THE CONCEPT STUDIES OF RURAL AREAS EXPOSED TO EXTREME WEATHER EVENTS

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Abstract
Each year, natural disasters affect various regions of the world. This is a profound problem, which leads to growing financial and human losses. It is believed that natural catastrophes are caused mainly by greenhouse gases, ozone depletion, deforestation, desertification, urbanization and land use. In rural areas, losses associated with natural disasters can also be exacerbated by local factors. These factors have caused the division of the area of research on subpopulations that showed homogeneous groups of factors. Areas covered by extensive forests, farmland, meadows, marshes and water bodies are more susceptible to financial losses in agriculture than territories with average share of those land features. Spatial attributes that are important determinants of agricultural production, including soil quality, climate, water availability and land relief, do not alleviate the negative consequences of extreme weather events. Spatial planning systems should be developed for managing high-risk areas in a way that minimizes the resulting losses.
Key words: climate change, extreme events, attributes of non-urbanized areas, spatial planning.

Introduction

Natural disasters and other calamities generate massive financial and human losses. Natural disaster is a natural event with catastrophic consequences for living things in the vicinity (Sivakumar et al., 2005). Andreson (1990) defines natural disasters as temporary events triggered by natural hazards that overwhelm local response capacity and seriously affect the social and economic development of a region. Susman et al. (1983) describe disasters as the interface between an extreme physical environment and a valuable human population. Natural disaster is also defined as “a serious disruption of the functioning of society, causing widespread human, material or environmental losses which exceed the capacity of the affected society parts” (Sivakumar et al., 2005). Humans have to learn to cope with natural disasters by adapting to their negative consequences or preventing such events whenever possible. According to the United Nations Office for Disaster Risk Reduction (UNISDR), 357 natural disasters were registered in 2002-2011 (Table 1), leaving behind 124.52 million victims and causing damages worth USD 157.34 billion.

The number of reported disasters in Europe (65) was above the annual average disaster occurrence between 2002 and 2011 (56). This is largely due to cold waves and extreme winter conditions, which affected most European countries in the beginning of the year. The number of such climatological disasters (45) is almost three times superior to its annual average for 2002-2011 (17). Inversely, the year 2012 shows a strong decrease in the number of hydrological disasters (16) compared to the annual average of 23. Such a decrease is still more pronounced for meteorological disasters: only one was reported in 2012 – the lowest number ever reported since the 1990s in comparison with the annual average of 14 in 2002-2011. Therefore,

Table 1

Natural disasters in Europe and global – occurrence and impacts

Type of natural disaster	No. of natural disasters	Global	Victims (millions)	Global	Damages (USD $ bn)	Global
Climatological 2012	45	85	0.45	36.65	4.15	26.63
Average 2002-11	17	59	0.27	102.29	2.76	9.49
Geophysical 2012	3	32	0.03	2.91	15.80	18.62
Average 2002-11	2	36	0.01	8.12	0.53	44.36
Hydrological 2012	16	150	0.10	64.74	4.24	25.61
Average 2002-11	23	197	0.28	117.71	4.73	23.66
Meteorological 2012	1	90	0.00	20.22	0.01	86.48
Average 2002-11	14	102	0.11	39.75	3.64	51.81
Total 2012	65	357	0.58	124.52	24.20	157.34
Average 2002-11	56	394	0.66	267.88	11.60	129.33

Source: own study based on Guha-Sapir et al., 2013.

compared to the previous decade, 2012 appears as an atypical year in Europe, with disasters occurring in proportions distinctly different from those of previous years. In 2012, the decrease in the number of victims (0.58 million) compared to their 2002-2011 annual average (0.66 million) is largely explained by the decrease in the number of victims of meteorological disasters (-99.7% in 2012 compared to the 2002-2011 annual average) and hydrological disasters (-62.2%). In contrast, the number of victims of geophysical disasters increased by 76.6% and climatological disasters – by 68.2% in comparison with the annual average for 2002-2011. In Europe, damages caused by natural disasters in 2012 (USD 24.2 billion) were the highest in the decade at more than twice the annual average for 2002-2011 (USD 11.7 billion). Damages from climatological disasters (USD 4.2 billion) were 1.5-times higher than the annual average for 2002-2011. Damages from hydrological disasters (USD 4.2 billion) were close to their 2002-2011 annual average (USD 4.7 billion) (Guha-Sapir et al., 2013).

