CLIMATE HAZARD MAPS – A TOOL TO SUPPORT COMMUNICATION WITH STAKEHOLDERS. A SHOWCASE OF BAIA MARE DEPRESSION, ROMANIA

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Key words: extreme weather events, multi-hazard map, stakeholder communication, Baia Mare Depression.

Abstract. Baia Mare Depression is an inter-hilly depression located in the north-western part of Romania bounded by mountain and hilly areas. Its position has granted it with specific environmental features which had exposed it to several climatic hazards while the historical industrial profile of the area (non-ferrous mining and metallurgical industry) and the related emissions (CO_2, SO_X, particulate matters and Pb) might still pose threats to the environment and human health. The article proposes a methodology for producing multi-hazard climate information (layers) and designing communication products (hazard maps) on extreme weather phenomena, to be used by relevant stakeholders at local level. The scientific method relies on the occurrence, frequency, and amplitude of the foremost extreme weather phenomena (snow cover, glazed frost, fog, heavy rainfall, strong winds) based on monthly and daily extreme climatic values from several weather stations. The stakeholder's interaction through focus groups meetings and cross analysis validated the resulted maps. The main findings of the current study are the assessment, and spatial (visual) representation of the climate hazards the study area is exposed to as key step in supporting adaptation strategies and increasing resilience at regional and local levels.

1. INTRODUCTION

Development will continue to occur in hazard-prone areas which is enhancing the potential for climate change induced damages (Balogun *et al.*, 2020). Over the last few decades, climate- and water-related hazards have increased in occurrence (IPCC, 2014) and served as trigger for more than 75% of the disasters globally, hence being tightly connected with issues such as food security, migration, and even national security (Mcbean and Rodgers, 2010). The impacts on local economies and communities are massive, and the recovery usually involves significant financial resources and takes a very long time (Newman *et al.*, 2017). That being so, between 1970 and 2019, over 11,000 disasters were attributed to climate and water-related hazards which accounted for over 2 million deaths and US$ 3.64 trillion in losses and they will continue to adversely affect human health, economic and social development in the future (WMO, 2021). Europe has faced several changes in its physical, technological and human/social systems. On that account, climate change impacts and responses are observed in the physical and ecological systems (Adger *et al.*, 2005; Kreibich *et al.*, 2014), this leading to an increasing effect of disasters caused by natural hazards and technological accidents (EEA, 2010). Evidence shows that Europe will likely face a progressive increase in overall climate hazards affecting highly populated areas, multiple sectors and causing systemic failures (IPCC, 2014); floods and windstorms, in particular, have become critical in combination with other climate hazards (Forzieri *et al.*, 2016). Accordingly, a continuous population growth will bring about an increased exposure of communities; hence a changing climate will lead to more people at risk (Mcbean and Rodgers, 2010). To better handle this unprecedented situation, there is need to build

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scientific capacity in disaster risk reduction through data collection and analysis infrastructure to maintain the complexity of the social and environmental interlinkages (Chen *et al*., 2021).

Europe suffered some of the world's damaging disasters: *e.g.*, storms (western, central, and parts of Eastern Europe), floods (central parts of the continent and the United Kingdom), forest fires (Greece), drought (Iberian Peninsula), several countries being more affected, *i.e.*, Turkey, Romania and France (EEA, 2010, 2017). Within the EEA-32 member countries, between 1980 and 2019, weather- and climate-related extremes accounted for around 81% of total economic losses driven by natural hazards which caused economic losses totalling nearly EUR 446 billion, of which 12,118 million euros in Romania (EEA, 2020). The growing interlinkage between our societies and countries have determined some of these impacts to cascade up from local to national and even international levels (WMO, 2021). As shown, climate change is likely to enhance the risk posed by extreme weather events considering the reported losses which are reaching historical high levels (Forzieri *et al*., 2016), cities being more affected in this respect by concentrating the largest population and buildings (OECD, 2014), thus increasing urban resilience to climate change being a major concern worldwide (World Bank, 2010). Because of the widespread negative impacts of climate change across different economic sectors (*e.g.*, aviation, farming, tourism), the demand for tailored weather information is constantly growing (Mills *et al*., 2016). To avoid such undesirable consequences in the future, the European Commission adopted its new EU Strategy on Adaptation to Climate Change to support climate change adaptation, particularly in key vulnerable sectors[1]. In addition, the Climate-ADAPT platform (developed by the European Commission and the EEA) was created to support climate action and governmental policy by sharing knowledge on climate change and its impacts, adaptation strategies and plans, and case studies[2]. The EU also supports the UN Sendai Framework for Disaster Risk Reduction 2015–2030 (Sendai Framework) in the evaluation of disaster-related losses and economic impacts, as well as in reducing such losses by 2030[3].

It has been estimated that environmental and social threats will be more pronounced in areas prone to multiple climate hazards. In this context, a multi-hazard assessment accounting for possible regional variations in intensity and frequency of climate extremes is essential to identify areas potentially more exposed to climate change (Forzieri *et al*., 2016). However, making scientific information on key environmental concerns available and easy to be used by different stakeholders is an issue researchers are dealing with even more in the recent years. In view of that, climate change "hotspots" mapping has become an important visual tool used by researchers to communicate issues in a manner that may be easier to interpret than text (De Sherbinin, 2014; De Sherbinin *et al*., 2019) and to be understood by different stakeholders and decision makers. Thus, a system mapping framework will turn into a helpful analytical and visual support tool able to enhance stakeholders' knowledge, experience and perception (Nikas *et al*., 2017). More recently, participatory mapping was widely used as effective techniques aimed at engaging local communities in developing decision support tools towards climate change adaptation (Nkoana *et al*., 2018; Yen *et al*., 2019; Mabon, 2020). As a result, an important step for carrying out impact and risk analysis consists in identifying areas where climate phenomena manifest on at larger scales and their intensities (Turco *et al*., 2015). On the long run, through climate mapping, identifying areas considered particularly vulnerable to different climate impacts might also have political, economic, and social consequences to spot regions at climate security risk (Gemenne *et al*., 2014).

The current paper aims to propose a methodology for the elaboration of GIS climate hazards maps at small spatial scale, *i.e.*, Baia Mare Depression, an area with particular local conditions in terms of the natural settings (*e.g.*, climate, relief, hydrology) and human-related impacts (exploitation

[1] https://ec.europa.eu/clima/eu-action/adaptation-climate-change/eu-adaptation-strategy_en
[2] https://climate-adapt.eea.europa.eu/
[3] https://ec.europa.eu/echo/sites/default/files/sendai_leaflet_draft_v6.pdf

and processing of mineral ore deposits, road traffic). As a first step, single hazards maps have been elaborated and, using standard indicators, a complex map resulted, which indicates areas considered as potential climate-related “hotspots”. The maps can be used as a support during the interaction with local stakeholders to increase their awareness and interest in climate change issues. Hence, this type of approach can be considered a climate service by way of the scientific information it provides to stakeholders. The study is part of a larger survey undertaken in the Baia Mare Municipality, where an intense interaction with stakeholders in terms of providing climate-tailored data and information has been undertaken, the results being reported in a previous paper (Sima *et al*., 2016).

2. STUDY AREA

The study area, Baia Mare Depression, located in the north-western part of Romania, is bordered by the Igniş Massive and by the Gutâi Mountains raised to over 1200 m altitude in the North and North-East, and by the Codrului and Chioarului Hills at 650–800 m in the West and South, framing into the Crişana Hills (Posea and Badea 1984; Badea *et al*. 2008). The area is drained by the Someş River and its tributaries Lăpus, Bârsău etc. (Fig. 1) According to the climatic regionalization, the area under analysis is part of the *low hills and tablelands climatic region*, since it benefits from a shelter topoclimate specific to depressionary areas imposed by its relief particular features (Bălteanu, 2016). The *western and northern climatic influences* complete the moderate temperate-continental climate of the Baia Mare Depression. These major climatic traits are completed by the variety of factors imposed by the local geographical environment (*e.g.*, orographic barrier of the mountains situated in the north and north-east and hills in the west and south, exposure, fragmentation, vegetation, soil and water bodies as well as the man-made changes) determining a wide range of local climatic features and exposing the area to several extreme weather phenomena.

