Response of Soil Erosion to Land Use Change with Particular Reference to the Last 200 Years (Julian Alps, Western Slovenia)*

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Key Words: geomorphology, erosion, erosion modelling, Gavrilović equation, land use, land use changes, Alps, Slovenia.

Abstract. Erosion changes in the Upper Soča Valley (Julian Alps, western Slovenia) during the last two centuries are discussed in the article. Erosion was calculated using a model in which land use was one of the principal factors. The empirical Gavrilović equation that has been partly modified by Lazarević was used. Erosion calculations covered five years: 1827, 1896, 1953, 1979 and 1999, enabling us to establish changes in the erosion process due to a change in land use over the last 200 years. The total annual erosion in the study area amounted to 4.76 million m^3 in 1827, and it was approximately the same also in 1999. Within that interval erosion increased, reaching 5.72 million m^3 in 1953, with a presumed maximum during the 1920's. In 1827, specific erosion was 133.4 tons/hectare/year year, in 1999 it was 135.5 tons/hectare/year, and in the meantime, in 1953, it reached 160.3 tons/hectare/year. The study shows that erosion changes may be established also by means of historical sources of land use, if a proper model is employed.

1. Introduction

Soil erosion and sediment deposition processes are determined by four main factors: regolith type, climate, topography and land use. Although all of these factors interact with human activity to a certain extent, land use is the most 'manageable' factor (Van Rompaey et al., 2003). Changes in soil erosion in the western part of the Julian Alps in Slovenia (591.5 km^2), more precisely in the drainage basin of the Soča river (Fig. 2), during the last two centuries were established exactly through the land use changes.

Required for such calculation was the erosion model in which land use was employed as one of the principal factors for the calculation of soil erosion. Selected was the empirical Gavrilović equation (Gavrilović, 1962; 1970; 1972) partly modified by Lazarević (1968a; 1985). The equation is applicable to the analytical determination of erosion coefficients and the quantification of erosion and average annual sediment yield. This method has been widely used in Slovenia and in the western Balkans for the last 30 years to predict erosion processes and implement torrent regulation and other erosion control works (Gavrilović, 1988; Globevnik et al., 2003; Zorn, 2008).

The study of Klanghofer, Hintersteiner and Summer (2002) has shown that the expansion of farm land into hilly/mountainous areas with steep slopes and changes in land use as well as in land management techniques significantly increased the soil erosion rates as well as the sediment yield from different subcatchments within the Danube drainage basin (in Austria) in the 1950–1990 period.

The trend was different in the Slovenian Alps, where an extensive process of depopulation and abandoning of agrarian activities took place, which led to the decline in farming areas and increase in the percentage of forests (Petek, 2005a; 2005b). Erosion played a greater role about a century ago than it does today, because the proportion of cultivated areas was substantially larger. But at the beginning of the 19th century erosion is supposed to have been approximately on the same level as at present. The amount of eroded material has decreased in the last decades, due to natural, social and economic factors. Reforestation is the key process. In the past decades different authors supposed (for sources see Komac, Zorn, 2005; 2007; Hrvatin et al., 2006) that annual soil erosion in Slovenia amounts to 5 to 6 millions m^3 of

*Paper presented at the *"IAG Regional Conference on Geomorphology: Landslides, Floods and Global Environmental Change in Mountain Regions", September 15-25, 2008, Braşov, Romania* material (~2.5 to ~3.0 m^3/ha). But according to the data that are presented in this article and according to the measurements of erosion in the Slovene Istria region (Zorn 2008), we can conclude that, in the past, soil erosion has been almost certainly underestimated.

2. Methods

2.1. Gavrilović's method for the calculation of annual soil erosion

For a quick and easy quantification of soil erosion quite a number of erosion models have been developed, the majority of which were based on the combination of short-term measurements and mathematical formulas. These are the so-called empirical models. Thus, the empirical models are based on the link-up of a dependent variable with a set of measured or assessed independent variables by means of regression analysis (Staut, 2004). Of such models, most widely used is the American erosion model USLE (Universal Soil Loss Equation), developed by Wischmeier and Smith (1965); based on it are the contemporary most widely spread empirical models (e.g. RUSLE).

