AIMS Environmental Science

http://www.aimspress.com/journal/environmental

AIMS Environmental Science, 10(1): 191–205.
DOI: 10.3934/environsci.2023011
Received: 29 November 2022
Revised: 30 December 2022
Accepted: 02 February 2023
Published: 14 February 2023

Research article

Soil erosion estimation using Erosion Potential Method in the Vjosa River Basin, Albania

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Abstract: Soil erosion is a major environmental threat to soil sustainability and productivity with knock-on effects on agriculture, climate change, etc. Factors influencing soil erosion are many and usually divided into natural and human causes. Massive deforestation, intensive agriculture, temperature and wind, rainfall intensity, human activities and climate changes are listed as the main causes of soil erosion. Calculation of the coefficient of soil erosion is very important to prevent the event. One of the methods used worldwide to calculate soil loss and the erosion coefficient is the Erosion Potential Method. In this study, 49 sub-basins of the Vjosa River Basin in Albania were evaluated. Results showed that the phenomenon of erosion is present in all sub-basins, varying from 0.01 to 0.71. Thus, the categorization of soil erosion varies from heavy to very slight erosion. Moreover, the overall sediment yield calculated for the Vjosa River Basin was 2326917 m^3/year. In conclusion, the application of the Erosion Potential Method is reliable for evaluating erosion and can further be applied in our country's conditions.

Keywords: soil erosion; Vjosa River Basin; Erosion Potential Method (EPM); sediment yield; Albania

1. Introduction

The concept of erosion is commonly considered as the displacement and transportation of various portions of the land [1]. The advancement of soil erosion is mainly dependent on natural and human factors, such as rainfall, temperature changes, wind, land use and climate changes [2–9]. Soil erosion is defined as slow, high or even very high when conditions causing it are very consistent. Moreover, other human activities, such as large deforestation, intensive use of agricultural land and the increasing population worldwide, are considered as events affecting soil erosion. Larger volumes of materials involved in the erosion process can cause major damages since these materials can travel long distances, causing the pollution of water bodies in terms of nutrients [10–15]. Likewise, flow rates can be influenced by these events when they settle down at one final point. Since the land degradation process is a very complex occurrence that is difficult to predict, the generation of maps showing land erosion and sediment yield is considered a very significant step to oppose the process. Many authorities and authors have been proposing different methods to evaluate sediment yield and soil erosion. Several models have been developed, including the universal Soil Loss Equation (USLE) [16], Revised Universal Soil Loss Equation (RUSLE) [17], Modified Universal Soil Loss Equation (MUSLE) [18] and Erosion Potential Method (EPM) [19].

The EPM estimates the amount of sediment production and transportation, thus indicating the zones potentially threatened by erosion. This method was first used by Gavrilovic in the former Yugoslavia. The method itself is a semi quantitative method that is applied in many countries [20–25], especially in the Balkans, to evaluate the erosion mainly in semi-arid and arid areas [26–33].

In our country's conditions, erosion of lands is consistent, especially in specific districts [34]. Furthermore, few studies have been done in Albania using the Erosion Potential Method to estimate erosion [26]. We assume that application of such methodology can help in identifying the zones with a high erosion rate, in order to prevent the phenomenon's progression.

2. Materials and methods

2.1. Study area

The Vjosa River basin (VRB) is the second largest river basin in Albania (6474 km^2), drained by the Vjosa River (Figure 1a). The Vjosa river is one of the last wild and free flowing rivers in Europe [35]. Moreover, the Vjosa River is one of the longest (272 km) transboundary rivers in the Balkan area. It flows from its source in the Pindos mountains in Greece through the south of Albania until its discharge in the Adriatic Sea. One third of it (80 km) is located in northwest Greece, where it is known as the Aoös (Αώος) River; and the other part is in Albania, where it continues as the Vjosa River and flows over a distance of 192 km before discharging into the Adriatic Sea north of the Narta Lagoon. The most important tributaries of the Vjosa River in Albania are the Drino, Bënça and Shushica. The Vjosa River Basin is configured in 49 sub-basins (Figure 1b), has a mean elevation of about 855 m above sea level and has a perimeter of about 906.13 km. Due to the large perimeter and surface of the Vjosa River Basin, its territory includes natural, agricultural and urban spaces.

