomenon and its diminished capacity to recover or adapt to impact's effects (Kasperson et al., 2002). As a result, the vulnerability points to the degree of exposure to different hazards of both individuals and their goods and indicate the potential level of damages triggered by a certain phenomenon on a scale 0 to 1 (Bălteanu, Costache, 2006). Furthermore, the concepts of *adaptation, adaptive capacity, vulnerability, resilience, exposure and sensitivity* are interconnected enclosing broad applications to global change science, on which in-depth vulnerability assessments mainly rely on (Smit and Wandel, 2006; IPCC, 2007a; IPCC, 2007b; EU FP6 CLAVIER project). Recent researches and projects undergone innovative, cost effective and user friendly action plans and assessment tools able to highlight climate change vulnerabilities and risks in urban areas aiming at contributing to strategic planning of climate change adaptation responses in cities and regions across Europe (Kingston, 2011a; INTERREG IVC GRaBS Project, 2008-2011). As a result, comprehensive vulnerability assessments of different urban systems in relation to the climate-related environmental issues are essential in identifying and implementing the most effective risk mitigation and/or adaptation measures for national and regional policy making.

2. STUDY - AREA

The current study is developed in the framework of the FP7 ECLISE project "Enabling climate change information for Europe", as Baia Mare Urban System represents one of the test areas of the above referred project. The Baia Mare Urban System is located in the north-western part of Romania in an intra-hilly depression bordered by mountain (in the north and north-east) and hill alignments (in the west and south) (Fig. 1). Due to its relatively diverse economic profile, mainly related to mining activities, the study-area acts as a polarizing center for the surrounding territory, thus leading to a wide range of threats that makes it sensitive to climatic hazards. Among them, the following might be ranked first: the high density of built-up areas (referring to block of flats and individual dwellings and villas, only) of over 30%; low coverage of green surfaces, only 5.8 m^2/inhabitant (3% of the total area), as compared to the recommended EU per capita for 2013 (26 m^2/inhabitant); total population exposed to climatic hazards is of 138,722 inhabitants (2010); highly industrialized area with specific emissions and waste deposits; low access of population to health infrastructure (5 hospitals, 3.02 doctors/1000 inh., 0.38 pharmacies/1000 inh. etc.); social risk factors (e.g. low income, high unemployment rate of over 1800 unwaged people in 2007); overall low awareness and adaptive capacity of the urban area to climate-induced hazards.

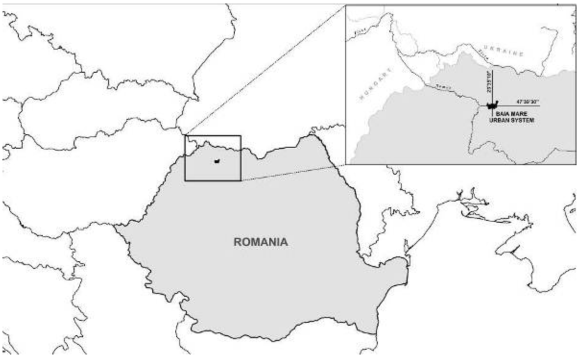

Fig. 1. Location of the Baia Mare Urban System

From climatic point of view, the study-area frames into the *low hills and tablelands climate region* completed by *western and northern climatic influences* bringing about a variety of extreme hydro-climatic events. Due to the shelter provided by the depresionary area, the weather phenomena could be either smoothened (summer heat waves) or augmented to the extreme (fog and acid depositions (Sima et al., 2012).

3. METHODOLOGY AND DATA

The authors used and processed annual, monthly and daily extreme climatic values for the interval 1896…2007 (temperature, precipitations, wind, dangerous atmospheric phenomena) from Baia Mare meteorological station. Based on their occurrence, frequency and amplitude several vulnerability classes were established (high, medium and low) to the most frequent climate hazards for the warm semester of the year: *fog, acid depositions, summer heat waves and positive thermal singularities; heavy rainfall; hail storms; thunderstorms*.

Furthermore, a GIS-based qualitative-heuristic method was used, each climatic hazard (represented by a GIS layer - ***L***) being evaluated on a 1 to 3 scale according to its significance/impact in the study area and assigned with a ***weight (w).*** Considering its designed susceptibility class (low, medium, high and very high) a ***rank (r)*** has been assigned (Tab. 2), resulting two climate hazard maps, both for warm and cold semester of the year (Fig. 2).

