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EROSION POTENTIAL OF SNOW COVER IN THE CZECH REPUBLIC

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Abstract

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Amount of water derived from snow and melting rate can be collectively described as the erosion potential of water accumulated in the snow. The erosion potential of snow was calculated for thirty cold periods i.e. 1st November to 30th April (1980/1981 to 2009/2010) based on climatilogical data of fifty stations of Czech hydrometerological station from different climatic conditions according to Climatic region of Estimated Pedological Ecological Unit. Snow erosive potential statistically significantly depends on altitude (r = 0.726**, α = 0.01) and also on climatic region (r = 0.790**, α = 0.01). Mapping expression was based on average values of thirty-year period. Range of snow erosive potential in the map responces to quantile values, quintile values respectively ($Q_{0.2}$, $Q_{0.4}$, $Q_{0.6}$, $Q_{0.8}$). A map of erosion potential of snow cover for arable land deals with an assumption of arable land incidence. It was determined by excluding forests, built area, land with a slope of 12 ° and areas with an altitude of 700 m.

snow erosion potential, EPEU, snow melting rate

Both spring snow melting and melting of snow during winter both participate in annual runoff and transport of soil particles from the entire basin (REKOLAINEN, 1989). Erosion caused by snow melting is closely related to the amount and the maximum speed of flowing water that can be enhanced by rainfall, which occurs simultaneously with snow melt. According to McCOOL (2002), soil erosion plays a very important role in many areas of the world due to the effect of winter precipitation. Snow melt in winter and early spring is a frequent cause of soil erosion in the northern parts of Europe such as Norway, Sweden and Finland (LUNDEKVAM and SKØIEN, 1998). Erosion caused by snow melt was also reported in Germany, Poland, the Slovak Republic, Austria, Italy and Switzerland (KVÆRNØ and ØYGARDEN, 2001). OLLESCH *et al.* (2005) characterized spatial dynamics of erosion processes in the 'Schäfertal' (northeastern Germany) during the process of snow melt.

The results of erosion studies in the Northern, Central or Eastern Europe and the Northern America show that the intensity of erosion during snow melt may either reach or even exceed the intensity of erosion caused by rain. (DEMIDOV *et al.*, 1995; EDWARDS *et al.*, 1998; LUNDEKVAM, 2002). The protection effect of vegetation in the spring is weak. Erosion risk is particularly high in grain production area as autumn tillage leaves the soil unprotected (LUNDEKVAM *et al.*, 2003).

Cool-period soil erosion from farmland in Prince Edward Island occurs predominantly through rilling mainly due to snowmelt. This is mostly evident on potato fields. Cool-period erosion amounted to about 30 t ha^{-1} for 2-yr rotation (with cereal grains) and 3-yr rotations (with cereal grains and a forage crop for hay), thus an annual seasonal average of 15 t ha^{-1} and 10 t ha^{-1}, respectively (EDWARDS *et al.*, 1998).

Snow melt, soil freezing and related erosion events exhibit considerable spatial variability (OLLESCH *et al.*, 2005). The intensity of erosion caused by snow melt may be several times higher on the leeward side of the slope in the terrain depressions than on the windward side or on the southern slopes. Intensity of erosion caused by snow melt is determined by the speed of melting, the amount of melting water, soil permeability, disintegration of soil aggregates caused by frost, moisture in the soil and vegetation. Melt rates are usually much smaller than the intensity of rain but soil is frozen in winter and filled with water in the surface layer, thereby reducing infiltration rate. Discharge coefficient of the frozen soil is usually higher than in the case of rainfall. Surface runoff occurs mainly during the continuous melting of snow within 10 to 20 days. Average runoff from melting snow ranges from 1.0 to 15.0 mm.day^{-1} (ZACHAR, 1982). Repeated freezing and thawing of soil plays a considerable role in the degradation of soil erosion by water. The combination of intense rainfall, frozen soil and saturated soil surface during the process of snow melt leads to erosion and development of serrated ravines (ØYGARDEN, 2003). Future trend of snow melting erosion risks is closely depended on climate change (number of ice days, arctic days, winter precipitation, the rate of melting snow in the winter and spring period, etc.). MUŽÍKOVÁ *et al.* (2011) worked out climatological analysis including the presence of characteristic cold days for current and future periods (based on climate scenarios outputs) in the Czech Republic. Average annual number of frost days in the first period on all chosen localities varied from 98.9 to 136.4 days. There is a decrease to 74.5 and 111.3 days respectively in the second period (2021–2050). Average number of these days is 87.1 days for all localities (decrease 25 days compared with the previous period). Further decrease occurs in the third period (2071–2100); average value for all localities is 66.9 days (20.2 days fewer than in previous period).

