Hailstorm risk assessment for crop areas in Moldova Region (Romania)

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Abstract: Estimating the impact of hail on agricultural land is needed in order to streamline damage reduction methods. In this regard, hail risk maps were prepared for the region of Moldova for the main types of crops (wheat and rye, corn, potato, sugar beet, sunflower, vegetables, orchards and vineyards). The methodology that we used consists in determining the risk map, as the product between the hazard map (average annual number of days with hail), the exposure map (agricultural crop value) and the vulnerability map (the percentage occupied by a certain agricultural crop in the administrative units). Areas with severe hail risk are in the eastern half of Vrancea County, the western part of Galați County and the northeastern part of Iași County, where there are large areas cultivated with vines, orchards and vegetables. In Vaslui County, the most exposed ATUs are those in the vicinity of Bârlad, Fălciu Hills and the Huși wine area. Most AUs in Bacău and Suceava counties, in the southern part of Neamț County, are included in the medium and high-risk classes due to the suitable conditions for cultivating most plants and the higher frequency of hail. The ATUs from Botoșani County are included in the low and medium risk classes. The lowest level of risk is registered in the case of AUs from the mountainous area, the Curvature Subcarpathians and the areas with higher altitudes from the Central Moldavian Plateau and Tutova Hills.

1. Introduction

Perils associated with severe convective storms, such as large hail, heavy rainfall, strong wind gusts, or tornadoes, are among the most important perils in several regions of the world (Virts et al., 2013; Cecil et al., 2014). Of all severe convective storms - related hazards, hail causes the largest economic damage (Kunz and Geissbuehler, 2017). However, the modelling of severe convective storms risk is still in its infancy (Allen et al., 2016; Martius et al., 2018). The effects of hailfalls usually interest limited areas, the damages can be severe (Baldi et al., 2014), especially to agriculture (Lemons et al., 1942; Gall et al., 2011; Changnon et al., 1978; Changnon et al., 2009). Therefore, assessing the risk of hail disaster is crucial in promoting sustainable agriculture.

Although some scholars further explored the spatiotemporal characteristics of hail disasters, there are few studies concerned with specific hail-affected bodies (Vinet et al., 2001; Changnon et al., 2008; Webb et al., 2009; Sioutas et al., 2009; Machidon 2006; Wang et al., 2016). However, the results of these studies can only reflect the regional

differentiation of hail disasters, and cannot reveal the differences between specific hail-affected bodies, because these studies take a region itself as the research object.

Romania is one of the countries subject to the most severe hailstorms (Maier et al., 2010; Apostol, Machidon, 2011; Burcea et al., 2017; Istrate et al., 2017), and is also the one of the largest grapes, cereals and fruits-producing country in the Europe (<https://ec.europa.eu/>). Unfortunately, hail disasters occur frequently in most of Romania's major grapes and fruits-producing areas (Machidon 2006; Istrate et al., 2019a). The hail occurrence periods almost coincide with the growth periods of plants, thus causing very severe losses. Although the hail phenomenon is not the weather or climate risk that most affects crops, it can sometimes cause significant damage (Istrate et al., 2019a).

Therefore, the main goal of this study is to propose an analytical procedure that helps assess the risk of hail affecting crop areas from Moldova region, using the hail data in the GIS environment. Due to its geographical position within the European continent (fig. 1), the studied region is sheltered in the western part by the Carpathian chain, which induces a series of climatic peculiarities. The Carpathians represents an extremely important natural border in the climatic variety specific to the region. The Eastern Carpathians contribute to the foehnization process of the Atlantic air masses and to creating a transitional climate between Central Europe and Eastern Europe (Apostol, Sfică, 2013). Maximum temperatures have increased in the last half century in the extracarpathian area (Croitoru et al., 2012), a phenomenon that increases evapotranspiration and intensifies thermal convections.

Figure 1. Geographical location, morphometry, and relief units of study area

The damages in the urban, industrial and transport environment can be much higher than in the agricultural areas, but they have not yet been, in our country, still subjected to a complex analysis. This type of analysis is not present here either, because we did not have access to the statistics of insurance companies, which can give an image, at least general, of the phenomenon.

In the present study, the risk calculation methodology was applied at the level of the administrative unit (AU). For each AU a hail risk estimation was made for most types of crops grown on large plots in the study area. These types of crops are: wheat and rye, corn, sunflower, sugar beet, potato, vegetables, vines and fruit trees.

