

EVALUATION OF ENVIRONMENTAL INDUCED SUSCEPTIBILITY TO WINDFALLS IN THE HYDROGRAPHIC BASIN OF MOLDOVA RIVER

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ABSTRACT. - Evaluation of environmental induced susceptibility to windfalls in the hydrographic basin of Moldova River. Windfalls are caused by the interaction of several factors and occur in a meteorological context characterized mainly by high wind speeds. In the present study we tried to develop a method for predicting windfalls in a test region, determining areas of high susceptibility of this climatic risk. For this purpose we evaluated parameters regarding the morphometric (slope, exposition, altitude) and morphological (mountain side concavity/convexity, slope break) properties of the relief, the types of forest and the soil on which these grow. We gave susceptibility scores for each parameter considered, resulting in a series of classified layers. These were subsequently added up to form the final cartographic material which highlights the vulnerable areas. For validating the results we utilised LandSat images from different time periods. The existence of a major windfalls event in the studied region (March 2002) allowed us to compare the situation before and after the event, and to check if there is a correlation with the model developed in this analysis. On the basis of this study it may be possible to predict the future evolution of trees susceptibility to windfall which could be helpful in establishing silvic measures to be implemented in order to minimize the damage caused by these phenomena.

Keywords: susceptibility, windfalls, GIS analysis, morphology of mountain sides.

1. INTRODUCTION

Extreme meteorological events that can cause windfalls will get more comon, as a result of climate change (IPCC Fifth Assessment Report, 2014). These events cause the damage of forest ecosystems, as a result of high wind speeds, which leads to economic losses.

The current system for mapping windfall risk areas – made official through technical regulations (Popa, 2005) – doesn't fully clarify the problem because of the general nature of the criteria used for assigning risk classes. The variability of the factors which determine windfall risk imposes approaching the problem from a microzonal point of view, at the level of an hydrological basin which has a relatively homogenous air flow pattern. (Popa, 2005).

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In the present study we tried an alternate method – one that can be improved – for predicting windfalls in a test region – the mountain basin of the Moldova River. The region has a high degree of afforestation, with a high percentage of pure spruce forests. It has witnessed many large windfall events over the years – in 1947, 1948, 1969, 1982, 1993 and more recently in 2002 (Suceava Silvic Direction Annual Report, 1998)

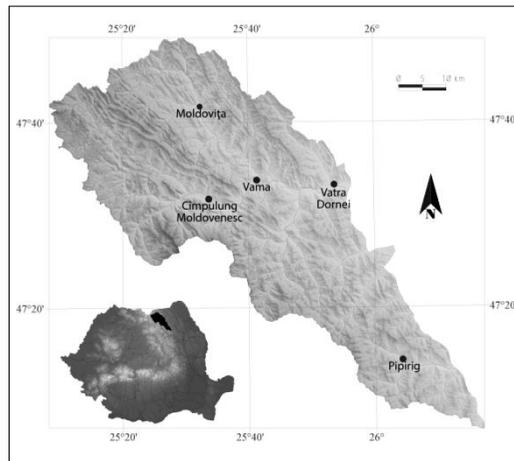


Fig. 1. Study Area – Upper Moldova River Basin

The study area has valleys with predominantly NNW-SSE disposition (Fig. 1). This disposition of the mountain sides is overimposed on the main wind direction from the west, with an annual percentage of 17.8% (Clima României, 2008).

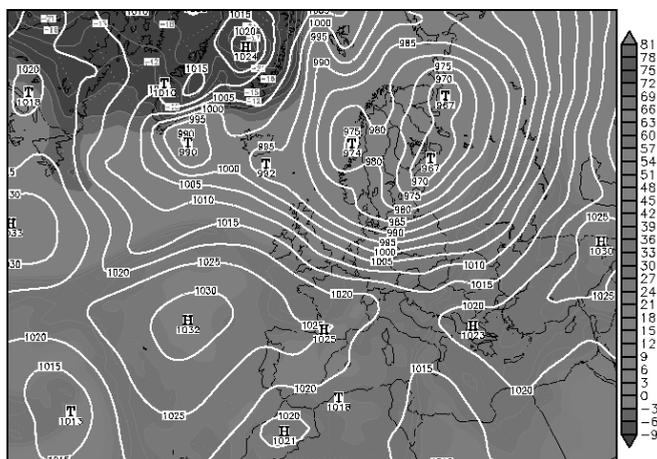


Fig. 2. Air pressure(white lines) and equivalent-potential temperature at 850 hPa geopotential height on 7.III.2002 (wetter3.de)

