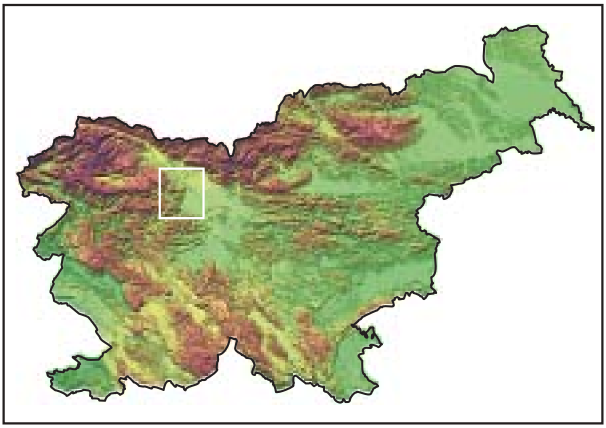
Acta geographica Slovenica, 45-1, 2005, 53–86

SOIL EROSION ON AGRICULTURAL LAND IN SLOVENIA – MEASUREMENTS OF RILL EROSION IN THE BESNICA VALLEY

EROZIJA PRSTI NA KMETIJSKIH ZEMLJIŠČIH V SLOVENIJI – MERITVE ŽLEBIČNE EROZIJE V DOLINI BESNICE

Blaž Komac, Matija Zorn

Soil erosion on a field in the Besnica valley (photograph: Matija Zorn, November 2004).
Erozija prsti na njvi v porečju Besnice (fotografija: Matija Zorn, november 2004).



Soil erosion on agricultural land in Slovenia – measurements of rill erosion in the Besnica valley

UDC: 911.2:631.459(497.4)
COBISS: 1.01

ABSTRACT: The article describes soil erosion in Slovenia. There is little concrete data on soil erosion due to the lack of awareness of this process and the fragmentation of farmland. Long-term measurements of soil erosion have only been done at one location; elsewhere, there have only been short observations and calculations and modeling on the basis of empirical equations. To increase our knowledge of this phenomenon, we took measurements of soil erosion on a field in the Besnica Valley northwest of Kranj.

With the decrease of agricultural land use in Slovenia due to natural, social, and economic factors, the amount of material lost to erosion has decreased in the last few decades.

For protection from erosion, various preventive methods such as terracing, mulching, and contour plowing are employed. The awareness that protection against erosion is a demanding and long-term task is gradually increasing, but nothing can replace the soil that has been lost due to erosion.

KEYWORDS: geomorphology, erosion, soil erosion, Besnica, Slovenia

The article was submitted for publication on May 10, 2005.

ADDRESSES:
Blaž Komac, M. Sc.
Anton Melik Geographical Institute
Scientific Research Centre of the Slovenian Academy of Sciences and Arts
Gosposka ulica 13, SI – 1000 Ljubljana, Slovenia
E-mail: blaz.komac@zrc-sazu.si

Matija Zorn, B. Sc.
Anton Melik Geographical Institute
Scientific Research Centre of the Slovenian Academy of Sciences and Arts
Gosposka ulica 13, SI – 1000 Ljubljana, Slovenia
E-mail: matija.zorn@zrc-sazu.si

Contents

1 Introduction

In this article, we present soil erosion in Slovenia, particularly measurements of erosion taken on a field in the Besnica Valley northwest of Kranj.

The term »soil erosion« denotes a process that affects the soil, the few dozen centimeters thick layer of lithosphere characterized by fertility, the quality that enables the growth of plants. When water runs on the surface and does not permeate into the ground, it can cause erosion (Lovrenčak 1994, 9).

Denudation is the exposure of the surface as a consequence of weathering and the removal or carrying away of material. It usually has a leveling effect on the surface in contrast to erosion, which works linearly through excavation, dissection, and the removal of rock particles or regolith by flowing water, snow, glaciers, and wind. Humans and animals also cause erosion. Denudation occurs on areas with inclinations over 2–3° (Penck 1924, 84), while erosion or the stronger linear removal of material is mainly characteristic of inclinations above 6° (Natek 1983, 66).

Erosion can occur when the intensity of precipitation exceeds the infiltration capacity of the soil and causes the occurrence of surface flow. Erosion depends particularly on the erosive force of the precipitation

Table 1: Types of erosion (Auerswald 1998, 37–38; Hočevar et al. 2000, 14; Geografija 2001, 90–91).

Agents	Type of process	Operation	
water	river (fluvial) erosion	Linear excavation of surface and removal of material by flowing water.	1 *Vertical erosion* acts mainly vertically. 2 *Lateral erosion* acts mainly laterally.
snow	snow (nival) erosion	Removal of material by erosive action of snow.	
ice	glacial erosion	Removal of material by erosive action of glaciers.	
wind	wind (Aeolian) erosion	Removal of material by erosive action of wind.	
sea/lakes	sea/lake erosion or abrasion	Removal of material by erosive action of waves.	
Combination of natural factors and human and animal actions	soil erosion	Any removal of soil particles and regolith by natural agents is accelerated in many places due to human activities (clearcutting, excessive grazing, paths) and animal activity that are more intensive than the development of soil.	1 *Surface wash* is the consequence of splash erosion and sheet erosion that occur before the water unites in rivulets and begins to work vertically. Although this is actually a denudation process, it is considered soil erosion. The process is hard to notice and quantify without constant measurement, and therefore its effects are often underestimated. 2 *Rill erosion* is a form of vertical erosion where water joined in rivulets cuts small erosion rills up to 30 cm deep and several meters long in a hillslope. 3 *Gully erosion* is a form of vertical erosion where the uniting of erosion rills creates erosion gullies that are several meters deep and several dozen meters long. 4 *Piping* occurs due to the flow of water parallel to the hillslope in the regolith. The water removes particles and ever-larger channels or »pipes« develop in the regolith. They normally occur in a less resistant lower layer of regolith under a more stable upper layer.

and the water flow and the resistance of the parent material. It normally occurs in three stages. Particles of soil are first separated from the parent material, then carried to a secondary location by water or other agents, and finally deposited (Lovrenčak 1994, 161–163).

In Slovenia, which has extremely diverse relief, water erosion occurs on large surfaces. Areas with high inclinations on less cemented and less resistant rock are especially vulnerable to erosion.

2 Soil erosion in Slovenia

There is little data available on soil erosion in the past due to the lack of awareness of this process and the fragmentation of farmland. In 1991, the average Slovene farm had 5.9 hectares of land (Kladnik 1998, 197), while in 2000, 61% of family farms were smaller than five hectares (Popis 2000). In addition, in the second half of the 20th century until 1989 (Jesenovec 1995, 221), only one station for measuring erosion was operational in Slovenia, located in the village of Smast near Kobarid. Indirect data on erosion was acquired from measurements of the suspension and bedload transport in the reservoirs of hydroelectric power plants on the Soča, Sava, and Drava rivers and calculations using various models. We assume that erosion was greater in the past than it is today because the proportion of cultivated fields was substantially higher and the proportion of forest lower. In 1896, cultivated fields occupied 18.1% of all land, but only 10.3% in 2000. Forest occupied 41.6% of all land in 1896, and 60.3% in 2000 (Gabrovec and Kladnik 1997, 34; Petek 2004, 107).

With the decrease of agricultural land use in Slovenia due to natural, social, and economic factors, the amount of material lost to erosion has decreased correspondingly in the last few decades. Since the 1960's, industrialization and urbanization have been encroaching upon arable land, completely removing the soil. In the 1970's, about 1,000 hectares of former farmland was converted to new uses every year; in the 1980's, about 500 hectares changed use annually; and after 1990, the conversion of farmland from agricultural to other uses again increased. Between 1993 and 1997, built-up and road areas increased by 4,078 hectares while farmland decreased by 81,092 hectares (Poročilo 2002). The area of farmland further decreased in the last decade due to new expressways.

Intensive agricultural production accelerates erosion by compacting the soil and thus reducing its infiltration capacity, but counters this by covering the land with plants or their remains (mulching). Mulching is the best method of protection since a 30% to 50% cover is enough to provide good protection. Higher plants such as 2.5-meter high corn offer less protection while still higher plants such as six-meter high hop offer almost no protection. There is no plant cover for several months at a time on cultivated land, so it is important that plants germinate before erosive precipitation occurs. In the fall, the soil is protected from erosion by the roots of dead plants and the remains of stalks, which also provide good food for earthworms. In such conditions, these reproduce quickly and by making channels in the soil increase the infiltration capacity of the soil, which reduces the erodibility of the soil (Auerswald 1998, 39–42).

The Law on Agricultural Land (Zakon 1996), which defines measures for the protection of agricultural land, mentions only land improvement, water improvement, and commassation. Although no funds are anticipated in the state budget for protection from erosion, farmers must adapt their agricultural production to local conditions and use appropriate methods to prevent erosion. The law does not prescribe any anti-erosion methods, which farmers in any case are already using. The standard methods employed include the selection of suitable crops, crop rotation, and planting intermediate crops. The erodibility of soil in Slovenia is further reduced by the decreasing cultivation of the ground and grassing over, mulching, and sowing immediately after the harvest. In the coastal hills, belts between different types of crops are grassed, and in eastern Slovenia, drainage ditches are dug to redirect the water. Due to the fragmentation of land parcels, there are frequent boundaries and intermediate belts of grass or brush, which reduce the speed of the water flowing off the surface. In fruit-growing and winegrowing areas, terracing and contour plowing have become the norm and decrease erosion by more than a third. In places, water collectors have been constructed to allow the settling and collection of eroded material. Erodibility is also reduced by the proper use of appropriate mechanization (Lovrenčak 1994, 165; Zupanc et al. 2000, 110; Zupanc and Mikoš 2000, 490–493).

On inclined surfaces, borders up to four meters high where eroded material accumulates form along the lower edges of fields due to strong surface wash and tillage erosion (Natek 1989a, 45). In hilly regions, farmers often used to carry the eroded soil back to their fields in baskets. Prežihov Voranc (1893–1950) vividly described the hard physical labour of mountain farmers in his novel »Passion above the Precipice« (1994, 81–82):

> *The Radmans owned only four strips of fields, and even these were so steep that in the olden days when there were enough people to work them, they used hoes instead of ploughs. But now, they had been ploughing them for years, even though they could not use the ordinary yoke for this kind of work; they needed a special harness, designed for work on sloping ground. The ploughman always needed another man to follow him; his job was to pack down, with his feet and hands, the new furrow, so that it did not tumble down the slope and get lost in the gorge below.*
> *Radman ploughed and planted, but more than that he did not care about his fields; his wife, on the other hand, was faced with all the work that remained to be done. Her job was to move the first furrow after it had been ploughed, from the bottom edge of each field back to its top. All mountain farmers have had to wrestle with this kind of labour since time immemorial; if they did not do it, all their ploughed soil would gradually slide downhill, and they would be left with nothing but dry, rocky ledges.*
> *Since this additional task was particular to the mountain farmers and unknown on the farms situated in the valleys and on more level ground, it was called bondage.*
> *That morning, Radmanca got up early, before dawn; she took her head pad and her basket and attacked the first, largest field. She started at this early hour because the bondage had to be accomplished in addition to all other, regular daily chores. Before the sun poured its light from behind the hills, she had crossed the field already fifty times; she had moved fifty baskets, or over two thousand kilograms of soil. More than two thousand kilograms of soil!*

Similarly, on the ridges and upper parts of hillslopes in the Gabrovško and Šentjanško hills in the Mirna Valley, soil had to be hauled in periodically due to the heavy erosion of cultivated fields (Topole 1998, 25, 29) or carried in baskets from the lower parts of the fields.

According to Vrišer (1953), soil erosion most affects areas composed of young and poorly cemented marl and sandstone sediments in the Pannonian hills and flysch areas in the Mediterranean hills. In past centuries many farms settled at the height of medieval colonization in the 14^{th} and 15^{th} centuries were abandoned due to soil erosion.

Bračič (1967) established that heavy erosion on sloping vineyards in Haloze carried the already modest soil down to the valleys. To protect it as much as possible, they grew various crops between the vines and elsewhere covered the soil with mowed grass. He believes that erosion would be substantially reduced with the introduction of vineyard terraces.

The construction of cultivated terraces in the Koper littoral brought many positive consequences. Water flowing off the hillslopes during rain slows down on the terraces and no longer carries away fertile soil (Titl 1965). However, there are also examples where cultivated fields on terraces were abandoned due to erosion (Valenčič 1970, 145).

Soil erosion in karst areas is unique. While few farmers are aware of how intensively the soil is washed away into the underground, most of them know that rocks »grow« on karst ground. On steep hillslopes, surface wash during downpours is an additional factor, and therefore abandoned vineyards in places look like rocky deserts. Soil erosion on karst surfaces is established indirectly. Numerous rocks protruding on the surface still show signs that their tops were truncated. If they were truncated in a meadow, the height of the rock above the ground shows the extent of soil erosion; if the rocks were truncated on a cultivated field, it is necessary to add as many centimeters as deep the rock was truncated below the surface.

Furthermore, compact limestone has a smooth surface due to subsoil corrosion at the contact with soil, while rock that has always protruded from the ground is fissured and has a rough surface. A trained eye can distinguish whether the surface of the rock developed in the soil or above it, even though decades have passed since the lowering of the soil. On flat meadows, rocks usually protrude 20 to 30 centimeters from the soil, and this is the effect of erosion. In vineyards, the erosion is usually much greater (Hrvatin et al. 2006). Gams (1974) offers the hypothesis that erosion was rapid immediately after the clearing of forests and the first plowing and later gradually slowed down.

How rapidly soil erosion occurs is a controversial question. Hrovat (1953), who described erosion in the cultivated fields and vineyards of southeastern Slovenia in detail, established that the soil lowers one centimeter per year on average. Hrovat's estimate of the intensity of soil erosion is quite exaggerated and probably applies only to areas most vulnerable to erosion.

In the Slovene literature, there is varying data regarding the total surface area of erosion areas. The most frequently given figures are 42% to 44% of Slovenia's territory or 880,000 to 900,000 hectares (Zemljič 1972, 234; Kolbezen 1979, 73; Horvat 2002, 268). Another source states that erosion occurs on 95% of Slovenia's territory (Lazarević 1981, 9). Every year, Slovenia loses about thirteen square kilometers of fertile soil twenty centimeters thick (Rainer and Zemljič 1975).

Torrential erosion at 370 erosion foci and 700 torrents threaten almost one fifth or 400,000 hectares of Slovenia (Rainer and Pintar 1972, 23; Zemljič 1972, 234). Sensitive areas include alpine dolomite mountains (Kunaver 1990) and hills (Komac 2003b) and low hill and hilly areas on less resistant noncarbonate bedrock. At an erosion focus in the Polhov Gradec hills on a dolomite surface with an inclination of 42° (Komac 2003a, 75), a release of 175 t/ha/year of material was measured (Komac 2003b, 31; Komac and Gabrovec 2004, 196).

In the anthropogenetically degraded area due to lead pollution of the Meža Valley in the Eastern Karavanke Mountains, the vegetation was completely destroyed. During the operation of the mine's separator, the average annual erosion in the 0.5 km^2 dolomite area was 83 t/ha. In the mountainous world of the Western Karavanke Mountains, the specific erosion totals 48 t/ha annually, and on the Soča River side of the Julian Alps it is 45 t/ha annually. On average, 2.5 million m^3 of material or 10 t/ha annually is released in the erosion areas of the mountain world (Zemljič 1972, 234).

Estimates of the material released over all of Slovenia range between five and six million cubic meters annually (Rainer and Pintar 1972, 23; Kolbezen 1979, 73) or between 5,200,000 and 5,300,000 cubic meters annually (Zemljič 1972, 234; Rainer and Zemljič 1975, 98; Horvat 1987, 36; Horvat and Zemljič 1991, 3; Horvat 2002, 268). Specific erosion averages about 4.2 t/ha annually. Some researchers give lower estimates of the eroded material release, for example Lazarević (1981, 9) with 3,960,200 m^3 annually or about 3.1 t/ha annually. On the basis of a simple model based on published data on erosion relative to land use categories (Table 2), we established that the quantity of released material in Slovenia totals 3,924,002–5,722,895 m^3 annually (Table 3).

One half to three fifths of the released material settles on hillslopes, screes, and fans and in erosion and torrent ravines. The remaining material reaches streams and rivers, but almost a quarter stops in the upper parts of catchment areas. Due to the deposit of material, the bottoms of riverbeds constantly rise, gravel beds widen at the expense of other land, and the flood threat increases (Zemljič 1972, 234–236; Horvat 1987, 37; Natek 1989b, 58). Data on the sediment yield according to water basins indicates that about 15.2 t/ha of material is deposited in rivers and streams each year in the Soča River region, about 6.3 t/ha annually in the Sava River catchment, about 5.6 t/ha annually in the Drava River catchment, and about 2.6 t/ha annually in the Kolpa River catchment. In the coastal hills, about 6.4 t/ha of material is deposited annually in rivers and streams (Zemljič et al. 1970).