MATERIALS AND METHODS

Assessment of erosion intensity from melting snow by ZACHAR (1982) is based on universal soil loss equation by WISCHMEIER and SMITH (1978). Rain factor is replaced by factor of snow melting rate ***m*** (mm day^{-1}) in maximum 20-day period, in which the most intense thawing takes place and factor of amount of water derived from snow during the 20-day period ***h*** (cm). Combination of the both factor m and h could be assigned as erosive potential of snow cover. Czech Hydrometeorological Institute (CHMI) data on total snow depth and snow water content was used for its estimation. Snow water content means a total amount of water derived from snow cover thawing (mm of water column).

The stations of interest were chosen with regard to their regular distribution on different altitudes and different climatic conditions due to climatic region (CR) of Estimated Pedological-Ecological Unit (EPEU) see Tab. I. EPEU five positions code expresses main soil and climatic conditions that affect land productive ability and its economic evaluation.

Data from fifty CHMI stations was used for the evaluation (Fig. 1, Tab. II). The stations were selected according to availability of required data (in particular their relevance and homogeneity). Measurements inhomogeneity is related to observations at meteorological stations, especially with their relocation, change of observation terms, sensors exposure etc. (ŠTĚPÁNEK, 2004).

This paper evaluates the erosive potential of snow cover in territory of the Czech Republic for thirty "cold periods" from 1980/1981 to 2009/2010. The cold period includes months with snow cover occurrence and risk of its intense thawing i.e. November to April.

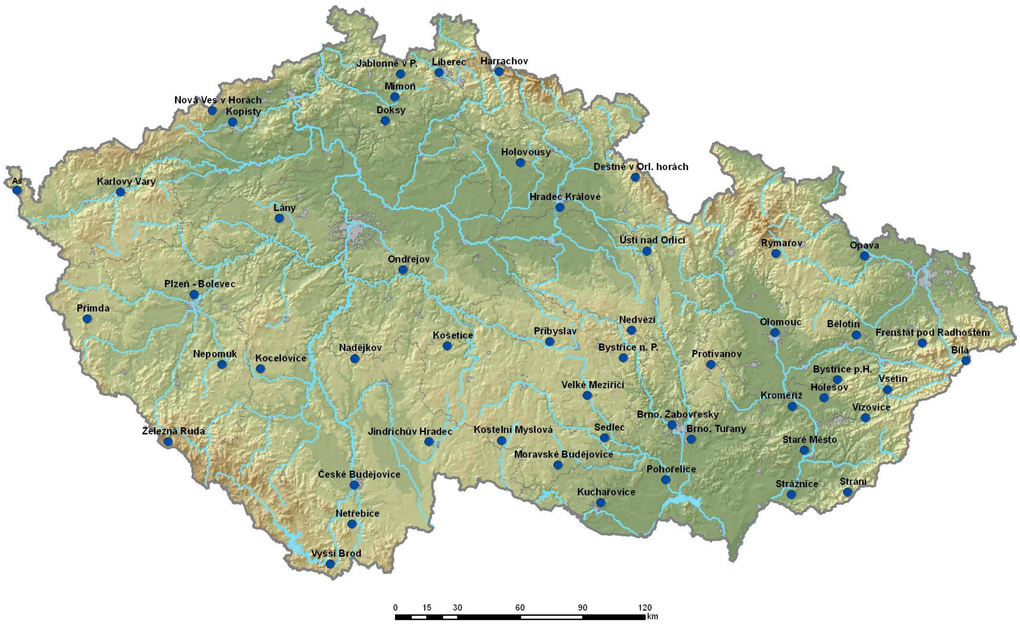
RESULTS

The snow melting rate ***m*** (mm day^{-1}), amount of water derived from snow ***h*** (cm), erosive potential of snow and lasting of melting period (days) were determined for each cold season. Tab III. presents the processing for Staré Město station.