The effects of observed and future climate change are differentiated both spatially and socially (Adger, 2010). That being so, the natural conditions of the study area (inter-hilly depression) have a particular influence on the distribution, dynamics and intensity of the extreme weather phenomena and the related impacts on the ecological and social systems. Thus, the intensity of weather phenomena can be smoothened (summer heat waves) or enhanced to the extreme (fog and acid depositions) by its sheltered position provided by the inner hilly area (Sima *et al*., 2012). In the previous years, the pollutant emissions (CO_2, SO_X, particulate matters and Pb) in relation to the industrial profile of Baia Mare, Baia Sprie or Cavnic cities (non-ferrous mining and metallurgical industry) posed significant threat to environment and human health by increasing in concentration in the presence of some weather phenomena (*e.g.*, fog, snow cover, wind, temperature inversions) (Dragotă *et al*., 2013).

During winter the depressionary relief favours the persistence of low temperatures driven by temperature inversions under the atmospheric calm. At inferior levels, where the entire human activity unfolds, this phenomenon is amplified and upheld. Under specific genetic (advective-radiating and orographic processes) and local (*e.g.*, the presence of the solid snow layer, the existence of closed depressions) conditions, the combination of some extreme weather events becomes significantly dangerous. In these conditions, the gravitational leakage of the cold air on the surrounding slopes generates temperature inversions of orographic nature which contribute to the intensification of the cooling process and to the increase in thickness of the inversion stratum. The more closed the depression, the more shielded is the horizon by the bordering mountain slopes which leads to the reduction of the insolation time, and implicitly to the increase in duration and intensity of the thermal inversions that, on a daily regime occurs in the early evening and persists longer in the mornings. That being so, the narrow opening of the depression to the north-west gives a slight smoothening of the extreme weather events in the centre and north-western parts, while the narrowing of the depression in the southern and south-eastern parts under the form of tapered valleys surrounded by mountains, the effects of the extreme weather phenomena are amplified.

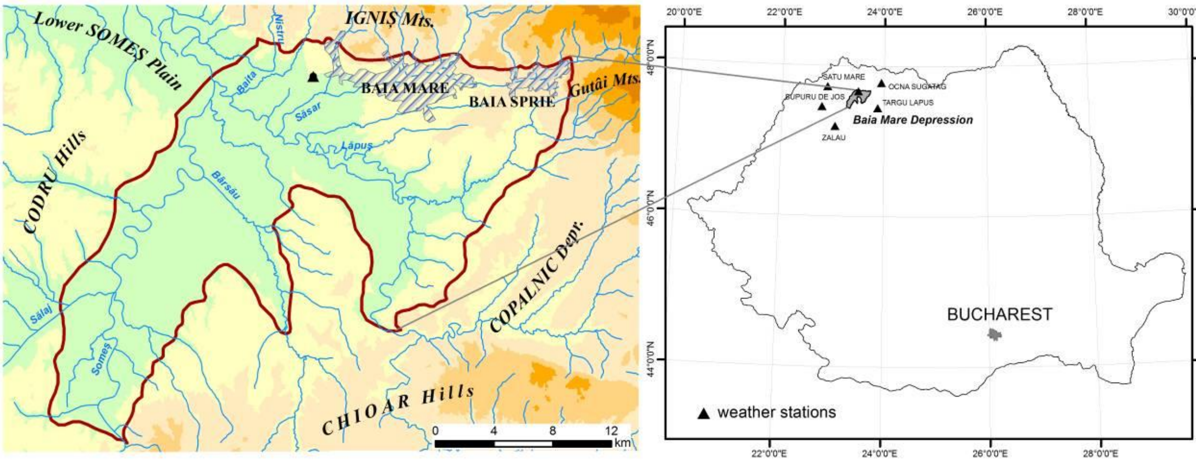

Fig. 1 – The physical-geographical location of the Baia Mare Depression.

Nevertheless, the general climatic feature of the Baia Mare Depression is characterized by a spatial uniformity of thermal parameters imprinting the type of climate known as moderate temperate continental with hot summers and gentle winters, early springs, and late autumns. The most important climate hazards the study area is exposed to, are generated by the main climatic factors: the general atmospheric circulation, solar radiation, and the active surface.

3. METHODOLOGY

A large body of literature on climate change-related events and impacts has been mainly dedicated to issues that involve vulnerability assessment of different weather events, mostly drought or heavy rainfall and vulnerable communities (Wilhite, 2000; Brooks *et al*., 2005; Füssel and Klein, 2006; Iglesias *et al*., 2009; Yusuf and Francisco, 2009; Preston *et al*., 2011), impacts on vulnerable sectors such as agriculture (Van der Velde *et al*., 2012; Sima *et al*., 2015; Lesk *et al*., 2016), urban areas and human health (Stone *et al*., 2010; Bambic *et al*., 2011; Schmeltz and Marcotullio, 2019) etc. More recently, climate change "hotspots" mapping has become of growing concern in the scientific community (De Sherbinin, 2014; Turco *et al*., 2015; De Sherbinin *et al*., 2019) because of the extended range of practical applications the resulted maps provide. Above all, the development of adaptation and mitigation measures and strategies (Wilhite *et al*., 2007; Füssel, 2009; Reckien *et al*., 2014; Felton *et al*., 2016) with implications across various regions or fields is another research direction largely addressed in relation to climate change-related maps. In addition, several theoretical (Peduzzi *et al*. 2005; Gwilliam *et al*. 2006; Helmer and Hilhorst, 2006; De Sherbinin *et al*. 2007; IPCC 2007; IPCC 2014; Cueva-Luna *et al*. 2008) and applied (Yusuf and Francisco, 2009; Amarnath *et al*., 2017; Leis and Kienberger, 2020; Sutanto *et al*., 2020) studies have been elaborated on the impact extreme events have on the environment (climate-related, in particular). Most of them used the overlaying climate hazard sensitivity, and adaptive capacity maps following the vulnerability assessment framework of the United Nations' Inter-Governmental Panel on Climate Change (IPCC) to identify regions most vulnerable to climate change. However, spatial assessments of the extreme weather events which included mapping, spatial analysis and regionalisation have been little addressed in the scientific literature. At larger scales (European level), several impact studies have often relied on a single decisive factor, *i.e.*, climate hazard or extreme weather event, such as heat waves (Fischer and Schär, 2010; Russo *et al*., 2015; Papathoma-Köhle *et al*., 2016; Savić *et al*., 2018), heat stress (Vitolo *et al*., 2019), droughts (Lehner *et al*., 2006; Kim *et al*., 2014) or windstorms (Outten and Esau 2013). These studies described a limited set of climate hazards which limits the delineation of areas potentially affected by climate change-related events. This is also the case of a risk assessment and mapping methodology developed within the European project SEERISK and adapted for a number of climate change-related hazards individually (floods, heat waves, wildfires, and storms) which was applied to some areas of central and south-eastern Europe (Papathoma-Köhle *et al*., 2016; Savić *et al*., 2018). Hence, considering multiple, compound, or cascading hazards for future approaches becomes critical to identifying areas potentially more exposed to the complex effects of climate change (Forzieri *et al*., 2016) and understanding the transformations in the ecological and social systems, given that the impacts of one hazardous event are often exacerbated by interaction with another (Marzocchi *et al*. 2009), causing more severe impacts than a single hazard event alone (Sutanto *et al*., 2020). As a result, Sutanto *et al*. (2020) developed a novel methodology for the identification of hotspots and patterns of compound and cascading dry hazards (heatwaves, droughts, and fire) at pan-European scale.

