Delimitation of frost-risk territories with GIS tools

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Abstract

In spite of its 4% share out of the GNP agricultural production in Hungary is pursued on extended territories. The climate of the Carpathian basin bears significant risk for this activity. One of them is the conformation of the so-called cold air lakes, and frost-risk, as an immediate consequence. The exact delimitation of such areas is very important for planting frost-sensitive vegetation.

During our work, with the help of digital terrain models, land use databases and climatic maps, we determine those lands where we may expect collection of cold air, and night frost. The examination is carried out in several steps. First of all, we defined the direction of the downward flowing cold air of the slopes, and the places of their collection. In the next step we tried to model the radiation terms of a territory using digital elevation model. Finally, we added up the outcome of the two analyses, and marked the frost-risk territories. In order to determine these lands, we used Surfer 8 (by Golden Software Inc.), SAGA (by Georg-August University, Göttingen, Germany) and ArcView GIS software (by ESRI Inc.) and its module used in spatial examinations (e.g. AV Spatial Analyst).

Key words: frost-risk, cold air lake, digital terrain model.

1 Introduction

Frosts (measured at two meters as well as frost above the ground) are harmful phenomena for plants. The sensitivity of plants to temperatures below zero is different in different periods of their growth. In Hungary’s climate one can expect frost damages to occur in three seasons. In spring and fall air with temperature not much below the freezing-point causes losses to farmers, as in winter, the extreme cold weather can be damaging. In the Southern, warmest part of Hungary the frost free period is between 195–200 days. This period is 180–195 days in most parts of Hungary, but in the higher mountain areas it decreases below 180 days. Frost above the ground can even occur in the beginning of June (this is very rare), and in the end of August this phenomenon occurs again. So, if frost pocket places are not considered, ground frost does not occur only during summer in Hungary (Botos and Varga-Haszonits, 1974).

Climate change will probably cause temperature rising in Hungary as well. Numerous studies have been prepared on this topic to compensate its harmful effects. Decision makers are planning to make a governmental action plan. There is less emphasis on studying frost occurring in spring and autumn. According to the measurements of the Hungarian Meteorological Service (HMS) the frequency and durability of the early (spring) frost has risen in the last decades. This is an important phenomenon that gives us reason to devote more attention to the determination of frost risk territories.

Irradiation causes cold air to overlay the surface during the night. This cold air covers the surface homogeneously and in calm situation it does not move. But on the slopes, like water, it starts to move because of its weight. Warmer air coming from higher layers replaces the cold air moving downward on
the slopes. This circulation causes special surface wind on the slopes. Cold air flowing downward on the slopes collects in depressions. Moreover, masses of cold air follow the valleys and ditches even when they move. Flowing cold air collects in deep depressions or behind mounds perpendicular to the direction of movement, where it creates “cold air lakes”. In this region the thickness of the cold masses rises, inside the masses the wind may be calm that may cause further cooling down. Severe frost can occur in this situation (Unger, 1997; Bridier et al, 2004).

![Fig. 1 Illustration of site topography effects on air temperatures during a radiation cooling event (source: Wolf, T. K. and Boyer, J. D.; 2003)](image)

2 Material and methods

2.1 Site description

Our research locality was the Northern part of Somogy county, situated in the Western part of the outward-Somogy loess that is the part of the South-Balaton wine-growing area. This area is characterized by valleys and N-S direction backs.

![Fig. 2 Location and elevation of the sample area](image)

2.2 Used data

To determine the potential frost risk territories, the most important task was to define weight factors of different effecting parameters. It happened in a subjective way. We marked the weight factors on a five-class scale. The most important factors got the weight factor 5, while the most unimportant ones got 1.

One of the bases of research was the digital terrain model (DTM), including parameters originating from it. We used the SRTM (Shuttle Radar Topography Mission) database developed in cooperation between NASA, the US National Imagery and Mapping Agency (NIMA), the German Space Agency (DLR), and
the Italian Space Agency (ASI); and the DTM generated from this database. The obtained results in three (angle) seconds resolution are freely available on the Internet. We had to consider, when we used this data that it was made by radar technology. Water surfaces give uncertain signs because of the waves, so we get false data on these surfaces (lakes, rivers and seas). A part of this data was filtered and these pixels were given ZERO values. Many of the pixels of mountain areas got ZERO values, mainly those that are so deep in the valleys, that the radar echo did not return to the detector according to the radar shadow. Consequently, the higher the landscape, the more data is missing because of this phenomenon. Another fault in the database is that the height of buildings and trees appears in the data. This is caused by the fact that radio waves of few centimetres are not able to penetrate the thick leaves or even leaves of medium thickness, and they are reflected back from the roofs and buildings. The pixel size in the DTM is 90 m that is enough to determine the frost risk territories. Since the frost risk is not the direct function of the altitude, we have to determine different parameters from the DTM. One of these parameters is the slope category (Fig. 2.). In this classification we considered that cold air flows downward very fast on steep slopes, so these areas are not called frost risk lands. The movement of cold air slows down on moderate slopes, therefore cold air lakes can form behind smaller landmarks. The classification of slope is contained the Table 1.