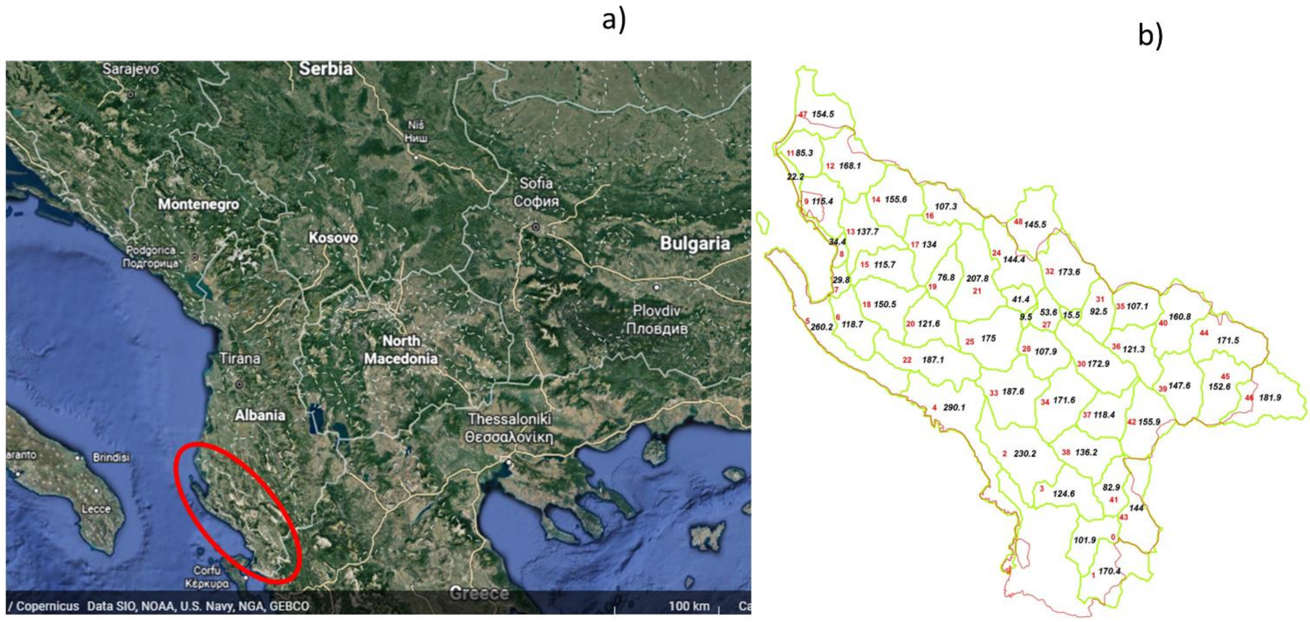

Figure 1. Location of Vjosa River Basin, Albania (a) (*source: Google Earth*); sub-basin divisions (b).

2.2. Description of erosion potential method

EPM is a widely known methodology first designed by Gavrilovic [19] for the estimation of erosion coefficient and for the evaluation of sediment production and transportation.

The methodology was used for the first time in the Balkan area (Serbia and Croatia), followed by studies conducted all over Europe and worldwide [20–24, 26–33]. According to the original description of the method, for the Vjosa River Basin, the following parameters were calculated: the annual volume of soil loss *Wa* (Eq 1), the temperature coefficient *T* (Eq 2), the erosion coefficient *Z* (Eq 3), the actual sediment yield *G* (Eq 4) and the sediment delivery ratio *Dr* (Eq 5). Moreover, the specific eroded sediment *E* per sub-basin of the Vjosa River Basin was calculated as a report of the eroded material and the surface of the sub-basin, expressed in ha. For the assessment of parameters used in Eq 3, the land use coefficient, soil erodibility and active erosion processes, the classification was based on the Zemljic classification system [36]. Equations, followed by detailed description of the data set used to evaluate the Erosion Potential Method, are shown in Table 1.

