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HAIL SENSITIVE AREAS IN THE REPUBLIC OF MOLDOVA

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Abstract

In this study, the geographical and local topographic factors have been incorporated into geo-statistical approaches and also various models have been developed relating hail events to site position to assess of a hail hazard at high resolution in the Republic of Moldova. An assessment of the average number of hail days, frequency of a year with hail incidences and peak values by natural zones of Moldova has been derived based on the hail incidence records for 68-years (1949-2015). Hail Sensitive Areas (HSAs) at high resolution are delineated to design resilience for coping with this climate hazards at community level. The research findings ensure more effective use of the hail data and better understanding climatology of hail risk across the Republic of Moldova, and, therefore, facilitate decision making and determination of hail insurance rates throughout the country.

Key words*: *Hail Sensitive Areas, Multivariate Regression Model, Geo-statistical Approach

INTRODUCTION

Hail hazard assessment is a great challenge since hail falls are not reliable monitored by observation systems. Due to small spatial extent of hail falls the estimates based on the existing observation network cannot describe the complexity of surface hail occurrence [13]. Hail frequency research has been carried out in various countries using data from weather stations, hail pads and radar or satellite proxy data sets [2, 3, 5, 8, 20, 23]. However, the analysis are limited in scope because of the constraints inherent in hail related to lack of an appropriate monitoring systems and short time data sets. Sioutas et al. [23] revealed a strong correlation of hail falls with the topographical factors for northern Greece, since the hail maxima are located close to the lee sides of mountain barriers. Baldi et al. [2] studied hailstorm intensity in Italy by using observational data sets and a statistic model. They identified areas of greatest intensity in the Alpine region. The results of the statistical approach estimated maximum hail occurrences in north-west Italy and south Tuscany with values ranging between 1.5 and 2 annual events.

Hail have been well studied in North America, particularly in the USA, where there are large societal impacts of hazardous convective weather (tornadoes, hail, and damaging wind) and a long observational record. Early hailstorm studies in USA [6,7] reviewed hail information at various time and space scales, and pointed out the principal hail areas in North America. Recent studies [1, 25] has been developed an empirical model relating monthly hail occurrence to the large-scale environment for the United States. An effort to update hail climatology has been made also in China [18] with the use of a long record of observations from 1959 to 2014.

Information about the hail incidence in the Republic of Moldova can be found in a number of sources. The most comprehensive information on hail is given by Lasse [14]. There are a number of other sources and cartographic references [11, 12, 16, 17, 21, 22]. These studies represent an important stage in the climatology of hail risk in the Republic of Moldova which allowed significantly increasing the awareness (guidelines, cartographic materials, etc.) of the main stakeholders on the hail as a hazardous weather phenomenon over the Republic of Moldova. However the early regional hail studies, based on a regime-reference approach and limited data sources, are fail to illustrate the true complexity and fine details of surface hail occurrence since the complex topography of the Moldova gives a specific climate response to hail variability [10].

Nevertheless, they do indicate some important general trends in hail distribution patterns. These appear to be related to topographical factor such as altitude.

In this study, by using the most recent data, an attempted to incorporate local topographic factors to develop model relating to climatology of hail risk over the Republic of Moldova at high-resolution. In particular, the combinations of statistical and geo-spatial approach have been used to be effective in spatial modeling the hail hazard in the complex terrain of the country. It was undertaken in an effort to obtain hail information at high resolution which could eventually lead to a better definition of the Hail Sensitive Areas (HSAs), and, therefore, facilitate the decision making and determination of hail insurance rates throughout the country.

MATERIALS AND METHODS

Data

Climatologically hail records, as provided by conventional stations of the State Hydro-meteorological Service of Moldova (SHS), are referred to days of hail observed on the ground. In the research, a hail day is defined as a day during which hail is observed and recorded at each meteorological station. An assessment of the average number of hail days, frequency (%) of a year with hail incidences and peak values by natural zones of Moldova was derived based on the hail incidence records for 68-years (1949-2015). For building a robust statistical model to obtain the hail hazard estimates in the complex terrain of the Republic of Moldova, 13 stations were included in the analysis with a reduced length of the hail time series (1963-2015). The mean annual hail frequency at a station is defined as the mean number of hail days per year. The mean monthly hail frequency is defined as the average number of hail days in each month.

Multivariate nonlinear regression model.