On average 5 t/ha of soil is eroded annually on Earth (Myers 1991, 41).

2.1 Measurements of soil erosion in Slovenia

Longer-term measurements of soil erosion on agricultural land have been made only on a measuring field in Smast near Kobarid, while elsewhere only shorter observations (Straža near Novo mesto, Limbuš near Maribor) and calculations and modeling on the basis of empirical equations have been done (Latkova vas in the Savinja Valley, the Dragonja Valley, and the Mirna Valley).

Near the village of Smast, where the average annual precipitation is approximately 1,700 mm (Klimatografija 1995, 99), the erosion was 6.3 kg/ha annually measured on a surface with a 29° inclination in a mixed forest, 39 kg/ha annually on a meadow, 3.5 t/ha annually on a potato field, and 22.4 t/ha annually on a plowed field (Horvat and Zemljič 1998, 422).

Ravbar (1975, 15) performed two erosion measurements on karst clay in the vicinity of Straža near Novo mesto. The inclination of the surface was 16–18°. He observed the removal of soil when 36 mm of precipitation fell and during an extreme downpour when there was 107 mm of precipitation. In the first event, 290 grams (0.56 t/ha) of material was released, and in the second event, 1,160 grams of material (2.5 t/ha). Using this data on soil erosion and the average annual precipitation of 1,138 mm for this area (Klimatografija 1995, 186), we calculated the average annual soil erosion to be 22 t/ha. The anticipated extreme daily precipitation with a one-year return period in this area is 47 mm (Povratne 2004, 36).

Soil erosion was measured at the Meranovo estate in Limbuš near Maribor in a vineyard with the inclination of the surface 14.9°. Average yearly soil erosion on permanent grass-covered surface was 156 kg/ha and 10.76 t/ha on short-time grass-covered surface (Vršič et al. 2000, 113). The average annual precipitation for this area is 1,046 mm (Klimatografija 1995, 152). The anticipated extreme daily precipitation with a one-year return period in this area is 45 mm (Povratne 2004, 29).

Calculations using the GLEAMS 2.1 mathematical model show that erosion in Latkova vas amounts to 5 t/ha/year on a hop plantation with an inclination of 0.18° (Zupanc et al. 2000, 109). The average annual precipitation in this area is approximately 1,300 mm (Klimatografija 1995, 60), while the anticipated extreme daily precipitation with a one-year return period is 49 mm (Povratne 2004, 5). In spite of the low inclination of the surface, hop growing, which is the characteristic culture of the Celje basin, presents a relatively high threat of soil erosion.

Erosion was also modeled in the Dragonja and Rokava watersheds (Paulič 1971; Globevnik 2001; Petkovšek 2002; Staut 2004), where the average annual precipitation is 1,017 mm (Klimatografija 1995, 47). According to Gavrilović's method, the calculated annual erosion is 22 t/ha in vineyards and 11 t/ha on cultivated fields, and according to the RUSLE (Revised Universal Soil Loss Equation) method, 51 t/ha annually in vineyards and 22 t/ha annually on cultivated fields (Petkovšek 2002, 141–142). The anticipated extreme daily precipitation with a one-year return period in this area is 44 mm (Povratne 2004, 41).

On the basis of data on the annual material transport in the streams of eastern and southeastern Pohorje, Kolbezen (1979, 81) concluded that the average erosion totals 2.4 t/ha. In this area, the average annual precipitation is 1,100 mm (Klimatografija 1995, 53).

Calculations based on the USLE (Universal Soil Loss Equation) method for the Mirna Valley show that erosion was lower than 35 t/ha annually on more than half of the area studied and more than 75 t/ha annually on just under a fifth of the area. The annual average erosion in the Mirna watershed is approximately 6.4 t/ha. Due to the less resistant rock, the low hills in the Mirna Valley are more vulnerable to erosion than the hills, in spite of the small height differences (Topole 1998, 83–84). The average annual precipitation in this area is approximately 1,190 mm (Klimatografija 1995, 92).

Mikoš and Zupanc (2000, 419) state that every year Slovenia loses an average of 5 to 10 mm of »*fertile soil*« on »*agricultural surfaces*« due to erosion. The specific erosion calculated from this data totals 80–100 t/ha/year. Given the other available data on soil erosion (Table 2), this figure is probably too high.

Table 2: Erosion in Slovenia according to land use categories and erosion in selected watersheds. Most of the data is based on empirical models that characteristically overestimate erosion in areas where it is low and underestimate it in areas where it is high (Nearing 1998, 15). Surface areas of land use categories are taken from the *Map of Land Use* (Raba 2002) and Hrvatin and Perko (2003, 84).

Surfaces (method, area)	Surface relative to entire territory of Slovenia (%)	Specific erosion (t/ha/year)	Erosion lowering of the surface (mm)	Referrences
Slovenia	100.00	3.13	0.20	Lazarević 1981, 9
Slovenia	100.00	4.18	0.26	Zemljič 1972, 234; Rainer and Zemljič 1975, 98; Horvat 1987, 36; Horvat and Zemljič 1991, 3; Horvat 2002, 268
Slovenia	100.00	3.70–4.52	0.23–0.28	Komac and Zorn 2005, in this article
Vineyard (RUSLE, part of Rokava watershed)	0.002	51.31	3.21	Petkovšek 2002, 134, 141
Vineyard (Gavrilović, part of Rokava watershed)	0.002	22.12	1.38	Petkovšek 2002, 134, 141
Vineyard (measurement, Straža near Novo mesto)	0.00001	22.00	1.38	Ravbar 1975, 15
Vineyard (measurement, Limbuš near Maribor)	0.00001	0.16–10.76	0.01–0.67	Vršič et al. 2000, 113
Meadow (RUSLE, part of Rokava watershed)	0.006	4.80	0.30	Petkovšek 2002, 134, 141
Meadow (Gavrilović, part of Rokava watershed)	0.006	4.67	0.29	Petkovšek 2002, 134, 141
Meadow (measurement, Smast near Kobarid)	0.00001	0.04	0.03	Horvat and Zemljič 1998, 422
Orchard (RUSLE, part of Rokava watershed)	0.0007	20.88	1.31	Petkovšek 2002, 134, 141
Orchard (Gavrilović, part of Rokava watershed)	0.0007	4.77	0.30	Petkovšek 2002,134, 141
Pasture (RUSLE, part of Rokava watershed)	0.01	3.39	0.21	Petkovšek 2002, 134, 141
Pasture (Gavrilović, part of Rokava watershed)	0.01	1.89	0.12	Petkovšek 2002, 134, 141
Field, plowed and stubbly (measurement, Zgornja Besnica)	0.00000005	36.00	2.25	Komac and Zorn 2005, in this article
Field, plowed (measurement, Smast near Kobarid)	0.00001	22.40	1.40	Horvat and Zemljič 1998, 422
Field, covered with potato (measurement, Smast near Kobarid)	0.00001	3.47	0.22	Horvat and Zemljič 1998, 422
Field (RUSLE, part of Rokava watershed)	0.01	21.60	1.35	Petkovšek 2002, 134, 141
Field (Gavrilović, part of Rokava watershed)	0.01	10.94	0.68	Petkovšek 2002, 134, 141
Hop plantation (GLEAMS 2.1; K = 0.2; Latkova vas; 1997)	0.00001	4.22	0.26	Zupanc et al. 2000, 109
Hop plantation (GLEAMS 2.1; K = 0.2; Latkova vas; 1998)	0.00001	1.16	0.07	Zupanc et al. 2000, 109
Agricultural land (calculation, Slovenia)*	10.56	80.00–160.00	5.00–10.00	Mikoš and Zupanc 2000, 419
Forest (RUSLE, part of Rokava watershed)	0.006	2.55	0.16	Petkovšek 2002, 134, 141
Forest (Gavrilović, part of Rokava watershed)	0.006	0.46	0.03	Petkovšek 2002, 134, 141
Forest, mixed (measurement, Smast near Kobarid)	0.00001	0.006	0.0004	Horvat and Zemljič 1998, 422
Erosion areas, dolomite (measurement, Polhograjsko Hills)	0.0003	175.0	10.94	Komac 2003b, 31; Komac and Gabrovec 2004; 196
Erosion areas, dolomite (Meža Valley)	0.002	83.20	5.20	Horvat and Zemljič 1998, 414
Erosion areas (Western Karavanke Mountains)	0.01	48.00	3.00	Zemljič 1972, 234; Rainer and Zemljič 1975, 98
Erosion areas (Soča Valley above Tolmin)	0.36	44.80	2.80	Zemljič 1972, 234; Rainer and Zemljič 1975, 98
Erosion areas (calculation, mountain and high-mountain areas of Slovenia)	1.88	9.92	0.62	Zemljič 1972, 234; Rainer and Pintar 1972, 23; Rainer and Zemljič 1975, 98; Horvat 1987, 36; Horvat and Zemljič 1991, 3; Kolbezen 1979, 73; Horvat 2002, 268
Dragonja watershed (Gavrilović, 1955)	0.44	2.96	0.19	Staut 2004, 112
Dragonja watershed (Gavrilović, 1971)	0.44	4.53	0.28	Globevnik 2001, 114 (PUH 1971)
Dragonja watershed (Gavrilović, 1971)	0.44	4.79	0.30	Globevnik et al. 2003, 5
Dragonja watershed (Gavrilović, 1971)	0.44	4.54	0.28	Staut 2004, 112
Dragonja watershed (Gavrilović, 1995)	0.44	1.85	0.12	Globevnik 2001, 115
Dragonja watershed (Gavrilović, 1995)	0.44	1.89	0.12	Globevnik et al. 2003, 5
Dragonja watershed (Gavrilović, 1995)	0.44	1.85	0.12	Staut 2004, 112
Dragonja watershed (Gavrilović, 2003)	0.44	1.14	0.07	Staut 2004, 112
Pivka watershed, flysch areas (measurement)	0.24	0.25	0.02	Kranjc 1982, 15
Pivka watershed, karst areas (measurement)	0,55	0.15	0.01	Kranjc 1982, 15
Mirna Valley (USLE)	1.45	6.41	0.40	Topole 1998, 83
Predelica watershed (adapted Gavrilović equation)	0.04	15.41	0.96	Mikoš et al. 2002, 324
Koritnica watershed (adapted Gavrilović equation)	0.43	23.86	1.49	Mikoš et al. 2002, 324

* Value is not considered in graphic presentations due to the large deviation from other data (Figure 1, Figure 2, Figure 10).

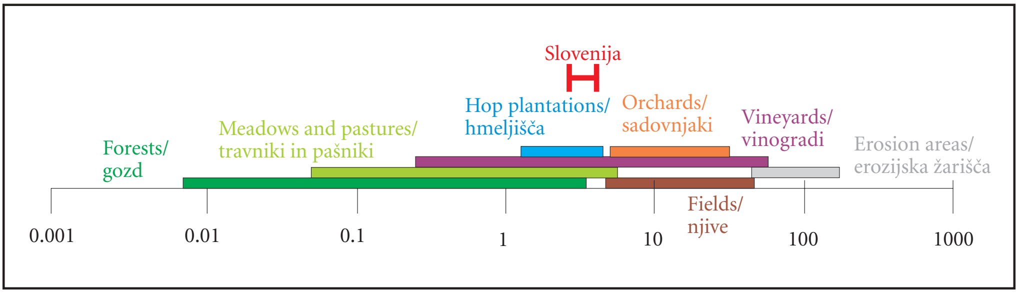


Figure 1: Erosion according to land use categories in Slovenia in t/ha/year (according to data and sources shown in Table 2).

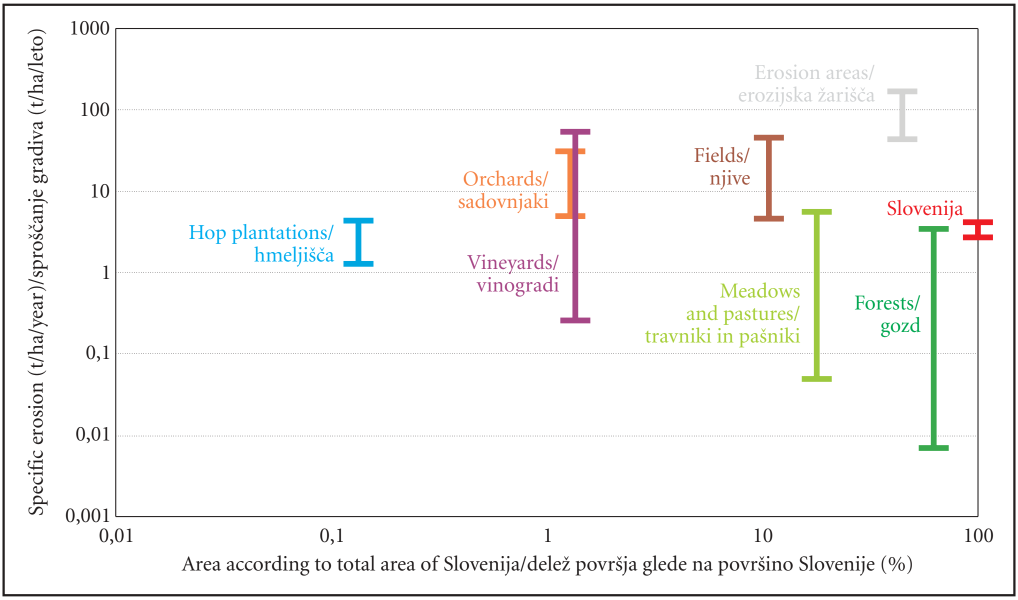


Figure 2: Erosion according to land use categories in Slovenia relative to the proportion of their surface area in comparison with the total surface area of Slovenia (according to data and sources shown in Table 2).

Table 3: Erosion, specific erosion and erosion lowering of surface according to lands use categories in Slovenia (sources for land use data: Raba 2002; Hrvatin and Perko 2003, 84; source for erosion data: Table 2).

Land use categories	Erosion (t/year)	Specific erosion (t/ha/year)	Erosion lowering of surface (mm)	Erosion (t/year)	Specific erosion (t/ha/year)	Erosion lowering of surface (mm)
		slope 2–90°			slope 0–90°	
Cultivated fields	1,464,156.86	0.86	0.05	3,918,386.92	1.93	0.12
Barren and high-mountain areas	2,211,748.99	1.30	0.08	2,232,884.86	1.10	0.07
Grasslands (meadows and pastures)	1,343,734.42	0.79	0.05	1,642,895.78	0.81	0.05
Vineyards	437,215.59	0.62	0.02	462,838.74	0.23	0.01
Forest and overgrown surfaces	537,825.96	0.32	0.02	573,335.72	0.28	0.02
Orchards	283,234.28	0.17	0.01	319,561.62	0.16	0.01
Hop plantations	487.06	0.0003	0.00002	6,728.19	0.003	0.0002
Total	6,278,403.16	3.70	0.23	9,156,631.84	4.52	0.28
Average	784,800.40	0.46	0.03	1,144,578.98	0.56	0.04

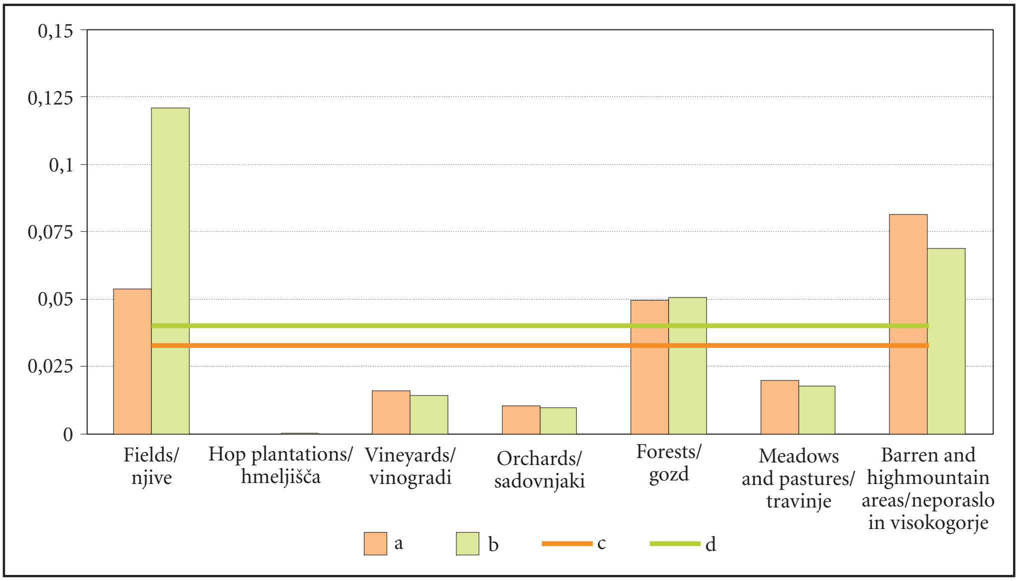


Figure 3: Erosion (mm/year) according to land use categories in Slovenia (according to data in Table 3).
a – erosion lowering of surface in areas with slope 2–90°.
b – erosion lowering of surface in areas with slope 0–90°.
c – average of erosion lowering of surface in areas with slope 2–90°.
d – average of erosion lowering of surface in areas with slope 0–90°.