In Romania, some studies have attempted to develop a methodology to map and regionalise climate hazards (Dragotă *et al*., 2013; Dragotă *et al*., 2016; Dumitrașcu *et al*., 2016). These studies have used the classification of hazardous meteorological phenomena carried out for the Romanian territory by Croitoru and Moldovan (2005) derived from the complex classification of Bryant (1991). Based on these classifications, and yet adapted to the particularities (*e.g.*, climate, relief, industrial profile, associated economic effects) and the scale of the study area, the authors have selected the foremost climatic hazards with impact on both ecological and social systems: snow cover, glazed frost, fog, heavy rainfall, strong wind (Fig. 2).

Forzieri *et al*. (2016) pinpointed as major challenges in addressing multiple hazards the lack of compatibility in relation to the different metrics used to measure the processes and their interaction triggering cascade effects and coupled dynamics. Hence, standardization approaches are required (Kappes *et al*, 2012; Lung *et al*., 2013). That being so, the authors have chosen to use a standard indicator for the statistical reckoning of each extreme climate phenomena selected, *i.e.*, the *maximum absolute frequency* (Fq) which plays a key role in the hazard assessment (Dragotă *et al*., 2009b; Dragotă *et al*., 2013; Grigorescu *et al*., 2013). The maximum absolute frequency was calculated using the real data (1896–2010 period) from the Baia Mare weather station, considered as a reference station for the study area. In addition, due to the lack of additional backing weather stations, the database of Satu Mare, Târgu Lăpuş, Ocna Şugatag, Supuru de Jos and Zalău adjacent weather stations was also used in order to obtain a good GIS interpolation. Furthermore, based on the selected class values, three hazard classes have been set up: high, medium and low (Fig. 2).

Each climate hazard was spatially represented in GIS as a single-hazard layer and, based on its significance for the study area, was not considered as equally contributing to the overall equation, being evaluated on a 1 to 3 scale and assigned with a ***weight (w).*** Having in view its attributed hazard class (3 – high, 2 – medium and 1 – low), a ***rank (r)*** has been also assigned (Tab. 1) (Dragotă *et al*., 2013; Dragotă *et al*., 2016; Dumitrașcu *et al*., 2016).

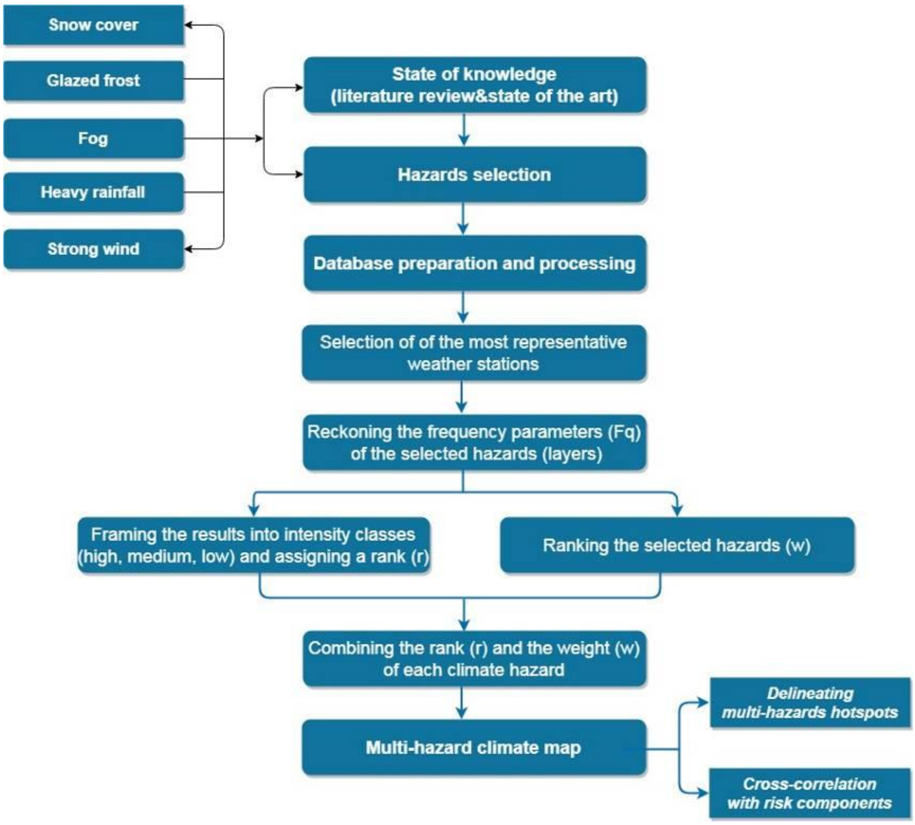

Fig. 2 – Methodological flow of the climate multi-hazard mapping and assessment.

Table 1

The selected climate hazards and the assigned classification (rank) importance (weight)

Climate hazards		**rank**	**weight**
F	*Fog*	3...1	3
Sw	*Strong wind*	2	3
$\mathbf{H_{rf}}$	*Heavy rainfall*	3...1	2
Gf	*Glazed frost*	3...1	2
$\mathbf{S_{cov}}$	*Snow cover*	3...1	1

Finally, the mathematical formula summing up the layers and the assigned ***weight (w)*** and ***rank (r)*** was computed with the aim of completing the complex multi-hazard climate map:

$$\mathbf{Scov\mathit{r} + 2(Gf\mathit{r} + Hrf\mathit{r}) + 3(Sw\mathit{r}+F\mathit{r})}$$

Thus, the resulted GIS-based complex multi-hazard climate map is a comprehensive way of representing the spatial susceptibility to a group of severe climatic events at regional scale (Baia Mare Depression). By weighting and ranking the selected extreme weather events, the resulted final map clearly delineates which areas or identifies which communities are more exposed in order to provide effective monitoring and coordination of the mitigation actions. However, it should be noted that the weight might have a significant influence in upgrading or downgrading the hazard classes in the final map. *E.g.*, low fog hazard will be multiplied by 3 or low heavy rainfall hazard will be multiplied by 2, thus increasing the overall hazard class of the area due to a higher rank.

The visual impact and effectiveness of the climate hazard map has been subjected to **stakeholder analysis** using the focus group research method. Two meetings with local stakeholders were organised at Baia Mare City Hall. For each of the two meetings, two focus groups were established: (1) an ***institutional focus group*** consisting in local authorities and selected institutions (*e.g.*, Regional Meteorological Centre North Transylvania, Counties Inspectorates for Emergency Situations – Maramureș, Satu Mare and Zalău, Maramures Public Health Authority) and (2) an ***academic focus group*** with experts in climate hazards assessment, mapping and communication. These two focus groups provided qualitative information and feedbacks on the easiness of understanding and readability of the data which significantly improved the visual display of the maps. The interaction between the outcomes of the two focus groups allowed the authors to select the best way to transpose the climate information to be better interpreted by the potential users.

4. RESULTS AND DISCUSSIONS

Given the specific environmental features of the Baia Mare Depression, the selected extreme weather events occurring during the cold semester of the year (snow cover, glazed frost, fog) stand out due to their increased hazardous potential as compared to the warm semester (heavy rainfall, strong winds). Generally, they are triggered by the negative thermal deviations from the normal state caused by the positioning of the baric centres in relation to the study area, the frequency and intensity of the cooling processes and the speed of air masses. These genetic conditions are amplified or diminished by the characteristics of the active surface.