We have attempted to incorporate local topographic factors into geo-statistical approach to produce accurate spatially-distributed estimates of hail days in the Republic of Moldova by using a multivariate nonlinear regression model. Seven geographical factors (latitude (φ) and longitude (λ) and meso- and microscale topographical factors (altitude (h), relative altitude (Δh), rugosity (r), slope (s) and aspect (a)) have been used as explanatory variables. The quantified values of the explanatory variables used to develop the model were derived from a digital elevation models (DEM) for 90 m x 90 m resolution grid using ArcGIS. The analytical function obtained was then used to produce spatially-distributed estimates of hail at high resolution.

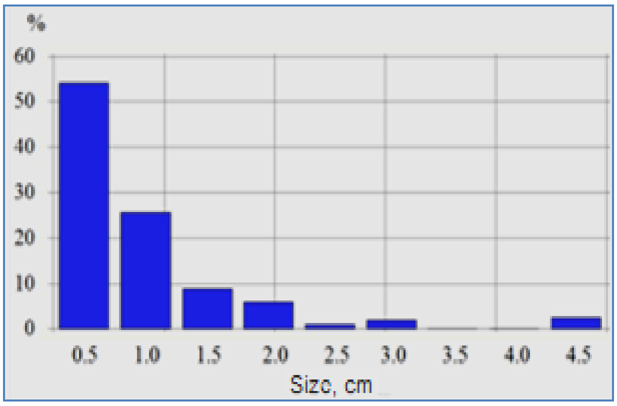
The selection criterion for explanatory variables was based on the highest value of F - statistics which is equal to the square of t-statistics for variables included in the regression equation. The model equation was calculated for all possible combinations of explanatory variables with limitations for significantly correlated (at $\alpha < 0.01$) and the number of explanatory variables (not to be exceeding 30% of the total number of observations) included in the equation [15]. The "best" model equation was chosen from all combinations based on the value of the adjusted determination coefficient, R^2 *adj*.

RESULTS AND DISCUSSIONS

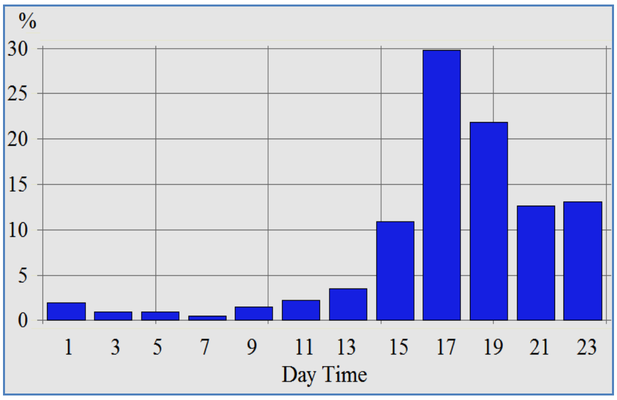
Hail climatology

The number of days with hail is a highly variable parameter. The season of occurrence of hail in Moldova extends from April to September. The peak period of hail is from May to August, when over 90% of the cases occur. The most active months are May and June (respectively 21% and 26%). In August hail had been observed in 14% of years. In early spring (March) and late fall (November) hail is rare. There are also isolated cases of hail in the winter, for example, in February 1966 [14].

The occurrence hail also has diurnal variation. The peak time of day hail activity is observed from 17 to 19 hours (Fig.1).



a)



b)

Fig. 1. The size (a) and day time (2) of hail occurrence, % (Republic f Moldova)

Source: Adapted from Daradur M., Cazac V., Fedotov., L. 2009

Hail is usually accompanied by strong thunderstorms, intense torrential rainfall, squally wind, which greatly increase the destructive potential of hail by the formation of flash floods, runoff topsoil on slopes, soil erosion and other negative effects. More than 50% of the hail size is less than 0.5 cm and in some cases (approximately 2%) may exceed 4 cm the maximum hail size (7 cm) had been observed on August 29, 1969 at the Bricheni meteorological station [4].

The Table 1 presents averages for the climate zone and sub-zone of Moldova with records of 68 years (1949-2015).

Table 1. Average number of hail days, frequency (%) of a year with hail incidences and peak values by natural zones of Moldova with 68-years (1949-2015) records.