The data from measurements and calculations with models indicate that in Slovenia erosion presents the greatest threat to cultivated fields, from which it annually removes or transfers to lower positions 0.92–2.45 million m^3 of soil. About 0.34–0.36 million m^3 of material is released from forest areas, about 0.27–0.29 million m^3 of material from vineyards, and from meadows and pastures 0.84–1.03 million m^3. Soil erosion in orchards encompasses approximately 0.18–0.20 million m^3 annually, while approximately 1.38–1.40 million m^3 of material is released annually on barren and high-mountain areas. In total, approximately 3,924,002–5,722,895 m^3 of material is released in Slovenia (the data were calculated from table 3 with conversion factor 1.6; Horvat and Zemljič 1998, 422).

In the model, we partly considered the inclination of the surface. At this stage of becoming familiar with the phenomena in Slovenia it is difficult to consider its real influence. The importance of soil erosion on cultivated fields decreases if inclination is considered since more than half (54%) of our cultivated fields lie on land with inclinations less than 2°, where according to Natek (1983, 66) the removal of material is relatively weak, and just under a third (29%) of cultivated fields lie on land with inclinations higher than 6°, where the removal of material is strong. The importance of soil erosion in forests is significant since some 85% of the forests lie on land with inclinations over 6° (66% on land with inclinations greater than 12°), and only 6% of the forests lie on land with inclinations less than 2°. The same applies to meadows since 62% of the meadows lie on land with inclinations greater than 6° (36% on land with inclinations greater than 12°) (Podobnikar et al. 2000; Raba 2002).

3 Soil erosion in the Besnica Valley

The Besnica River is a right tributary of the Sava River and flows into it a few kilometers above Kranj. Its watershed covers 15.5 km^2 and extends from 357 meters to 941 meters above sea level. It is important for hillslope processes that 80% of the watershed has inclinations of more than 6°, 70% of more than 12°, and 44% of more than 20°. Rockfalls are possible on just under 8% of the watershed which has inclinations greater than 32°. Flat land with inclinations of less than 2° comprises only about 3% of the watershed.

More than a third of the watershed is composed of various limestones and dolomites, and a third of keratophyres and porphyres. There are also some pseudozilian beds and stream deposits, and a fifth of the watershed is composed of fluvioglacial conglomerate (Grad and Ferjančič 1974).

Dystric brown soil dominates on noncarbonate rock, brown soil and rendzina alternate on limestone and dolomite, and on conglomerate there is leached soil (Pedološka 2002).

Forest covers more than 80% of the watershed, meadows occupy 10% of the watershed, and cultivated fields and gardens occupy 3.5% of the watershed (Raba 2002).

The Besnica River was named for its torrential character because it »rages« (the verb »*besneti*« in Slovene) during periods of high water (Grebenc 1991, 21). The name of the nearby Nemiljščica River is similarly linked to the word *nemil* (»pitiless, cruel«), reflecting the periodic ruthless nature of the torrential Nemiljščica (Bezlaj 1961, 50). The Josephian Military Maps from the second half of the 18th century record the torrential character of the streams in this area, stating that »*strong surface wash by streams*« occurs in rainy weather and specifically mentioning that the »*roads toward Besnica and into the hills*« are in »*poor condition*« due to »*heavy erosion*« by streams in rainy weather (Rajšp and Serše 1998, 111).

Up to now monitoring of suspended material in streams and rivers has not been done in the Besnica Valley, nor have measurements of erosion been made. We can therefore only infer its intensity on the basis of

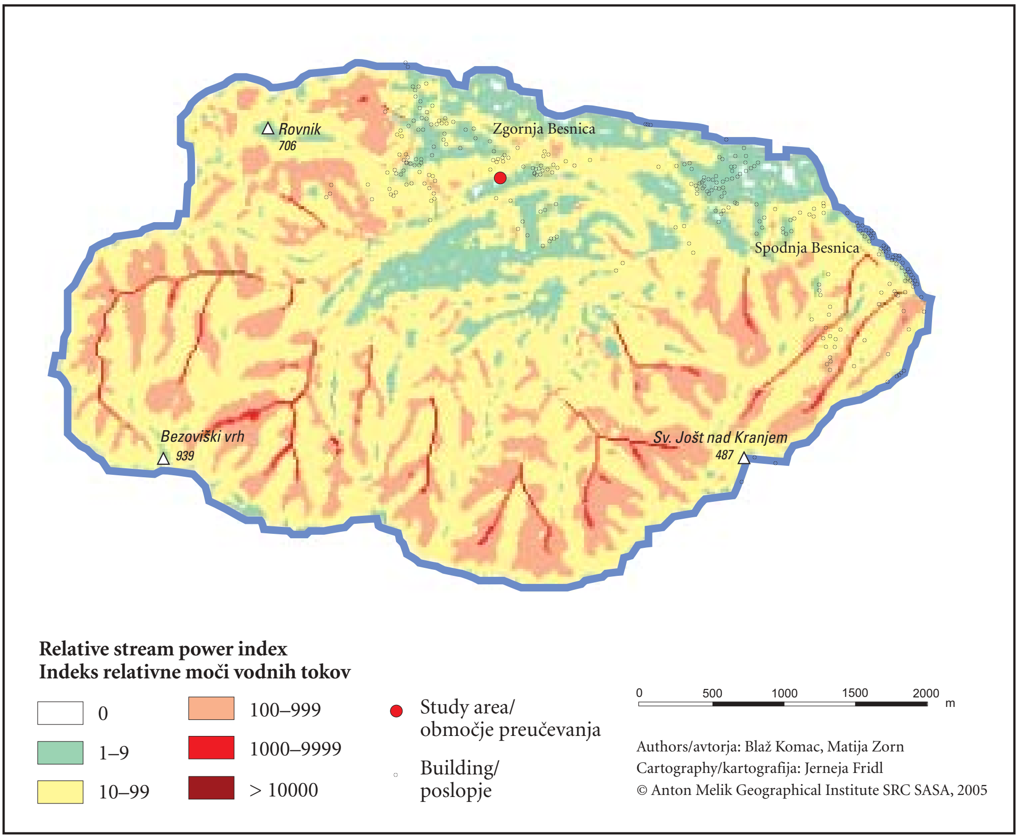


Figure 4: Watershed of the Besnica River with settlements, measurement point and the erosive power of surface waters calculated using the relative stream power index (Wilson and Gallant 2000, 8) on the basis of a 20 × 20 meter digital elevation model. The figure illustrates where the greatest water erosion can be expected in the watershed.

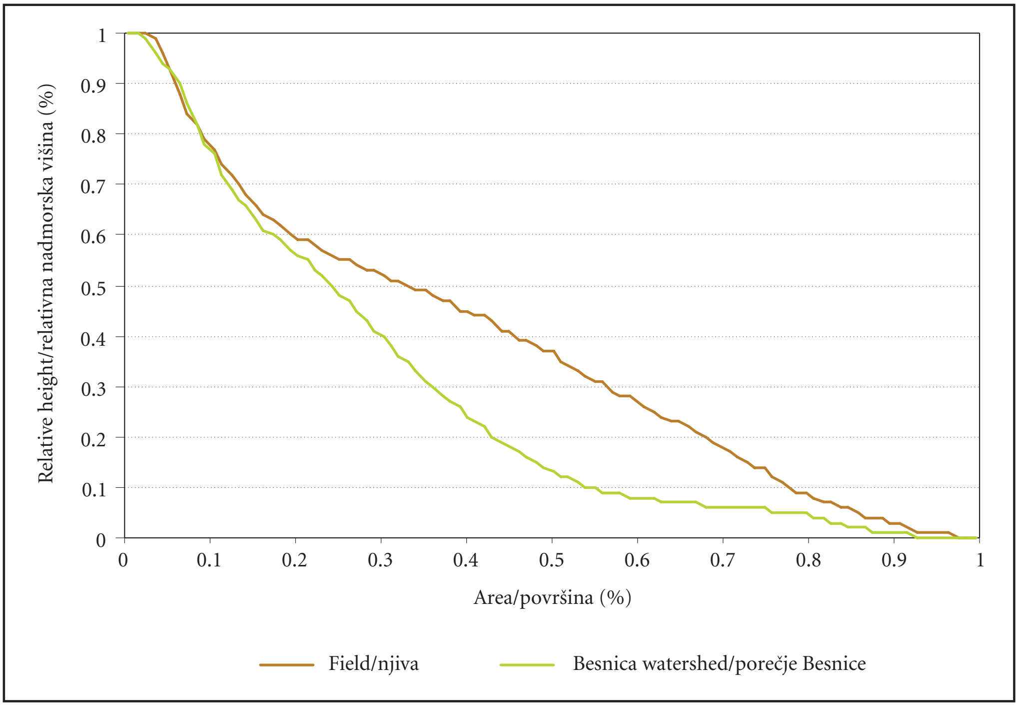


Figure 5: A hypsometric integral is calculated with the help of the hypsometric curve that illustrates the proportion of the watershed lying at specific altitudes. The hypsometric curves for the area of measurements (chapter 3.1) and the Besnica watershed are shown.

Figure 6: Aerial photograph of the Zgornja Besnica village with the area studied (Source: Ortofoto, © Geodetska uprava republike Slovenije 2000).

geomorphic forms and using morphometric analyses. One such analysis is the calculation of the hypsometric integral, which according to Strahler (1952) illustrates the degree of geomorphic development of the watershed and shows what proportion of the area is not yet eroded. Higher values indicate that a large proportion of the original surface has not yet been removed (Ritter et al. 1995, 155). The hypsometric integral for the entire Besnica watershed is 27.83%, and for the area of measurements on the field described in chapter 3.1, 37.63%.

3.1 Results of Measurements

We measured soil erosion on a plowed field located on a fluvio-periglacial terrace, above which is a karstified terrace of the Günz age (Šifrer 1969) with the settlement of Zgornja Besnica. The location of the centroid of the measured plane is defined in the Gauss-Krüger coordinate system by coordinates 5444870 and 5124245 and the altitude of 422.5 meters.

Sliding occurs on the 18-meter-high hillslope of the Günz terrace, probably linked to the periodic springs on the lower edge of the hillslope. There are thirteen such springs in the immediate vicinity of the studied area.

From one of the springs, water runs toward the Besnica across a meadow. The gully ends in a small basin above the field where water collects during downpours.

On the conglomerate terrace where the study field is located, luvisol dominates (Pedološka 2002), while at lower sites along the Besnica River, gleyed riverine soil occurs on clayey river sediment.

Figure 7: In the upper part of the field, which was not plowed and where lower parts of corn stalks and roots remained in the soil, the flow of water created barely visible rill (photograph: Matija Zorn, October 17, 2004).

Figure 8: In the lower plowed part of the field, the flow of water carved a rill 7.6 meters long, 15 centimeters to one meter wide, and 1.7 to 26 centimeters deep (photograph: Matija Zorn, October 17, 2004).

According to the international texture classification (Lovrenčak 1994, 20), the soil on the study field is clayey loam. It contains 5.5% $CaCO_3$ and 12.7% organic material and has a pH of 6.2. The soil is composed of 17.3% coarse sand, 20.1% fine sand, 27.2% silt, and 17.4% clay (analysis by the Physical geography laboratory of the Department of Geography of the University of Ljubljana, Simona Lukič, December 1, 2004).

In the last few years, corn and winter wheat have been grown on the field. In the upper part of the field, the corn had been reaped before our measurements were taken, but the lower parts of corn stalks and the roots remained in the soil (Figure 7). The lower part of the field had been plowed and sown with winter wheat (Figure 8).

During the October 2004 rains, differential erosion occurred due to varying resistance of the parent material. From the basin above the field, the water first flowed onto the stubbly corn field where it created a shallow, barely visible depression. At the contact with the newly-plowed surface, heavier erosion occurred. The depression narrowed and deepened into a rill. When the farmer cleared the field of previous vegetation and sowed the new crop, the resistance and infiltration capacity of the soil was greatly decreased. The water flow and its erosive power increased, creating erosion rill in the lower part of the field with newly-sown winter wheat. The downcutting occurred quickly, largely due to the undercutting of the headwater of the erosion rill where the lower, less resistant layer of the soil was exposed to the activity of the water (Ritter et al. 1995, 146–148).

On agricultural land where downcutting occurs to the depth of cultivation (30 cm), the consequences of erosion can be removed by plowing, which is why the expression »ephemerical rill erosion« can be used. Such erosion is frequent on concave hillslopes where there is an influx of water. Its effects are first visible in the form of a sequence of almost parallel erosion rills running down the hillslope. In sandy soil, the rills are about one meter apart. Surface wash (interrill erosion; Petkovšek 2000, 43) occurs on the surface between them. Erosion rills occur due to small initial variations in the resistance and formation of the surface and the water outflow, which causes the water to flow only to certain areas. As the streams of water join, the erosive power of the water increases and the erosion accelerates. This positive-return process leads to ever deeper erosion rills. Finally, a network of erosion rills can occur on a hillslope that in favourable conditions develop into an erosion gully (Ritter et al. 1995, 146–148; Auerswald 1998, 37–38).

The soil loss measurements are traditionally based on estimations from runoff plots, but these measurements overlook losses by ephemerial rill/gully erosion, that are far from negligible and may comprise 44–80% of the total soil lost (Martínez-Casanovas et al. 2002, 126).

We determined the extent of erosion in the study area indirectly using morphometric measurements. We first measured the inclinations of the surface in the area of the erosion rill, and then measured its length, width, and depth in detail.

We measured the inclinations using a 1.5-meter long pantometer and elaborated a grid of 576 or 16×36 cells (1269 m^2; 24×54 m). From the measured inclinations, we calculated the relative height differences between individual points and elaborated a digital elevation model, which due to the size of the basic cell (1.5 m $\times$ 1.5 m) allowed a quantitative analysis of the surface. A similar methodology was used in Catalonia during soil erosion measurement in vineyards after an extreme rainfall event (Martínez-Casanovas et al. 2002, 128–132). The average inclination of the field's surface is 2.6° and is higher on the stubbly field in the upper part (3°) than on the lower plowed section (1°).

During the October 2004 rains, a 7.6 m long, 0.15–1 m wide, and 2–26 cm deep erosion rill developed on the field. Its average width was 55 cm, and average depth 9 cm. The rill was oriented southeast (130°), while its individual sections were oriented from northeast (65°) to south-southwest (205°). The total volume of erosion rill was 1.7 m^3. The evaluation of the digital elevation model showed that the rill developed in a larger depression.

An important question is how much erosive precipitation can be anticipated annually. According to Auerswald (1998, 38), Central Europe has about fifteen major precipitation events annually that enable the occurrence of erosion phenomena. To this we must add the period of melting snow, which also causes erosion. In addition, even larger precipitation events that cause erosion of greater dimensions occur on average less than once a year. In spite of their rarity, these usually contribute greatly to erosion.

In Zgornja Besnica, the average annual precipitation is 1,588 mm, with 138 mm falling in October. The highest measured October precipitation was 448 mm (Klimatografija 1995, 350). The calculated maximum 24-hour precipitation with a hundred-year return period in this area is 150–200 mm (Maksimalne 1995).

In October 2004, 311.4 mm of precipitation was measured in Zgornja Besnica, which is 2.4 times more than long-term monthly average. The average daily intensity of October 2004 precipitation was 26 mm. It has been determined that precipitation with an intensity above 25 mm can cause visible erosive effects on the surface (Kolbezen 1979, 75).

Table 4: Minimum, average, and maximum number of days with precipitation above 30 mm, above 40 mm, above 50 mm, and above 70 mm in the 1961–2002 period for 177 Slovene meteorological stations (Buh 2004, 53, 56, 60, 63, 67).

Daily precipitation	Number of precipitation days		
mm	Minimum	Average	Maximum
30	2.7	12.6	31.8
40	0.8	7.0	23.7
50	0.3	4.1	18.6
70	0.0	1.3	10.2

Two precipitation periods during which a total of 195.6 mm of rain fell are significant for the development of the erosion rill that we measured. In the first two-day period (October 10–11, 2004), 118.2 mm of precipitation fell with an average daily intensity of 59 mm. In the second five-day period (October 14–18, 2004), another 77.4 mm of precipitation fell with an average daily intensity of 19.35 mm and with an average 24-hour intensity of precipitation for the two wettest days of 34.1 mm.

On October 11, 2004, the daily precipitation climax measured in Zgornja Besnica totaled 63.1 mm of precipitation. This intensive daily precipitation has a one-year return period (Povratne 2004, 23).