The ***fog*** is basically represented by atmospheric suspensions in the form of microscopic droplets which reduce visibility on a horizontal level to less than 1 km. The presence of the fog, no matter in what form, has a negative impact on the transportation means and on the state of health of the population. The highest monthly value for the fog frequency throughout the year is registered during winter (December–January), and the lowest during the summer months (June–August). Fog becomes significantly dangerous on certain sectors of the European roads where, the low visibility along with the higher speeds and increased traffic can result into severe accidents with casualties and property damages (Dragotă *et al*., 2016).

Whenever fog is associated with different polluting substances, its effect on the environment increases in direct proportion with the polluting factor's concentration level, and the intensity and duration of the parameters characteristic for this meteorological phenomenon amplify or decrease the content of polluting substances existing in the microclimatic space (Bogdan and Frumuşelu 2002).

In polluted areas, *i.e.*, Baia Mare Depression, 5% of the polluting factors present in the free atmosphere can be engulfed by the precipitations fallen on the earth (*wash-out*). When these precipitations come from a dirty cloud with a high concentration of polluting substances (*rain-out*), these substances reach the soil at the same time the precipitations do, at large distances from the emission source. The Baia Mare Depression was one of the three *hotspots* in the country, alongside Copşa Mică and Zlatna, which has been facing atmospheric pollution for the last decades (Farcaş and Croitoru, 2003; ANPM, 2020). Thus, Baia Mare town was a historical hot spot in terms of atmospheric pollution with sulfuric dioxide, sulfuric trioxide, and sulfuric acid from the non-ferrous metallurgy activity (S.C. ROMPLUMB Company) which thrived during the communist period (before 1990). By its position in the north-eastern part of the Baia Mare Depression (Firiza Valley), and because of the reduced dispersion of polluting agents (low air circulation, atmospheric calm and frequent thermal inversions) high levels of pollution with specific toxic substances (heavy metals such as Cd, As, Pb) were registered (Şerban and Bălteanu, 2005). Recently, reducing its capacity and the implementation of new technologies after 1990, the air pollution level in and around Baia Mare had decreased significantly. However, the main environmental threat comes from the heavy metal dust of the tailing ponds and waste dumps in relation to the former non-ferrous metallurgy activity (Baia Mare, Baia Sprie areas), as well as from the polluting emissions in the atmosphere from the fuel burnings (*e.g.*, steam power plants) and from the road traffic (Fig. 3). All of these are more likely to expose Baia Mare Depression to acid rains, the surrounding heights in the north being an obstacle against the dispersion of the polluting air (Dragotă *et al*., 2013).

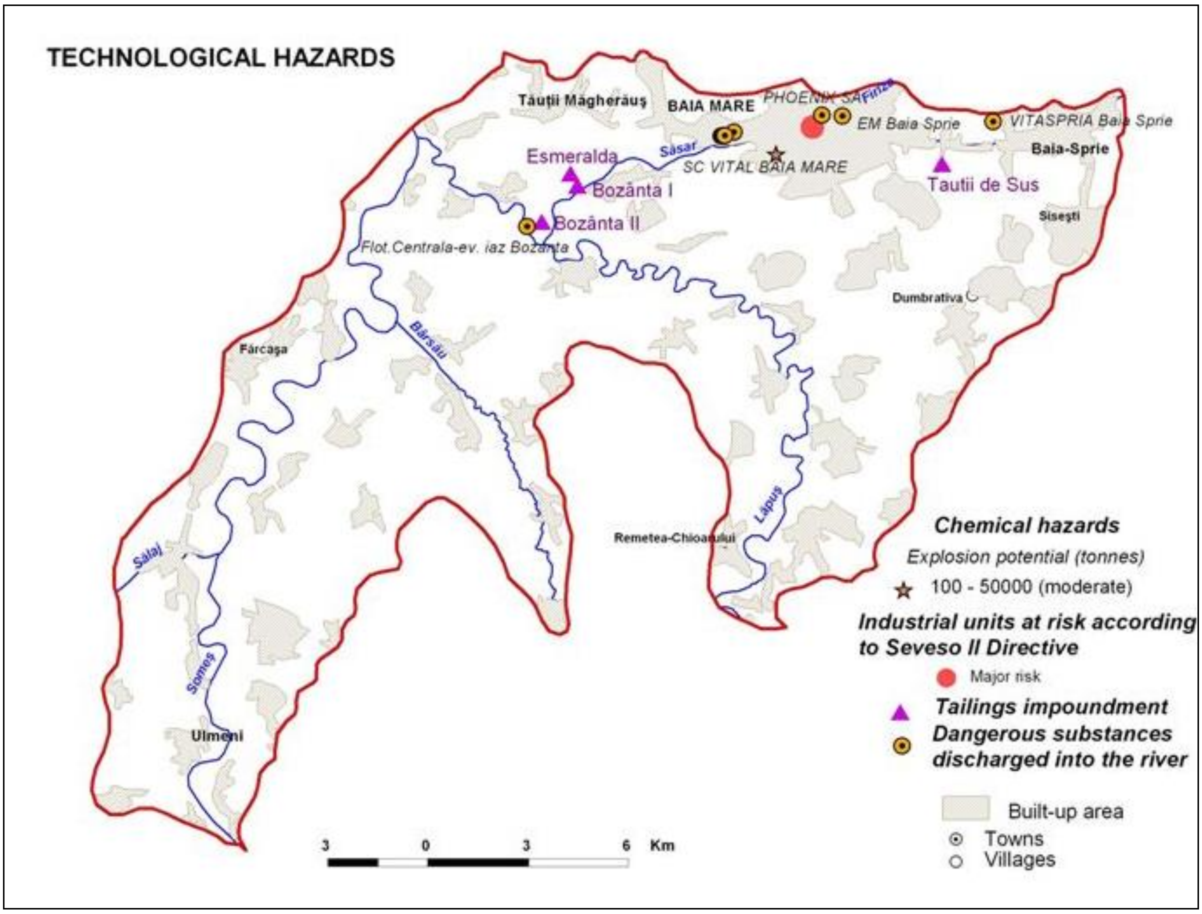

Fig. 3 – Industrial hot-spots in the Baia Mare Depression.

In the absence of rain or other types of precipitation, the atmospheric polluting substances are taken from the atmosphere and deposited on various surfaces (soil, vegetation and buildings). The dry deposition could also contribute to the increasing of the acidity level and together with humid deposition are known as *acid depositions* (Farcaş and Croitoru, 2003). When associated with fog, acid deposition may increase the environmental risk in the topoclimatic conditions of the Baia Mare *heat island*. The increase in road traffic has amplified the contamination sources and in association with the risk meteorological phenomena (*e.g.*, smog, mist, acid depositions) have had a major impact on the environment and on population health.

The areas most exposed to this couple of extreme weather and human-induced phenomena have the largest extent in the northern and north-eastern parts of the study area where the industry (pollution sources) and the foremost settlements are located (Fig. 4), thus posing an increased threat to the natural ecosystems and human health.