Westerly winds are often accompanied by high precipitations, contributing to the wetting of soils and to lowering the mechanical resistance of trees. Such winds can cause a slight jump in air temperature (foehn), leading to rapid snow melt and implicitly thawing of the soil, reducing the rooting strength of trees (Păuna, 2011).

Windfalls occur in the presence of a very high thermo-baric gradient which is oriented perpendicular over an orographic dam (Bogdan & Coșconea, 2010).

Such a situation occurred in the morning of 7th of March 2002, when some of the largest windfalls ever recorded in Suceva county took place, with a downed volume of over 4,000,000 m³ (according to the Suceava Silvic Direction). Wind speeds of 110-145 km/h (and probably more taking to account the limit of 144 km/h in the wind measurements on classical weather stations) affected mainly the upper Moldova River basin where on Beaufort scale at Rarău weather station the wind speed exceeded 160 km/h.

This situation was generated by the existence of an very well organized low pressure system centred in the Baltic Sea (south of Finland), and a high pressure system in west Turkey (Fig. 2).

2. METHODOLOGY

Windfalls result from the interaction of many factors. This study focused on a series of abiotic factors: climate, topographic factors and soils on which forests develop. Morphometric and morphologic features of the topographic relief (elevation, slope, aspect and concavity/convexity of hillsides) are basic topographical parameters utilised in studies about windfalls (Quine, 1995; Kramer et al. 2001; Evans et al. 2007).

In order to compute the susceptibility to windfalls, we chose a quantitative analysis consisting in assigning susceptibility points to the parameters we are interested in.

The digital materials representing the relief features have been extracted by processing the European digital elevation model Copernicus EU-DEM (2013) which has a spatial resolution of 25 meters. This digital model has been utilised as a reference layer for generating the cartographical materials regarding the slope, aspect, elevation and terrain curvature.

The windfall rate in spruce forests situated on mountain sides with high relief energy (700-1700m elevation) distributes after a Gauss bell. The maximum values score between 1200 and 1400 meters (Barbu, 1991). The risk classes range from 2 (low) up to 5 (high) (Fig. 3.a). The most exposed are the valleys (due to the wind channeling effect) and the mountain ridges (directly in the path of the wind). On ridges windfalls occur when air speed exceeds 17 m/s (Bogdan & Coșconea, 2010).