Natural disasters and human-caused threats to space and the environment have social and economic impacts. Floods, draughts, landslides, tornados, fires and ground frost can lead to crop failure, loss of safety, property or life, migration and economic losses. The adverse consequences of extreme weather events are accumulating in agriculture and forestry. New standards for communicating information about extreme events and evaluating their consequences should be developed. Advancements in technology and science contribute to the accuracy of disaster forecasts and estimations of probable losses. This vital information can be used to effectively mitigate and alleviate the consequences of extreme weather. According to the UNISDR, disaster risk reduction is “the conceptual framework of elements considered with the possibilities to minimize vulnerabilities and disaster risks throughout a society, to avoid (prevention) or to limit (mitigation and preparedness) the adverse impacts of hazards, within the broad context of sustainable development”. Many studies focus on the covariate losses generated by extreme events, including partial or total loss of household assets, loss of income or productivity. In recent years, researchers have also emphasized the linkages between rapid urbanization and disasters (Sanchez-Rodriguez et al., 2005). Urbanization has become the dominant feature of human settlement patterns in the past century. The linkages between rapid urbanization and disasters were sometimes described as reflexive: cities create their own risks by causing degradation of local, regional, and global environments (Hardoy et al., 2001; Sanchez-Rodriguez et al., 2005).

Many studies have explored the financial and economic impacts of extreme events, such as hurricanes, floods, earthquakes, heat waves and wild fires, at the local and regional level (Pielke, 2008; Zhang et al., 2008). This study generally focuses on aggregate impacts of natural disasters, including business interruption costs, infrastructure damage, loss of business structures and productive capital, as well as the available measures for minimizing economic risks, such extended insurance cover, enforcement of construction code standards and development of disaster preparedness plans. Vulnerability is not evenly distributed across society, and some individuals, households or groups are likely to be disproportionately affected by climate change or disasters. This is also relevant to extreme events related to climate change. It should also be noted that the context in which climate extremes and hazards occur is constantly changing as the result of many factors, including rates of economic development, resource exploitation, urbanization, deforestation and land use changes (O’Brien et al., 2008; Kocur-Bera and Dudzińska, 2014b).

A spatial planning system should identify areas characterized by high risk of natural and human-made hazards and should propose land management methods that would minimize damage resulting from extreme events (Olsen and Bindi, 2002; Falloon and Betts, 2010). The main goal of the study is to identify local factors that reinforce the negative effects of extreme events because this is an important part of every risk reduction strategy. The aim of the research was carried out with the help of such tasks as identifying areas where natural disasters have occurred, a description of local and regional conditions, the use of cluster analysis and discussion of analytical results. Historical data concerning natural disasters and similarities in their geographic, geophysical and environmental determinants (Kocur-Bera and Dudzińska, 2014a) can be used to create groups of homogeneous objects with specific features. This approach is adopted to determine a given area’s susceptibility to extreme events on local scale and to identify high-risk locations. According to O’Brien (2008), lowland areas, coastal areas and small areas with high population density and high concentration of physical capital are most susceptible to natural disasters.

Groups of objects susceptible to extreme weather events on local scale can be identified, and the resulting knowledge can be used to develop planning documents, introduce adaptive measures (Olsen et al., 2011; Dudzińska et al., 2014) and teach people how to cope in a changed environment. At present, we are unable to forecast the location of extreme weather events with high accuracy. The gap between climate forecasts and local needs calls for effective natural disaster risk reduction measures. There is a great demand for local research into the determinants and attributes of locations threatened by extreme weather events and climate change.