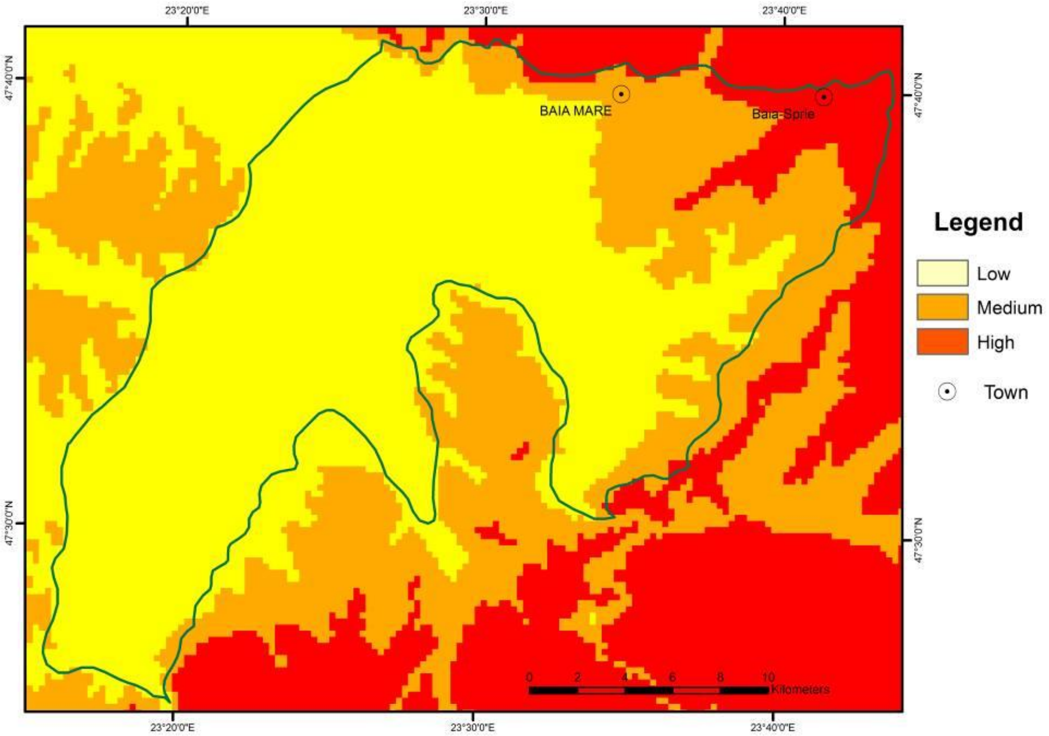

Fig. 4 – The annual frequency of days with fog.

Strong wind is generated by the thermo-baric contrasts between the regions characterized by high-value horizontally gradients and can occur any time of the year. If, during the cold semester of the year, wind is associated with the snow layer and snowfall, during the warm semester of the year it become climate hazard when associated with extreme heat episodes or with heavy rainfall, in particular. Also, it has a key role in changing the dispersion of polluting substances into the atmosphere in relation to the air circulation at the terrestrial surface, which depends on the speed of air masses, as well as on the relief morphology. On the other hand, the atmospheric calm, coupled with the lack of precipitation could lead to the stagnation of polluting substances for long periods of time, usually at low altitudes, in the same regions of their emission. The annual mean value of the wind's dominant frequency is from the western direction (12.5% of cases), followed by the eastern direction (11.9%), and the atmospheric calm is felt in over 50% of cases (51.2%).

The climate hazard aspect induced by the wind is related to its strong intensifications characterized by the sudden shifts in direction and intensities higher than 16 m/s. These can manifest themselves as strong winds and windstorms of a convective origin or associated with the passing of cold air fronts, causing severe damages to buildings, road infrastructure causing restrictions to traffic flow, breaking the aerial cables, toppling the electricity transmission poles, falling over the trees along the transportations means (Dragotă *et al*., 2016) and vegetation, especially in the case of frontal winds (due to their large expansion). At Baia Mare meteorological station, the mean annual number of days with strong winds exceeds 10 days, and the maximum number can exceed, during the warm semester of the year, 40 cases (Sandu *et al*., 2008). The mechanic effect generated by the strong winds is doubled by the amount of polluting substances dispersed into the atmosphere. The obstruction of the depression to the north by the Igniş Massif determines an annual (%) prevalence of air masses coming from western and north-western (19%), as well as eastern and south-eastern (19.8%) directions. This leads to an increased effect of the wind activity in the northern and north-eastern parts of the depression in relation to potential transportation of pollutant substances, thus enhancing its environmental damaging effects. On the other hand, the specific topography of Baia Mare depression determines a high frequency of the atmospheric calm (51.2%) which enables the stagnation of pollutants in the lower atmosphere. This situation also applies to the most urbanised areas located in the northern and north-eastern parts where the main pollutant sources are located.

The hazardous character of the ***heavy rainfall*** depends on its specific parameters (intensity, length, quantity), as well as on the particular features of the active surface: lithology, presence/absence of the vegetation cover, declivity, occurrence period (*e.g.* after long periods of drought when the soil is extremely dry and has a low cohesion; after a rainy period; before or after snowmelt when soil is over-moist), and on the role Carpathian Mountains play against the humid air advections. The highly active dynamics of the humid tropical air or of the polar maritime air over the Romanian territory, as well as the unequal heating of the terrestrial surface leads, during summer leads to heavy rainfalls triggering floods. The hilly regions, wherein the study area falls into, the occurrence of floods is conditioned by a certain amount of rainfall water (Milea et. al. 1974): in the case of dry soil, an amount of water of 30 l/m^2 or more is needed within a 24-hour time span; in the case of moist or humid soil, an amount of water between 10 and 20 l/m^2 or more is needed within a 24-hour time span.

In the Baia Mare Depression, the maximum monthly pluviometric value is registered in June when on a multi-annual scale reaches 103.5 mm. The maximum precipitation amounts accumulated in short intervals (24 h, 48 h or 72 h) are mostly owed to the torrential character of the summer rains in terms of high intensities and relatively small durations, having significant effects on the environment by triggering erosional processes on the mountain slopes (*e.g.*, floods, landslides), as well as in riverbeds (lateral erosion). The pluvial intensity reaches values that rank 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 (Dragotă *et al*., 2013). By way of the floods they cause, exceeding rainfall affects the crops, the economic infrastructure (*e.g.*, roads, bridges, railroads, electric energy transportation networks, sewage system, water pipes, gas pipes), and the houses, having a direct and incidental influence on people’s lives. The frequency of days with rain showers pinpoints high and medium hazard in the northern, north-eastern and eastern parts of the analysed territory and low in the central, western and southern parts (Fig. 5). Once more, the areas most exposed to this hazardous phenomenon overlap the areas where human communities are more developed.

The ***glazed frost*** corresponds to a crystal ice deposit with a very fine structure that generally comes from the freezing of overcooled water drops out of fog or clouds during very cold weather and mild winds. The wind favours the deposition of white frost leading to ice deposits of significant sizes and shapes influenced by its direction. In the study area, the mean annual number of days with glazed frost is up to 4 and a maximum number reaches or exceeds 10 days per year, posing a significant threat to the environment and human health. It has a negative impact on all transport means primarily due to the significant decrease of friction coefficient on ice layer that hinders transportation and increases the risk of accidents. In addition, ice accumulations can cause breaks in the canopy of trees (Dragotă *et al*., 2016). The areas most affected by glazed frost are located in the central, south-western and western parts of the Baia Mare Depression, generally overlapping the roads that connect the city of Baia Mare with other important cities outside the analysed area: Satu Mare to the north-west, Zalău to the south-west or Cluj-Napoca to the south (Fig. 6).