Natural zone	Landscape region	mean	Frequency, % years	max
A. Forest-steppe zone	I. Region of elevations and forest steppe	0.8	70	7
	II. Balti region of steppe elevations and plains	0.6	48	5
	III. Region of Codrii forest deviations	1.5	84	8
B. Steppe Zone	IV. Steppe plain region of the lower Dniester terraces	1.0	60	5
	V. Region of fragmentary plains of Bugeac steppe	1.0	66	4

Source: State Hydrometeorological Service, the Republic of Moldova

Calculations carried out in the State Hydrometeorological Service based on the observational data, shows wide range variability of hail occurrence over the territory of Moldova. Based on these statistics, on average, 0.6-1.4 hail days can be expected in Moldova every year. The lowest hail-days values are 0.6 days at Balti region and the highest values are in the hilled central regions (Codri) where averaged is 1.4 days. The maximum number varies from 4 hail days at South (Bugeac steppe zone) up to 8 days in the forested Region of Codrii.

However the complex topography of the Republic of Moldova considerably changes the hail formation environment and gives a specific climate response to hail distribution, particularities of which are not accurately and uniquely captured by the observation network.

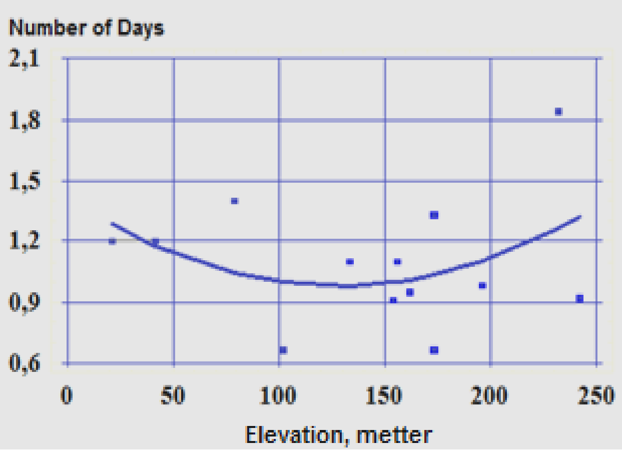
Hail sensitive areas at high resolution

A limited study have investigated the terrain impacts on hail occurrence show that the complex topography gives a specific climate response to hail variability by modifying the heat transport and triggering forced convection resulting in considerably changes in natural environment of hail formation and climatology of hail risk [7, 9, 24]. A few empirical studies [9, 10, 15, 19] indicated that the relationship between frequency of hail and the topographic variable is non-linear.

Table 2. Correlation coefficient matrix for mean annual hail days (N) and explanatory variables

Pa-ra-me ters	N	φ	λ	h	Δh	r	s	a
N	1.00	0.25	0.29	0.39	0.23	0.51*	0.66*	0.20
Φ		1.00	-0.46	0.44	-0.11	0.04	-0.25	-0.17
λ			1.00	-0.69*	0.02	-0.06	-0.27	-0.28
H				1.00	0.00	0.01	0.24	0.49
Δh					1.00	-0.14	0.37	0.30
R						1.00	-0.14	0.37
S							1.00	0.26
A								1.00

*Note: * α < 0.01*



a)

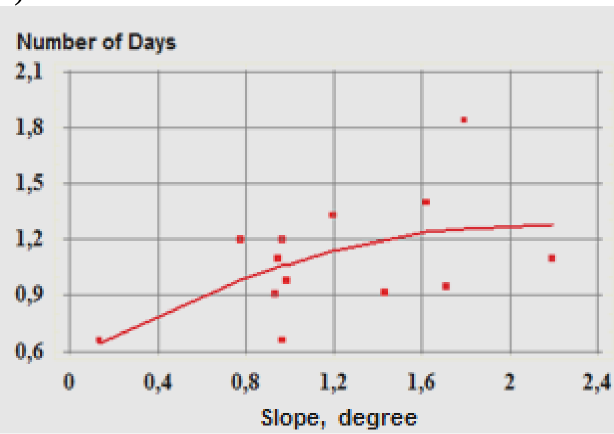


Fig. 2. Non-linear approximation of the relationship between average hail days (a) and topographic factors (elevation and slope) – (b)
Source: Daradur M., Cazac V., Fedotov., L. 2009

For example, the study found that in the specific conditions of Moldova, geographical factors (latitude, r = -0.41), and the meso- and micro topographical factors (rugosity, r = 0, 51 and slope, r = 0, 66) influence a noticeable impact (significant at α <0.01) on the hail formation. Terrain elevation has also an effect forcing convective processes and hail intensity (r = 0.39).

Applying a m*ultivariate nonlinear regression*, lead to obtaining a great improvement of the informational context of the statistical model. The most informative factors selected through the stepwise regression procedure are presented in the table 3.