The erosion rill on the plowed field in the valley of the Besnica River began to develop on October 10 or 11, 2004, since heavy erosion can occur with an intensity of precipitation above 40 mm/day (Kolbezen 1979, 75).

The large depression in which the erosion rill developed occupies 31.5 m^3 and developed through numerous repetitions of events that cause erosion like those in October 2004. It lies on the part of the field where during heavy rains, water from the Günz terrace (Šifrer 1969) sixty meters away flows in after crossing a meadow. The depression is almost nineteen times larger that the erosion rill, so its development would therefore require at least nineteen similar events that over an unknown time span would have transferred approximately 0.09 m^3/m^2 of material to lower positions.

Plants normally begin to grow at the end of February or at the beginning of March when temperatures reach the spring vegetation threshold of 5° C (Žust 2004, 33). Agricultural plants that with the exception of winter varieties are sown at the end of April or at the beginning of May when soil temperatures reach 8–10° C (Zrmec and Matajc 2004, 48) protect the soil from erosion only when their roots have branched out sufficiently and their aboveground parts are full enough. In Slovenia, this is usually between June and August or September, and the anti-erosion role of plants depends on the location and type of the plants. Corn is usually sown with a density of eight plants per square meter (Bavec 2002, 4).

In an average year, snow falls in the Besnica Valley from November to April. On average, a snow blanket covers the surface for one sixth of November, half of December, three quarters of January, two thirds of February, two fifths of March, and one seventeenth of April (Klimatografija 2000, 373). Snow covers the ground for 75 days on average between November and April, while plants cover the surface between June and September. The surface is therefore exposed to erosion for about 5.5 months when it is not covered by snow and not protected by plants.

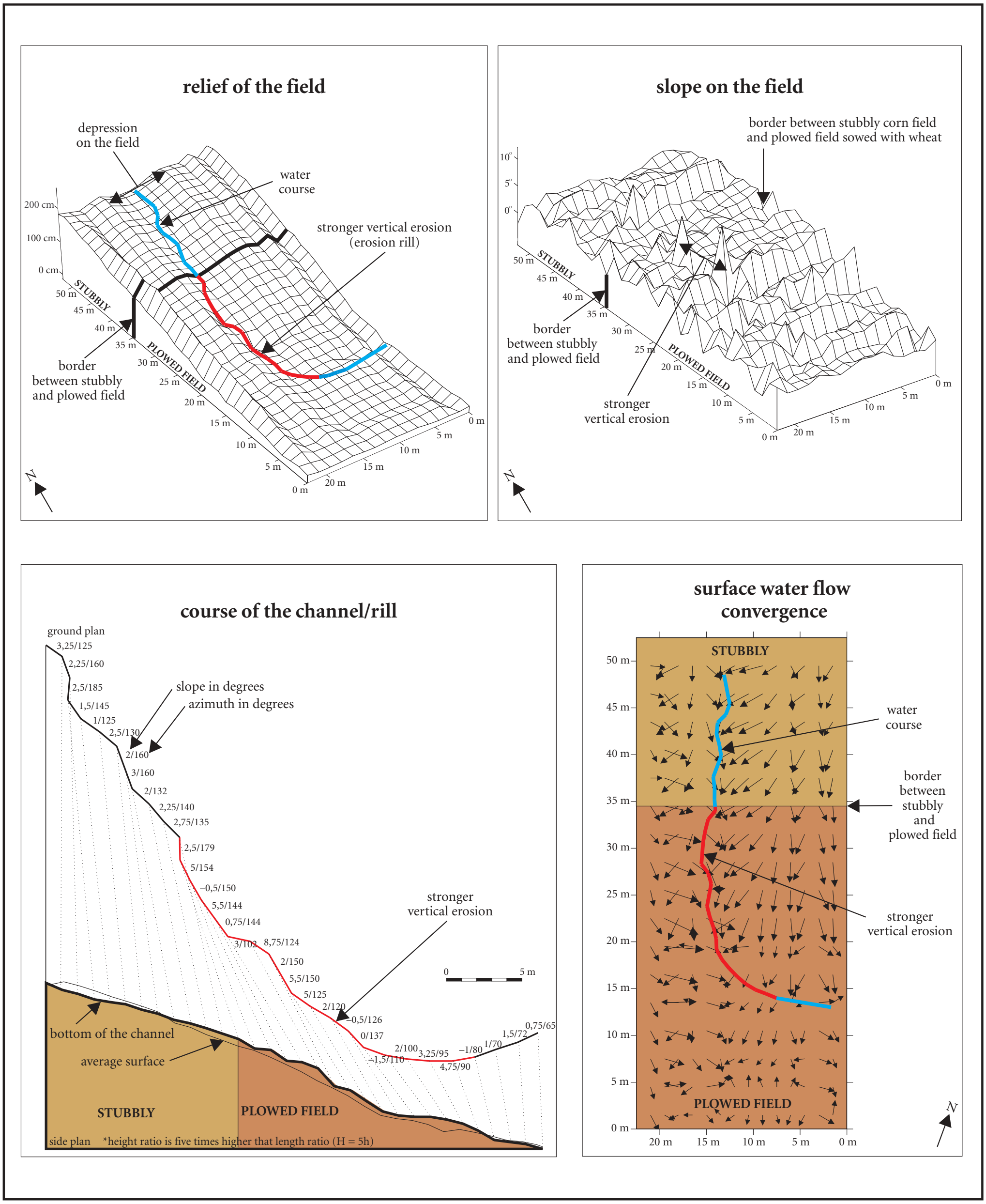


Figure 9: Presentation of the relief (top left) and inclinations (top right) of the study field with base cells of 1.5 m × 1.5 m and the cross-section (bottom left) and ground plan (bottom right) of an erosion rill in the Besnica Valley.

This exposure is greatest in April and May when the snow cover is gone and the plants do not yet protect the soil, and in October when the farm land is no longer covered by plants and not yet by snow. While the wettest month in Zgornja Besnica is November, the maximum daily precipitations fall most frequently in October during the period of greatest vulnerability of the soil.

In the fall of 2004, the field was exposed to erosion only in October, since this was the only period when there was no vegetation or stubble on it. The field was plowed anew in October and wheat was sown, which in November was already high enough to partly protect the soil and prevent the development of new erosion rills.

Strong erosive rains such as those on October 11 and 12, 2004, occur in the valley of the Besnica River with a one-year-return period. Because the period when the soil is exposed to erosion is usually shortened by plant growth and snow, we can expect about one erosive event every two years. The frequency of the occurrence of erosion may possibly be lower since although intensive precipitation sometimes occurs year after year or even several times a year, it sometimes occurs only after longer intervening periods (Kolbezen 1979, 81).

Based on these assumptions, the specific erosion on the study field in the Besnica watershed totals approximately 36 t/ha/year, with the surface lowered due to erosion by 2.6 mm/year (Table 5).

Table 5: Number of erosive precipitation events annually in Zgornja Besnica, specific erosion caused by precipitation (t/ha/year), and the lowering of the surface by erosion (mm/year).

Frequency of erosion events (return period in years)	Specific erosion (t/ha/year)	Lowering of surface by erosion (mm/year)
1.0	77.9	5.6
2.2*	36.0	2.6
3.0	25.7	1.8
5.0	15.0	1.1

*We assumed that erosive precipitation has an approximately two-year return period, but it is possible that erosive precipitation occurs less frequently. The table also shows the calculated soil erosion for precipitation with three- and five-year return periods.

The calculated values are high because the measurements were carried out after a major erosion event. From the literature we recognize the influence of the length of observation on the results. Due to the scattered distribution of major events, soil erosion calculated on the basis of short-term measurements during major events is always higher than that calculated with prolonged periods of observation. To a great extent, geomorphic changes are the consequence of periodic events, and longer observation periods may contain long time spans during which geomorphic processes are far less intensive (Phillips 2003, 7).

4 Conclusion

The measurements taken provide an insight into the intensity of erosion on agricultural land in Slovenia. The data collected to date is not sufficient for a statistical analysis, but we can get an insight into the dominant processes and the relationships between them.

Erosion is heavier on cultivated land with higher inclinations and where planted cultures do not cover the soil in a compact fashion. The erodibility of the soil is primarily influenced by the type of soil, the inclination of the surface, and precipitation, while other important factors include the type of cultures planted and the manner in which the land is cultivated.

In the studied area, the farmers fight erosion mainly by contour plowing and early fall sowing. Although the erosion rills are filled in with each plowing, the depression in the study field continues to deepen due to the annual removal of material.

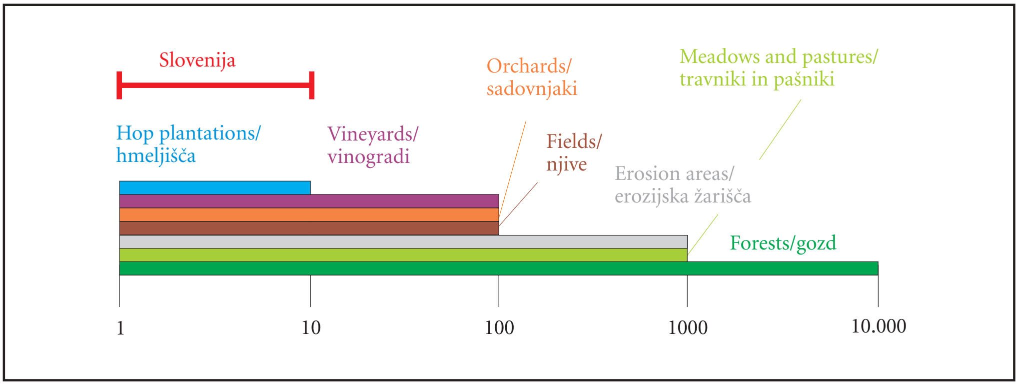


Figure 10: Ratios between lowest and highest erosion rates for individual land use categories in Slovenia, shown consecutively by size and logarithmic classes (according to data and sources cited in Table 2).

Erosion on agricultural land is less important for Slovenia from the economic viewpoint than the torrential erosion that affects the expensive road infrastructure more often than farm land, which suffers greater damage from drought and floods than from erosion. In contrast with several European countries, Slovenia only invests in erosion protection in designated erosion foci, while heavy erosion on cultivated fields and other arable land surfaces is ignored. The reason for this may be mainly economic, but it is probably also a result of the fragmentation of farmland into small parcels on which farmers can easily level possible erosion foci with plowing.

Our measurements prove that erosion on agricultural land is by no means negligible and is most intensive on cultivated fields. Because of their spatial distribution and in spite of its low intensity, the erosion of soil or regolith in forests is very important since it is especially characteristic of areas affected by human activities such as clearcutting and constructing trails and forestry roads. An important contributing factor is that the average inclination of forest surfaces is higher than the average inclination of field surfaces.

Fertile soil is an asset that takes a long time to develop through the complicated processes of pedogenesis (Lovrenčak 1994, 47) that, judging by the thickness and age of the soil on Pleistocene terraces (Šifrer 1997), take place at speeds of 0.01–0.1 mm/year (Čeh 1999, 6; Mikoš and Zupanc 2000, 419) and are considerably slower than accelerated erosion. Protection from erosion requires planned and long-term investments that would, according to experiences abroad and given the high intensity of the processes, soon be repaid. There is nothing, however, that can replace the several million tons of soil that Slovenia loses every year.

5 References

Auerswald, K. 1998: Bodenerosion durch Wasser. Bodenerosion: Analyse und Bilanz eines Unweltproblems. Wissenschaftliche Buchgesellschaft. Darmstadt.
Bavec, M. 2002: Setev koruze. Kmetijski nasveti, poljedelski nasveti, 2. Kmetijsko gozdarski zavod Maribor. Maribor. Medmrežje: http://www.kmetzav-mb.si/nasveti/nasveti.htm (25. 11. 2004).
Bezlaj, F. 1961: Slovenska vodna imena, II. del. Dela 9. Inštitut za slovenski jezik SAZU. Ljubljana.
Bračič, V. 1967: Vinorodne Haloze. Socialnogeografski problemi s posebnim ozirom na viničarstvo. Obzorja. Maribor.
Buh, Š. 2004: Esktremne padavine v Sloveniji med obdobjema 1961–1990 in 1991–2002. Diplomsko delo. Filozofska fakulteta, Oddelek za geografijo. Ljubljana.
Čeh, B. 1999: Izgubljamo rodovitne površine. Kmetovalec 67-8. Ljubljana.
Gabrovec, M., Kladnik, D. 1997: Some new aspects of land use in Slovenia. Geografski zbornik 37. Ljubljana.
Gams, I. 1974: Kras: zgodovinski, naravoslovni in geografski oris. Slovenska matica. Ljubljana.

Geografija: tematski leksikoni. 2001. Učila International. Tržič.
Globevnik, L. 2001: Celosten pristop k urejanju voda v povodjih. Doktorska disertacija. Fakulteta za gradbeništvo in geodezijo. Ljubljana.
Grad, K., Ferjančič, L. 1974: Osnovna geološka karta SFRJ 1 : 100.000, list Kranj. Zvezni geološki zavod. Beograd.
Grebenc, P. 1991: Besnica in njenih 700 let. Župnijski urad. Besnica.
Hočevar, M., Nagle, G., Natek, K., Spencer, K., Vidmar, M. 2000: Geografija: shematski pregledi. Tehniška založba Slovenije. Ljubljana.
Horvat, A. 1987: Hudourniške vode na Slovenskem. Ujma 1. Ljubljana.
Horvat, A. 2002: Erozija. Naravne nesreče in varstvo pred njimi. Uprava Republike Slovenije za zaščito in reševanje. Ljubljana
Horvat, A., Zemljič, M. 1991: Problematika urejanja hudourniških območij. Gradbeni vestnik 41, 1–2. Ljubljana.
Horvat, A., Zemljič, M. 1998: Protierozijska vloga gorskega gozda. Gorski gozd. Biotehniška fakulteta, Oddelek za gozdarstvo in obnovljive gozdne vire. Ljubljana.
Hrovat, A. 1953: Kraška ilovica: njene značilnosti in vpliv na zgradbe. Državna založba Slovenije. Ljubljana.
Hrvatin, M., Komac, B., Perko, D., Zorn, M. 2006: Slovenia. Soil Erosion in Europe. Wiley. New York. In Press.
Jesenovec, S. (ur.) 1995: Pogubna razigranost: 110 let organiziranega hudourničarstva na Slovenskem: 1884–1994. Podjetje za urejanje hudournikov. Ljubljana.
Kladnik, D. 1998: Zemljiška razdrobljenost. Geografski atlas Slovenije. Državna založba Slovenije. Ljubljana.
Klimatografija Slovenije. 1995. Padavine 1961–1990. Hidrometeorološki zavod. Ljubljana.
Klimatografija Slovenije. 2000. Število dni s snežno odejo 1961–1990. Hidrometeorološki zavod. Ljubljana.
Kolbezen, M. 1979: Transport hribinskega materiala na potokih vzhodnega in jugovzhodnega Pohorja kot posledica erozije tal. Geografski vestnik 51. Ljubljana.
Komac, B. 2003a: Geomorfne oblike in procesi na dolomitu. Magistrsko delo. Oddelek za geografijo Filozofske fakultete Univerze v Ljubljani. Ljubljana.
Komac, B. 2003b: Dolomite Relief in the Žibrše Hills. Acta Geographica Slovenica, 43-2. Ljubljana.
Komac, B., Gabrovec, M. 2004: Some characteristics of dolomite relief in Slovenia. Geografický časopis 56-3. Bratislava.
Kranjc, A. 1982: Erozija v porečju Pivke. Geografski vestnik 54. Ljubljana.
Kunaver, J. 1990: H geomorfologiji dolomitnega prevala Vršič v Julijskih Alpah. Geografski vestnik 62. Ljubljana.
Lazarević, R. 1981: Erozija zemljišta u Jugoslaviji. Geographica Iugoslavica 3. Ljubljana.
Lovrenčak, F. 1994: Pedogeografija. Filozofska fakulteta, Oddelek za geografijo. Ljubljana.
Maksimalne 24-urne padavine za 100 letno povratno dobo: merilo 1 : 250.000. 1995. Hidrometeorološki zavod Slovenije, Oddelek za klimatologijo. Ljubljana.
Martínez-Casanovas, J. A., Ramos, M. C., Ribes-Dasi, M. 2002: Soil erosion caused by extreme rainfall events: mapping anad quantification in agricultural plots from very detailed digital elevation model. Geoderma 105. Amsterdam.
Mikoš, M., Zupanc, V. 2000: Erozija tal na kmetijskih površinah. Sodobno kmetijstvo 33-10. Ljubljana.
Myers, N. 1991: Gaia, modri planet: atlas za današnje upravljalce jutrišnjega sveta. Mladinska knjiga. Ljubljana.
Natek, K. 1983: Metoda izdelave in uporabnost splošne geomorfološke karte. Magistrska naloga. Filozofska fakulteta, Oddelek za geografijo. Ljubljana.
Natek, K. 1989a: Vloga usadov pri geomorfološkem preučevanju Voglanjskega gričevja. Geografski zbornik 29. Ljubljana.
Natek, K. 1989b: Erozija. Enciklopedija Slovenije 3. Mladinska knjiga, Ljubljana.
Nearing, M, A. 1998: Why soil erosion models over-predict small soil losses and under-predict large soil losses. Catena 32. Amsterdam.
Paulič, V. 1971: Erozija tal in hudourniki: Dragonja v slovenski Istri. Diplomsko delo. Biotehniška fakulteta, Oddelek za gozdarstvo. Ljubljana.
Pedološka karta Slovenije 1 : 25.000. 2002. Biotehniška fakulteta, Oddelek za agronomijo, Center za pedologijo in varstvo okolja. Ljubljana.
Penck, W. 1924: Die Morphologische Analyse: ein Kapitel der physikalischen Geologie. Engelhorns. Stuttgart.