Table 1. Equations and descriptive variables used in the Erosion Potential Model (EPM).

Equation		Parameter descriptions
1	$W_a = \pi \times S \times T \times h \times \sqrt{Z^3}$	W - the annual volume of soil loss (m^3/year)
		S - the sub-basin area (km^2)
		T - the temperature coefficient (-)
		h - the mean annual precipitation (mm)
		Z - the erosion coefficient (-)
2	$T = \sqrt{\frac{t}{10} + 0.1}$	t - the mean annual temperature (°C)
3	$Z = x \times y \times (\varphi + \sqrt{i_m})$	x - land cover coefficient
		y - soil erodibility
		φ - active erosion processes
		i_m - the mean slope (%)
4	$G = W \times D_r$	G - the real sediment production (m^3/year)
		Dr - the sediment delivery ratio (-)
5	$D_r = \frac{\sqrt{H \times P}}{0.25 \times (L + 10)}$	H - the mean height distance of the basin (km)
		P - the perimeter of the basin (km)
		L - the length of the basin (km)

The application of the Erosion Potential Method was based on data gathered from different field surveys and satellite sources, given in Table 2.

Coefficient of soil erodibility *y* for each sub-basin was determined using the geological maps of 2021 with a scale of 1:650000 (Figure 2) of the Albanian Geological Service, as shown in Table 2.

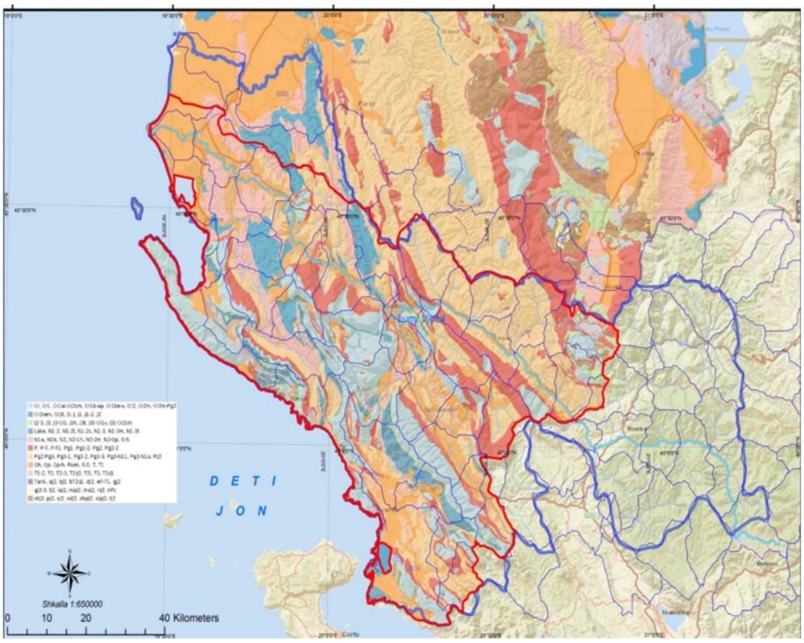

Figure 2. Geological map of the Vjosa River Basin, Albania.

For the evaluation of the land cover coefficient ***x*** (data in Table 2), the CORINE Land Cover (2018) map with a scale of 1:650000 (Figure 3) was used.