Table 3. Regression statistics and evaluation of the multivariate regression model

Prediction variables and method of selection		R	R^2 adj, %
All variables	φ, λ, h, Δh, r, s, a	0,94	86
Forward	λ, s	0,79	64
Backward	φ, h, r, s	0,93	85

Note: R^2 adj is the adjusted determination coefficient, which compensates for the limitation of the determination coefficient by taking into account the size of the sample and the number of prediction variables.

The capability of the models to explain the spatial variability of hail incidence varies depending on the method of variables selection: its accuracy is 64% to 86%. Considering the limitations for significantly correlated (at *α < 0.01*) and the number of explanatory variables (not to be exceed 30% of the total number of observations), the set of explanatory factors selected by backward method was chosen as the "best" model equation. The model explains 85% spatial variability of the hail days. The root mean squared error (RMSE) - a parameter for estimating relative error is 9%. The equations for annual hail pass the *F* tests at significance level 0.01. The high *adjusted determination coefficient* R^2*adj* show the goodness-of-fit of the equations.

The listed explanatory variables are then derived for a 90 x 90 m gridded surface and used with the model equation to estimate hail days on that gridded surface. Terrain-related sensitivity to hail falls is displayed in the fig.3. Geographical hail distribution indicates some important general trends of spatial hail falls patterns over the territory of Moldova, which appear to be related to the local topographic features.

The Moldova's areas of greatest hail frequency are in the hilly and highly segmented regions (Codri) where averages are more than 1.5 hail days (1-2 hail event per year).

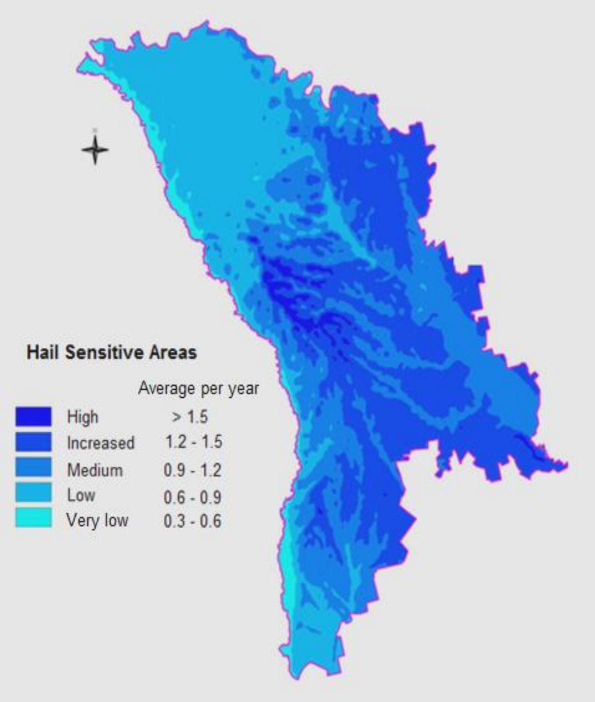


Fig. 3. Hail sensitive areas in the Republic of Moldova

The areas with lowest hail intensities are found in the Balti plains region where hail is a rare event and occurs only once every two - three years. Thus, the complex topography of Moldavian territory gives a specific response to the climatology of the hail risk. In the hilled and highly segmented areas the natural environment are considerably modified by the complex topography resulting in the forced convection and the intensification of a hail formation.

CONCLUSIONS

High level of the physical exposure to hail, combined with insufficient capacity to manage risks creates a challenge for the natural and socio-economic subsystems of the Republic of Moldova. In the study an attempted has been to incorporate local topographic factors into geo-statistical approach to produce accurate spatially-distributed estimates of climatology hail risk in the Republic of Moldova.

The investigation ensures more effective use of the hail data in terms of aligning with extreme climate management design information and suggests an effective mapping of climatically predisposed to hail risk areas (HRAs) at high resolution. In particular, research findings show that the complex topography of Moldavian territory gives a specific climate response to hail spatial variability by changing the natural environment and promoting forced hail formation in the hilled and highly segmented areas of the country.

The Moldova's areas of greatest hail frequency are in the hilly regions (Codri) where averages are more than 1.5 hail days (1-2 hail event per year). The areas with lowest hail intensities are found in the Balti region where hail occurs only once every two - three years.

Hail climatology risk assessment at high resolution is an innovative task and that is required by a variety of models and decision support tools that are essential for designing resilience for coping with this high impact weather phenomenon at community level as well as for the determination of hail insurance rates throughout the country

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