Data of all chosen stations were processed analogously. The thirty-year average values were computed on the base of this data. Mapping of erosive potential of snow cover deals with the

I: *Climatic region characteristics (Notice No. 327/1998 Coll. Ministry of Agriculture)*

Region code	Region symbol	Region characteristic	Temperature sum TS10 (°C)	Average air temperature (°C)	Average annual precipitation total (mm)	Probability of dry vegetation seasons	Moisture certainty
0	VT	very warm, dry	2 800–3 100	9–10	500–600	30–50	0–3
1	T1	warm, dry	2 600–2 800	8–9	< 500	40–60	0–2
2	T2	warm, moderate dry	2 600–2 800	8–9	500–600	20–30	2–4
3	T3	warm, moderate wet	2 500–2 800	(7) 8–9	550–650 (700)	10–20	4–7
4	MT1	moderate warm, dry	2 400–2 600	7–8.5	450–550	30–40	0–4
5	MT2	moderate warm, moderate dry	2 200–2 500	7–8	550–650 (700)	15–30	4–10
6	MT3	moderate warm (to wart), wet	2 500–2 700	7.5–8.5	700–900	0–10	> 10
7	MT4	moderate warm, wet	2 200–2 400	6–7	650–750	5–15	> 10
8	MCH	moderate cold, wet	2 000–2 200	5–6	700–800	0–5	> 10
9	CH	cold, wet	< 2 000	< 6	> 800	0	> 10



1: *A map of chosen station of CHMI*

II: *Altitude and climatic region of evaluated stations*

Station	Altitude (m n. m.)	CR	Station	Altitude (m n. m.)	CR
Strážnice	176	0	Vsetín	387	6
Pohořelice	183	0	Jablonné v Podještědí	315	7
Kopisty	240	1	Strání	383	7
Brno,Žabovřesky	235	2	Ústí nad Orlicí	402	7
Brno, Tuřany	241	2	Frenštát pod Radhoštěm	436	7
Kuchařovice	334	2	Velké Meziříčí	452	7
Olomouc	215	3	Nepomuk	465	7
Staré Město	221	3	Kocelovice	519	7
Kroměříž	235	3	Jindřichův Hradec	524	7
Hradec Králové	278	3	Přibyslav	530	7
Holovousy	321	3	Košetice	534	7
Kuchařovice	334	3	Kostelní Myslová	569	7
Doksy	279	4	Bystřice n. P.	573	7
Plzeň-Bolevec	328	4	Nadějkov	615	7
Lány	436	4	Protivanov	675	7
Opava	272	5	Liberec	398	8
Mimoň	305	5	Vyšší Brod	559	8
Karlovy Vary	377	5	Netřebice	616	8
České Budějovice	388	5	Rýmařov	645	8
Moravské Budějovice	457	5	Aš	675	8
Sedlec	473	5	Nedvězí	722	8
Ondřejov	485	5	Přimda	742	8
Bělotín	306	6	Bílá	720	9
Vizovice	313	6	Nová Ves v Horách	725	9
Bystřice p.H.	317	6	Železná Ruda	820	9

average values of each station. Tab. IV contains the results of erosion potential of snow cover for all chosen stations – average value for the entire 30-yr period plus average value of each characteristic.