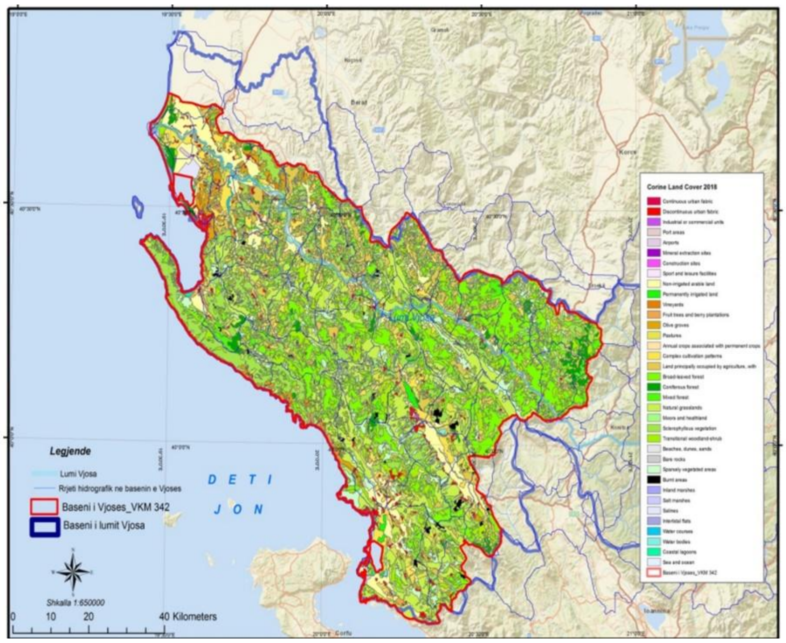

Figure 3. Land cover distribution of Vjosa River Basin, Albania.

The slope map (Figure 4) of the Vjosa River Basin generated by a Digital Elevation Model (DEM) of the Albanian State Authority for Geospatial Information with a DTM cell size of 10 x 10 m was used to evaluate the mean slope of each sub-basin i_m (data in Table 2). The slope for each sub-basin was defined as the ratio between the difference of the extreme quotations (max-min quotes) and the length of the two extreme points under the basin. Since the slope is referred to as a percentage, the upper value is multiplied by 100.

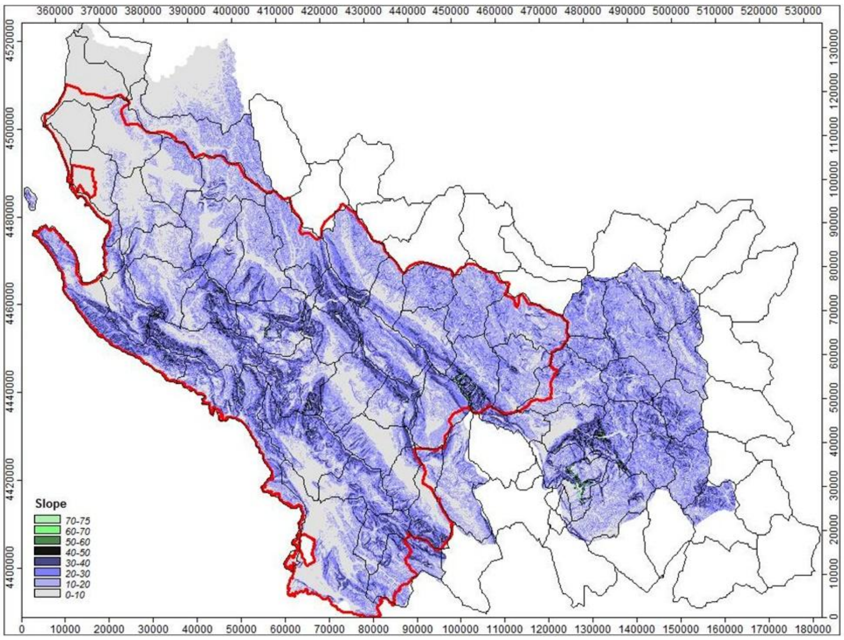

Figure 4. Slope mean in percentage of Vjosa River Basin, Albania.

The mean elevation of the Vjosa River Basin is about 885 m and is derived from the elevation map of the studied area, as shown in Figure 5. The mean elevation of each sub-basin was determined from the minimum and maximum elevations' values extracted by the elevation map.