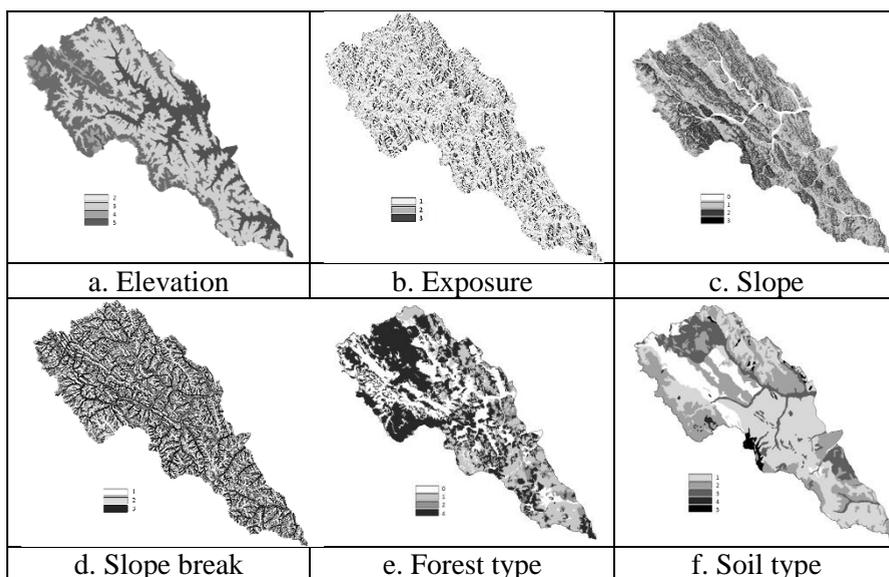


Fig. 3. Layers used for obtaining the prediction model

The most threatened forests are those situated on west facing sides, perpendicular on the wind direction. The windfall rate is double in the long term on the exposed side compared to the sheltered side (Barbu, 1991). The medium susceptibility class was given to the eastern, sheltered sides where turbulences can form when the airflow descends (Bogdan & Coşconea, 2010). The lowest score was given to the northern and southern sides, affected by the currents formed by air going around the mountain side (Fig. 3.b).

For the slope, scores were given between 0 for slope values $0-3^\circ$ (considered quasi-horizontal) and 3 for slope values over 32° (Fig. 3.c). An increase in slope value is directly proportional with a rise in windfall susceptibility as a result of intensification of windpressure brought by the concentration of airflow lines up the mountain side (Păuna, 2011).

The profile curvature is parallel to the direction of the maximum slope. A negative value indicates that the surface is upwardly convex at that cell, and a positive profile indicates that the surface is upwardly concave at that cell. A value of zero indicates that the surface is linear (flat). Profile curvature affects the acceleration or deceleration of flow across the surface (blogs.ESRI.com, 2010). The classes have been assigned by analysing the hystogram of the curvature raster. The forests situated on concave surfaces were given the highest susceptibility as the shape increases the effect of the slope. We also believe that it models accurately the slope break where the sudden change in slope would increase the effects of the wind (Fig. 3.d).

The highest decennial windfall rates are recorded in the spruce areas (Fig. 3.e), especially in stations with skeletal soils in which the spruce has a weak rooting (Barbu, 1991). As a result, the highest susceptibility was given to the

spruce forests, and the lowest to mixed forests. An equal score to the spruce was given to areas of former windfalls where the forest started to recover (324 Corine Land Cover category).

There were created 5 classes for soil texture. (Fig. 3.f). The most susceptible soils are the ones that exhibit skeleton, that are less evolved and have a coarser texture (Bogdan & Coşconea, 2010).

3. ANALYSIS AND DISCUSSIONS

After adding up all the above mentioned layers, a cartographic material was obtained. It shows the susceptibility to windfall events in the upper basin of the Moldova river.

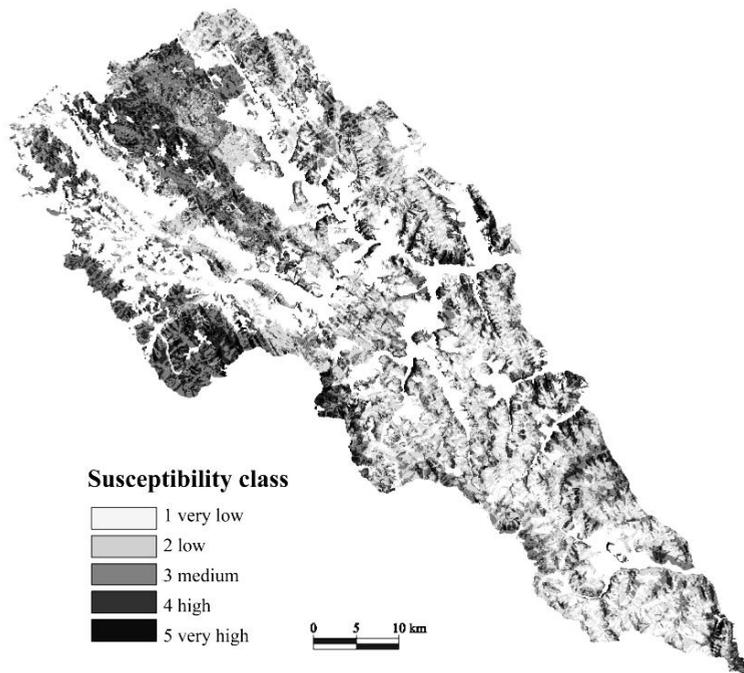


Fig. 4. Final prediction model

Validation of the model is based mainly on the comparison of satellite images taken before and after the 2002 event. We used 2 LandSat 7 ETM+ images (4-3-2 band combination) taken in July 2001 and July 2002. Because of the band combination chosen, visual analysis of the images is easily done.