III: *Erosive potential of snow cover Staré Město station for thirty "cold period" from 1980/1981 to 2009/2010 – demonstration of processing*

Period	h (cm)	Thawing period (day)	m (mm day^{-1})	Erosive potential
1980–1981	4.6	8	5.75	26.5
1981–1982	3.21	5	6.42	20.6
1982–1983	2.45	13	1.88	4.6
1983–1984	2.05	7	2.93	6.0
1984–1985	2.55	13	1.96	5.0
1985–1986	2.16	12	1.80	3.9
1986–1987	3.50	10	3.50	12.3
1987–1988	0.86	7	1.23	1.1
1988–1989	1.03	2	5.15	5.3
1989–1990	0.70	11	0.64	0.4
1990–1991	0.55	8	0.69	0.4
1991–1992	1.50	15	1.00	1.5
1992–1993	1.24	10	1.24	1.5
1993–1994	1.00	1	10.00	10.0
1994–1995	0.95	9	1.06	1.0
1995–1996	5.30	16	3.31	17.6
1996–1997	2.40	18	1.33	3.2
1997–1998	0.80	9	0.89	0.7
1998–1999	1.60	1	16.00	25.6
1999–2000	2.10	13	1.62	3.4
2000–2001	1.20	5	2.40	2.9
2001–2002	3.40	4	8.50	28.9
2002–2003	1.90	4	4.75	9.0
2003–2004	2.70	3	9.00	24.3
2004–2005	4.80	4	12.00	57.6
2005–2006	5.90	16	3.69	21.8
2006–2007	1.70	1	17.00	28.9
2007–2008	0.40	2	2.00	0.8
2008–2009	2.20	8	2.75	6.1
2009–2010	3.37	7	4.81	16.2
average	2.27	8.07	4.51	11.6

The highest value of erosion potential of snow cover (197.52) was found at Bílá station, which is a part of climatic region 9 in 720 m a. s. l. This locality does not represent an agricultural land. Due to other factors of soil loss estimation (factor of soil, vegetation factor etc) the risk of soil erosion is not relevant here. For a spatial expression of the snow cover erosive potential in arable land just stations with altitude lower than 700 m a. s. l. were taken into account.

The erosive potential of snow cover 4.32 was determined for Olomouc station with altitude of 215 m in climatic region 3. This station can be affected by the urban heat island causing a gradual increase of air temperature towards the central parts of the city. It could also affect a snow depth and thereby erosive potential of snow cover calculation. The second lowest value of the snow erosive potential (4.75) was assessed for Pohořelice station which lies at 183 m a. s. l. in climatic region 0.

The results of the average erosion potential of entire evaluated period i.e. cold periods from 1980/1981 to 2009/2010 were interpolated according to the elevation by ArcGIS system. It means a conversion of point expression to the spatial one. The result of the mapping is a map of erosion potential of snow cover for arable land of the Czech Republic (Fig. 1). Partial results of snow erosion potential in Southern Moravia region were published by SMOLÍKOVÁ *et al.* (2009).

An accurate map layer of arable land was not available for the mapping. Although a map of land blocks at cadastral level is available in the database parcel identification system (LPIS) due to its very detailed spatial resolution the areas with expected incidence of arable land were determined by excluding of forests, settlements, land with a slope

IV: *Average value of erosion potential of snow cover for all selected stations for 30-yr period (from 1980/1981 to 2009/2010); tp = thawing period*