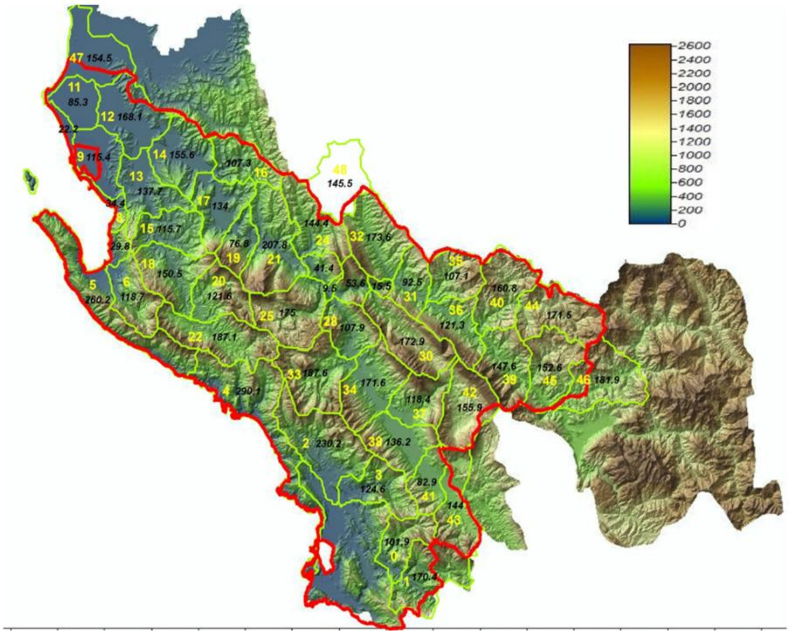

Figure 5. Elevation map of Vjosa River Basin, Albania.

Meteorological data, regarding the precipitation (***h***, mm) and temperature (***t***, °C), were obtained from 11 meteorological stations situated in the area: Brataj, Fratar Kelcyre, Krahes, Kuc, Llongo, Nivice, Permet, Polican, Selenice and Tepelene. For each meteorological station, daily temperature and precipitation data were processed to determine the mean annual value. The mean annual values of the meteorological stations are given in Table 3.

3. Results and discussion

As mentioned previously in this study, a very large dataset comprising the surface and perimeter, the coefficient of soil erodibility, land cover and mean slope and mean elevation for the sub-basins of the Vjosa River Basin was collected and used for the application of the Erosion Potential Method. Detailed information about these parameters is given in Table 2.

Table 2. Values of different parameters needed for the application of EPM in the study area.

Sub-basin	Surface (km^2)	Coef. Of soil erodibility	Land cover coefficient	Mean slope
0	101.9	0.6	0.5	25
1	170.5	0.8	0.7	20
2	230.3	0.8	0.6	15
3	124.7	0.6	0.5	18
4	290.3	0.8	0.7	22
5	260.4	0.1	0.2	28
6	118.8	0.6	0.4	17
7	29.8	0.6	0.4	15
8	34.5	0.4	0.3	15
9	115.5	0.6	0.4	5
10	22.2	0.8	0.6	2
11	85.3	0.7	0.5	2
12	168.3	0.6	0.4	4
13	137.8	0.4	0.3	8
14	155.8	0.6	0.4	10
15	115.8	0.6	0.4	13
16	107.4	0.5	0.3	12
17	134.1	0.7	0.4	14
18	150.6	0.4	0.3	12
19	76.9	0.4	0.3	20
20	121.6	0.4	0.3	24
21	207.9	0.6	0.4	14
22	187.2	0.7	0.5	21
23	41.5	0.6	0.4	16
24	144.5	0.5	0.3	18
25	175.1	0.4	0.3	20
26	9.5	0.4	0.3	19
27	53.6	0.7	0.4	17
28	107.9	0.5	0.3	18
29	15.6	0.5	0.3	16
30	172.9	0.8	0.6	21
31	92.5	0.3	0.3	23
32	173.7	0.3	0.3	24
33	187.7	0.6	0.4	23
34	171.7	0.9	0.5	26
35	107.1	0.5	0.3	22
36	121.4	0.4	0.3	20
37	118.4	0.8	0.6	23
38	136.2	0.8	0.6	21
39	147.6	0.7	0.3	20
40	160.9	0.4	0.2	22
41	83	0.8	0.6	24
42	156	0.4	0.4	21
43	144.1	0.7	0.6	18
44	171.5	0.4	0.2	19
45	152.7	0.4	0.4	18
46	182	0.4	0.3	18
47	154.6	0.6	0.4	2
48	145.6	0.4	0.3	22