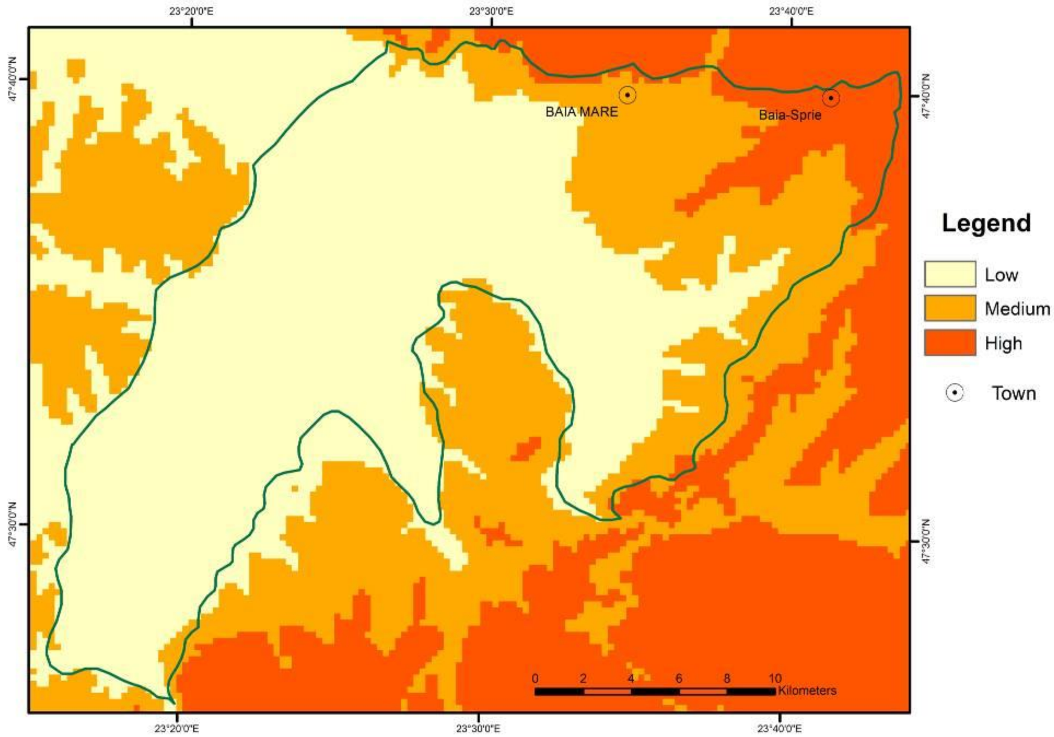

Fig. 5 – The annual frequency of days with heavy rainfall.

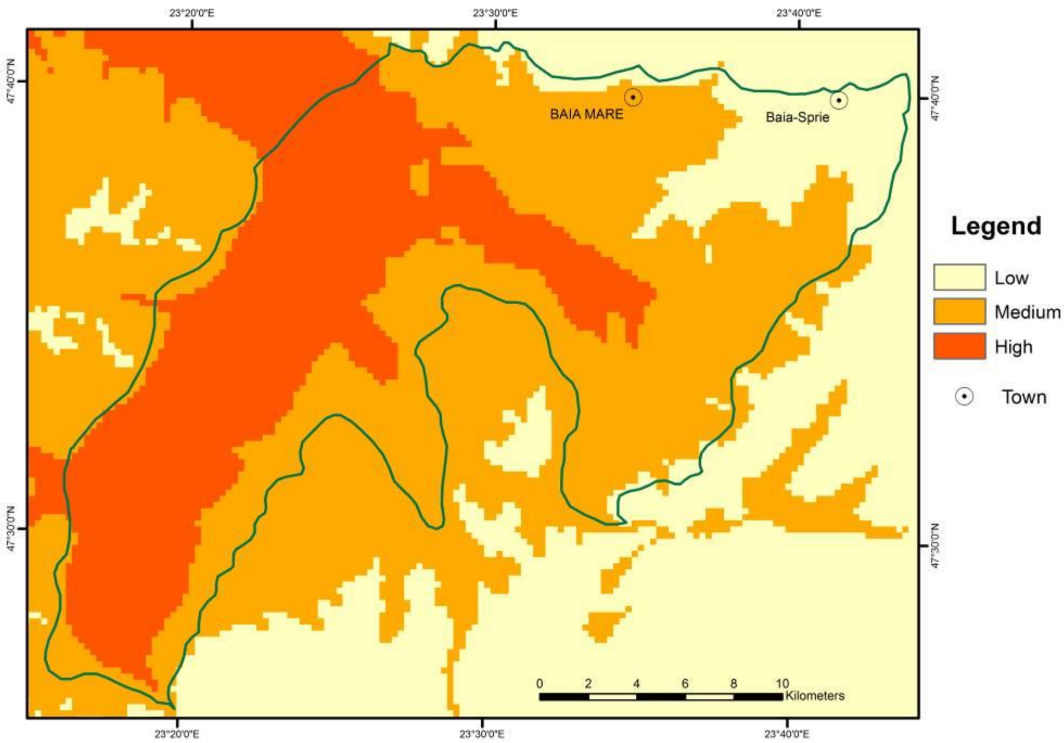

Fig. 6 – The annual frequency of days with glazed frost.

The ***snow cover*** is considered a dangerous winter phenomenon, and it occurs in Baia Mare Depression almost every year. It is characterized by thickness, uniformity, structure and density. On a multi-annual mean value, the first day with snow layer usually occurs in the second third of November in the eastern and north-eastern sectors, expanding up on the slopes of Igniş and Gutâi Mountains, and in the western sector in the last third of November. The last day with snow cover is usually registered in the second third of March for the western sector, while in the eastern and northern sectors they last longer, until the end of March. Thus, a mean duration of a stable snow layer ranges from 50 to 100 days in the western side of the depression to 150 days in the rest of the area. The maximum thickness of the snow layer has reached 98 cm, and under the action of the wind, the layer is not levelled, and the snow is blasted over distances and piled up in mounds.

Generally, the snow cover becomes climate hazard when its thickness is significantly high and the wind has elevated speeds (Dragotă *et al*., 2016); mounds of snow are causing damages both related to its presence and its absence. Thus, under the influence of the atmospheric calm or of the wind with speeds lower than 2 m/s, as well as under the influence of the active surface's particularities, significant snow depositions are favoured. On the other hand, in particular synoptic conditions and in association with wind speeds exceeding 15 m/s, the snow cover could enhance its hazardous character turning into blizzard. That being so, blizzards-built snowbanks on all the traffic routes that are perpendicular on the wind direction, especially on the European and national roads that cross Baia Mare Depression. When the blizzards become violent, and the mean snow layer thickness goes over 25 cm, significant damages and environmental unbalances might result (Fig. 7).

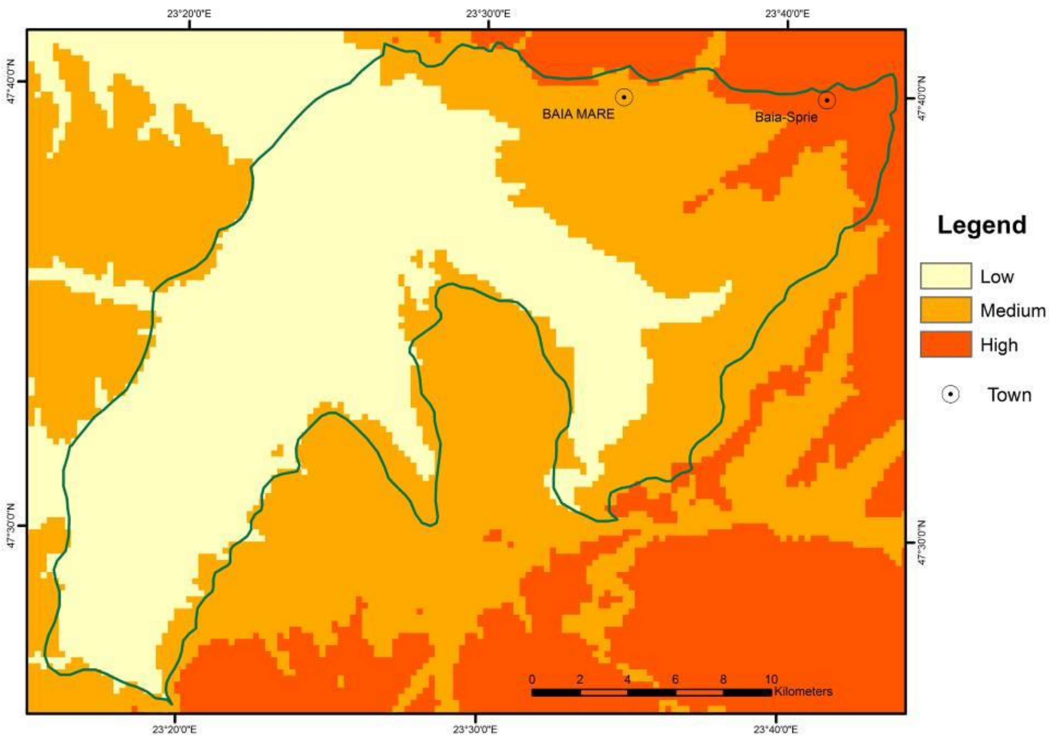

Fig. 7 – The annual frequency of days with snow cover.