In the western Balkans the most widely used have been the so-called Gavrilović equation (1962; 1970; 1972) and its modifications (Lazarević, 1968a; 1985; Pintar, Mikoš, Verbovšek, 1986), which are similar to the USLE model (Mikoš, Fazarinc, Ribičič, 2006). The advantage of this equation, according to Z. Gavrilović (1994), lies in the fact that it is not meant primarily for the calculation of soil erosion on arable lands – for this purpose the USLE method was worked out – but was developed for the hydro-regulation needs and is suitable for the calculation of soil erosion irrespective of land use. The equation is based on several years of measurements performed on several tens of erosion plots in central Serbia (Lazarević, 1968b).

S. Gavrilović (1962; 1970; 1972) proposed an analytical equation for determining the annual volume of detached soil due to surface erosion:

$$W_a = T * P_a * \pi * \sqrt{Z^3} * F$$

where:

W_a = total annual erosion (m^3/year)
T = temperature coefficient
P_a = average yearly precipitation (mm)
Z = erosion coefficient
F = study area (km^2).

$$T = \sqrt{\frac{T_0}{10} * 0.1}$$

T_0 = average yearly temperature (°C)

$$Z = Y * Xa * \left(\varphi + \sqrt{J_a}\right)$$

Y = soil erodibility coefficient
Xa = soil protection coefficient
φ = erosion and stream network development coefficient
J_a = average slope of the study area (%).

Table 1. **Descriptive factors used in the Gavrilović model** (based on Lazarević, 1985; Vente, Poesen, 2005)

Soil protection coefficient	***Xa***
Mixed and dense forest	0.05–0.20
Thin forest with grove	0.05–0.20
Coniferous forest with little grove, scarce bushes, bushy prairie	0.20–0.40
Damaged forest and bushes, pasture	0.40–0.60
Damaged pasture and cultivated land	0.60–0.80
Areas without vegetal cover	0.80–1.00
Soil erodibility coefficient	***Y***
Hard rock, erosion resistant	0.1–0.3
Rock with moderate erosion resistance	0.3–0.5
Weak rock, schistose, stabilised	0.5–0.6
Sediments, moraines, clay and other rock with little resistance	0.6–0.8
Fine sediments and soils without erosion resistance	0.8–1.0
Erosion and stream network development coefficient	***φ***
Little erosion on watershed	0.1–0.2
Erosion in waterways on 20–50% of the catchment area	0.3–0.5
Erosion in rivers, gullies and alluvial deposits, karstic erosion	0.6–0.7
50–80% of catchment area affected by surface erosion and landslides	0.8–0.9
Whole watershed affected by erosion	1.0

For details on the coefficients used in the article (Table 1) see S. Gavrilović (1962; 1970), Z. Gavrilović (1988), Lazarević (1968a; 1985), Staut (2004) or Vente and Poesen (2005).

The great generality of variables and parameters used in the Gavrilović method renders the assessment of erosion processes possible also in the case of rough information that can be obtained even without fieldwork. Thus, the insight into the past erosion activity is possible as long as good historical (cartographic) bases and aerial shots exist, which can be integrated into the national network of coordinates (Petek, Fridl, 2004), as well as climatic data strings (Staut, 2004).

Calculations following the Gavrilović equation are done by hydrogeographical units, i.e. by drainage basins or by sections of drainage basins. Our calculations had to be done by cadastral municipalities, the boundaries of which correspond pretty well to the boundaries of drainage basin sections. Thus, the cadastral municipalities could be assumed as the hydrogeographical units.

2.2. Data preparation and GIS manipulation techniques

Erosion was calculated for five terms, i.e. for the years 1827, 1896, 1953, 1979 and 1999. On the basis of the obtained calculations for these terms, it was possible to establish the changes in the erosion process as a consequence of land use changes in the last 200 years (Komac, Zorn, Gabrovec, 2007; Zorn, Komac 2008).