The geology of the Vjosa Basin in Albania is part of five geotectonic zones, the largest of which is the Ionian zone. This zone is dominated by sand and gravel alluvial deposits in the river valley, formed by Neogene's deposits composed of sandstone, siltstone, conglomerate and partly marlstone, flysch deposits, karstic calcareous deposits and ultrabasic rock [35].

The mean slope of the area varies between 2 and 28%, where the steeper sub-basin slope belongs to the upper reach, while the low slope is in the lower part for the last 40 km before discharging.

The Vjosa river basin has high ecological values due to the presence of rare flora species. In Albania there is growth of different species, like rare Macedonian fir (Abies borisii-regis), plane trees, willows, maples, linden trees and hornbeams. Another important zone of the Vjora river basin is where salt tolerant vegetation species grow, such as Arthrocnemum fruticosum, Polypogon monspeliensis, Juncus acutus, Juncus maritimus, Agropyron litorale, Tamarix dalmatica and Limonium vulgare.

The climate of the VRB is mainly characterized by mild winters with abundant precipitation and hot, dry summers. Due to the geographical position, the Vjosa River Basin covers different climate zones, including Alpine conditions, without glacials, in the higher altitudes; Mediterranean continental conditions in the highlands; and typical Mediterranean clime for the coastal area. For the 11 meteorological stations of the Vjosa River Basin (Table 3), the mean annual temperature varies from 11 to 17 °C, while for the precipitation, the mean annual values vary between 75 and 200 mm.

Table 3. Average annual temperatures and precipitations of the meteorological stations of the Vjosa River Basin.

Meteorologic station	Brataj	Fratar	Kelcyre	Krahes	Kuc	Llongo	Nivice	Permet	Polican	Selenice	Tepelene
h (mm)	190.2	83.3	114.8	75.9	195	173.2	198.4	109.8	167.7	81.2	11.4
t (°C)	16.1	15.6	15.4	16.2	13.5	14.6	12.6	14.4	11.1	17	16.8

The application of the Erosion Potential Method using all the parameters of Table 2 and 3 gave the following results: the erosion coefficient, the amount of eroded sediment, the sediment delivery ratio, the specific eroded sediment and the sediment yield of the sub-basins. Table 4 present the results obtained for all sub-basins of the Vjosa River Basin from the calculations made according to Eqs 1 and 3 of the Erosion Potential Method. Meanwhile, the results about the specific eroded sediment were obtained as a report of eroded material and the surface of the sub-basins, expressed in ha.

Table 4. Results of the EPM for all sub-basins of the Vjosa River Basin.

Sub-basin	Erosion coefficient Z (--)	Eroded sediment W (m^3/yr)	Specific eroded sediment E (m^3/ha/yr)
0	0.27	86786.5	8.52
1	0.47	338242.6	19.84
2	0.38	423430.6	18.38
3	0.28	144098.7	11.56
4	0.71	583837.4	20.11
5	0.02	1866.75	0.07
6	0.19	34329.45	2.89
7	0.16	6701.8	2.25
8	0.07	2166.9	0.63
9	0.1	12568.75	1.09
10	0.26	10006.75	4.5
11	0.12	11828.65	1.39
12	0.1	16805.05	1
13	0.08	10850.55	0.79
14	0.17	37274.4	2.39
15	0.28	117918.5	10.19
16	0.11	14745.55	1.37
17	0.19	40305.7	3.01
18	0.11	39927.6	2.65
19	0.11	10799.95	1.41
20	0.13	39842	3.28
21	0.19	53987.3	2.6
22	0.44	378983.1	20.24
23	0.19	27632.4	6.66
24	0.12	20369.2	1.41
25	0.13	61734.5	3.53
26	0.12	3295.15	3.47
27	0.23	30029.05	5.6
28	0.14	28767.85	2.67
29	0.14	3996.5	2.57
30	0.46	261423.2	15.12
31	0.08	9985.8	1.08
32	0.08	20334.3	1.17
33	0.19	120224.3	6.41
34	0.5	333346	19.41
35	0.1	16503.25	1.54
36	0.09	15798.65	1.3
37	0.33	121326.8	10.25
38	0.46	233690.9	17.15
39	0.18	46965.05	3.18
40	0.05	8447.7	0.53
41	0.38	117632.9	14.18
42	0.01	43662.65	2.8
43	0.35	178184.5	12.37
44	0.05	8343.35	0.49
45	0.13	31009.1	2.03
46	0.12	33253.05	1.83
47	0.08	12173.4	0.79
48	0.1	25325.1	1.74