Materials and Methods

Study Area

The study covered the Region of Warmia and Mazury in Poland. The region spans the distance of 146 km along the north-south axis (1°18′44″) and 240 km along the east-west axis (3°39′28″). Warmia and Mazury has a total area of 24 173.47 km^2 (7.7% of Poland's territory) and the population of 1.45 million. Its population density of 60.06 persons per km^2 is one of the lowest in the country (the national average is 123.24 persons per km^2), and its rural population density is estimated at only 25 persons per km^2. Forests occupy nearly 30% of the region's territory. Farmland spans the area of 1.3 million ha and covers 55% of the region's territory (the national average is 61%). The remaining land-use types in Warmia and Mazury include the land covered by trees and shrubs (32%), water bodies (6%), developed land (3.5%) and other land types (3.5%). Rural areas occupy 2,359.600 hectares, i.e. 97.5% of the region's territory, and have the highest share in the country. Warmia and Mazury comprise 21 counties which are divided into 116 municipalities, including 16 urban municipalities, 33 urban and rural municipalities and 67 rural municipalities. The region is divided into three subregions (NTS 3) of Elbląg (31% of the region's territory and 37% of the region's population), Olsztyn (43% of the region's territory and 43% of the region's population) and Ełk (26% of the region's territory and 20% of the region's population). In Poland and Europe, Warmia and Mazury are renowned for their rich nature and diverse natural features such as varying land relief, lakes, forests and clean air. Nature conservation areas, including areas that are part of pan-European programs (Natura 2000, CORINE), account for half of the region's territory. Warmia and Mazury have an extensive network of water bodies, including numerous lakes, ponds, rivers, canals and a section of the Vistula Lagoon (5.7% of the region's territory) that are popular tourist destinations.

Data Collection and Methods

The study analyzed losses sustained by rural areas in the Region of Warmia and Mazury in 2012 in consequence of extreme weather events. Losses totalling nearly PLN 40 million (EUR 1 = PLN 4.18) were recorded in 37 municipalities. The study was performed in two stages. In the first stage, the occurrence of natural disasters in the evaluated region was determined in a quantitative spatial analysis, and in the second stage, the main focus was on the homogeneity of object groups affected by extreme weather (extracting similar groups). Data were supplied by the Regional Agricultural Advisory Center in Olsztyn, the Central Statistical Office and the Geographical Information System. The assessed parameters were selected based on a review of literature, data availability and the researcher's arbitrary decisions. The selected attributes had to represent land use structure in the analyzed territory, local geographic, climatic and environmental parameters, and losses sustained in agriculture due to extreme weather. Data were subjected to quantitative analysis (first stage) and hierarchical cluster analysis (CA) involving Ward's method to identify groups of objects that were homogeneous in terms of the analyzed attributes (second stage). In the second stage of the study, primary data were normalized. A dendrogram was generated by stepwise clustering of operational taxonomic units. Ward's method for estimating distance between clusters relies on the analysis of variance and minimizes the sum of squares of any two clusters. The adopted method was used to identify subpopulations, which were then subjected to factor analysis.

Results and Discussion

Figure 1 presents the level of damages within the studied area in 2012. The largest damages (50% losses) in rural areas (losses in the urbanised and built up areas were not included) are caused by the negative consequences of wintering (about 17 mln PLN). Sudden ground frosts during the late autumn, winter without snow, strong solar radiation during the day and low temperature at night as well as high air humidity coming from water reservoirs are the main causes for such high losses. Hail is the second most arduous extreme phenomenon (36% losses) that in most cases damages crops by hitting them strongly (about 13 mln PLN). Plants in mature stages of growth are unlikely to recover from physical damage inflicted by hail, their development is arrested before full ripening, and much of the crop goes to waste. The latest extreme events bring losses by torrential rain (6% - about 2 mln PLN), lightning (5% - 1.7 mln PLN), hurricane (0.5 mln PLN) and flood (0.3 mln PLN) (where 1 PLN = 4.3 EURO). Extreme weather events contributed to greatest losses in the central-eastern part of the evaluated region in the municipalities of Budry, Reszel, Węgorzewo, Kętrzyn, Sępopol, Biskupiec Pomorski, Mrągowo, Braniewo, Bartoszyce, Korsze and Bisztynek (see Fig. 3). In the pie chart, 50% are not defined on the right side of the chart.