The data on land use for the year 1827 were obtained on the basis of the Franziscean cadastre, i.e. the land cadastre measurement project that was started according to the emperor's patent in 1817 (the territory of Slovenia was part of the Austrian empire at that time), and completed for the majority of Slovenian territory by the year 1828 (Petek, Urbanc, 2004). The data were taken from the written part of the Franziscean cadastre (Fig. 1), separately for each cadastral municipality (Petek, 2005a).

From the land cadastre the data on land use for the year 1896 were also taken (Petek, 2005a). In order to establish land use changes after the Second World War, we likewise used the data from the land cadastre, aggregated on the level of cadastral municipalities for the years 1953, 1979 and 1999 (Petek, 2005b). Calculations were done in the form of raster with the basic cell size of 25 x 25 metres, by means of the *Idrisi* program package.

The data on the lithological structure of the area were obtained from a digital geological map at a scale of 1:100,000 (Buser, 1986; Jurkovšek, 1987) and the data on soils from a digital pedological map at the scale of 1:25,000 (Pedološka, 1999), while the data on landforms were obtained from the digital elevation model 25 x 25. Since no data on climate are available for older periods, the data set for the 1961–1990 reference period was applied to the entire period (Zupančič, 1995).

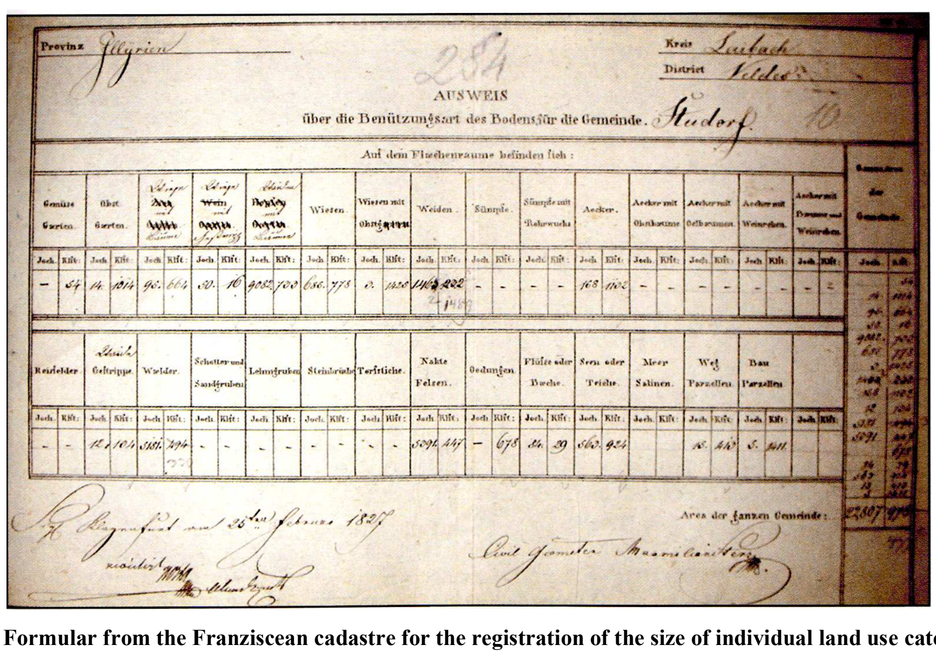
Provinz Illyrien
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Fig. 1. **Formular from the Franziscean cadastre for the registration of the size of individual land use categories by cadastral municipalities** (source: Archives of the Republic of Slovenia)