Visual analysis of images before and after the event clearly shows the affected areas which can be used as test zones where the situation is clear (Fig. 5,6,7).

The LandSat images do not show a perfect overlay between windfall areas and zones of very high susceptibility. This may be explained by the use of a single scenario with westerly, linear circulation, by not taking into account the possible (and likely) turbulences and shifts in wind direction. On the other side, in the areas

of low susceptibility but with inserts of high susceptibility, large windfalls can be triggered by smaller ones originating in the high susceptibility areas which spread through the domino effect into the zones with a lower score.

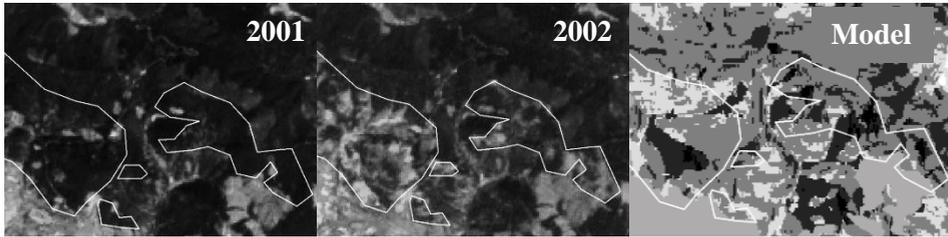


Fig. 5. Situation before and after the 2002 windfall event compared to the prediction model (Cîmpulung Moldovenesc area)

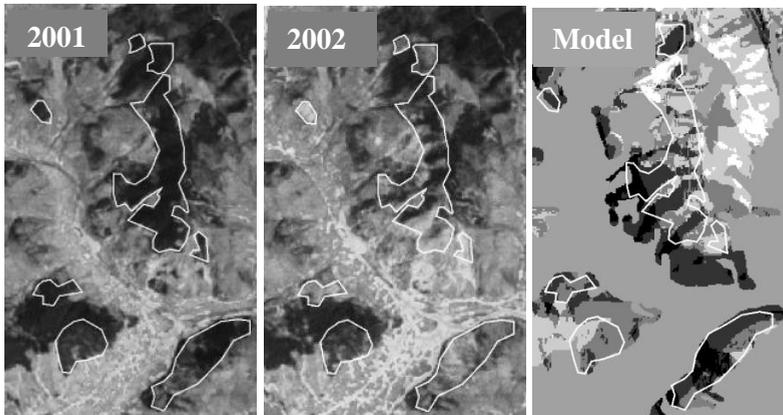


Fig. 6. Situation before and after the 2002 windfall event compared to the prediction model (Vama area)

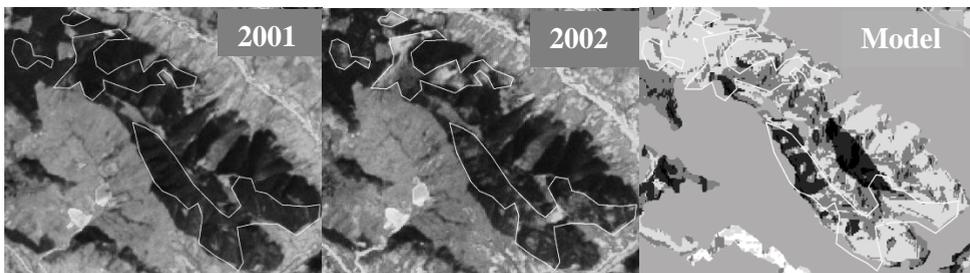


Fig. 7. Situation before and after the 2002 windfall event compared to the prediction model (Pojorâta area)

The spatial repartition of the obtained data allowed us to rank the forest districts based on their average susceptibility score. The map shows 3 main susceptibility areas, decreasing in susceptibility from NW towards SE. The high susceptibility of the Moldovița, Breaza and Pojorâta districts can be attributed to their high proportion of spruce forests combined with the effects of local topography factors (Fig. 8).