In the second stage of the study, cluster analysis was performed to identify four groups of objects (subpopulations) with similar spatial (geoinformation) features. The analyzed parameters were: value of losses in 2012 (X1), affected area (X2), value of agricultural losses caused by ground

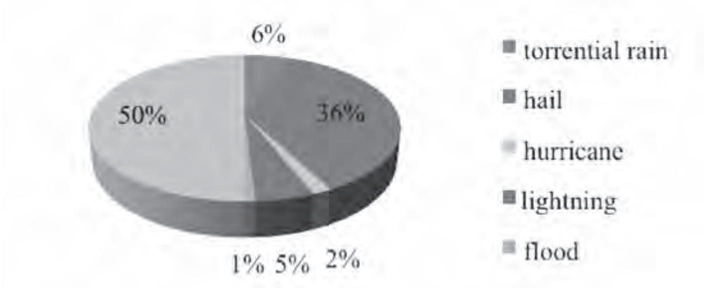

Figure 1. Losses on Warmia and Mazury region in 2012.

Source: own study.

frost (X3), torrential rain (X4), hail (X5), hurricane (X6), lightening strike (X7), flood and submergence (X8), surface area of flowing and stagnant waters in the analyzed municipality (X9), area of swamps and waterlogged soils (X10), area of the analyzed administrative unit (X11), area of farmland (X12), area of grasslands in the municipality (X13), area of land covered by trees, shrubs and forests (X14), soil class and soil complex (X15) established for the purpose of adjustment of agricultural production area in Poland (Witek et al., 1981) [scale 100-points], local climate and crop requirements (X16) established for the purpose of adjustment of agricultural production area in Poland (Witek et al., 1981) [scale 16-points], terrain parameters based on diversity of land relief and farming conditions (X17) established for the purpose of adjustment of agricultural production area in Poland (Witek et al., 1981) [scale 5-points], water availability based on soil moisture levels (X18) [scale 5-points]. Data were standardized. Homogeneous object groups were presented in the form of a dendrogram in Figure 2. Four homogeneous subpopulations were created at cut-off value of 11.2.

The first subpopulation covers observations C_1, C_5 and C_10, the second subpopulation – observations C_2, C_11, C_4, C_7, C_17, C_14, C_16, C_15, C_20, C_21, C_22, C_9, the third subpopulation – observations C_28, C_26, C_30, C_29, C_27, C_25, C_13, C_32, C_12, C_8, C_18, C_6, and the fourth subpopulation – observations C_33, C_34, C_35, C_24, C_37, C_36, C_23, C_19, C_31, C_3. The number, name and average value of diagnostic attribute in a group are given in Table 2.

The greatest losses (722 020 PLN) were noted in subpopulation 4 comprising the municipalities of Bartoszyce, Barciany, Prostki, Węgorzewo, Zalewo, Lidzbark Warmiński, Dobre Miasto, Ostróda, Kalinowo, Mrągowo, Pasłęk and Kętrzyn. Subpopulation 4 was also characterized by the highest values of the following parameters: area of

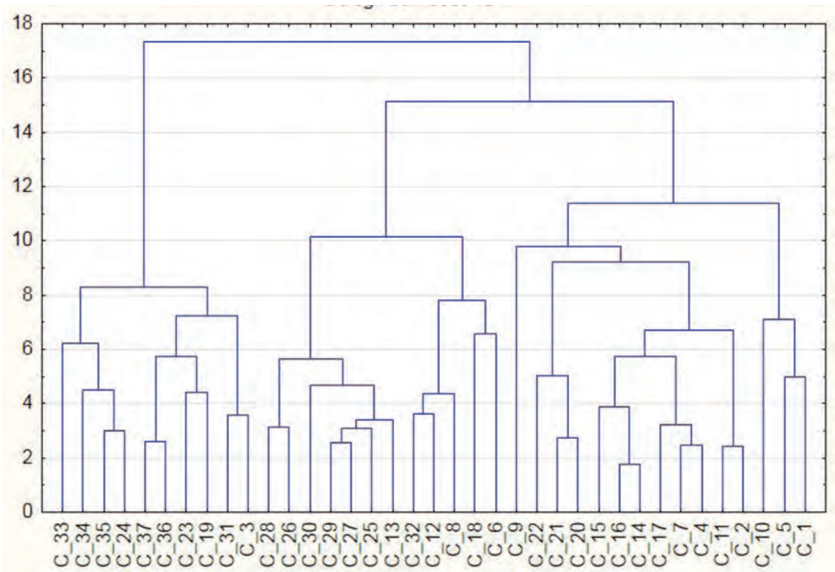

Figure 2. Dendrogram of groups (subpopulations) homogeneous in terms of spatial attributes and losses sustained by rural areas in 2012.