Ultimately, the summation of the layers (***L***) and the consequent ***weight (w)*** and ***rank (r)*** of each analysed dangerous weather phenomenon had turned into the following mathematical formula:

Table 2. Framing the study-area into different susceptibility classes to climate hazards

L	Susceptibility to:	*weight*
F	*Fog*	3
A_{dp}	*Acid depositions*	3
S_{hw}	*Summer heat waves and thermal singularities*	2
H_{rf}	*Heavy rainfall*	3
H_{st}	*Hail storms*	3
Th	*Thunderstorms*	1

Susceptibility to extreme weather phenomena

Th*r* + 2**Shw*r*** + 3(**F*r*** + **Adp*r*** + **Hrf*r*** + **Hst*r***)

Susceptibility class	low	medium	high
	< 30	30 - 38	>38

The authors related the climate vulnerability areas to the socio-economic vulnerability: *demographic* (population-related indicators etc.) and *economic* (infrastructure, housing etc.) supplied by National Institute of Statistics, Romanian Statistics Yearbooks 1990-2010 as well as field surveys. Additionally, a thorough mapping of the functional zoning in the Baia Mare Urban System was undertaken based on several field surveys. The following functional areas categories were selected as representative for the study-area: residential areas with block of flats, residential areas with private dwellings and villas, agricultural areas, industrial areas, green areas, water bodies and others (degraded lands, roads etc.). Furthermore, the hazard maps for both cold and warm semester of the year were extended beyond the functional zoning map in order identify the spatial distribution of the areas more vulnerable to extreme weather phenomena in the Baia Mare Urban System. As a final output, the current study is aiming to provide valuable data for further in-depth analysis on the effects of climate change on human health in relation to the physical and socio-economic environment by using aggregate indicators categories (socio-economic, epidemiological and environmental) through geo-statistical and GIS methods (Sima et al., 2012).

4. RESULTS

Based on the above described methodology, on the complex classifications (Bryant, 1991; Croitoru şi Moldovan, 2005) and the regional studies undertaken up to now (Dragotă et al., 2009; Dragotă, Grigorescu, 2010), the present study is aiming to provide a regionalization of the main dangerous meteorological phenomena that occur during the warm semester of the year in the Baia Mare Urban System. Therefore, the selected extreme weather phenomena rely on the frequency, duration and intensity parameters tailored according to the particularities and to the scale of the study-area: *heat waves and positive thermal singularities, heavy rainfall, fog and acid depositions, hail storms and thunderstorms.* This climatic hazard assemblage is defined by the positive variations against the multi-annual mean values triggered by the general atmospheric circulation correlated with the solar radiation and the particularities of the active surface.

Summer heat waves and positive thermal singularities are generated by warm tropical air advections classified according to the following criteria (Bogdan, Marinică, 2007): mean monthly temperatures of the hottest months (July, August) $\geq 25^0$C; maximum daily temperatures that exceed 35^0C (canicular days); minimal night temperatures of $\geq 20^0$C (tropical nights). When considering the environmental impact of these thermal extreme phenomena, the exceeding of the 35^0C threshold is of great importance through the disturbances it causes to the environment (Tab. 3).

Table 3. Absolute extreme temperatures registered in the Baia Mare weather station (1921-1940; 1950-2007).

Month	Absolute Maximum Temp.	Date of occurrence
April	31.5	26/1934
May	33.4	25/1929
June	35.5	11/1928
July	39.0	17/1928
August	**39.2**	**22/1943**
September	37.6	22/2007

Source: National Meteorological Administration Database

Heavy rainfalls. In the Baia Mare Urban System, on a mean multi-annual scale, during the *April-September interval of the rainiest years* the pluviometric historical record for the climatic area under discussion has had, particular maximum values of up to 327.0 mm in 1913 (Tab. 4).

Table 4. The highest monthly (warm semester) precipitation amounts registered at Baia Mare weather station (1896-1915, 1921-1943, 1950-2007)

Extreme	**Month**						**Semestrial**
	IV	**V**	**VI**	**VII**	**VIII**	**IX**	
Max.	204.0	235.1	235.7	327.0	304.0	217.0	327.0
Year	1924	1970	1974	1913	1915	1912	1913

Source: National Meteorological Administration Database

On a multi-annual regime the maximum precipitation amounts accumulated in short intervals reached and even exceed the necessary values of 27.9 mm/24 h (June/July), 35.2 mm/48 h (July) and 40.9 mm/72 h (June) for triggering climatic hazards, such as the heavy rainfall (Dragotă, 2006).

The hazard character of this climatic phenomenon relies on the ***pluvial intensity*** which in the area under analysis reaches values that ranks among the highest in Romania: the mean intensity of between 0.03 and 0.04 mm/minute, the maximum mean intensity of 0.20 and 0.30 mm/minute, and the average of the highest 5 pluvial intensity ranging between 3 and 4 mm/minute.