An estimation of hail risk (and implicitly of the damages produced by it) using kinetic energy measured meteorological radars was done in some case studies for southern Romania (Cică et al., 2015) or northern Moldavia (Istrate et al., 2019b).

In the following sections, we will first describe the methodological framework. Then, the proposed method will be applied to assess the hail risk for main types of crops regarding the spatial pattern and evaluation.

2. Materials and Methods

The risk assessment methodology is based on the definition of risk provided (Dilley et al., 2005) and the Intergovernmental Panel on Climate (Oppenheimer, M. et al. 2014; Reisinger, A. et al., 2020) also used in the SEERISK project (Bojariu et al., 2014; Bojariu et al., 2015). These authors agree that risk results from the interaction of vulnerability, exposure, and hazard. Exposure is an important property of crops, compared with other hail-affected bodies, such as cars and buildings. For every agricultural crop, its exposure covers the spatial distribution of planting and temporal distribution of growth. Hence, the hail disaster risk (R) is a function of the hail hazard (H), spatial exposure (E) and vulnerability (V) of cotton, as Equation:

$$R = f(H, E, V)$$

There are generally two methods for assessment on hail hazard (H). One is to assess H according to hail diameters, hailfall duration and, accordingly, wind speed (Sioutas et al., 2009). But the above hail parameters are very difficult to get. For the region of Moldova there are recent studies that address the size of hail but these are limited to case studies (Axinte, 2019; Ilie et al., 2020). The other method calculates H using the frequency of hail days (McMaster et al., 2001; Leigh et al., 2001). In some studies, were directly applied as the index for assessment on H the total hail days (Berz et al., 2001) or average annual hail days (McMaster et al., 2001). In this paper, we used average annual hail days as the index for assessment on H . The average number of days with hail is the parameter that highlights the qualitative aspect of the phenomenon. Knowing the number of days with hail has a great practical importance because it gives an indication of the possibility of production of this phenomenon and therefore, the possibility of damage occurrence in some days of the year. The monthly and annual average number of days with hail is expressed by a ratio between the monthly or annual number of days with hail and the number of years of that period (Apostol, Machidon, 2011; Machidon, Apostol, 2011).

A residual kriging algorithm was used to interpolate the irregularly spaced station data. This method is a stochastic one that allows the estimation of errors (Patriche, 2009) and is better adapted to identify local variability as opposed to other methods (Farnell et al., 2018). The data regarding the hail frequency come from the meteorological and the pluviometric stations of the National Meteorological Administration. Data from 39 weather stations and 76 rain stations were used for the

period 1967–1998. The use of the residual Kriging method gives this distribution a strong correlation with altitude. The decrease of values takes place from 3 days/year with hail on the highest peaks of the Moldavian Subcarpathians and the Curvature Subcarpathians, to less than 0.6 days / year with hail in the south of the Moldavian Plain, the Bârlad valley and most of the Prut valley. These values correspond to those registered in the Republic of Moldova where in the whole Prut meadow there are on average between 0.3 and 0.6 days / year and in the hilly central area over 1.5 days / year (Daradur et al., 2016).

Exposure (E) refers to crop being exposed to the effects of hail. Administrative units exposed to risk were considered those in which there are cultivated areas. The areas occupied with wheat and rye, maize, sunflower, potato, beet and vegetables for each LAU (Local Administrative Unit) were taken from official INSSE reports (INNSE). For the areas occupied with vines and fruit plantations, Corine land cover 2018 adapted for Romania (Ursu et al., 2006), was used as a source (<https://land.copernicus.eu/pan-european/corine-land-cover>).

Figure 2. Distribution of the average annual number of days with hail in Moldova (1967–1998)

From this database were available the production quantities of wheat and rye, corn, sunflower, sugar beet, potato, vegetables, grapes and fruits in tons per year, at AU level, from 1990–2003. An average production was achieved during this period, and the economic value was estimated by using the base price per kg from 2020. In the case of vegetables and fruits, an average price obtained from the prices of the main vegetables and fruits grown in the agricultural areas in the studied area was used. The economic value of the average annual production was assimilated with the degree of exposure of each AU to the meteo-climatic hazard of hail. The impact map resulted from the product between hazard and exposure.

V is usually calculated using data of loss. However, because of data limitation we used another methodology (Wang et al., 2016). It was expressed as the area ratio of every agricultural crop type-planting areas in a LAU, and the greater the value is, the higher the LAU's possibility to loss of crop subject to hail hazard will be, and vice versa. Finally, the risk maps have been defined as a multiply of the impact and vulnerability maps (Figure 3).