Station	h (cm)	tp (day)	m (mm day⁻¹)	Erosive potential	Station	h (cm)	tp (day)	m (mm day⁻¹)	Erosive potential
Bystřice p. H.	2.64	8.03	4.81	14.51	Železná Ruda	14.24	15.00	10.57	162.66
Holešov	1.87	7.33	2.87	6.79	Přimda	9.73	11.00	10.25	112.09
Kroměříž	2.51	7.73	3.93	11.62	Aš	6.69	12.13	6.14	45.72
Protivanov	4.99	9.63	6.56	41.16	Karlovy Vary	2.19	7.37	4.27	13.00
Staré Město	2.27	8.07	4.51	11.56	Bělotín	2.68	7.57	4.71	14.16
Strání	5.20	7.63	7.86	52.28	Bílá	15.95	16.13	11.29	197.52
Strážnice	1.59	5.17	3.67	8.59	Frenštát pod R.	5.31	9.50	7.21	51.97
Vizovice	3.84	6.60	7.95	33.68	Opava	2.95	6.47	5.21	19.52
Brno, Tuřany	2.21	8.37	4.24	9.51	Rýmařov	10.47	14.53	7.82	87.81
Bystřice n. P.	5.99	9.73	8.69	66.82	Olomouc	1.50	8.50	2.38	4.32
Brno Žabovřesky	2.03	8.00	2.76	6.52	Vsetín	6.21	10.10	6.55	47.68
Kostelní Myslová	4.99	8.80	7.41	45.12	Košetice	3.38	9.97	5.29	24.28
Kuchařovice	1.57	7.13	3.88	7.15	Ondřejov	3.66	9.13	7.88	32.10
Mor. Budějovice	2.14	7.17	4.21	10.70	Přibyslav	7.82	9.10	13.06	128.97
Nedvězí	6.69	9.93	9.12	82.66	Nová Ves v H.	10.13	13.70	8.17	94.23
Pohořelice	1.57	6.60	2.52	4.75	Doksy	2.45	7.17	4.81	12.24
Sedlec	2.98	6.83	6.03	22.03	Jablonné v Pod.	4.16	10.83	6.03	28.25
Velké Meziříčí	4.15	10.60	5.68	26.15	Liberec	6.75	10.47	7.97	62.83
Kocelovice	2.92	9.47	4.73	15.74	Plzeň-Bolevec	1.84	5.63	5.02	12.14
České Budějovice	1.78	6.23	3.75	7.99	Lány	2.13	7.87	4.32	12.59
Jindřichův Hrad.	3.93	10.63	4.03	21.80	Kopisty	1.21	5.60	3.18	4.87
Nadějkov	3.89	8.50	6.02	32.39	Mimoň	3.14	10.20	4.00	14.76
Vyšší Brod	4.43	10.10	6.24	35.11	Netřebice	3.40	10.53	5.46	23.82
Ústí nad Orlicí	4.93	9.47	6.51	40.44	Holovousy	3.53	10.70	3.89	16.38
Nepomuk	2.21	8.67	4.26	12.65	Hradec Králové	1.96	7.90	2.97	8.57

of 12°, and areas with altitude above 700 m (Fig. 2). Due to this assumption the area of arable land used for snow erosive potential mapping is rather a professional estimation and reality may differs a little.

A similar procedure for the approximate estimation of agricultural land area is not possible due to the problematic assessment of maximum altitude for occurrence of forage stands. Erosion from melting snow is not a threat for the areas with snow erosive potential lower than 1 (especially the flat lowland Polabí and Podyjí in Fig. 2) marked by light green.

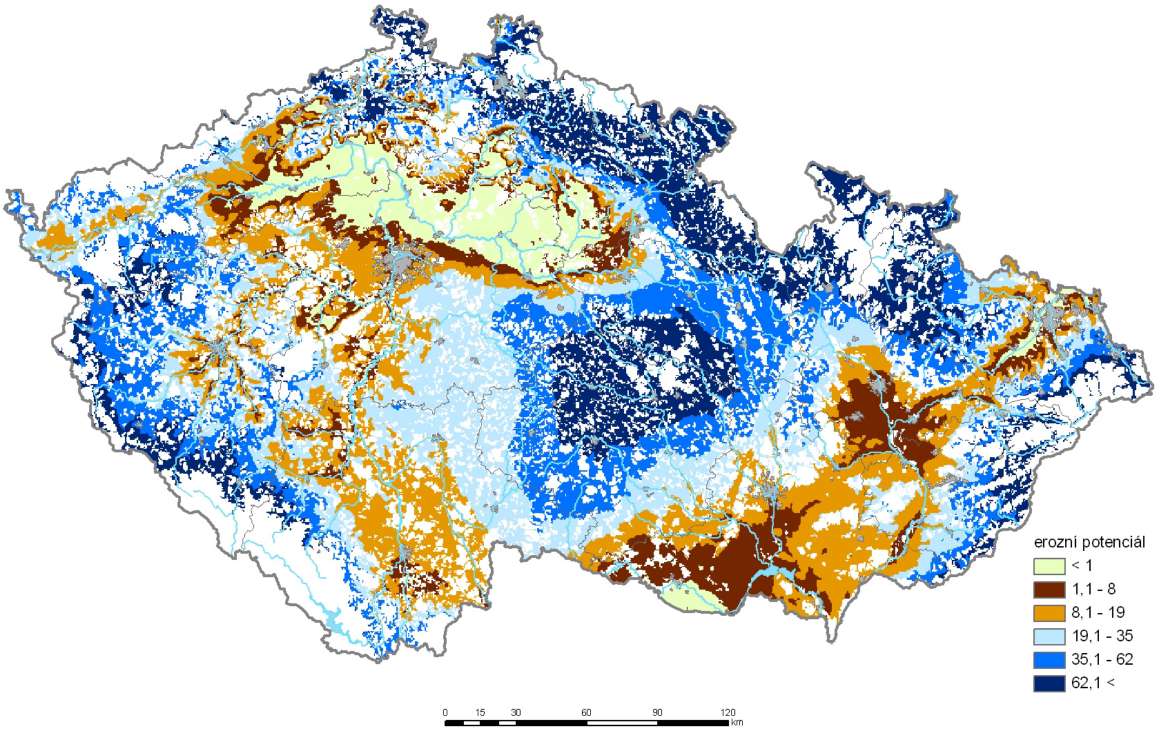
V: *Range of snow erosive potential categories presented in a map (Fig. 2)*