During early springs, sudden snow melts can trigger floods, as well as river blocking caused by ice breakup having major impact on river transportation. Under partial or total absence of the snow layer, the frostiness is favoured at the soil level leading to severe damages to vegetation and crops (especially during fall). The northern, north-eastern and eastern parts of the Baia Mare Depression are highly exposed to this climate hazard putting at risk the main settlements, as well as the roads connecting them.

The final ***multi-hazard climate map*** indicates that 88.8 % of the study area is highly and medium exposed to the selected extreme weather events. Geographically, the exposed territory overlies a large depressionary area which favours the persistence and even intensification of some weather phenomena, *i.e.*, fog, due to the topography and the mixture with different pollutant substances. The lowest exposure (11.2 %) overlaps the north-eastern extremity (Baia Sprie area), where the proximity to the mountain areas provides shelter to the occurrence of most of the extreme phenomena (Fig. 8).

An extension of the current study is a cross-correlation between the multi-hazard climate map and the local conditions to quantify the potential risk which might involve population or infrastructure. At local administrative units' level, the localities with high exposure to the selected extreme weather phenomena (with over 90% of their surface) are Ardusat, Ariniş, Farcaşa, Salsig, Satulung etc. These localities are highly exposed to at least three of the four analysed phenomena (primarily snow cover, glazed frost and heavy rainfall). Medium exposure is depicted by some localities (*e.g.*, Recea, Sisteşti, Salsig, Satulung) with relatively low to moderate exposure to all considered climate hazards.

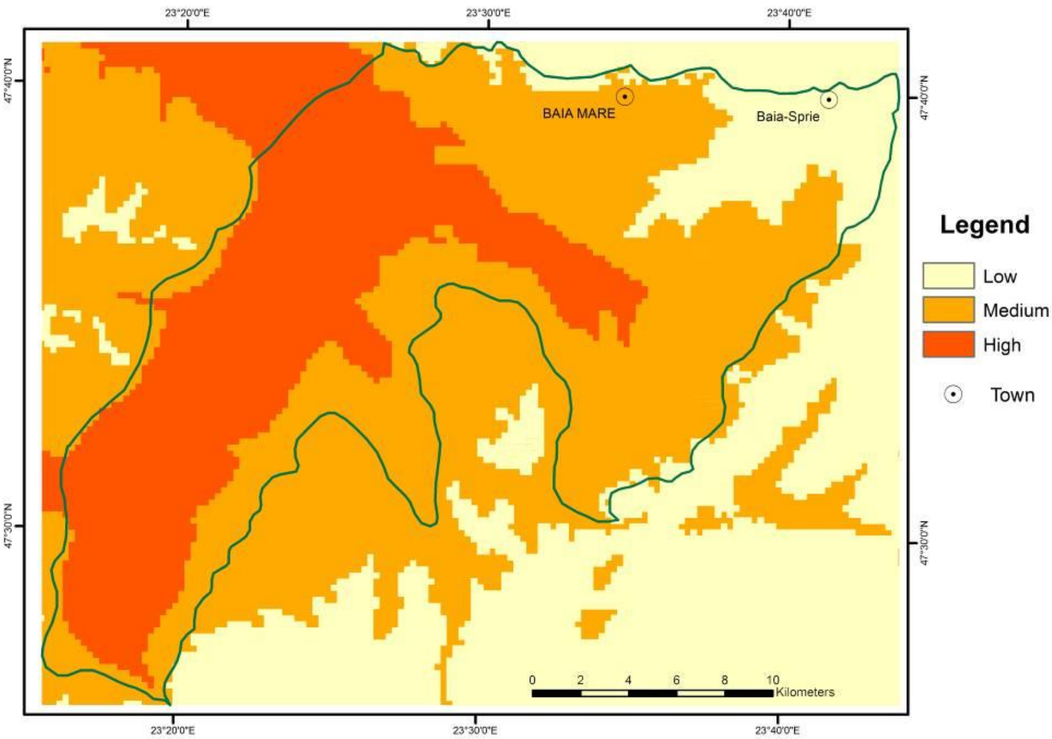

Fig. 8 – Climate hazards in Baia Mare Depression.

A reduced number of localities (*e.g.*, Baia Sprie, Copalnic-Mănăştur, Siseşti) have low exposure to this group of dangerous weather phenomena, generally given by the lowest values recorded to all extreme weather events (Fig. 9).

LAU	HEAVY RAINFALL low	medium	high	FOG low	medium	high	GLAZED FROST low	medium	high	SNOW COVER low	medium	high	MULTI-HAZARD INDEX low	medium	high
ARDUSAT	86	14	0	0	12	88	86	14	0	81	19	0	86	14	0
ARINIS	82	18	0	0	16	84	82	18	0	66	34	0	82	18	0
BAIA MARE	6	18	76	75	16	9	6	18	76	0	25	74	6	19	75
BAIA SPRIE	0	8	92	90	10	0	0	8	92	0	11	89	0	10	90
CICÂRLAU	24	12	64	62	14	24	24	12	64	22	19	60	24	14	62
COAS	24	35	41	38	35	27	24	35	41	14	51	35	24	38	38
COLTAU	78	22	0	0	17	83	78	22	0	70	30	0	78	22	0
COPALNIC-MANASTUR	0	30	70	67	33	0	0	30	70	0	35	65	0	33	67
DUMBRAVITA	23	68	9	7	63	30	23	68	9	39	37	24	23	70	7
FARCASA	57	43	0	0	38	62	57	43	0	47	53	0	57	43	0
GÂRDANI	53	47	0	0	43	57	53	47	0	42	58	0	53	47	0
GROSI	23	72	5	3	63	34	23	72	5	13	85	2	23	73	3
MIRESU MARE	52	22	26	25	20	54	52	22	26	39	37	24	52	22	25
RECEA	98	2	0	0	0	100	98	2	0	83	17	0	98	2	0
REMETEA CHIOARULUI	15	69	15	14	67	19	15	69	15	9	80	11	15	71	14
SACALASENI	79	21	0	0	17	83	79	21	0	57	43	0	79	21	0
SALSIG	91	9	0	0	8	92	91	9	0	82	18	0	91	9	0
SATULUNG	91	9	0	0	6	94	91	9	0	72	28	0	91	9	0
SISESTI	0	4	96	95	5	0	0	4	96	0	6	94	0	5	95
SOMCUTA MARE	13	41	46	45	40	15	13	41	46	4	54	42	13	42	45
TAUTII MAGHERAUS	24	10	66	65	9	25	24	10	66	21	15	64	24	11	65
ULMENI	54	34	12	12	30	58	54	34	12	40	48	11	54	34	12

Fig. 9 – The share of climate hazards & multi-hazard classes at LAU level in Baia Mare Depression.

Following the focus groups meetings and interactions, the mapping of the selected extreme weather events was constantly improved so as the scientific information to be better visualised and understood by the potential end users. As a result, the main purpose of the climate map is to provide a simple tool to identify and prioritise areas ("hotspots") where extreme weather-related impacts are assumed to be the greatest. The resulted product becomes a valuable climate service to be further used for adaptation interventions by different stakeholders in relation to the specific needs of different sectors of local importance (*e.g.*, tourism, agriculture, transport, health). In the study area, two sectors stand out: transport and health which can be analysed through assessing the interaction between the hazard classes and infrastructure (road, rail) and population (Fig. 10).