Petek, F. 2004: Land use in Slovenia. Slovenia: a Geographical Overview. Zveza geografskih društev Slovenije. Ljubljana.
Petkovšek, G. 2000: Procesno utemeljeno modeliranje erozije tal. Acta hydrotechnica 18-28. Ljubljana.
Petkovšek, G. 2002: Kvantifikacija in modeliranje erozije tal z aplikacijo na povodju Dragonje. Doktorska disertacija. Fakulteta za gradbeništvo in geodezijo. Ljubljana.
Phillips, J. D. 2003: Sources of nonlinearity and complexity in geomorphic systems. Progress in Physical Geography 27-1. London.
Podobnikar, T., Stančič Z., Oštir, K., 2000: Data integration for DTM production. International Archives of Photogrammetry and Remote Sensing 32–6W8/1. Ljubljana.
Popis kmetijskih zemljišč. 2000. Statistični urad Republike Slovenije. Ljubljana. Medmrežje: http://www.stat.si/pxweb/Database/Kmetijstvo/Popis%20kmetijstva/Raba%20zemlji%9A%E8/Raba%20zemlji%9A%E8.asp (5. 11. 2004).
Poročilo o stanju okolja. 2002. Ljubljana. Medmrežje: http://www.sigov.si/mop/podrocja/uradzaokolje_sektorokolje/porocila/stanje_okolja/tla.pdf (11. 7. 2003).
Povratne dobe za ekstremne padavine. 2004. Agencija RS za okolje, Urad za meteorologijo. Ljubljana.
Raba kmetijskih zemljišč. 2002. Različica 1.0. Ministrstvo za kmetijstvo, gozdarstvo in prehrano. Ljubljana.
Rainer, F., Pintar, J. 1972: Ogrožanje tal zaradi erozije, hudournikov in plazov. Zelena knjiga o ogroženosti okolja v Sloveniji. Prirodoslovno društvo Slovenije, Zavod za spomeniško varstvo Socialistične Republike Slovenije. Ljubljana.
Rainer, F., Zemljič, M. 1975: Vpliv gozdov na vodni režim in erozijske procese. Gozdovi na Slovenskem. Borec. Ljubljana.
Rajšp, V., Serše, A. (ur.) 1998: Slovenija na vojaškem zemljevidu 1763–1787. Opisi, 4. zvezek. ZRC SAZU, Arhiv Republike Slovenije. Ljubljana.
Ravbar, M. 1975: Kraška erozija v okolici Straže pri Novem mestu. Geografski obzornik 22, 1–2. Ljubljana.
Ritter, D. F., Kochel, R. C., Miller, J. R. 1995: Process Geomorphology. Wm. C. Brown Publishers. Dubuque.
Stahler, A. N. 1952: Hypsometric (area-alitude curve) analysis of erosional topography. Geological Society of America Bulletin 63. New York.
Staut, M. 2004: Recentni erozijski procesi v porečju Dragonje. Diplomsko delo. Filozofska fakulteta, Oddelek za geografijo. Ljubljana.
Šifrer, M. 1969: Kvartarni razvoj Dobrav na Gorenjskem. Geografski zbornik 11. Ljubljana.
Šifrer, M. 1997: Površje v Sloveniji. Elaborat. Geografski inštitut Antona Melika ZRC SAZU. Ljubljana.
Titl, J. 1965: Socialnogeografski problemi na koprskem podeželju. Lipa. Koper.
Topole, M. 1998: Mirnska dolina: regionalna geografija porečja Mirne na Dolenjskem. Založba ZRC. Ljubljana.
Valenčič, V. 1970: Vrste zemljišč. Gospodarska in družbena zgodovina Slovencev: Zgodovina agrarnih panog 1. DZS. Ljubljana.
Voranc, P. 1969: Ljubezen na odoru. Izbrano delo, III. Mladinska knjiga. Ljubljana.
Voranc, P. 1994: The self-sown and Passion above the precipice. Litterae Slovenicae 32-2. Ljubljana.
Vrišer, I. 1953: Erozija prsti. Proteus, 16, 4–5. Ljubljana.
Vršič, S., Valdhuber, J., Pulko, B., Stergar, A. 2000: Einfluß der Bodenpflege auf Erosion und Nährstoffbilanz. Bergrünung im Weinbau: XIII. Kolloquium des Internationalen Arbeitskreises. Fakulteta za kmetijstvo. Maribor.
Wilson, J. P., Gallant, J. C. 2000: Digital Terrain Analysis. Terrain Analysis: Principles and Applications. Wiley. New York.
Zakon o kmetijskih zemljiščih. Uradni list RS 95. 1996. Ljubljana.
Zemljič, M. 1972: Erozijski pojavi v Sloveniji. Gozdarski vestnik 30-8. Ljubljana.
Zemljič, M., Blažič, J., Pirnat, M. 1970: Stanje, problemi in suvremene metode za borbu protiv erozije i bujca. Biotehnična fakulteta, Inštitut za gozdarstvo in lesno gospodarstvo, Oddelek za erozijo tal. Ljubljana.
Zrmec, C., Matajc, I. 2004: Agrometeorologija. Mesečni bilten Agencije RS za okolje 11-5. Ljubljana.
Zupanc, V., Mikoš, M. 2000: Protierozijski ukrepi na kmetijskih površinah. Sodobno kmetijstvo 33, 11–12. Ljubljana.
Zupanc, V., Pintar, M., Mikoš, M. 2000: Simulacija erozije tal s poskusnega polja v Latkovi vasi s pomočjo modela GLEAMS 2.1. Novi izzivi v poljedelstvu 2000. Slovensko agronomsko društvo. Ljubljana.
Žust, A. 2004: Agrometorologija. Mesečni bilten Agencije RS za okolje 11-3. Ljubljana.

Erozija prsti na kmetijskih zemljiščih v Sloveniji – meritve žlebične erozije v dolini Besnice

UDK: 911.2:631.459(497.4)
COBISS: 1.01

IZVLEČEK: V članku je opisana erozija prsti v Sloveniji. O njej je malo konkretnih podatkov, kar je posledica majhnega zavedanja o tem procesu in razdrobljenosti zemljišč. Dolgotrajnejše meritve erozije prsti so namreč izvajali le na enem mestu, drugje pa so potekala krajša opazovanja in izračunavanja ter modeliranje na podlagi empiričnih enačb. Za poglobitev védenja o tem pojavu smo opravili meritve erozije prsti na njivi v porečju Besnice severozahodno od Kranja.

V zadnjih desetletjih se je v Sloveniji zaradi opuščanja kmetijske rabe zaradi naravnih, socialnih in ekonomskih dejavnikov zmanjšala količina erodiranega gradiva.

Za varovanje pred erozijo prsti se uporabljajo različne preventivne metode, kot so terasiranje, mulčenje ali oranje vzporedno s plastnicami. Počasi narašča zavest, da je varovanje pred erozijo zahtevna in dolgoročna naloga. Nič ne more nadomestiti prsti, ki jo izgubimo zaradi erozije.

KLJUČNE BESEDE: geomorfologija, erozija, erozija prsti, Besnica, Slovenija

Uredništvo je prejelo prispevek 10. 5. 2005.

NASLOVA:
Blaž Komac, mag.
Geografski inštitut Antona Melika
Znanstvenoraziskovalni center Slovenske akademije znanosti in umetnosti
Gosposka ulica 13, SI – 1000 Ljubljana, Slovenia
E-pošta: blaz.komac@zrc-sazu.si

Matija Zorn, univ. dipl. geogr. in prof. zgod.
Geografski inštitut Antona Melika
Znanstvenoraziskovalni center Slovenske akademije znanosti in umetnosti
Gosposka ulica 13, SI – 1000 Ljubljana, Slovenia
E-pošta: matija.zorn@zrc-sazu.si

Kazalo

1 Uvod

V članku predstavljamo erozijo prsti v Sloveniji, posebej pa meritve erozije, opravljene na njivi v porečju Besnice severozahodno od Kranja.

Izraz erozija prsti je primeren za oznako procesa, ki prizadene prst, to je do nekaj deset centimetrov debel del litosfere za katerega je značilna rodovitnost, lastnost, da v njej lahko rastejo rastline. Kadar voda teče po površini in ne pronica v prst, lahko povzroča erozijo (Lovrenčak 1994, 9). Kjer erozijski procesi segajo globlje v preperelino, ki ni več rodovitna, bi bilo bolje uporabljati izraz erozija preperelino.

Denudacija je razgaljanje površja, ki je posledica preperevanja in odnašanja gradiva. Učinkuje ploskovno v nasprotju z erozijo, ki deluje linijsko z dolbenjem, razjedanjem in odnašanjem delcev kamnine ali prepereline s tekočo vodo, snegom ter z ledeniki in vetrom. Erozijo povzročajo tudi človek in živali. Denudacija poteka na območjih z naklonom nad 2–3° (Penck 1924, 84), erozija oziroma močnejše linijsko odnašanje gradiva pa je značilno za naklone nad 6° (Natek 1983, 66).

Preglednica 1: Vrste erozije (Auerswald 1998, 37–38; Hočevar s sod. 2000, 14; Geografija 2001, 90–91).

dejavnik	vrsta procesa	delovanje	
voda	rečna/fluvialna erozija	Linijsko dolbenje površja in odnašanje gradiva s tekočo vodo.	1 *Globinska erozija* deluje pretežno navpično. 2 *Bočna erozija* deluje pretežno bočno.
sneg	snežna/nivalna erozija	Odnašanje gradiva zaradi erozijskega delovanja snega.	
led	ledeniška/glacialna erozija	Odnašanje gradiva zaradi erozijskega delovanja ledu.	
veter	vetrna/eolska erozija	Odnašanje gradiva zaradi erozijskega delovanja vetra.	
morje/jezera	morska/jezerska erozija ali abrazija	Odnašanje gradiva zaradi erozijskega delovanja valov.	
omenjeni naravni dejavniki in človek ter živali	erozija prsti	Vsako odstranjevanje delcev prsti in prepereline z naravnimi dejavniki, marsikje pospešeno zaradi delovanja človeka (goloseki, čezmerna paša, poti) in živali, ki je intenzivnejše od nastajanja prsti.	1 *Površinsko spiranje* je posledica dežne erozije in ploskovne erozije površinskega vodnega toka, ki poteka, preden se voda združi v curke in deluje globinsko. Čeprav gre procesno še za denudacijo, ga že štejemo k eroziji prsti. Proces brez stalnega merjenja težko opazimo in kvantificiramo, zato njegove učinke pogosto podcenjujemo. 2 *Žlebična erozija* je globinska erozija, pri kateri voda, združena v curke, vrezuje erozijske žlebiče, majhne, največ do 30 cm globoke in lahko več metrov dolge vdolbine v pobočju. 3 *Jarkovna erozija* je globinska erozija, pri kateri z združevanjem erozijskih žlebičev nastajajo več metrov globoki in več deset metrov dolgi erozijski jarki. 4 *Cevčenje* nastane zaradi tokov vode v preperelini, ki so vzporedni s pobočjem. Pri tem voda odnaša delce, v preperelini nastajajo vedno večji kanali oziroma »cevi«. Ponavadi nastajajo v manj odpornem spodnjem sloju prepereline pod bolj stabilnim zgornjim slojem.

Erozija nastopi, ko intenzivnost padavin preseže infiltracijsko sposobnost prsti in nastane površinski odtok. Odvisna je zlasti od erozivne sile padavin in vodnega toka ter odpornosti podlage. Običajno poteka v treh stopnjah. Najprej se delci prsti ločijo od podlage, nato jih voda ali drugi dejavniki prenesejo v drugotno lego, kjer se nazadnje odložijo (Lovrenčak 1994, 161–163).

V reliefno razgibani Sloveniji se vodna erozija pojavlja na velikih površinah. Na erozijo so občutljiva zlasti območja z velikimi nakloni na manj sprijetih in manj odpornih kamninah.

2 Erozija prsti v Sloveniji

O eroziji prsti v preteklosti je malo konkretnih podatkov, kar je posledica majhnega zavedanja o tem procesu in razdrobljenosti zemljišč. Leta 1991 je imela povprečna slovenska kmetija 5,9 ha zemlje (Kladnik 1998, 197), leta 2000 pa je bilo 61 % družinskih kmetij manjših od 5 ha (Popis 2000). Poleg tega je v Sloveniji v drugi polovici 20. stoletja do leta 1989 (Jesenovec 1995, 221) delovala le ena postaja za merjenje erozije, in sicer v vasi Smast pri Kobaridu. Posredne podatke o eroziji so dale meritve suspenzije in prodonosnosti v akumulacijskih jezerih hidroelektrarn na Soči, Savi in Dravi ter izračuni z različnimi modeli. Domnevamo, da je imela erozija nekdaj pomembnejšo vlogo kot danes, saj je bil delež njivskih površin bistveno večji, delež gozda pa manjši. Njive so leta 1896 obsegale 18,1 % vseh površin, leta 2000 pa le še 10,3 %, gozd je leta 1896 obsegal 41,6 %, leta 2000 pa 60,3 % površin (Gabrovec in Kladnik 1997, 34; Petek 2004, 107).

Z opuščanjem kmetijske rabe zaradi naravnih, socialnih in ekonomskih dejavnikov se je v zadnjih desetletjih ustrezno zmanjšala količina erodiranega gradiva. Od šestdesetih let 20. stoletja na plodna zemljišča posegata industrializacija in urbanizacija, ki popolnoma odstranita prst. V sedemdesetih letih se je spremenila namembnost približno 1000 ha kmetijskih zemljišč letno, v osemdesetih letih približno 500 ha letno, po letu 1990 pa se je spreminjanje namenske rabe zemljišč znova povečalo. Med letoma 1993 in 1997 so se pozidane in cestne površine povečale za 4078 ha, kmetijska zemljišča pa zmanjšala za 81.092 ha (Poročilo 2002). Površino kmetijskih zemljišč so v zadnjem desetletju zmanjšale nove avtoceste.

Intenzivna kmetijska pridelava z zbijanjem tal in zmanjševanjem infiltracijske sposobnosti pospešuje erozijo, ki jo preprečujejo s pokrivanjem zemljišč z rastlinami ali njihovimi ostanki (mulčenje). Mulčenje je najboljši način varovanja, saj že 30–50 % pokritost zadošča za dobro zaščito. Pri visokih rastlinah, na primer do 2,5 m visoki koruzi, je zaščita manjša, pri še višjih, kot je do 6 m visok hmelj, pa zaščite skoraj ni. Na obdelovalnih zemljiščih običajno več mesecev ni rastlinske odeje, zato je pomembno, da rastline poženejo še pred erozivnimi padavinami. Jeseni prst pred erozijo varujejo korenine odmrlih rastlin in ostanki stebel, ki so dobra hrana za deževnike. Ti se v takšnih razmerah hitro razmnožujejo in z izdelovanjem kanalčkov v prsti povečajo infiltracijsko sposobnost prsti, kar zmanjša njeno erodibilnost (Auerswald 1998, 39–42).

Zakon o kmetijskih zemljiščih (1996), ki določa ukrepe za varovanje kmetijskih zemljišč, omenja le agromelioracije, hidromelioracije in komasacije. Čeprav v državnem proračunu niso predvidena sredstva za varovanje pred erozijo, morajo lastniki zemljišč kmetijsko proizvodnjo prilagajati krajevnim razmeram ter uporabljati primerne metode za preprečevanje erozije. Zakon ne predpisuje protierozijskih metod, ki jih kmetje sicer že uporabljajo. Med starimi metodami so na primer izbira ustreznih poljščin, kolobarjenje in zasajanje vmesnih posevkov. Erodibilnost prsti v Sloveniji zmanjšujejo še z zmanjšano obdelavo tal in zatravljanjem, mulčenjem in takojšnjo setvijo po žetvi. V obalnem gričevju zatravljajo pasove med posameznimi vrstami poljščin, v vzhodni Sloveniji kopljejo odtočne jarke za preusmerjanje vode. Zaradi razdrobljenosti zemljišč so pogosti omejki in vmesni pasovi iz travinja ali grmovja, ki zmanjšujejo hitrost površinsko odtekajoče vode. V sadjarstvu in vinogradništvu je v navadi terasiranje in obdelovanje vzporedno s plastnicami, s čimer se erozijo zmanjša za več kot tretjino. Ponekod so zgradili vodne zadrževalnike, ki so namenjeni tudi usedanju erodiranega gradiva. Erodibilnost zmanjšujejo tudi s pravilno uporabo ustrezne mehanizacije (Lovrenčak 1994, 165; Zupanc s sod. 2000, 110; Zupanc in Mikoš 2000, 490–493).