The area the most affected by ***hail storms*** is the southern extremity of the Baia Mare Urban System with annual mean values of 2-6 days and up to 5-10 days maximum values (Bogdan, Marinică, 2007). Less affected is the north-eastern part of the study-area (Ferneziu and Blidari quarters).

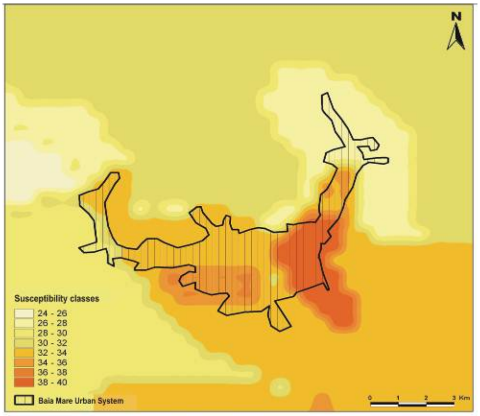

Fig. 2. The susceptibility to climate hazards during the warm semester of the year in the Baia Mare Urban System

Thunderstorms are also extreme climatic phenomena associated with heavy rainfall which is affecting the study-area through the annual average number of days of occurrence of up to 37 days at the Baia Mare weather station.

Fog and acid deposition. Although this mixed meteorological phenomenon occurs throughout the year, it has a particular influence upon the environment during the warm semester mainly due to the geographical position of the Baia Mare Urban System (intra-hilly depression) and the several pollution sources (with emissions of CO_2, SO_X, particulate matters and Pb etc.) related to the road traffic and the industrial activity (non-ferrous mining and metallurgical industry). These pollution sources, coupled with certain extreme climatic events, expose the study-area to atmospheric pollution by way of the mechanic (fog) and chemical (acid depositions) actions. The areas most affected by this couple of extreme wheatear phenomena are located in the northern parts of Baia Mare Urban System.

5. DISCUSSIONS AND CONCLUSIONS

Overlapping the areas susceptible to climatic hazards during the warm semester of the year to the functional zones of Baia Mare Urban System one may delineate the areas the most exposed to the analysed extreme weather phenomena, which are located in the south-eastern and central parts of the urban system (Gării, Bogdan Voda, Traian, New Center, Depozitelor quarters, Grivita Quarter and the Eastern Industrial Area) up to the north-eastern areas (Ferneziu Quarter and the Northern Industrial Area) (Fig. 3).

Over the last decades, urban systems grow to be increasingly vulnerable to global environmental change, mainly climate-induced, thus defining urban vulnerability is imperative due to physical, socio-economical and even political problems related to spatial development.

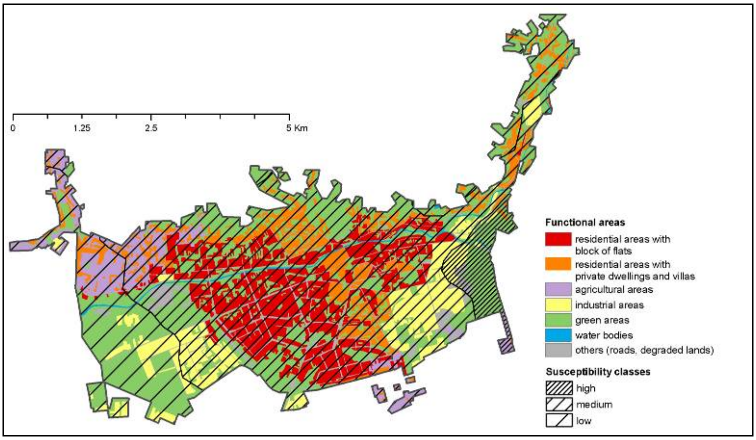

Fig. 3. The functional areas vulnerable to climatic hazards during the warm semester of the year in the Baia Mare Urban System

Therefore, it becomes decisive to find the best ways and means to address the ongoing environmental changes, such as natural extreme wheatear events and their potential societal and economic impacts in an urban system. In this respect, comprehensive vulnerability assessments of different urban systems in relation to the climate-related environmental issues are essential in identifying and implementing the most effective risk mitigation and/or adaptation measures for national and regional policy making.

Acknowledgements. The research for this paper was undertaken in the framework of FP7 ECLISE project „Enabling CLimate Information Services for Europe", no. 265240 (2011-2014), coordinated by the Royal Netherlands Meteorological Institute.

