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The morphogenetic impact of the bora type wind (19th November 2004) on the relief of Danielov dom area (The High Tatras)

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Abstract: The paper presents a study on geomorphic effect of an extremely strong wind which occurred on 19th November 2004 (southern slopes of the Tatra Mountains.). At that time a large amount of soil-waste material was displaced with root systems of windthrows (uprooted trees). Its volume was estimated at 40 000 m^3 within the study area (1.6 km^2). Lithology of soil-waste material was assumed as the most important factor on which the amount of the displaced material (with roots of a windthrow) depends.

Key words: geomorphic effect, uprooting, blowdown, windthrow

Introduction

19th November 2004 is considered to be a turning point in the history of southern slopes of the Tatra Mountains. An extremely strong bora wind, whose maximum velocity exceeded 60 $m \cdot s^{-1}$, caused significant changes to the geographic environment of this region. This includes uprooting forest stand on the area of 12,600 ha with a total volume of wood 3,000,000 m^3 (Argalács 2005, Koreň 2005). At that time a significant quantity of a soil-waste material was displaced with the roots of fallen trees. The aim of this paper is to estimate its volume within the study area considering the most important factors on which it may depend.

Study area

The area of the study called Danielov dom (1.6 km^2) is situated within the zone of destruction caused by the bora wind on 19th November 2004 in the High Tatras, between villages Nová Polianka and Tatranská Polianka (Fig. 1), southwards from the so-called *Cesta Slobody* (49°07'04"–49°08'02" N, 20°08'58"–20°10'10" E). It stretches between the altitude of 923 and 1,284 m a.s.l. Slope angle ranges from 4 to 20°. Before the calamity the area was covered with a mixed spruce-larch forest (*Lariceto Piccetum)* which is now replaced by a blowdown (Fleischer & Koreň 2007) (Fig. 2).

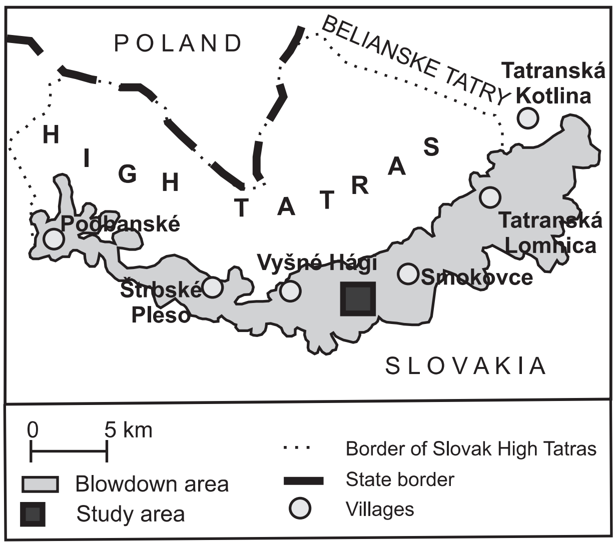

Fig. 1. Localisation of the study area

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Fig. 2. General view of the study area

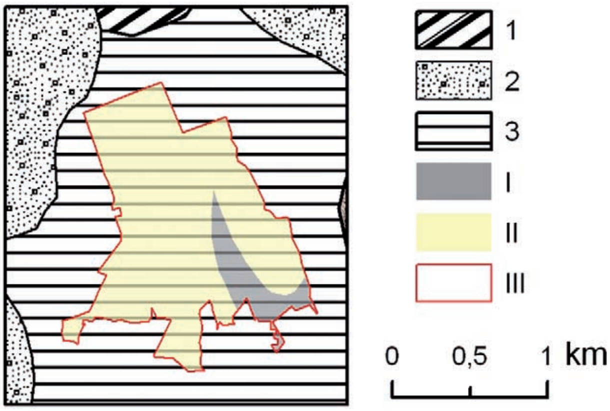

Fig. 3. Geomorphic regionalisation of the study area and its surroundings (Lukniš 1973): 1 – region of levelled relief on granodiorite, 2 – region of latteral morains, 3 – region of foothills on lower pleistocene fluvioglacial fans. Areas where windthrows with different soil-waste material type occur. I – area with "cobble windthrows", II – area with "sandy windthrows", III – area of study

According to geomorphic regionalisation of the High Tatras (Lukniš 1973) the area of the study is situated within foothills on lower pleistocene fluvioglacial fans (Fig. 3). The main characteristics of this unit are: small slope inclination and slight relief dismemberment. Bedrock within this unit consists of a thick layer (up to 20 m) of fluvioglacial and colluvial granite sediments (gravels and cobbles which are often weathered).

Methods

The research included two stages: field work and calculations. Within the first one 105 windthrows (uprooted trees) were randomly chosen and measured. Measurements included: circumference of a trunk (next to the root system), length (a), width (b) and thickness of soil-waste material adjoining the root system and angle of a slope on which the windthrow is situated. Prevailing fraction of material, according to the geotechnical classification (Mycielska-Dowgiałło 1995), was assessed visually.