Na nagnjenih površinah nastajajo zaradi močnega površinskega spiranja in orne erozije na spodnjih robovih njiv do 4 m visoki omejki, kjer se akumulira erodirano gradivo (Natek 1989a, 45). Kmetje v hribovitih pokrajinah so izprano prst pogosto nosili v koših nazaj na njive. Prežihov Voranc (1893–1950) je v povesti Ljubezen na odoru (1969) težaško delo gorjancev slikovito opisal:

> *»… Pri Radmanu so imeli vsega štiri njive, a vse tako strme, da so jih v starih časih, ko je bilo še dovolj rok na razpolago, kopali, a ne orali. Zdaj so jih že dolgo orali, dasiravno za oranje niso mogli uporabljati jarma, temveč posebne telege za brežno delo. Za oračem je moral iti zmeraj še tretji, ki je z nogami in rokami krotil svežo brazdo k tlom, da se ni skotalila po strmini in se zgubila v globači.*
> *Radman je zoral, posejal, več se pa za njive ni brigal; Radmanco pa je čakalo še veliko delo. Imela je na skrbi, da na vsaki njivi spravi prvo zorano brazdo z roba na odor vrhu njive. To je delo vseh strmincev že od davnih časov, kajti če ne bi tega delali, bi bila vsa zemlja kmalu odorana v nižavo, za njo bi pa ostali le suhi, kamniti odori.*
> *Ker je bilo to odvečno, posebno delo strmincev, ki ga dolinci in kmetje na zložnejših položajih niso poznali, se je imenovalo: robota.*
> *Radmanca je vstala zjutraj, ko še pridno svitalo ni, vzela svitek in jerbas in se lotila prve, največje njive. Tako zgodaj zato, ker je robota morala biti opravljena poleg drugega, vsakdanjega dela. Ko je prišla na rob njive, je pokleknila na ral ter vzdihnila: »Bog in ta sveti križ, menda ja ne bo greha!« Po starem izročilu je greh prenašati zemljo; ta greh se je pa moral odkupiti s posebno prošnjo.*
> *Nato je z rokama začela grebsti vlažno brazdo v jerbas, ga napolnila, zadela na glavo in počasi odnesla po strmini na vrh njive, kjer je spet počenila ter kleče izsula zemljo v odor zadnje brazde, rekoč: »Menda bo ja gratalo!«*
> *Preden je sonce razgrnilo svojo svetlobo izza pobočja, je Radmanca že petdesetkrat prehodila njivo; petdeset jerbasov ali več kakor dva tisoč kilogramov zemlje je že znosila na odor njive. Več kot dva tisoč kilogramov zemlje!*
> *Toda zemlja je prekleta, kadar jo mora nositi siromak, ki je ima premalo, zemlja je hudič, kadar se je lotiš golorok. Odkoplješ je en jerbas, nosiš jo, glavo ti hoče raznesti in boki ti pokajo, a brazdi se niti ne pozna; znosiš je deset, dvajset jerbasov, a komaj za spoznanje se je skrčila brazda, ki leži tu na robu kakor črna, tolsta ubita kača …«*

Podobno so morali na slemenih in zgornjih delih pobočij v Gabrovškem hribovju in v Šentjanškem hribovju v Mirnski dolini prst zaradi močne erozije na njivah občasno dovažati (Topole 1998, 25, 29) ali v koših prenašati s spodnjih delov njiv.

Po mnenju Vrišerja (1953) so zaradi erozije prsti najbolj prizadeta območja, ki jih sestavljajo mladi in slabo sprijeti lapornati in peščeni sedimenti v panonskih gričevjih in fliš v sredozemskih gričevjih. Prepričan je, da je bila v preteklih stoletjih zaradi erozije prsti opuščena marsikatera kmetija, ki je bila poseljena ob višku srednjeveške kolonizacije v 14. in 15. stoletju.

Bračič (1967) je v Halozah ugotovil, da močna erozija na pobočnih vinogradih odnaša v doline že tako skromno prst. Da bi jo kar se da dobro zaščitili, so med vinskimi trtami gojili različne podsevke, drugod pa so prst zastrli s pokošeno travo. Menil je, da bi erozijo bistveno zmanjšala uvedba vinogradniških teras.

Gradnja kulturnih teras v Koprskem primorju je prinesla več pozitivnih posledic. Voda, ki se ob deževju preliva po pobočjih, se na terasah umirja in ne odnaša več rodovitne prsti (Titl 1965). Poznamo pa primere, ko so bile zaradi erozije opuščene njive na terasah (Valenčič 1970, 145).

Svojevrstna je erozija prsti na krasu, kjer se intenzivnega spiranja v podzemlje zavedajo le redki kmetje, čeprav večina ve, da kamenje na kraških tleh »raste«. Na strminah deluje še površinsko spiranje ob nalivih, zato so opuščeni vinogradi ponekod prave kamnite puščave. Erozijo prsti na krasu ugotavljamo posredno. Na številnih skalah, ki molijo na površje, se še pozna, da so bile na vrhu odbite. Če so bile odbite na travniku, pomeni višina skale nad zemljo obseg erozije prsti, če pa je bilo kamenje odbito na njivi, je treba pridati še toliko centimetrov, kolikor globoko je bil kamen odbit pod površjem. Poleg tega ima kompakten apnenec zaradi subkutane korozije na stiku s prstjo gladko površino, od nekdaj ven štrleče kamenje pa je špranjasto z robato površino. Vešče oko razpozna, ali je površina kamna nastala v prsti ali nad njo, četudi je od znižanja prsti preteklo že več desetletij. Na ravnih travnikih moli kamenje običajno 20 do 30 cm iz zemlje, tolikšen je torej učinek erozije. V vinogradih je erozija običajno mnogo večja (Hrvatin s sod. 2006). Gams (1974) domneva, da je bila erozija prsti po poseki gozda in po prvem oranju hitra, kasneje pa se je postopoma upočasnila.

Kako hitro poteka erozija prsti, je sporno vprašanje. Hrovat (1953), ki je podrobno opisoval erozijo na njivah in vinogradih jugovzhodne Slovenije, je ugotovil, da se prst znižuje v povprečju za 1 cm na leto. Hrovatova ocena intenzivnosti erozije prsti je močno pretirana in verjetno drži le za erozijsko najbolj občutljiva območja.

V slovenski literaturi se pojavljajo različni podatki o skupni površini erozijskih območij. Največkrat navajajo vrednosti 42–44 % slovenskega ozemlja oziroma 880.000–900.000 ha (Zemljič 1972, 234; Kolbezen 1979, 73; Horvat 2002, 268). Pojavlja se tudi podatek, da poteka erozija na 95 % slovenskega ozemlja (Lazarević 1981, 9). V Sloveniji vsako leto izgubimo približno 13 km^2 plodne prsti debeline 20 cm (Rainer in Zemljič 1975).

Hudourniška erozija na 370 erozijskih žariščih in 700 hudournikih ogroža skoraj petino ali 400.000 ha Slovenije (Rainer in Pintar 1972, 23; Zemljič 1972, 234). Občutljiva so dolomitna območja alpskih gorovij (Kunaver 1990) in hribovij (Komac 2003b) ter hribovita in gričevnata območja v manj odpornih nekarbonatnih kamninah. V erozijskem žarišču v Polhograjskem hribovju je bilo na dolomitnem površju z naklonom 42° (Komac 2003a, 75) izmerjeno sproščanje gradiva 175 t/ha/leto (Komac 2003b, 31; Komac in Gabrovec 2004, 196).

V antropogeno degradirani pokrajini v dolini Meže v Vzhodnih Karavankah je bilo zaradi onesnaženja s svincem popolnoma uničeno rastje. Med delovanjem rudniške separacije je bila erozija na 0,5 km^2 velikem dolomitnem območju povprečno 83 t/ha letno. V goratem svetu zahodnih Karavank je specifično sproščanje 48 t/ha letno, na soški strani Julijskih Alp pa 45 t/ha letno. Povprečno se na erozijskih območjih gorskega sveta sprosti 2,5 milijona m^3 gradiva oziroma približno 10 t/ha letno (Zemljič 1972, 234).

Ocene sproščanja gradiva za celo Slovenijo so med 5.000.000 m^3 in 6.000.000 m^3 letno (Rainer in Pintar 1972, 23; Kolbezen 1979, 73) oziroma med 5.200.000 do 5.300.000 m^3 letno (Zemljič 1972, 234; Rainer in Zemljič 1975, 98; Horvat 1987, 36; Horvat in Zemljič 1991, 3; Horvat 2002, 268). Specifično sproščanje je povprečno okrog 4,2 t/ha letno. Nekateri navajajo tudi nižje ocene sproščanja gradiva, na primer Lazarević (1981, 9) s 3.960.200 m^3 letno oziroma približno 3,1 t/ha letno. Na podlagi enostavnega modela, ki temelji na objavljenih podatkih (preglednica 2) o eroziji po kategorijah rabe tal, ugotavljava, da je količina sproščenega gradiva v Sloveniji 3.924.002–5.722.895 m^3 letno (preglednica 3).

Polovica do tri petine sproščenega gradiva zastaja na pobočjih, meliščih in vršajih ter v erozijskih in hudourniških grapah. Preostalo gradivo pride v vodotoke, vendar se ga približno četrtina zaustavlja že v povirjih. Zaradi zastajanja gradiva se dna strug stalno dvigajo, prodišča se širijo na račun drugih zemljišč, povečuje se nevarnost poplav (Zemljič 1972, 234–236; Horvat 1987, 37; Natek 1989b, 58). Podatki o odlaganju gradiva po porečjih kažejo, da se v Posočju v vodotokih odlaga približno 15,2 t/ha gradiva letno, v Posavju približno 6,3 t/ha letno, v Podravju približno 5,6 t/ha letno in v Pokolpju približno 2,6 t/ha letno. V obalnem gričevju se v vodotokih odlaga približno 6,4 t/ha gradiva letno (Zemljič s sod. 1970).

Za primerjavo navedimo podatek, da je na Zemlji povprečno erodiranih 5 t/ha prsti letno (Myers 1991, 41).

2.1 Meritve erozije prsti v Sloveniji

Dolgotrajnejše meritve erozije prsti na kmetijskih zemljiščih so izvajali le na merilnem polju v Smasteh pri Kobaridu, drugje (Straža ob Krki, Limbuš pri Mariboru) pa so potekala le krajša opazovanja in izračunavanja ter modeliranje na podlagi empiričnih enačb (na primer Latkova vas v Savinjski dolini, dolina Dragonje, Mirnska dolina).

Pri vasi Smast, kjer je povprečna letna količina padavin približno 1700 mm (Klimatografija 1995, 99), je bila izmerjena erozija pri naklonu površja 29° v mešanem gozdu komaj 6,3 kg/ha letno, na travniku 39 kg/ha letno, na krompirjevi njivi 3,5 t/ha letno, na zorani njivi pa 22,4 t/ha letno (Horvat in Zemljič 1998, 422).

Preglednica 2: Erozija v Sloveniji po kategorijah rabe tal in erozija v izbranih porečjih. Večina podatkov temelji na empiričnih modelih, za katere je značilno, da precenjujejo erozijo na območjih, kjer je nizka in jo podcenjujejo na območjih, kjer je visoka (Nearing 1998, 15). Površine kategorij rabe tal so povzete po karti rabe kmetijskih zemljišč (Raba 2002) ter Hrvatinu in Perku (2003, 84). Vrednost, ki je v preglednici označena z zvezdico (*), ni upoštevana v grafičnih prikazih zaradi velikega odstopanja od ostalih podatkov (slika 1, slika 2, slika 9).

oznaka površin (metoda, območje)	površine glede na celotno Slovenijo (%)	specifično sproščanje gradiva (t/ha/leto)	erozijsko zniževanje površja (mm)	viri in literatura
Slovenija	100,00	3,13	0,20	Lazarević 1981, 9
Slovenija	100,00	4,18	0,26	Zemljič 1972, 234; Rainer in Zemljič 1975, 98; Horvat 1987, 36; Horvat in Zemljič 1991, 3; Horvat 2002, 268
Slovenija	100,00	3,70–4,52	0,23–0,28	Komac in Zorn 2005, v tem članku
vinograd (RUSLE, del porečja Rokave)	0,002	51,31	3,21	Petkovšek 2002, 134, 141
vinograd (Gavrilović, del porečja Rokave)	0,002	22,12	1,38	Petkovšek 2002, 134, 141
vinograd (meritev, Straža pri Novem mestu)	0,00001	22,00	1,38	Ravbar 1975, 15
vinograd (meritev, Limbuš pri Mariboru)	0,00001	0,16–10,76	0,01–0,67	Vršič s sod. 2000, 113
travnik, (RUSLE, del porečja Rokave)	0,006	4,80	0,30	Petkovšek 2002, 134, 141
travnik (Gavrilović, del porečja Rokave)	0,006	4,67	0,29	Petkovšek 2002, 134, 141
travnik (meritev, Smast pri Kobaridu)	0,00001	0,04	0,03	Horvat in Zemljič 1998, 422
sadovnjak (RUSLE, del porečja Rokave)	0,0007	20,88	1,31	Petkovšek 2002, 134, 141
sadovnjak (Gavrilović, del porečja Rokave)	0,0007	4,77	0,30	Petkovšek 2002,134, 141
pašnik (RUSLE, del porečja Rokave)	0,01	3,39	0,21	Petkovšek 2002, 134, 141
pašnik (Gavrilović, del porečja Rokave)	0,01	1,89	0,12	Petkovšek 2002, 134, 141
njiva, zorana in strnišče (meritev, Zgornja Besnica)	0,00000005	36,00	2,25	Komac in Zorn 2005, v tem članku
njiva, zorana (meritev, Smast pri Kobaridu)	0,00001	22,40	1,40	Horvat in Zemljič 1998, 422
njiva, porasla s krompirjem (meritev, Smast pri Kobaridu)	0,00001	3,47	0,22	Horvat in Zemljič 1998, 422
njiva (RUSLE, del porečja Rokave)	0,01	21,60	1,35	Petkovšek 2002, 134, 141
njiva (Gavrilović, del porečja Rokave)	0,01	10,94	0,68	Petkovšek 2002, 134, 141
hmeljišče (GLEAMS 2.1; K = 0,2; Latkova vas; 1997)	0,00001	4,22	0,26	Zupanc s sod. 2000, 109
hmeljišče (GLEAMS 2.1; K = 0,2; Latkova vas; 1998)	0,00001	1,16	0,07	Zupanc s sod. 2000, 109
kmetijske površine (izračun, Slovenija)*	10,56	80,00–160,00	5,00–10,00	Mikoš in Zupanc 2000, 419
gozd (RUSLE, del porečja Rokave)	0,006	2,55	0,16	Petkovšek 2002, 134, 141
gozd (Gavrilović, del porečja Rokave)	0,006	0,46	0,03	Petkovšek 2002, 134, 141
gozd, mešani (meritev, Smast pri Kobaridu)	0,00001	0,006	0,0004	Horvat in Zemljič 1998, 422
erozijska območja, dolomit (meritev, Polhograjsko hribovje)	0,0003	175,00	10,94	Komac 2003b, 31; Komac in Gabrovec 2004; 196
erozijska območja, dolomit (Meža)	0,002	83,20	5,20	Horvat in Zemljič 1998, 414
erozijska območja (Zahodne Karavanke)	0,01	48,00	3,00	Zemljič 1972, 234; Rainer in Zemljič 1975, 98
erozijska območja (Posočje nad Tolminom)	0,36	44,80	2,80	Zemljič 1972, 234; Rainer in Zemljič 1975, 98
erozijska območja (izračun, gorska in visokogorska območja Slovenije)	1,88	9,92	0,62	Zemljič 1972, 234; Rainer in Pintar 1972, 23; Rainer in Zemljič 1975, 98; Horvat 1987, 36; Horvat in Zemljič 1991, 3; Kolbezen 1979, 73; Horvat 2002, 268
porečje Dragonje (Gavrilović, 1955)	0,44	2,96	0,19	Staut 2004, 112
porečje Dragonje (Gavrilović, 1971)	0,44	4,53	0,28	Globevnik 2001, 114 (PUH 1971)
porečje Dragonje (Gavrilović, 1971)	0,44	4,79	0,30	Globevnik s sod. 2003, 5
porečje Dragonje (Gavrilović, 1971)	0,44	4,54	0,28	Staut 2004, 112
porečje Dragonje (Gavrilović, 1995)	0,44	1,85	0,12	Globevnik 2001, 115
porečje Dragonje (Gavrilović, 1995)	0,44	1,89	0,12	Globevnik s sod. 2003, 5
porečje Dragonje (Gavrilović, 1995)	0,44	1,85	0,12	Staut 2004, 112
porečje Dragonje (Gavrilović, 2003)	0,44	1,14	0,07	Staut 2004, 112
porečje Pivke, flišna območja (meritev)	0,24	0,25	0,02	Kranjc 1982, 15
porečje Pivke, kraška območja (meritev)	0,55	0,15	0,01	Kranjc 1982, 15
Mirnska dolina (USLE)	1,45	6,41	0,40	Topole 1998, 83
porečje Predelice (prirejena Gavrilovićeva enačba)	0,04	15,41	0,96	Mikoš s sod. 2002, 324
porečje Koritnice (prirejena Gavrilovićeva enačba)	0,43	23,86	1,49	Mikoš s sod. 2002, 324

Ravbar (1975, 15) je izvedel dve meritvi erozije na kraški ilovici v bližini Straže pri Novem mestu. Naklon površja je bil 16–18°. Opazoval je odnašanje prsti ob 36 mm padavin in ob 107 mm padavin. Ob prvem dogodku se je sprostilo 290 g gradiva (0,56 t/ha), ob drugem pa 1160 g gradiva (2,5 t/ha). Iz podatkov o eroziji prsti in podatka o 1138 mm povprečne letne količine padavin na tem območju (Klimatografija 1995, 186), smo izračunali povprečno letno erozijo prsti 22 t/ha. Pričakovane ekstremne dnevne padavine s povratno dobo eno leto so na tem območju 47 mm (Povratne 2004, 36).