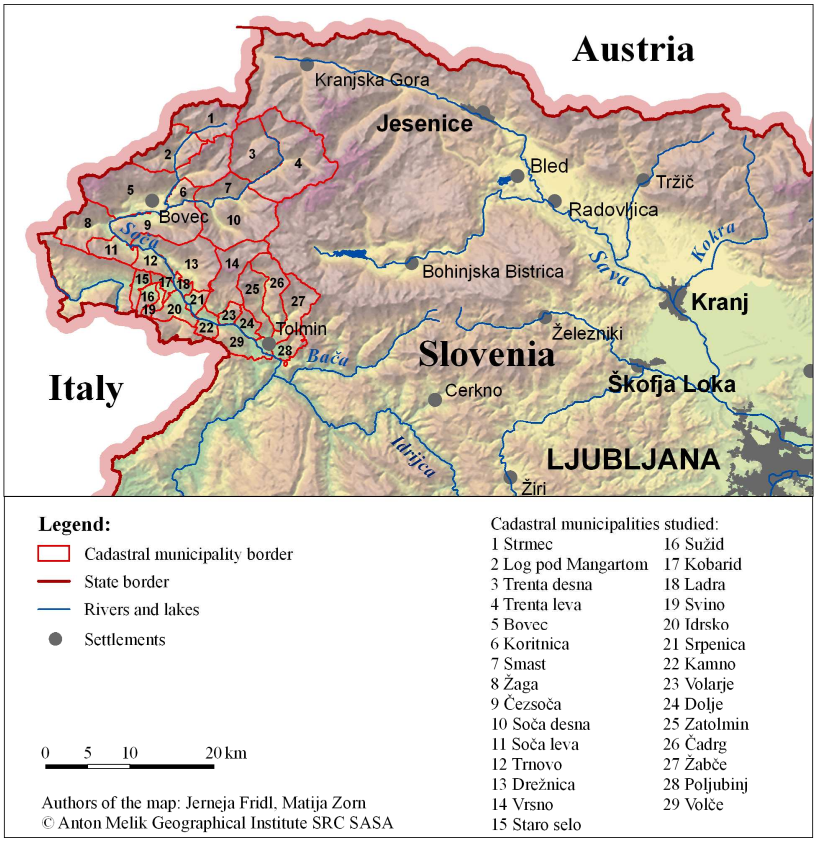

Fig. 2. **Map of the study area**

4. Results

Between 1827 and 1900 changes in land use in the Slovenian Alps were minimal, as they were registered on less than half a percent of the surface. Among the processes involved in the change of land use, intensification prevailed. Intensification primarily involved the transformation of grassland into cultivated fields. Between 1900 and 1953, selective limitation of cultivated fields only to the most favourable land began. Abandoned fields turned into grassland (primarily meadows), and thus overgrowing with grass dominated during this period, when varying social conditions had the greatest influence on the changes in land use. Between 1953 and 2000, changes in land use were the greatest, with the prevailing afforestation. However, we established a difference in the degree of afforestation between the first and the second half of this period: in the first half, changes in land use were generally the most intensive in the entire period studied. Between 1953 and 1979, the largest proportion of agricultural land was transformed to forests. Between 1979 and 2000, the intensity of afforestation decreased slightly, possibly due to the legislative changes and measures adopted after 1970 to stimulate agriculture. Between 1900 and 2000, a quarter of the land in Slovenia's alpine region was subject to afforestation that took place mostly because of economic changes (Petek, 2005b).

The total annual erosion in the discussed area amounted to 4.76 million m^3 in 1827, and it was approximately the same also in 1999. In the meantime erosion increased and reached 5.72 million m^3 in 1953, with presumed maximum during the 1920's. The main cause of the increase in erosion was the agrarian overpopulation of the area, which gave rise to economic emigration towards the end of the 19th century.

Interesting are the specific values of erosion which point to the great significance of erosion focal points. These are numerous in the studied area, especially on the steep dolomite slopes, scree slopes, steep slopes in quaternary sediments and partly also on the flysch slopes dissected by a dense network of valleys. In 1827, the specific erosion amounted to 133.4 tons/hectare/year, in 1999 it was 135.5 tons/hectare/year, and in the meantime, in 1953, it reached 160.3 tons/hectare/year (Fig. 3; Fig 6).