Category	Range of snow erosive potential	Average value of snow erosive potential
1	1.1 to 8	4.5
2	8.1 to 19	13.5
3	19.1 to 35	27.0
4	35.1 to 62	48.5
5	> 62.1	62.1*

Range of snow erosive potential in the map responces to quantile values, quintile values respectively ($Q_{0.2}$, $Q_{0.4}$, $Q_{0.6}$, $Q_{0.8}$) see Tab. V.

DISCUSSION

According to Reports of the Technical Working Groups Established under the Thematic Strategy for Soil Protection the snow melt erosion is not a significant problem in the Czech Republic. However the importance of erosion caused by snow thawing confirm for instance KLIMENT *et al.* (2007). Their results proved that a third of annual amount of suspended load in investigated flows response to spring season. Snow melting in combination with frozen soil in area Schäfertal (northwest Germany) is characterized by up to 40 times higher sediment concentration than surface runoff water on unfrozen soil (OLLESCH *et al.*, 2005). If the soil under snow is frozen the water cannot infiltrate into (SLAVÍKOVÁ *et al.*, 2007). Snow melting erosion is not often mentioned in Czech literature. The reason is probably an insufficient and difficult determination of individual factors of snow melt intensity equation. Thereby the evaluation of erosive potential of snow cover for the Czech Republic territory is an



2: *Map of erosion potential of snow cover for arable land of the Czech Republic*

important input for snowmelt intensity erosion. Snow thawing and connected erosive processes are spatially variable (SUI and KOEHLER, 2001). Snow erosive potential statistically significantly depends on altitude (r = 0.726**, α = 0.01) and also on climatic region (r = 0.790**, α = 0.01).

SUMMARY

The intensity of erosion caused by snow melt can be determined according to the empirical formula (ZACHAR, 1982). Amount of water derived from snow ***h*** and melting rate ***m*** (mm day^{-1}) can be collectively described as the erosion potential of water accumulated in the snow. This paper evaluates the erosion potential of snow cover for a thirty-year period (1980/1981 to 2009/2010). For purposes of the the analysis, data was used from 50 chosen CHMI stations, with regard to their equal representation in different altitudes and different climatic conditions, expressed by climate region (CR) from Estimated Pedological Ecological Unit (EPEU) system.
This data was calculated for the average thirty-year period, which was the basis for mapping expression. The highest erosion potential (197.52) was detected at station Bílá (CR 9, 720 m a.s.l.). Erosion potential of 4.32 was calculated for the station in Olomouc (CR 3, 215 m a.s.l.) with a possible application of the so-called heat island effect of the city. The second lowest erosion potential (4.75) corresponds to station Pohořelice (CR 0, 183 m a.s.l.). The results of the average erosion potential for thirty years were used for surface expression by GIS tools. The results of the average erosion potential for thirty years were used to create the surface expression of a point using GIS tools. Areas with expected incidence of arable land were determined by excluding forests, settlements, land with a slope of 12 ° and areas with an altitude of 700 m.

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