Meritve erozije prsti so potekale na posestvu Meranovo južno od Limbuša pri Mariboru v vinogradu z naklonom površja 14,9°. Na stalno zatravljenem površju je bila letna erozija 156 kg/ha, na občasno zatravljenem površju pa 10,76 t/ha (Vršič s sod. 2000, 113). Povprečna letna količina padavin na tem območju je 1046 mm, pričakovane ekstremne dnevne padavine s povratno dobo eno leto so 45 mm (Povratne 2004, 29).

Izračuni z matematičnim modelom GLEAMS 2.1 v Latkovi vasi kažejo, da je erozija na hmeljišču pri naklonu 0,18° do 5 t/ha/leto (Zupanc s sod. 2000, 109). Povprečna letna količina padavin na tem območju je približno 1300 mm (Klimatografija 1995, 60), pričakovane ekstremne dnevne padavine s povratno dobo eno leto pa 49 mm (Povratne 2004, 5). Pridelava hmelja, ki je značilna za Celjsko kotlino, povzroča močno erozijo.

Erozijo so modelirali tudi v porečju Dragonje oziroma Rokave (Paulič 1971; Globevnik 2001; Petkovšek 2002; Staut 2004), kjer pade povprečno 1017 mm padavin letno (Klimatografija 1995, 47). Po Gavrilovićevi metodi so v vinogradih izračunali erozijo 22 t/ha in na njivah 11 t/ha letno, po metodi RUSLE (Popravljena splošna enačba izgub prsti) pa v vinogradih 51 t/ha letno in na njivah 22 t/ha letno (Petkovšek 2002, 141–142). Pričakovane ekstremne dnevne padavine s povratno dobo eno leto so na tem območju 44 mm (Povratne 2004, 41).

Kolbezen (1979, 81) je na podlagi podatkov o letnem transportu gradiva na potokih vzhodnega in jugovzhodnega Pohorja sklenil, da je povprečna erozija 2,4 t/ha. Na tem območju je povprečno 1100 mm padavin letno (Klimatografija 1995, 53).

Izračuni na podlagi metode USLE (Splošna enačba izgub prsti) za Mirnsko dolino kažejo, da je bila erozija na več kot polovici obravnavanega ozemlja nižja od 35 t/ha letno, na slabi petini pa močnejša kot 75 t/ha letno. Povprečna erozija v porečju Mirne je približno 6,4 t/ha/leto. Zaradi manj odpornih kamnin je gričevje v Mirnski dolini kljub manjšim višinskim razlikam za erozijo bolj občutljivo kot hribovje (Topole 1998, 83–84). Povprečna letna količina padavin na tem območju je približno 1190 mm (Klimatografija 1995, 92).

Mikoš in Zupanc (2000, 419) sta ugotovila, da v Sloveniji zaradi erozije izgubimo povprečno 5–10 mm »*plodnih tal*« na »*kmetijskih površinah*« letno. Specifično sproščanje, izračunano iz tega podatka, znaša 80–100 t/ha/leto. Glede na ostale podatke o eroziji prsti (preglednica 2) je ta vrednost verjetno previsoka.

Preglednica 3: Sproščanje in specifično sproščanje gradiva ter erozijsko zniževanje površja po kategorijah rabe tal v Sloveniji (viri za podatke o rabi tal: Raba 2002; Hrvatin in Perko 2003, 84; vir za podatke o eroziji: preglednica 2).

kategorije rabe tal	sproščanje gradiva (t/leto)	specifično sproščanje gradiva (t/ha/leto)	erozijsko zniževanje površja (mm)	sproščanje gradiva (t/leto)	specifično sproščanje gradiva (t/ha/leto)	erozijsko zniževanje površja (mm)
		naklon nad 2°			naklon nad 0°	
njive	1.464.156,86	0,86	0,05	3.918.386,92	1,93	0,12
neporasla in visokogorska območja	2.211.748,99	1,30	0,08	2.232.884,86	1,10	0,07
travinje	1.343.734,42	0,79	0,05	1.642.895,78	0,81	0,05
vinogradi	437.215,59	0,62	0,02	462.838,74	0,23	0,01
gozd in površine v zaraščanju	537.825,96	0,32	0,02	573.335,72	0,28	0,02
sadovnjaki	283.234,28	0,17	0,01	319.561,62	0,16	0,01
hmeljišča	487,06	0,0003	0,00002	6728,19	0,003	0,0002
skupaj	6.278.403,16	3,70	0,23	9.156.631,84	4,52	0,28
povprečno	784.800,40	0,46	0,03	1.144.578,98	0,56	0,04

Slika 1: Sproščanje gradiva po kategorijah rabe tal v Sloveniji v t/ha/leto (po podatkih in virih, navedenih v preglednici 2).
Glej angleški del prispevka.

Slika 2: Sproščanje gradiva po kategorijah rabe tal v Sloveniji glede na delež njihove površine v primerjavi s površino Slovenije (po podatkih in virih, navedenih v preglednici 2).
Glej angleški del prispevka.

Podatki meritev in izračuni z modeli kažejo, da erozija v Sloveniji najbolj ogroža njive, s katerih letno odnese oziroma premesti v nižjo lego 0,92–2,45 milijonov m^3 prsti. Na gozdnih območjih se sprošča približno po 0,34–0,36 milijona m^3 gradiva, v vinogradih približno po 0,27–0,29 milijona m^3 gradiva, na travnikih in pašnikih pa 0,84–1,03 m^3 gradiva. Erozija prsti v sadovnjakih obsega približno 0,18–0,20 milijona m^3 letno, na neporaslih in visokogorskih območjih pa se letno sprošča približno 1,38–1,40 milijona m^3. Skupaj se v Sloveniji sprošča približno 3.924.002–5.722.895 m^3 gradiva (preračunano iz podatkov v preglednici 3 ob pretvornem količniku 1,6; Horvat and Zemljič 1998, 422).

Pri modelu smo deloma upoštevali naklon površja. Na tej stopnji poznavanja pojava v Sloveniji bi težko v celoti upoštevali vpliv naklona. Pomen erozije prsti na njivah bi se ob upoštevanju naklonov zmanjšal, saj dobra polovica (54 %) njiv leži na površju z naklonom manjšim od 2°, kjer je po Nateku (1983, 66) relativno šibko odnašanje gradiva in le slaba tretjina (29 %) njiv leži na površju z naklonom večjim od 6°, kjer je močno odnašanje gradiva. Pomen erozije prsti v gozdovih je verjetno večji, saj je kar 85 % gozdov na površju z naklonom večjim od 6° (66 % na površju z naklonom večjim od 12°), le 6 % gozdov pa je na površju z naklonom manjšim od 2°. Podobno lahko velja tudi za travnike, saj jih 62 % leži na površju z naklonom večjim od 6° (36 % na površju z naklonom večjim od 12°) (Podobnikar s sod. 2000; Raba 2002).

Slika 3: Erozija (mm/leto) po kategorijah rabe tal v Sloveniji (po podatkih v preglednici 3).
a – erozijsko zniževanje površja na območjih z naklonom 2–90°.
b – erozijsko zniževanje površja na območjih z naklonom 0–90°.
c – povprečno erozijsko zniževanje na območjih z naklonom 2–90°.
d – povprečno erozijsko zniževanje na območjih z naklonom 0–90°.
Glej angleški del prispevka.

3 Erozija prsti v porečju Besnice

Besnica je desni pritok Save in se vanjo izliva nekaj kilometrov nad Kranjem. Njeno porečje meri 15,5 km^2. Porečje se razteza v nadmorskih višinah 357–941 m. Za pobočne procese je pomembno, da imajo štiri petine porečja naklone večje od 6°, sedem desetin večje od 12°, 44 % pa večje od 20°. Skalni podori so možni na slabi dvanajstini porečja z nakloni nad 32°. Ravnega sveta z nakloni do 2° je le za tridesetino porečja.

Več kot tretjino porečja sestavljajo različni apnenci in dolomiti, tretjino keratofir in porfir, nekaj je psevdoziljskih skladov in nanosov potokov, petino porečja pa gradi rečno-ledeniški konglomerat (Grad in Ferjančič 1974).

Na nekarbonatnih kamninah prevladuje distrična rjava prst, na apnencih in dolomitih se izmenjujeta rjava pokarbonatna prst in rendzina, na konglomeratu pa je izprana prst (Pedološka 2002).

Več kot osem desetin porečja pokriva gozd, travniki rastejo na desetini porečja, njive in vrtovi pa so na 3,5 % porečja (Raba 2002).

Besnico so poimenovali po njenem hudourniškem značaju, ker ob visoki vodi »*besni*« (Grebenc 1991, 21). Tudi izvor imena sosednje Nemiljščice povezujejo z besedami »*ne mil*« oziroma »*nemil*«, kar pomeni, da je hudourniška Nemiljščica občasno neusmiljena ali neprizanesljiva (Bezlaj 1961, 50). O hudourniškem značaju vodotokov na tem območju poročajo Opisi k Jožefinskim vojaškim zemljevidom iz druge polovice 18. stoletja, kjer je navedeno, da ob deževnem vremenu prihaja do »*močnega izpiranja potokov*«. Govorijo tudi o eroziji, ki se pojavlja na poteh, saj so »*poti proti Besnici in v hribovje*« tudi zaradi »*močnega izpiranja*« vodotokov ob deževnem vremenu »*v slabem stanju*« (Rajšp in Serše 1998, 111).

Slika 4: Porečje Besnice z naselji in mestom meritev ter erozijska moč površinskih voda izračunana z indeksom relativne moči vodnih tokov (Wilson in Gallant 2000, 8) na podlagi digitalnega modela višin 20×20 m. Slika prikazuje, kje v porečju lahko pričakujemo največjo vodno erozijo.
Glej angleški del prispevka.

V porečju Besnice ne poteka monitoring suspendiranega gradiva v vodotokih niti niso bile izvedene meritve erozije. Zato lahko na njeno intenzivnost sklepamo le na podlagi geomorfnih oblik in s pomočjo morfometričnih analiz. Ena takih je izračun hipsometričnega integrala, ki po Strahlerju (1952) prikazuje stopnjo geomorfnega razvoja porečja in pove, kolikšen delež površja še ni bil erodiran. Višje vrednosti pomenijo, da velik del prvotnega površja še ni bil odstranjen (Ritter s sod. 1995, 155). Hipsometrični integral za porečje Besnice je 27,83 %, za območje meritev na njivi, ki ga opisujemo v nadaljevanju, pa 37,63 %.

Slika 5: Hipsometrični integral je izračunan s pomočjo hipsometrične krivulje, ki prikazuje, kolikšen delež porečja leži v določeni nadmorski višini. Prikazani sta hipsometrični krivulji za območje meritev in porečje Besnice.
Glej angleški del prispevka.

Slika 6: Letalski posnetek Zgornje Besnice s preučevanim območjem (Vir: Ortofoto, © Geodetska uprava republike Slovenije 2000).
Glej angleški del prispevka.

3.1 Rezultati meritev

Erozijo prsti smo merili na zorani njivi na fluvio-periglacialni terasi, nad katero je zakrasela terasa günške starosti (Šifrer 1969) z naseljem Zgornja Besnica. Lego centroida izmerjene ploskve v Gauss-Krügerjevem koordinatnem sistemu določajo koordinati 5444870, 5124245 in nadmorska višina 422,5 m.

Na 18 m visoki ježi günške terase poteka plazenje, ki je verjetno povezano z občasnimi izviri na spodnjem robu ježe. Samo v neposredni bližini preučevanega območja je trinajst izvirov. Iz enega od njih je voda speljana proti Besnici v izgonski strugi po travniku. Struga se konča v manjši kotanji nad njivo, v kateri voda zastaja ob nalivih.

Na konglomeratni terasi, na kateri leži njiva, prevladuje izprana prst ali luvisol (Pedološka 2002), v nižjih legah ob Besnici pa je na ilovnatih rečnih nanosih nastala oglejena obrečna prst.

Prst na njivi je po mednarodni teksturni klasifikaciji (Lovrenčak 1994, 20) glinasta ilovica. V njej je 5,5 % $CaCO_3$ in 12,7 % organske snovi, njen pH pa je 6,2. Grobega peska je v prsti 17,3 %, drobnega peska 20,1 %, melja 27,2 % in gline 17,4 % (analiza, Fizičnogeografski laboratorij Oddelek za geografijo Filozofske fakultete Univerze v Ljubljani, Simona Lukič, 1. 12. 2004).

Na njivi v zadnjih letih pridelujejo koruzo in ozimno pšenico. V zgornjem delu njive so pred našimi meritvami koruzo že poželi, v prsti pa so ostali spodnji deli koruznih stebel in koreninice (slika 7). Spodnji del njive so kasneje na novo preorali in posejali ozimno pšenico (slika 8).

Slika 7: V zgornjem delu njive, ki ni bil preoran in so v prsti ostali spodnji deli koruznih stebel in koreninice, je vodni tok ustvaril komaj opazno strugo (fotografija Matija Zorn, 17. 10. 2004).
Glej angleški del prispevka.

Slika 8: V spodnjem preoranem delu njive je vodni tok vrezal 7,6 m dolgo, od 15 centimetrov do meter široko in od 1,7–26 cm globoko strugo (fotografija Matija Zorn, 17. 10. 2004).
Glej angleški del prispevka.

Ob oktobrskih padavinah je prišlo zaradi različne odpornosti podlage do diferencirane erozije. Voda je iz kotanje nad njivo najprej dotekala na koruzno strnišče, kjer je ustvarila plitvo in komaj vidno strugo. Na stiku z na novo preorano površino je prišlo do močne erozije. Struga se je zožila in poglobila. Potem, ko je kmetovalec zemljo očistil prejšnjega rastja in vanjo vsejal nove rastline, sta se namreč močno zmanjšali njena odpornost in infiltracijska sposobnost. Vodni odtok je narasel, erozivnost vode se je povečala, tako da je na spodnjem delu njive z novo posajeno pšenico ustvarila erozijski žlebič. Vrezovanje je potekalo hitro predvsem zaradi spodjedanja zatrepa erozijskega žlebiča, kjer je bila delovanju vode izpostavljena spodnja, manj odporna plast prsti (Ritter s sod. 1995, 146–148).

Na kmetijskih zemljiščih, kjer vrezovanje poteka do globine kmetijskega obdelovanja (30 cm), se z obdelovanjem še da odstraniti nastale posledice erozije, zato se je zanjo uveljavil izraz občasna žlebična erozija. Takšna erozija je pogostejša na konkavnih pobočjih, kjer prihaja do stekanja vode. Njeni učinki so najprej vidni v obliki niza skoraj vzporednih erozijskih žlebičev, ki potekajo v smeri padnice pobočja. Ugotovili so, da so v peščenih prsteh med seboj oddaljeni približno za en meter. Na površju med njimi poteka površinsko spiranje (medžlebična erozija; Petkovšek 2000, 43). Erozijski žlebiči nastanejo zaradi majhnih začetnih razlik v odpornosti in oblikovanosti površja ter vodnega odtoka, kar povzroči, da se voda usmeri le na nekatera območja. Zaradi združevanja vodnih tokov se poveča erozivna moč vode in pride do pospešene erozije. Pozitivno-povraten proces vodo usmerja v vedno globlje erozijske žlebiče. Končno lahko na pobočju nastane žlebičje – omrežje erozijskih žlebičev, ki v ugodnih okoliščinah preraste v erozijski jarek (Ritter s sod. 1995, 146–148; Auerswald 1998, 37–38).