Figure 3. Theoretical and applied methodology for obtaining the risk map

3. Results and discussions

The risk assessment for wheat and rye crops according to the methodology described in the previous subchapter indicates two areas where the sensitivity is highest. The first one is represented by the southwestern region of the studied area and the communes from Fălciu Hills and Prut meadow, south of Huși, where the level of risk is generally medium and high. The second area overlaps over the depression and hilly area between the Moldova valley to the north, the Bistrița valley to the south and the Siret Corridor to the west. Apart from these areas, there are also communes in the Suceava Plateau and the Moldavian Plain where the level of risk is medium or high. The administrative units from the higher areas of the Central Moldavian Plateau and the Bârlad Plateau are characterized by a low and very low level of risk. In the AUs from the Subcarpathian area, except for the hilly depressions from Neamț County, there are no areas cultivated with wheat and rye, the level of risk being zero. In the case of assessing the hail risk level of wheat, one of the limitations is the lack of hazard values in its vegetation period. As its cultivation takes place until the end of June, only hail in the first half of the warm semester can cause damage.

Corn being a cereal that has adapted better to different environmental conditions, its cultivation is carried out in all AUs in the studied area. Maize can also be affected by hail in all phenophases (Dwyer et al., 1994), but especially in the early stages (Olivier and Van Rensburg, 1992). The weather conditions following a hail phenomenon are very important for a possible natural recovery of the plants, especially if they have been

physically damaged. For the maize crop, the AUs in which the level of risk is the highest are those in the Siret Corridor, the Tazlău-Caşin Depression, the Tutova Hills and the Tecuci Plain. Medium or high risk is also registered in most communes in the Moldavian Plain (Figure 4).

The level of risk for sunflower is high for most AUs in Galați County, the southern half of Vaslui County and those in the south of Vrancea County. In the Moldavian Plain, the level of risk is generally low. The western half of the studied area, with some exceptions, and the high areas of the Central Moldavian Plateau and the Bârlad Plateau are without risk of hailstorms, because no areas cultivated with sunflower were registered.

The risk maps for sugar beet and potato faithfully follow the patterns imposed by the areas where their cultivation is carried out intensively. The two types of crops require a larger amount of water to have a good production. This is the main reason why their cultivation is carried out especially in the northwestern area, the richest in precipitation, of the studied area. In the case of sugar beet, most of the studied area is in the very low risk class. Medium and high risk AUs are in the Suceava Plateau, the Neamț Depression, the Cracău-Bistrița Depression and the Siret Corridor between Bacău and Pașcani (Figure 5).

For the potato crop in most AUs from Suceava and Neamț counties, the risk level is very high. The AUs from Bacău and Botoșani counties and those from the south and west of Iași County are low or medium risk. The rest of the territory, with some exceptions, falls into the very low risk class.

The hail risk map for vegetables clearly indicates the vegetable areas of Moldova as the most exposed (Figure 6). The first area, with the most AUs included in the high-risk class is Matca-Ghidigeni from Galați County. This area with very high vegetable production extends north to the localities in the Bârlad valley until its confluence with Vaslui. The AUs from the south and east of Vrancea County are also included in the high-risk class. Other areas with medium and high risk are located in the west and northwest of Iași County (Târgu Frumos-Paşcani area), the Cracău-Bistrița Depression and the Siret Corridor between Roman and Bacău. Most AUs in Botoșani County are in the medium risk class with significant vegetable production.

Hail risk maps for vineyards and fruit trees highlight very well the vineyards and orchards in the study area (Figure 7). In the case of vines, the highest level of risk is assigned to the ATUs in the wine area of Vrancea (Panciu-Țifești-Odobești-Cotești), Galați (Nicorești-Ivești and Dealul Bujorului), Vaslui (Huși Vineyards and Dealul Fălciului) and Iași (Iași-Răducăneni area and Cotnari Vineyard). Near large vineyards, there are also ATUs with low or very low risk level. The sub-Carpathian area, the north and the central-western part of the studied area are not exposed to the hail risk.

For fruit tree plantations, the areas with high and medium risk are larger than in the case of vineyards and are scattered over the entire surface of the studied area. The AUs from Dealul Mare-Hârlău and the Fălțiceni Plateau can be noticed for the northern part and from most of the central region (Corni-Runcu Peak, the Central Moldavian Plateau and the Bârlad Plateau). In the southern part, a higher degree of risk is maintained throughout the AUs with vineyards in Vrancea and Galați, on the Galați Municipality and neighboring communes.