Calculations were divided into several steps. The first one was computing the volume of the soil-waste material adjoining the roots of each windthrow (henceforth called: *volume of the windthrow*). Its shape was compared to a half of an ellipsoid in revolution (Kotarba 1970) so the volume was computed from the formula:

$$V = \frac{1}{2}\cdot\frac{4}{3}\cdot\pi\frac{a}{2}\cdot\frac{b}{2}c = \frac{\pi abc}{6}$$

a, b, c are the parameters measured during the field works.

Further steps included:

1. Creating classes of trunk circumference (Table 1) and slope angle (Table 2) on the basis of the histograms and dividing fraction of soil-waste material into sands (0.05–2 mm, symbol S), and cobbles (>25 mm, symbol C).
2. Assigning each windthrow to a suitable class e.g. windthrow whose trunk circumference is 90 cm, prevailing soil-waste material adjoining to its root is sand, situated on the slope with angle of 8° was assigned to class B3(S).

Table 1. Classes of trunk circumference

symbol	trunk circumference [cm]
A	55–80
B	81–100
C	101–140
D	140–223

Table 2. Classes of slope angle

symbol	slope angel (°)
1	3–4
2	5–7
3	8–9
4	10–13
5	14–19

Table 3. An example of a group with classes of the same trunk circumference and the same prevailing fraction of material

class	mean volume of soil-waste material (m^3)
B1(C)	0.81
B2(C)	0.53
B3(C)	1.64
B4(C)	0.36
B5(C)	0.61

3. Computing the mean volume of soil-waste material adjoining root system of the windthrow for each class.
4. Grouping the classes of the same trunk circumference and the same fraction of prevailing soil-waste material (Table 3).
5. Considering the relation between mean volume of soil-waste material and slope angle (the only parameter which changes within a group) in each group. The following possibilities were taken into consideration:
   a) increase of volume together with increase of slope angle
   b) increase of volume together with decrease of slope angle
   c) no relation.
6. Counting the groups in which the particular possibilities (from the ones mentioned above) occurred.
7. Analysing relations between: volume of soil waste material and prevailing fraction of soil-waste material, and volume of soil-waste material and trunk circumference in a way similar to the one used for the slope angle – volume of the windthrow relation.

The last step of the research was estimation of the total volume of soil-waste material displaced with roots of fallen trees within Danielov dom area. It consisted of:

1. Computing the mean volume of soil-waste material for the windthrows with sand and the ones with cobbles.
2. Computing the area within which windthrows with sand and windthrows with cobbles occur (on the basis of field recognition).
3. Computing the mean density of windthrows on the study area using the experimental squares (40×40 m).
4. Computing the number of windthrows with sands and cobbles within the study area
5. Computing the total volume of windthrows with sands and cobbles.

Results

Volume of the windthrows measured during the field works ranges from 0.17 to 20.4 m^3 (1.88 m^3 on average). Slope angle around the windthrows is 3–19°. Their trunk circumference (measured next to the root system) is equal 55–223 cm (109 cm on average, mostly 80–140 cm). Prevailing fraction of the soil-waste material adjoining roots of the measured windthrows is either sands (0.05–2 mm) (Fig. 4A) or cobbles (>25 mm, mostly 100–200 mm) (Fig. 4B). Material of the sandy windthrows usually has an admixture of cobbles or gravel (2–25 mm). Sandy particles can be also aggregated so they resemble gravel. Material in which cobbles prevail does not contain any admixture in most cases.

While analysing the relationship between volume of the windthrow and slope angle, 8 groups of windthrows were taken into consideration. Each of them contained classes of the same trunk circumference and prevailing fraction of the material so the slope angle was the only parameter that changed within a group. No relationship between slope angle and volume of the windthrow was observed in any of the groups (Table 4).

Relationship between prevailing fraction of material and volume of the windthrow was analysed in 18 groups containing classes of the same trunk circumference and slope angle. In 15 of them the volume of a sandy windthrow was larger than volume of a cobble one (Table 5). This means that lithology of the soil-waste material could be a significant factor which determines volume of the windthrow. This could be explained by the fact that in sandy material roots can penetrate the ground to a relatively deep level while in cobble one root penetration is usually limited by large rocky blocks. To prove this explanation a relationship between prevailing fraction of soil-waste material and thickness of the windthrow

Fig. 4. Windthrows with a different type of material A – sand is a dominant fraction, B – cobbles prevail

Table 4. Volume of soil-waste material (adjoining roots of the windthrow) within particular groups and classes. Colours mark groups of the same trunk circumference and prevailing fraction

class symbol	prevailing fraction of soil-waste material	
	sand (S)	cobbles (C)
A1	nd	0.22
A2	0.64	0.16
A3	0.14	0.11
A4	0.25	0.13
A5	0.51	0.27
B1	0.81	0.21
B2	0.53	0.17
B3	1.64	0.37
B4	0.36	0.69
B5	0.61	0.40
C1	1.35	0.89
C2	1.05	0.39
C3	0.55	0.32
C4	1.23	1.07
C5	1.17	1.23
D1	1.84	1.75
D2	6.95	1.02
D3	1.81	2.53
D4	1.28	0.79
D5	nd	nd