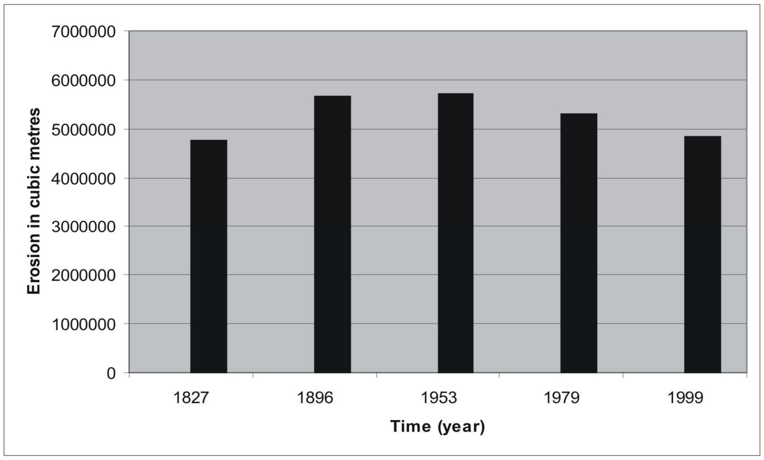

Fig. 3. **Erosion in the Upper Soča region between 1827 and 1999 (in m^3 per year)**

Fig. 4. **The Svinjak mountain near Bovec** (Upper Soča valley**) in the beginning of the 20th century** (left; photography: M. Klodič) **and in the beginning of the 21th century** (right; photography: Miha Pavšek)

The causes for such a course of development can be assumed to be found in land use changes, which reflect the complex socio-economic as well as the natural processes which were going on in the discussed area during the past two centuries.

The percentage of arable fields decreased throughout the region, and declined by a half between the years 1827 and 1999. Also, the percentage of pastures declined by about 40% and the percentage of meadows declined by 15%. In the same period the percentage of forest areas increased by one third (Table 2; Fig. 4). The protective role of ever larger forest areas on steep slopes significantly contributed to the reduction of erosion in the last decades. The decline in percentage of pasture areas, which are, due to high altitude and higher inclinations, more intensely exposed to erosion than meadows, also had a significant impact. The decrease in arable field areas had but relatively little influence on the erosion reduction. Arable fields on the discussed territory lie only at the bottom of valleys or on (river) terraces, where erosion is less due to slight inclinations of the surface.

With regard to the area occupied by a certain land use category, it can be concluded that the increased erosion in the past century was correlated with the insufficient percentage of forests and the high percentage of pasture areas. The extent of alpine pastures began to decrease only after the economic transition of the 1970s, when the active population got employed more intensely in industry and its survival no longer depended on animal husbandry or pasturing on the Alps or even haymaking on steep mountain meadows. The reduction of erosion in the past decades also resulted from a smaller percentage of fields (arable areas).

Table 2. **Percentage of areas by land use categories in the years 1827, 1896, 1953, 1979 and 1999** (Petek, 2005b)

%	1827	1896	1953	1979	1999	Difference 1827-1999	index
Field	7.73	7.93	7.37	4.77	4.04	-3.68	52.31
Meadow	20.74	21.30	20.81	20.61	17.96	-2.79	86.57
Pasture	27.77	23.43	21.73	18.72	16.09	-11.68	57.95
Forest	35.98	36.50	37.84	42.86	47.77	11.79	132.77
Other	7.78	10.84	12.25	13.03	14.14	6.36	181.70

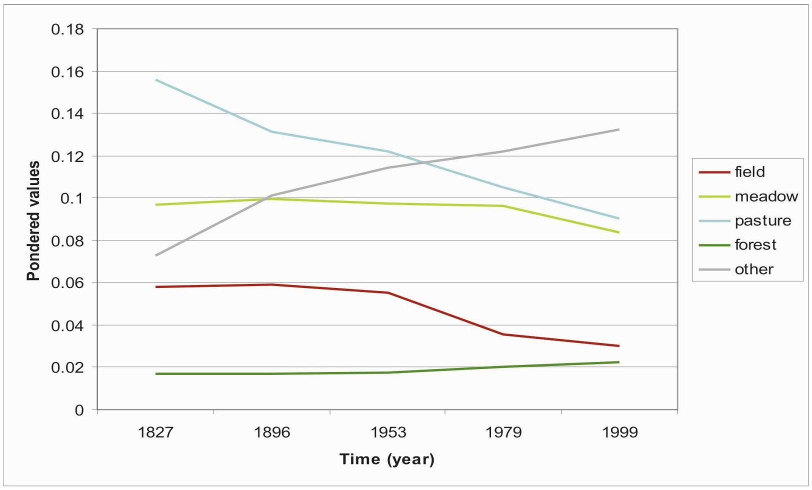

Fig. 5. **Pondered erosion values as to erodibility coefficient in the years 1827, 1896, 1953, 1979 and 1999**

In order to compare more easily the erodibility of lands of different land use categories, we standardized the areas. In this way it has been established that the pastures are the ones that exert the relatively most intense influence on the erodibility of a certain area. Also the influence of mountain pastures and meadows is very strong in the discussed mountainous region. It is also evident from Figure 5 that the erodibility of lands during the past times mainly depended on the decrease in arable fields and pasture areas and the increase in the extent of so called other areas, including bare land and urbanised areas.