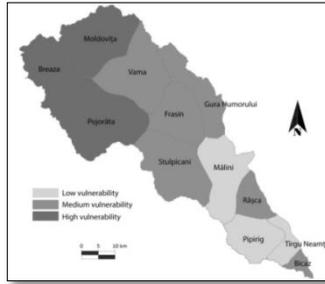


Fig. 8. Average susceptibility class per forest district

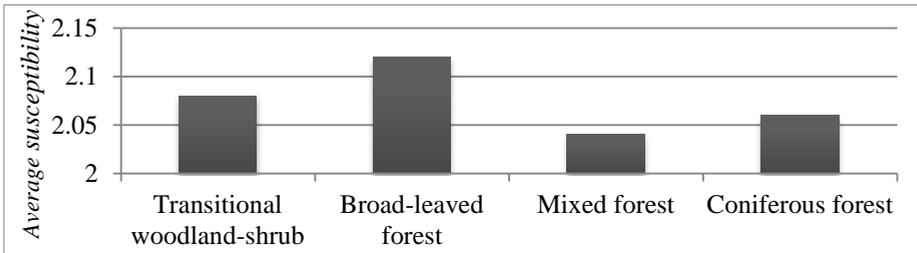


Fig. 9. Average susceptibility class per forest type

Figure 9 shows the average susceptibility class of each type of forest. In order to avoid self correlation, for this analysis the forest layer was eliminated from the model. It can be seen that broad leaved forests grow in areas of higher susceptibility to windfalls than the other types. This can be attributed to the fact that it was given a high score to valley corridors at lower elevations, where broad leaved forests are more common. Another explanation may be the adaptation of the forest to the environment, the natural replacement of spruce (which has been affected by windfalls) with more resistant species like broad leaved ones. Another category that has high susceptibility is the transitional woodland-shrub as defined by Corine Land Cover, which mainly represents areas where the forest is naturally recovering, possible from windfall damage.

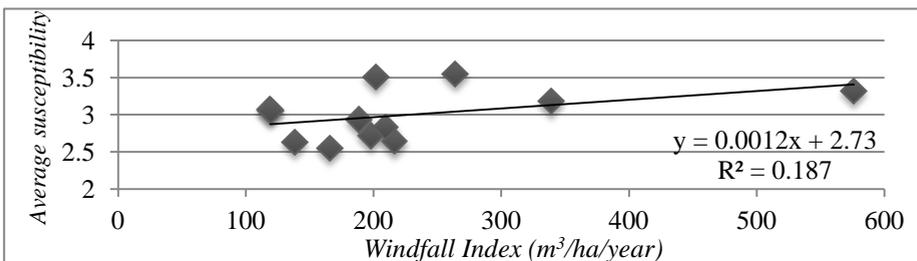


Fig. 10. Correlation between windfall index and average susceptibility class per forest district

The susceptibility scores obtained in the model have been compared with the database regarding the risk to windfalls at forest district level, composed by

ICAS Braşov (Fig.10). The windfall index has been calculated with the formula: $Idv = \frac{Vol. \cdot 10^5}{Area \cdot No.of\ years}$ (ICAS Braşov, 2008). The lack of correlation between the windfall index and the average susceptibility score can be explained by the use of the conditions belonging to one specific event (March 2002) for developing the model, while the ICAS study uses a 28 year interval. Also the official reports may include losses from other (unknown) sources. Some of the silvic districts extend beyond the limit of the analyzed river basin, and as such the ICAS database may contain losses recorded outside of the present study area.

4. CONCLUSIONS

The results presented in this article highlights the exposure risk of forest vegetation to the destructive action of the wind in relation to the pedogeomorphological factors (soil texture, aspect, slope, elevation, surface curvature). These should be complimented by biotic factors (health state of the forest) and also by a more accurate model of wind circulation inside the river basin, in order to create an useful instrument for mapping windfall susceptible areas, and also to help diminish the risk by taking the best decisions regarding landuse in high susceptibility areas.

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