Meritve erozije običajno temeljijo na ocenah z erozijskih polj, ki ne upoštevajo izgub zaradi občasne žlebične (jarkovne) erozije. Te niso zanemarljive in obsegajo 44–80 % skupne izgube prsti (Martínez-Casanovas et al. 2002, 126).

Obseg erozije na preučevanem območju smo določili posredno, z morfometričnimi meritvami. Najprej smo izmerili naklone površja v okolici erozijskega žlebiča, nato pa še detajlno izmerili dolžino, širino in globino erozijskega žlebiča.

Naklone smo merili s pantometrom dolžine 1,5 m in izdelali mrežo velikosti 576 ali 16 × 36 polj (1296 m^2; 24 × 54 m). Iz izmerjenih naklonov smo izračunali relativne višinske razlike med posameznimi točkami in izdelali digitalni model višin, ki je zaradi velikosti osnovne celice 1,5 m × 1,5 m omogočil kvantitativno analizo površja. Podobno metodo so uporabili pri meritvah erozije prsti po ekstremnih padavinah v vinogradu v Kataloniji (Martínez-Casanovas et al. 2002, 128–132). Povprečni naklon izmerjenega površja je 2,6° in je na strnišču oziroma v zgornjem delu (3°) večji kot na zorani njivi spodaj (1°).

Ob oktobrskih padavinah je na njivi nastal 7,6 m dolg, 0,15–1 m širok in 2–26 cm globok erozijski žlebič. Njegova povprečna širina je 55 cm, povprečna globina pa 9 cm. Erozijski žlebič je usmerjen proti jugovzhodu (130°), posamezni njegovi deli pa so usmerjeni od severovzhoda (65°) do juga-jugozahoda (205°). Skupna prostornina erozijskega žlebiča je 1,7 m^3. Digitalni model višin je pokazal, da je erozijski žlebič nastal v večji vdolbini.

Pomembno je vprašanje, koliko erozivnih padavinskih dogodkov lahko pričakujemo v enem letu. Po literaturi (Auerswald 1998, 38) je v srednji Evropi približno 15 padavinskih dogodkov letno, ki omogočajo nastanek erozijskih oblik. K temu moramo prišteti še obdobje taljenje snega, ki prav tako povzroča erozijo. Poleg tega povprečno manj kot enkrat letno pride do še večjih padavinskih dogodkov, ki povzročijo erozijo večjih razsežnosti. Slednji običajno kljub redkosti veliko prispevajo k eroziji.

Preglednica 4: Minimalno, povprečno in maksimalno število dni s padavinami nad 30 mm, nad 40 mm, nad 50 mm in nad 70 mm v obdobju 1961–2002 za 177 slovenskih meteoroloških postaj (Buh 2004, 53, 56, 60, 63, 67).

dnevne padavine	število padavinskih dni		
mm	minimalno	povprečno	maksimalno
30	2,7	12,6	31,8
40	0,8	7,0	23,7
50	0,3	4,05	18,6
70	0,0	1,30	10,2

V Zgornji Besnici je povprečno 1588 mm padavin letno, oktobra pa 138 mm. Najvišje izmerjene oktobrske padavine so bile 448 mm (Klimatografija 1995, 350). Izračunane maksimalne 24-urne padavine s stoletno povratno dobo so na tem območju 150–200 mm (Maksimalne 1995).

V Zgornji Besnici so oktobra 2004 izmerili 311,4 mm padavin, kar je 2,4 krat več od dolgoletnega mesečnega povprečja. Povprečna dnevna intenzivnost oktobrskih padavin je bila 26 mm. Ugotovljeno je, da lahko padavine z intenzivnostjo nad 25 mm na površju povzročajo vidne erozijske učinke (Kolbezen 1979, 75).

Za nastanek erozijskega žlebiča, ki smo ga izmerili, sta pomembni dve padavinski obdobji, v katerih je skupaj padlo 195,6 mm padavin. V prvih dveh padavinskih dneh (10.–11. oktober 2004) je padlo 118,2 mm padavin s povprečno dnevno intenzivnostjo 59 mm. Nato pa je v petih dneh (14.–18. oktober 2004) padlo še 77,4 mm padavin s povprečno dnevno intenzivnostjo 19,35 mm, povprečna 24-urna intenzivnost padavin dveh najbolj namočenih dni je bila 34,1 mm.

Enajstega oktobra 2004 so v Zgornji Besnici izmerili dnevni padavinski višek, ko je padlo 63,1 mm padavin. Tako intenzivne dnevne padavine imajo enoletno povratno dobo (Povratne 2004, 23).

Erozijski žlebič na zorani njivi v dolini Besnice je nastal 10. ali 11. oktobra 2004. Do močne erozije namreč lahko pride ob intenzivnosti padavin nad 40 mm/dan (Kolbezen 1979, 75).

Večja vdolbina, v kateri je nastal erozijski žlebič, obsega 31,5 m^3 in je nastala s številnimi ponovitvami dogodkov, v katerih je prišlo do erozije na podoben način kot oktobra 2004. Leži namreč na tistem delu njive, na katerega prek travnika ob nalivih doteka voda izpod 60 m oddaljene günške terase (Šifrer 1969). Vdolbina je za približno devetnajst krat večja od erozijskega žlebiča, torej bi bilo za njen nastanek potrebnih najmanj 19 dogodkov, ki so v neznanem času premestili v nižje lege približno 0,09 m^3/m^2 gradiva.

Rastline običajno začnejo rasti konec februarja ali na začetku marca, ko je presežen pomladni vegetacijski prag 5 °C (Žust 2004, 33). Kmetijske rastline, ki jih z izjemo ozimnih vrst sejejo običajno konec aprila ali na začetku maja, ko temperatura prsti doseže 8–10 °C (Zrmec in Matajc 2004, 48), prst varujejo pred erozijo le v obdobju, ko so njihovi podzemni deli dovolj razrasli, nadzemni deli pa dovolj visoki. V Sloveniji je to običajno čas od junija do avgusta ali septembra, pri čemer je protierozijska vloga rastlin odvisna od lege in vrste rastlin. Koruzo običajno sejejo tako, da na kvadratni meter zraste osem rastlin (Bavec 2002, 4).

Sneg v dolini Besnice povprečno leži od novembra do aprila. Snežna odeja pokriva površje šestino novembra, polovico decembra, 3/4 januarja, 2/3 februarja, 2/5 marca in 1/17 aprila (Klimatografija 2000, 373).

Sklenemo lahko, da leži snežna odeja v obdobju november–april povprečno po 75 dni, rastline pa površje prekrivajo v obdobju junij–september. Površje je eroziji izpostavljeno približno 5,5 mesecev, ko ni prekrito s snegom in ga ne varujejo rastline.

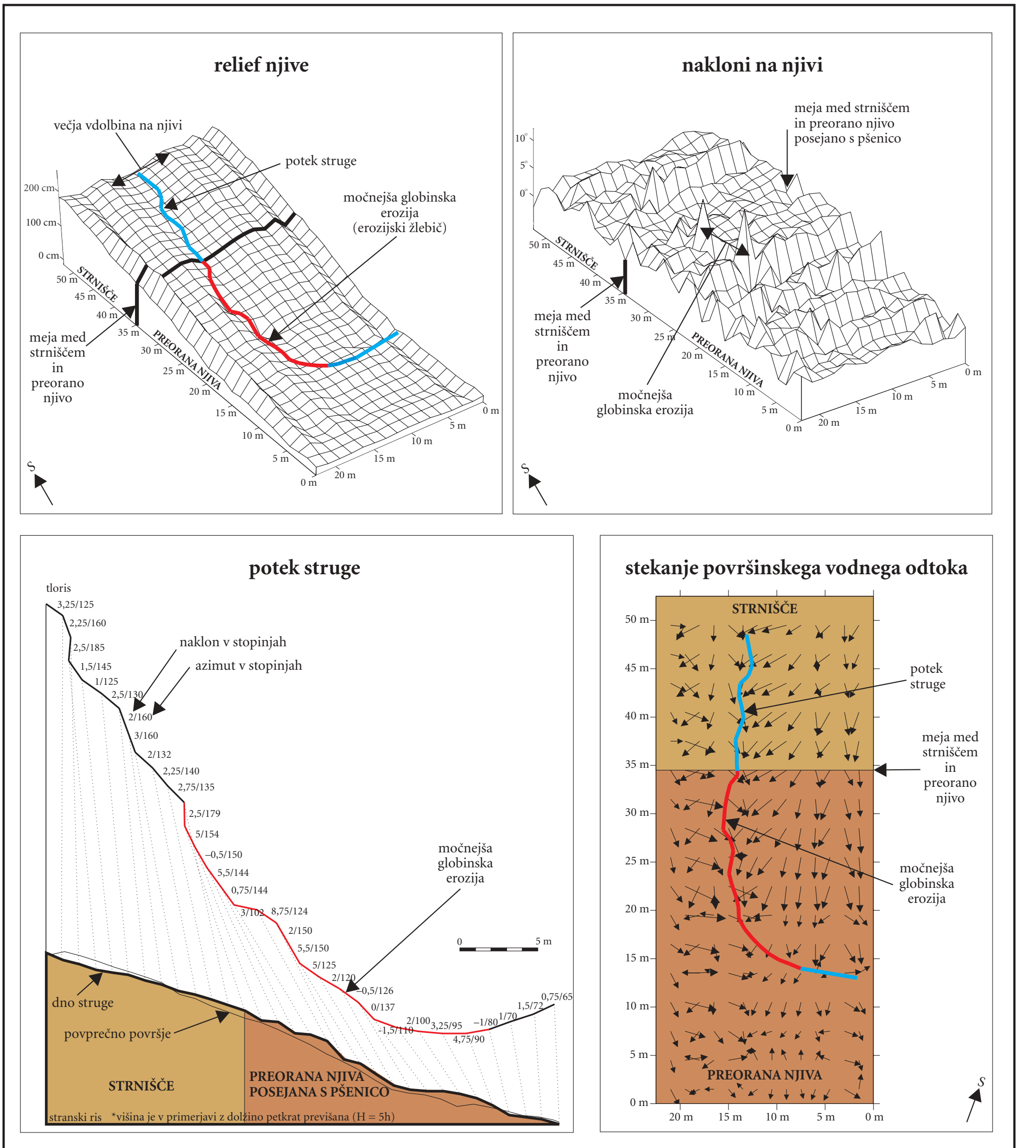
Izpostavljenost je največja aprila in maja, ko ni več snežne odeje in rastline še ne varujejo podlage ter oktobra, ko kmetijska zemljišča niso več porasla in še niso zasnežena. V Zgornji Besnici je najbolj namočen mesec november, maksimalne dnevne padavine pa so najpogostejše oktobra, v obdobju največje ranljivosti prsti.

Preglednica 5: Število erozivnih padavin na leto v Zgornji Besnici, specifično sproščanje, ki ga povzročajo padavine (t/ha/leto) in erozijsko zniževanje površja (mm/leto). Privzeli smo, da imajo erozivne padavine približno dvoletno povratno dobo (*). Ker je možno, da pride do erozivnih padavin redkeje, preglednica prikazuje tudi izračune erozije prsti za padavine za tri- in petletno povratno dobo.

pogostost erozije (povratna doba v letih)	specifično sproščanje (t/ha/leto)	erozijsko zniževanje površja (mm/leto)
1,0	77,9	5,6
2,2*	36,0	2,6
3,0	25,7	1,8
5,0	15,0	1,1

Njiva je bila jeseni 2004 izpostavljena eroziji le oktobra, saj le v tem obdobju na njej ni bilo vegetacije oziroma njenih ostankov. Oktobra so njivo na novo preorali in posejali pšenico, ki je novembra že bila dovolj visoka, da je deloma ščitila podlago in preprečevala nastajanje novih erozijskih žlebičev.

Močnó erozivne padavine, kot so bile 11. in 12. 10. 2004, se v dolini Besnice pojavijo z enoletno povratno dobo. Ker je obdobje, ko je prst izpostavljena eroziji, običajno skrajšano zaradi poraslosti in zasneženosti, lahko pričakujemo približno en erozivni dogodek na dve leti. Pogostost pojavljanja erozije je mogoče tudi manjša, saj se včasih pojavlja leto za letom ali celo v enem letu večkrat, včasih pa se intenzivne padavine pojavljajo šele po daljšem časovnem obdobju (Kolbezen 1979, 81).



Slika 9: Prikaz reliefa (zgoraj levo) in naklonov (zgoraj desno) njive z osnovno celico 1,5 × 1,5 m ter prečni prerez (spodaj levo) in tloris (spodaj desno) erozijskega žlebiča v dolini Besnice.

Ob teh predpostavkah znaša specifično sproščanje na njivi v porečju Besnice približno 36 t/ha/letno oziroma se površje erozijsko znižuje s hitrostjo 2,6 mm/leto (preglednica 4).

Izračunane vrednosti so visoke, ker so bile meritve opravljene ob velikem erozijskem dogodku. Iz literature je znan vpliv dolžine opazovanja na rezultate. Zaradi večje razpršenosti velikih pojavov je erozija prsti, izračunana na podlagi kratkotrajnih meritev ob velikih dogodkih, skladno s podaljševanjem časa opazovanja vedno nižja. Geomorfne spremembe so namreč v veliki meri posledica občasnih dogodkov, daljši časovni nizi meritev pa vsebujejo dolga obdobja, v katerih geomorfni procesi še zdaleč niso tako intenzivni (Phillips 2003, 7).

4 Sklep

Opravljene meritve dajejo vpogled v intenzivnost erozije na kmetijskih zemljiščih v Sloveniji. Do sedaj zbrani podatki še ne zadoščajo za statistično analizo, vendar dajejo vpogled v prevladujoče procese in razmerja med njimi.

Erozija je močnejša na obdelanih površinah z večjim naklonom površja in tam, kjer zasajene kulture prsti ne pokrivajo sklenjeno. Na erodibilnost prsti vplivajo zlasti vrsta prsti, naklon površja in padavine, pomembna dejavnika sta tudi vrsta zasajene kulture in način obdelovanja zemljišč.

Kmetje se na preučevanem območju proti eroziji borijo predvsem z oranjem oziroma sejanjem vzporedno s pobočjem in zgodnjim jesenskim sejanjem. Čeprav erozijske žlebiče z oranjem sproti zasipajo, se vdolbina na njivi poglablja zaradi vsakoletnega odnašanja gradiva.

Dosedanja praksa kaže, da je za Slovenijo erozija na kmetijskih zemljiščih z narodnogospodarskega vidika manj pomembna od hudourniške erozije, ki pogosteje prizadene drago cestno infrastrukturo kot kmetijska zemljišča, na katerih več škode kot erozija povzročajo suše in poplave. V nasprotju z nekaterimi evropskimi državami, vlagamo le v varstvo pred erozijo na erozijskih območjih, močno erozijo na njivskih in drugih obdelovalnih površinah pa zanemarjamo. Vzrok je morda ekonomski, verjetno pa tudi posledica razdrobljenosti parcel, kjer kmetje zmorejo sproti uravnavati površje.

Meritve dokazujejo, da erozija na kmetijskih zemljiščih nikakor ni zanemarljiva in je najintenzivnejša na njivah. Zaradi prostorske razširjenosti in kljub nizki intenzivnosti je zelo pomembna erozija prsti oziroma preperine v gozdovih, kjer je še posebej značilna za območja, ki jih je z goloseki ali izdelavo poti prizadel človek. Pomembno je dejstvo, da je povprečen naklon gozdnih površin višji kot naklon njivskih površin.

Slika 10: Razmerja med najmanjšo in največjo erozijo za posamezne kategorije rabe tal v Sloveniji, prikazana zaporedno po velikostnih – logaritemskih razredih (po podatkih in virih, navedenih v preglednici 2).
Glej angleški del prispevka.

Rodovitna prst je dobrina, ki nastaja zelo počasi z zapletenimi procesi pedogeneze (Lovrenčak 1994, 47), ki so glede na debelino in starost preperline na pleistocenskih terasah (Šifrer 1997), počasnejši od pospešene erozije in potekajo s hitrostjo 0,01–0,1 mm/leto (Čeh 1999, 6; Mikoš in Zupanc 2000, 419).

Varovanje pred erozijo zahteva načrtna in dolgoročna vlaganja, ki bi se, glede na izkušnje iz tujine in glede na visoko intenzivnost procesov, kmalu povrnila. Nič namreč ne more nadomestiti nekaj milijonov ton prsti, ki jo letno izgubimo v Sloveniji.

5 Literatura

Glej angleški del prispevka.