Although we have established that the results faithfully mirror the socio-economic development of the area, we have to be cautious about the source used. In the recent years, the land cadastre of Slovenia has no longer been a very reliable source of information on the actual land use, but only a useful source of information on the ownership situation. The land use map, updated and edited by the Ministry of Agriculture, Forestry and Food of the Republic of Slovenia (Raba, 2002), is a more relevant source. Judging from this map, the total annual erosion in 2000, for example, was lower (3.05 million m^3) than that of 1999 (4.84 million m^3), calculated from cadastral data.

However, it should be noted that the above-mentioned data on erosion represent the average, calculated by means of the model. To be sure, extreme events are not taken into account in such calculations (Staut, 2004); the amount of released material during such events equals the size class of the total annual erosion in the Upper Soča region. Thus, at the village of Log pod Mangartom, the debris flow alone in the year 2000 transported over a million of m^3 of material to lower-lying locations (Komac, Zorn, 2007). Therefore, the original Gavrilović equation was modified in Slovenia, so that instead of the annual precipitation amount the data on maximum daily precipitation were employed (Pintar, Mikoš, Verbovšek, 1986).

According to the calculation of Mikoš, Fazarinc and Ribičič (2006) average annual sediment production in the discussed area amounts to about 2200 t/km^2 or about 1400 m^3/km^2. Average annual sediment load is about 200 m^3/km^2, and average delivery ratio 0.31. The figures are rather low comparing to the results of our analysis for annual sediment production (8047 to 9670 m^3/km^2). But taking into account the fact that earthquakes and heavy rainfalls are rather frequent in the Upper Soča River basin the figures become more realistic. Earthquake-induced rockfalls and rainfall-induced landslides may release sediment in excess – about 125,000 m^3/km^2 annually (Mikoš, Fazarinc, Ribičič, 2006) i.e. about twelve times higher comparing to average sediment production in the area.