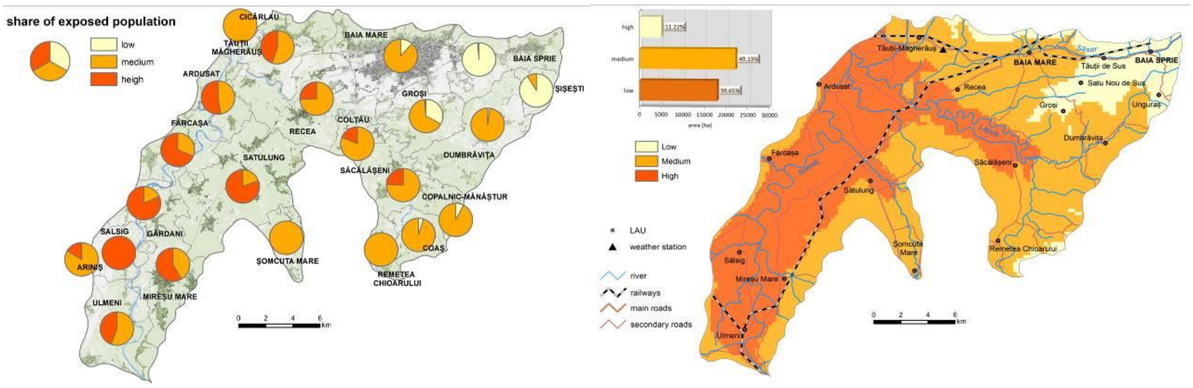

Fig. 10 – Communicating handy climate hazards to stakeholders. Share of exposed population (left) and distribution of exposed transport infrastructure (right)

Depending on the addressed extreme weather events, the climate hazard map turns into a useful tool for different categories of stakeholders and decision-makers: farmers, local/regional authorities, Emergency Inspectorates etc. However, to better communicate the climate information, the interaction with the potential end users (*i.e.*, stakeholders) is crucial since it provides the realistic feedback which allows scholars to design and produce useful final scientific products.

5. CONCLUSIONS

In the Baia Mare Depression out of the assemblage of the hazardous climate phenomena one could identify a distribution of “hotspot” areas according to the distribution of the main genetic factors: the altitude (from the surrounding mountain and hilly slopes), and air circulation (from west to east). In terms of intensity, frequency and duration, the extreme climate phenomena occurred during the cold semester of the year (snow cover, glazed frost) have an increased negative impact upon the environment then the ones unfolding during the warm semester (heavy rainfall) or throughout the year (fog). This is largely due to the general display of the relief, as well as to the dominant air circulation, favouring a sheltered climate for the cold, polar and arctic air advections.

In preparing the tailored scientific (*i.e.*, climate) information, the role of the GIS techniques is particularly important since it enables the creation of an interactive database, easily updatable and accessible to different users involved in disaster mitigation and management, as well as in the elaboration of the sustainable development strategies (Bălteanu and Şerban, 2004). These data can be further transposed into GIS-based climate hazard maps which are visually comprehensive communication tools in representing, at different scales, the spatial vulnerability to a single climatic phenomenon or to an association of other severe climatic events. These maps might also rank the natural hazards in a certain area and monitor the state of the environment to diminish and even avoid the damaging consequences resulting from their occurrence and in further supporting adaptation strategies and increase resilience.

Climate hazards mapping is an important component of the climate change mitigation and adaptation processes in terms of identifying areas prone to different extreme events in order to further design and apply tailored strategies at different spatial scales. Climate hazards maps, as comprehensible visual tools, have become increasingly useful in the communication process between academia and different categories of potential beneficiaries. On that account, they can be use not only to spatially identify areas exposed to different extreme events, but to understand the environmental, social and economic impacts and perform in-depth quantitative investigations on the potentially affected population, goods, assets and ecosystems through vulnerability and risk assessments. They come as an addition to the landslides and floods hazard maps, compulsory by legislation to be adopted by each municipality, offering them a more complex multi-hazard view on the natural dangerous phenomena.

Compared to an extended literature on single risks (Iglesias *et al*., 2009; Yusuf and Francisco 2009; Preston *et al*., 2011), integrating multi-hazards into a complex index (based on classifications and ranking) is a more comprehensive approach since it takes into consideration the possible interactions among them which often exacerbate their effects (Marzocchi *et al*., 2009). The combination of multiple extreme weather phenomena relied on both objective (with the highest impact on the study area) and subjective (expert judgement on ranking or assigning the weight of the selected phenomena) approaches. Thus, spatio-temporal information layers to be tailored in order to identify the concurrence of multiple hazards become necessary, especially in the context of Early Warning Systems (Vitolo *et al*., 2019). In line with the above, the current work proposes a simple methodology to integrate several climate extreme phenomena (layers) with impacts on a broader spectrum of sectors (*e.g.*, agriculture, health, infrastructure) and visually display (map) them in order to delineate areas prone to their effects. In this way, the overall multi-hazard exposure of the study area has been quantified in a more accurate manner, to identify areas that are likely to be most exposed (“hotspots”). The resulted multi-hazard information (layers and final map) could be valuable in disaster risk reduction and emergency response management to develop or to improve (according to the case) evidence-based decision making (Vitolo *et al*., 2019) at different spatial scales. Thus, cross-examining the spatial response of local administrative units, inquiring the share of exposed population or infrastructure were among some of the practical applications proposed by the authors that might be used to prepare handy products (maps, graphs) able to communicate climate hazards to stakeholders. They better illustrate the relationships between the spatial distribution of the multi-hazards and the environmental components, to be easily understood by the potential end users and to improve the knowledge about and response to change-related impacts.

Uncertainties. Even though it uses real data to integrate the key extreme weather events the area is exposed to, the proposed methodology has, however, several objective and subjective uncertainties. The objective uncertainties refer to the data limitations in terms of spatial and temporal resolution. It applies to the data used for the elaboration of the multi-hazard map (*e.g.*, climate data, Digital Elevation Model) and in the cross-correlation with the risk components (*e.g.*, statistical socio-economic data) to obtain the quantitative evaluation of hazard impacts. On the other hand, the subjective uncertainties reside in the use of expert judgement for the selection of extreme weather events and ranking them according to importance (weight). However, a qualitative approach to hazard, impact, and risk assessment is often preferred due to data limitations (Papathoma-Köhle *et al*., 2016). The overall uncertainties of the methodology were generally reduced by the stakeholder analysis which provided positive feedback, supported the overall scope of our research, *i.e.*, communicating handy multi-hazards climatic products to end users. Thus, stakeholder involvement throughout the process of building up the multi-hazard assessment and mapping has been recognized to improve the effectiveness of the final products.

Regardless of some data limitations, the output of the current study is expected to be useful to different stakeholders (*e.g.*, policymakers, local authorities, NGOs) and academics in better attracting financial resources towards developing mitigation and adaptation measures. In order to deliver a more complete picture of the potential risks an area is subject to, additional information on exposure and vulnerability would be required to quantify and spatialize the expected response of the risk components (*e.g.*, population, infrastructure). Moreover, visualising scientific data helps improve the access to transparent, updated and easy-to-read scientific information that can be used to improve social and economic progress at regional and local levels. Also, the possibility to regularly updating the resulted climate products would be another plus of the methodology, given the increasing variability of temporal and spatial patterns of extremes, as well as a in the magnitude and frequency of climate hazards (Forzieri *et al*., 2016). The current study proposes a simple methodology to generate climate hazard maps based on integrating multi-hazards information layers that can be easily replicated to different regions and adapted to local scale assessments. Such approach would contribute to one of UN Sendai Framework for Disaster Risk Reduction 2015–2030 (Sendai Framework) key targets, *i.e.*, increasing the availability and access to multi-hazard early warning systems and disaster risk information and assessments to people by 2030[4].

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