Source: own elaboration in *Statistica* application.

Table 2

Average values of diagnostic attributes in a given subpopulation

Name of the commune	Group characteristics																	
	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16	X17	X18
SUBPOPULATION 1 BRANIEWO (C_1) KORSZE(C_5) BISZTYNEK(C_10)	490.620	2.93	1.0	0.33	0.66	0.33	0.7	0	218.0	606.0	25.325	17.770	3.734	4.543	64.66	9.0	4.16	4.23
SUBPOPULATION 2 RYCHLIKI (C_2) SĘPOPOL (C_11) SROKOWO (C_4) BUDRY (C_7) MARKUSY (C_17) RESZEL (C_14) BISKUPIEC (C_16) KISIELICE (C_15) WYDMINY (C_20) KOLNO (C_21) WILCZĘTA (C_22) GODKOWO (C_9)	693.200	0.55	0.75	0.25	0.33	0.08	0.1	0.1	495.0	827.0	18.099	12.055	3.505	4.032	58.66	8.33	3.59	3.86
SUBPOPULATION 3 BANIE MAZURSKIE (C_3) JANOWIEC KOSC. (C_19) SORKWITY (C_23) GRODZICZNO (C_24) OLECKO (C_31) PIECKI (C_33) ŚWIĘTAJNO (C_34) JONKOWO (C_35) KURZĘTNIK (C_36) DŹWIERZUTY (C_37)	139.200	0.05	0.1	0.2	0.2	0.5	0.4	0	1.005	966.0	19.259	1.1431	3.403	5.230	44.83	7.62	3.15	2.84
SUBPOPULATION 4 BARTOSZYCE (C_6) BARCIANY (C_8) PROSTKI (C_12) WĘGORZEWO (C_18) ZALEWO (C_25) L.WARMIŃSKI (C_26) DOBRE MIASTO (C_27) OSTRÓDA (C_28) KALINOWO (_29) MRĄGOWO (C_30) PASŁĘK (C_32) KĘTRZYN (C_13)	722.020	0.53	0.41	0.08	0.58	0.25	0.1	0	1.734	1.343	30.453	19.631	6.104	6.850	58.11	8.18	3.23	3.82

Source: own elaboration.

municipality (30,453.0 ha), flowing and standing waters (1,743.0 ha), swamps (1,343.0 ha). farmland (19,631.0 ha), meadows and pastures (6,104.0 ha) and land covered by trees, shrubs and forests (6,850.0 ha). The remaining attributes were characterized by average values.

The highest number of extreme weather events (torrential rain, ground frost, hail and lightening) was reported in subpopulation 1 covering the municipalities of Braniewo, Korsze and Bisztynek. Subpopulation 1 was characterized by the highest soil quality index of 64.44 (which represents class III and IV arable land and grassland), the highest climate index of 9 (on a 16-point scale for Poland), the highest terrain index of 4.16 (on a scale where flat land with no obstacles for mechanical cultivation scores 10 points. and land with the most diverse relief – 0 points) and the highest water availability index of 4.23 in the studied population (on a scale where soils with optimal moisture levels score 1 point and permanently dry soils – 5 points). The remaining two subpopulations were not characterized by outstanding land features or excessive losses resulting from natural disasters in rural areas. The spatial distribution of municipalities that suffered losses in consequence of adverse weather effects in 2012 is shown in Figure 3.