Figure 4. Hail risk for wheat and rye and corn

Figure 5. Hail risk for sunflower and sugar beet

Figure 6. Hail risk for potato and vegetables

Figure 7. Hail risk for vineyard and orchards

By summing the value of the risk for each crop, a risk map for the agricultural areas of the studied zone was obtained (Figure 8). Although it does not contain information on the degree of exposure and vulnerability of all types of crops, it shows a spatialization of the level of risk for the main agricultural crops. Some areas suitable for several types of crops stand out, such as the eastern half of Vrancea County and the western half of Galati County, where there are large areas cultivated with vines, orchards, vegetables and large field crops. In Vaslui County, the most exposed AUs are those near Bârlad, Fălciului Hills and the Huși wine area.

Figure 8. Hail risk for the main types of agricultural crops

AUs from Bacău County are mostly included in the medium and high-risk classes, a situation specific to those in the southern half of Neamț County. The soil and geographical conditions in these areas are favorable for the analyzed types of crops, and the risk level is also influenced by the higher frequency of hail (over 2 days / year in subcarpathian areas). For Suceava County the situation is similar, the high level of risk being influenced by the high degree of exposure of crops such as sugar beet, potato or wheat and the average annual number of days with hail higher. AUs in the Moldavian Plain are classified as low and medium risk classes. There are also wine and fruit areas in Iași County (Iași-Răducăneni, Sârca, Cotnari) where the level of risk is high. The areas with the lowest level of risk are represented by AUs located in the mountain area, the Curvature Subcarpathians and the areas with higher altitude from the Central Moldavian Plateau and Tutova Hills. The mountainous region due to the fact that, despite the very high number of days with hail recorded here (Climate of Romania, 2008; Burcea et al.,

2016), the characteristics of land use determine a very low vulnerability of this region to hailfall, the area being covered mostly by forests (Popovici et al., 2013; Rusu et al., 2020).

5. Conclusions

In order to assess the degree of risk, it was necessary to know the spatial distribution of the phenomenon, as well as the specifics of agriculture in the studied area.

The areas with high risk for wheat and rye crops are in the southwest of the studied region, the communes from Dealurile Fălciului and the hilly and depression area between Moldovei valley to the north, Bistrița valley to the south and Culoarul Siretului to the west. For the maize crop, the areas where the level of risk is highest are those in the Siret Corridor, Tazlău-Cășin Depression, Tutova Hills and the Tecuci Plain. In the case of sugar beet, the regions with medium and high-risk level are in the Suceava Plateau, the Neamț Depression, the Cracău-Bistrița Depression and the Siret Corridor between Bacău and Pașcani. For potato cultivation, in most areas of Suceava and Neamț counties the level of risk is very high. The first area with the most administrative units included in the high-risk class for vegetables is Matca-Ghidigeni from Galați county and those from the south and east of Vrancea county. Other areas with medium and high risk are located in the west and northwest of Iași County (Târgu Frumos-Pașcani area), the Cracău-Bistrița Depression and the Siret Corridor between Roman and Bacău. In the case of vines, the highest risk level is characteristic of the wine-growing areas of Vrancea (Panciu-Țifești-Odoboești-Cotești), Galați (Nicorești-Ivești and Dealul Bujorului), Vaslui (Huși Vineyards and Dealul Fălciului) and Iași (Iași area -Răducăneni and Cotnari Vineyard). For fruit tree plantations, the areas with high and medium risk are larger than in the case of vineyards and scattered over the entire studied area. Areas from Dealul Mare-Hârlău and the Fălticeni Plateau can be noticed for the northern part and from most of the central region (Corni-Runcu Peak, the Moldavian Central Plateau and the Bârlad Plateau). In the southern part, a higher degree of risk is also maintained in the administrative units with the vineyards of Vrancea and Galați, on the administrative territory of Galați Municipality and of the neighboring communes.

Finally, we note that greater synergy is needed to link the progress made by the scientific community and the operational hail control units to the insurance industry. Hail can have a remarkable impact in terms of economic losses and yet the research carried out has not always been focused at answering the fundamental questions needed for concrete actions by decision-makers. The research carried out so far has not always been aimed at answering the fundamental questions needed for concrete action by decision-makers.

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