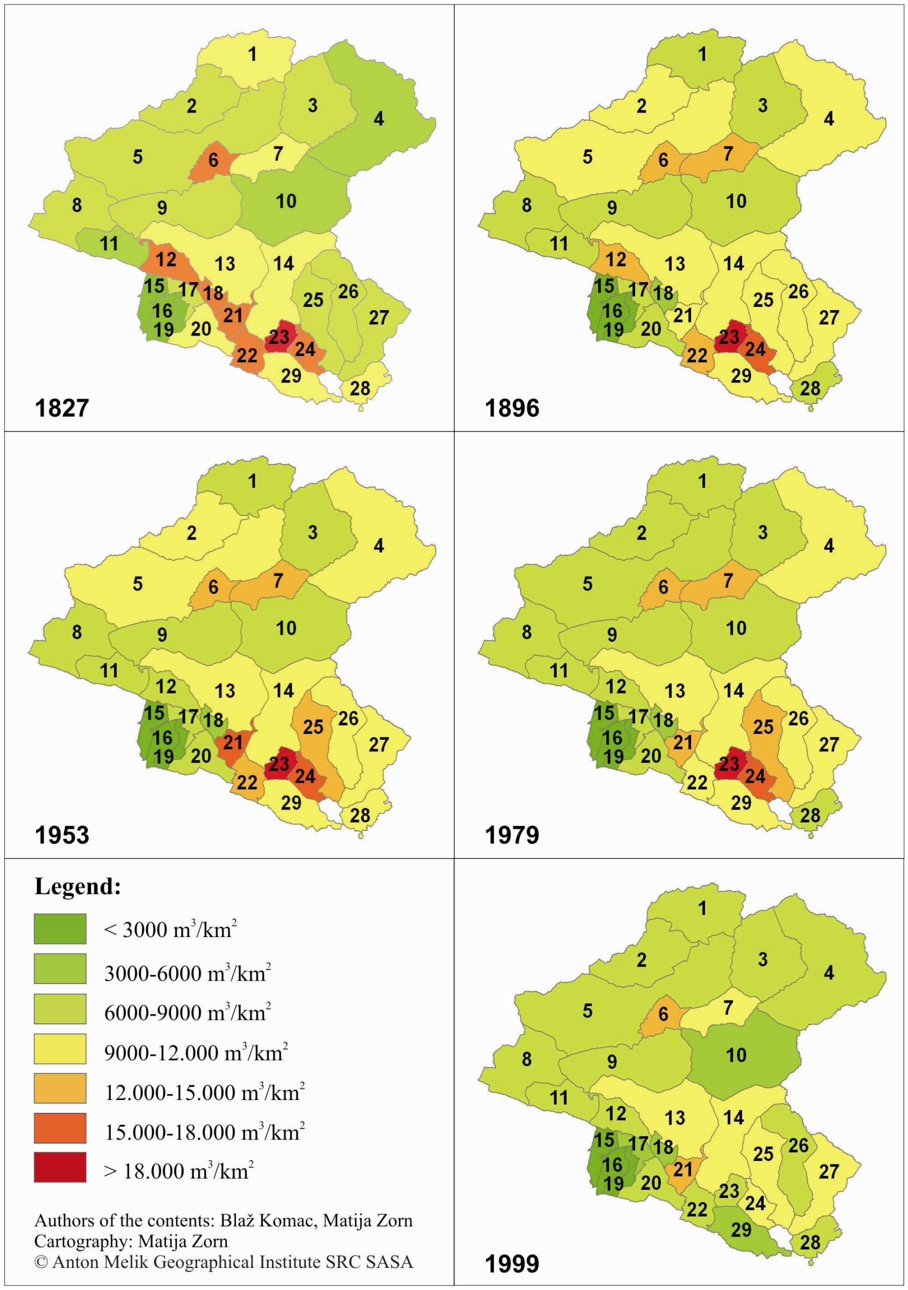

Fig. 6. **Specific annual sediment production according to cadastral municipalities in the studied years** (for numbers of cadastral municipalities see Figure 2).

5. Conclusion

The paper shows that historical sources on land use are very useful for establishing the changes in erosion, if a proper model is employed. Geomorphic response to land use is non-linear: a small change in the percentage of arable land usually results in relatively big changes in erosion risk and sediment delivery (Van Rompaey et al., 2003). Thus, an increase in the percentage of arable land results in a faster than linear increase of the mean soil erosion rate in the drainage basin, because the slope gradients of the newly deforested areas are systematically higher than the slope gradients of the original arable land. Afforestation, on the other hand, results in faster than linear decrease of the mean annual soil erosion rate in the drainage basin, because parcels on steep slopes are more likely to be converted into forest. For example, the decrease in percentage of arable lands in the drainage basin by 5%, may result in a 8.5% lowering of the mean annual soil erosion rate and as much as 13.5% lowering of sediment yield (Van Rompaey et al., 2003).

Complex studies of recent morphogenetic processes together with the comprehension of climate changes and human interventions in the landscape are necessary to understand the relationship between past land use changes and erosion. Human induced processes, such as land use changes, usually have long-term influences on landscape evolution. The changes in erosion processes, related to human-geographical processes, are thus more a distant reflection of past processes than a consequence of recent anthropogenic processes. In our case the loosened natural balance from previous phases of landscape evolution, especially to the climax of pasture usage in the 2nd half of the 19th century lead to bareness of soil and increased erosion in the 1st half of the 20th century. Even though the landscape has been renewing since then, the natural but labile equilibrium may suddenly collapse, leading to intensive erosion processes, such as rill erosion, strong denudation and slope processes, especially landslides. One of the most difficult tasks of geomorphology is to properly comprehend and evaluate weights of influence factors, e.g. natural and anthropogenic processes in the landscape with different and overlapping evolution periods.

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