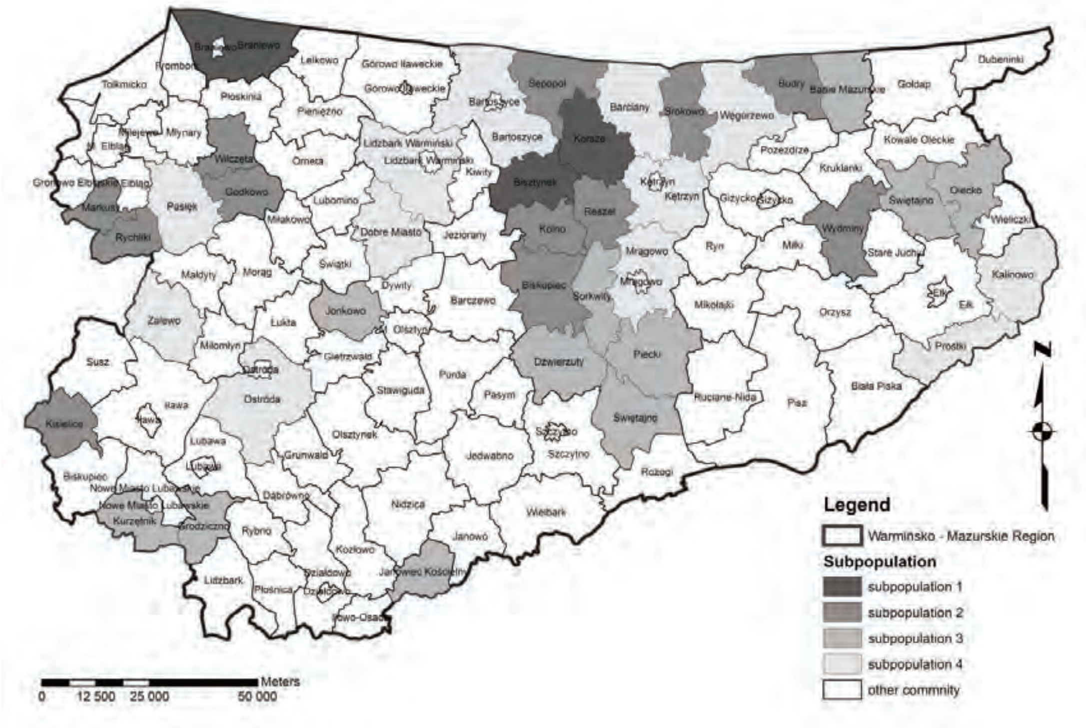

Figure 3. Spatial distribution of homogeneous subpopulations.

Source: own elaboration.

Conclusions

Natural processes and human activities are responsible for climate change and extreme weather events that generate vast financial and human losses (O'Brien et al., 2007). Natural disasters are increasingly often observed in Europe. They are caused mainly by greenhouse gas emissions, ozone depletion, deforestation, desertification, urbanization, land use and various local factors. The main purpose of research was to identify local factors that reinforce the negative effects of extreme events. In this study historic data were used to identify homogeneous objects that had been affected by extreme weather events. The study was performed in 37 rural municipalities in the Region of Warmia and Mazury, which suffered financial losses in 2012 in consequence of natural disasters. A total of 18 diagnostic parameters associated with adverse weather events were described. Four homogeneous subpopulations were identified in cluster analyses. Two groups clearly stood out in the analyzed population. The first subpopulation was characterized by the highest losses and the highest values of the following parameters: area of municipality, area of flowing and standing waters, area of swamps, area of farmland, area of meadows and pastures, area of land covered by trees, shrubs and forests. The remaining attributes had average values. This subpopulation covered the municipalities of Bartoszyce, Barciany, Prostki, Węgorzewo, Zalewo, Lidzbark Warmiński, Dobre Miasto, Ostróda. Kalinowo, Mrągowo, Pasłęk and Kętrzyn. The second outstanding population was characterized by optimal conditions for crop cultivation, including soil quality, climate, land relief and soil moisture and it comprised the municipalities of Braniewo, Korsze and Bisztynek. The identification of local conditions contributes to the reliability of extreme weather forecasts and supports the implementation of effective measures for preventing and alleviating the adverse consequences of natural disasters. Spatial planning systems should be developed for managing high-risk rural areas in a way that minimizes the resulting losses.

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