Table 5. Volume of soil-waste material (adjoining roots of the windthrow) within particular groups and classes. Colours mark groups of the same trunk circumference and slope angle

class symbol	prevailing fraction of soil-waste material	
	sand (S)	cobbles (C)
A1	nd	0.22
A2	0.64	0.16
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A4	0.25	0.13
A5	0.51	0.27
B1	0.81	0.21
B2	0.53	0.17
B3	1.64	0.37
B4	0.36	0.69
B5	0.61	0.40
C1	1.35	0.89
C2	1.05	0.39
C3	0.55	0.32
C4	1.23	1.07
C5	1.17	1.23
D1	1.84	1.75
D2	6.95	1.02
D3	1.81	2.53
D4	1.28	0.79
D5	nd	nd

Table 6. Volume of soil-waste material (adjoining roots of the windthrow) within particular groups and classes. Colours mark groups of the same slope angle and prevailing fraction

class symbol	prevailing fraction of soil-waste material	
	sand (S)	cobbles (C)
A1	nd	84
A2	73	35
A3	48	37
A4	53	38
A5	65	40
B1	70	40
B2	57	39
B3	117	46
B4	60	61
B5	64	49
C1	76	64
C2	94	44
C3	118	50
C4	80	58
C5	89	52
D1	80	64
D2	148	48
D3	96	71
D4	98	59
D5	nd	nd

was analysed. It turned out that thickness of the material significantly depends on prevailing fraction of material (in 17 out of 18 groups sandy windthrows had greater thickness) (Table 6).

Size of a tree could also have an important influence on volume of the windthrow. Bigger trees have more extensive root system so the volume of the windthrow should also be greater. Tree species is another significant factor (Phillips et al. 2008), however almost all the trees in Danielov dom area were spruces, therefore it cannot be taken into consideration in this study.

Trunk circumference was chosen as the measure of a tree size. While analysing relationship between

Table 7. Thickness of soil-waste material (adjoining roots of the windthrow) within particular groups and classes. Colours mark groups of the same trunk circumference and slope angle

class symbol	prevailing fraction of soil-waste material	
	sand (S)	cobbles (C)
A1	nd	0.22
A2	0.64	0.16
A3	0.14	0.11
A4	0.25	0.13
A5	0.51	0.27
B1	0.81	0.21
B2	0.53	0.17
B3	1.64	0.37
B4	0.36	0.69
B5	0.61	0.40
C1	1.35	0.89
C2	1.05	0.39
C3	0.55	0.32
C4	1.23	1.07
C5	1.17	1.23
D1	1.84	1.75
D2	6.95	1.02
D3	1.81	2.53
D4	1.28	0.79
D5	nd	nd

Table 8. Extrapolation of the results to the entire study area

study area [m^2]	1,576,712
area with "sandy windthrows" [m^2]	1,405,455
area with "cobble windthrows" [m^2]	171,257
number of windthrows per 100 m^2	2.30
number of "sandy windthrows"	32,325
number of "cobble windthrows"	3,939
total number of windthrows	36,264
total volume of displaced sandy material [m^3]	38,635
total volume of displaced cobble material [m^3]	3,035
total volume of displaced material [m^3]	41,670
volume of displaced material [$m^3 \cdot m^{-2}$]	0.03

the volume of the windthrow and trunk circumference, classes of the same slope angle and prevailing fraction of the material were grouped. The influence of trunk circumference on the volume of soil-waste material adjoining root system of the windthrow was not distinct. In 5 (out of 10) classes volume was increasing along with the tree circumference, however in the remaining 5 groups no relation was found (Table 7).

On the basis of the above-mentioned results the total volume of soil-waste material displaced with root systems of windthrows on Danielov dom area was estimated (Table 8). Prevailing fraction of material was assumed as the most important factor determining volume of the windthrow. The mean volume of a sandy windthrow which is 1.2 m^3 and the mean volume of a cobble one which equals 0.77 m^3 were extrapolated to the whole study area. The areas where cobble and sandy windthrows occur were taken into consideration. Total volume of windthrows on the study area was estimated at 40 000 m^3, total volume of sandy windthrows amounts to 93% of it.

Conclusions

Lithology of soil-waste material seems to be the most important factor which determines volume of the windthrow. In sandy material roots can penetrate the ground deeper than in cobbles, therefore both volume and thickness of a sandy windthrow are larger than volume and thickness of cobble ones.

On the study area approximately 40,000 m^3 of soil-waste material was displaced with the root systems of windthrows which is equivalent to a displacement of the entire surface area to a depth of 3 cm.

Uprooting did not trigger large-scale mass movements. However, it has started the development of the so-called pit and mound microrelief (Fig. 5).

Results presented in the paper refer to a small study area. Further research on a larger scale (on the field with more diversed lithology, slope angle, size and species of trees) with the use of multivariate statistical analysis is suggested.

Fig. 5. Initial stage of pit and mound microrelief development

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