![Fig. 3. Slope map of the sample area](image)

<table>
<thead>
<tr>
<th>Slope angle [degree]</th>
<th>Weight factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 3</td>
<td>5</td>
</tr>
<tr>
<td>3 – 6</td>
<td>4</td>
</tr>
<tr>
<td>6 – 10</td>
<td>3</td>
</tr>
<tr>
<td>10 – 14</td>
<td>2</td>
</tr>
<tr>
<td>more than 15</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 1 Class of slope according to the potential frost-risk

Beside the slope, another important secondary topographic attribute (Wilson and Galant, 2000) is the convergence of the surface (Fig. 3.). The convergence index was calculated by the SAGA (System for Automated Geo-scientific Analyses) program developed by the Georg-August University, Göttingen (Germany). The interpretation of the convergence index is very simple. Negative values indicate areas where the surface is concave, so these are the places of collection. The positive index is typical for the convex surface - from these areas cold air masses flow downward. The classification of the convergence index is contained in Table 2.
Fig. 4  Convergence index map of the sample area

Table 2  Class of slope according to the potential frost-risk

Among the parameters of the DTM modelling, determining **topographic solar radiation** is the most difficult. There are several methods to determine radiation that reaches the surface. These actually only differ slightly (Kang et al, 2002). In general, because of the applied physical connections, there are few radiation models that can be used generally in regional scale (Németh, 2004). In our work, we used one of the SAGA models. Using the model we determined the annual values of potential radiation energy in the sample area (Fig. 4.). The values of the radiation energy were classified in the abovementioned way. Those parts of the sample area where the incoming radiation energy is the smallest got the highest weight factor (5). On the contrary, lands that get lots of energy (in general the Southern slopes) were marked by a weight factor 1. The results of the classification are contained in Table 3.

Table 3  Class of the topographic solar radiation according to the potential frost-risk
Land use is slightly different from the previous parameters. Land use data were obtained from the Corine Land Cover database (Fig. 6). The land use database that we used was made by visual photo interpretation of Landsat TM shots. These space shots were made in the period of 1990-1992. The database was created according to the European methodology. In our study we simplified the original Corine Land Cover nomenclature. We extracted only three categories. Grapes and fruits plantations are in the first category that was given a weight factor 5. This is because most of the grapes and fruits are very sensitive to frost, particularly at the beginning of their growing period. The second category is composed of agricultural production lands. These lands were given a weight factor 3. All the other lands are unimportant in our examination, so they were given a weight factor one.
2.3 Method

The first step in determining frost risk territories was the classification of parameters and selection of weight factors according to the method of frost risk determination. According to the weight factors, we made each parameter’s raster category map. After this we put these maps on each other and simply added the values of each cell. The process is presented in Fig. 7.

The next step after the addition was to reclassify the results, as a result we obtained the territory’s frost risk map. We can see that the most of the risk occurs in the NW parts of the examined territories - in the valleys and where there are gentle slopes. We can see it more clearly if we put the potential frost risks map on the DTM (Fig. 8.). If we examine the results with the land use map (Fig. 6.), we can see that areas engaged in growing of grapes belong to frost risk areas. The frost in the winter time is only harmful for grapes in extreme situations. The roots can stand frost until -5 °C, while the vine-shod can stand it until -15 °C. But in the occurrence of late spring frost, a few degrees below 0 °C can injure the green parts of the plant. Below -2.5 °C these green parts of the plant can completely die (Botos and Varga-Haszonits, 1974). So, on these lands attention must be paid to prevent frost damages.

3 Conclusion

In our research we determined the potential frost risk areas. At present we are verifying this method, so this paper only contains preliminary results. During the verification we will conduct field measurements to determine exactly the frost-risk areas. Apart from this, we will make the temperature map of the area by analysing meteorological network data with applying the suitable interpolation. These together provide enough possibility to verify the results.

The method is under development presently. The implementation of albedo values determined by satellite data would refine the current model.
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5 References


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