REFERENCES

1. Bălteanu D., Costache Andra (2009), *Involving the population in environmental change and extreme events vulnerability assessment theoretical remarks and case-studies*, Human Geographies – Journal of Studies and Research in Human Geography, vol. 3, issue 2, 5-11
2. Bălteanu, D., Costache, Andra (2006), *Conceptul de vulnerabilitate. Aplicaţii in geografie*, Revista Geografică, tom 12, pp. 5-12
3. Bogdan, Octavia, Marinică, I., 2007. *Hazarde meteo-climatice din zona temperată*. Factori genetici şi vulnerabilitate cu aplicaţii la România, Editura Lucian Blaga, Sibiu, 422.
4. Bryant E. A., 1991. *Natural Hazards*, Cambridge University Press, 294 pg.
5. CLAVIER EU FP6 project: *Climate change and variability: Impact on Central and Eastern Europe* http://www.clavier-eu.org/
6. Costache A., Tanislav D., Muratoreanu G., Hodorogia A.M., Micu D., (2005), *Human Vulnerability to Environmental Change in the Mining Communities of Romanian*

Carpathians. Case Study of the Jiu Valley. A project of the Advanced Institute on Vulnerability to Global Environmental Change, http://www.start.org/Program/advanced_institute3_web/Final%20Papers/Costache(revised).doc
7. Croitoru A., Moldovan F., 2005. *Vulnerability of Romanian territory to climatic hazards*, Analele Universităţii de Vest din Timişoara, Seria Geografia, XV/2005, 55-64.
8. Dragotă Carmen-Sofia, 2006. *Precipitaţiile excedentare din România*, Editura Academiei Române, Bucureşti, 174.
9. Dragotă Carmen-Sofia, Grigorescu Ines, Mihaela Sima, (2009), *The main climatic hazard phenomena and their environmental impact in the Râmnicu Vâlcea – Ocnele Mari Depression*, Environment & Progress nr. 13/2009, 131-140, Cluj-Napoca.
10. Dragotă Carmen-Sofia, Grigorescu Ines, (2010), *Climatic hazards in the Bucharest Metropolitan Area. The assessment of the main extreme climatic phenomena in the Bucharest municipality and its surroundings*, LAP Lambert Academic Publishing, ISBN 978-3-8433-6911-4, paperback, 108 pages.
11. INTERREG IVC project Green and Blue Space Adaptation for Urban Areas and Eco Towns (2008-2011) http://www.grabs-eu.org/
12. Kasperson R.E., (2001), Vulnerability and global environmental change. IHDP Update, 2:2-3, Stockholm.
13. Kasperson J.X. and Kasperson R.E. (eds.), (2001), *Global Environmental Risk*. Tokyo/London: United Nations University Press and Earthscan.
14. Kingston R, (2011a), A *Planning Support System for adapting cities to climate change: the GRaBS Project*, School of Environment & Development University of Manchester, December 5th 2011, COP17, Durban: Cities as Green Economic Drivers: Ecosystem Services for Climate Smart Cities.
15. Kingston R, (2011b), *Tooling up for risk and vulnerability assessment*, The Journal of the Town and Country Planning Association, June 2011, Vol. 80, No. 6, the GRaBS project issue, 264-268. http://www.grabs-eu.org/downloads/TCP_June11.pdf
16. Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hansen CD (eds) (2007) *Climate change 2007: impacts, adaptation and vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge
17. Schmidt-Thomé, P. (edit.) (2006), *Natural and technological hazards and risks affecting the spatial development of European regions*. Geological Survey of Finland, Special Paper 42. 167 pages.
18. Sima Mihaela, Bălteanu D., Grigorescu Ines, (2012), *Connecting universities and stakeholders through integrated climate services at local and regional level. The EU-FP7 ECLISE project experience*, In “Sustainable Development at Universities. New Horizons”, Peter Lang Scientific Publishers, 691-696.
19. Smit B., Wandel Johanna (2006), *Adaptation, adaptive capacity and vulnerability*, Global Environmental Change 16, 282–292, doi:10.1016/j.gloenvcha.2006.03.008.
20. Tanislav D., Costache Andra, Murătoreanu G. (2009), *Vulnerability to natural hazards in Romania*, Forum Geografic. Studii şi cercetări de geografie şi protecţia mediului, Year 8, No. 8/ 2009, pp. 131- 138
21. Turner II, B.L., Kasperson, R.E., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luers, A., Martello, M.L., Polsky, C., Pulsipher, A., Schiller, A. (2003), *A framework for vulnerability analysis in sustainability science*, PNAS, Vol. 100, No.14, pp. 8074-8079.
22. https://statistici.insse.ro/shop/