The erosion coefficient Z of the studied area varies between 0.01 and 0.71. The lowest value corresponds to sub-basin 42, while the highest corresponds to sub-basin 4. According to the Gavrilovic classifications, the results of Table 4 show heavy erosion (II erosion category) only for sub-basin 4 (Z = 0.71); medium erosion (III erosion category) for sub-basin 1 (Z = 0.47), sub-basins 30 and 38 (Z = 0.46) and sub-basin 22 (Z = 0.44); slight erosion (IV erosion category) for sub-basins 2, 41, 43, 37, 15, 3, 0, 10 and 27; and very slight erosion (V erosion category) for all the other sub-basins. According to these results, erosion in the Vjosa River Basin, is categorized as follows (see Figure 6): 2% heavy erosion, 8% medium erosion, 18% slight erosion and 72% very slight erosion.

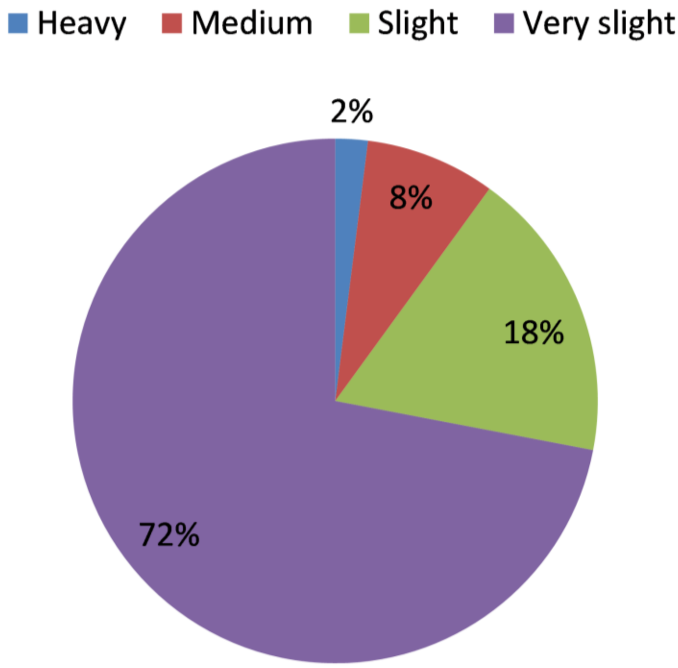

Figure 6. Soil erosion categories according the erosion coefficient Z.

As shown in Table 4, the application of EPM estimated a volume of 4230759 m^3/year of eroded sediment for the Vjosa River Basin. From Table 4 and Figure 7, it is clear that the largest contribution to the annual amount of eroded sediment was given by the volume of sub-basin 4, followed by sub-basins 2, 22, 1 and 34, with these respective values: 583837.4 m^3/year, 423430.6 m^3/year, 373883.1 m^3/year, 338242.6 m^3/year and 333346.0 m^3/year. On the other hand, the smallest contribution to this value was given by sub-basin 5, with 1866.8 m^3/year of eroded sediment, followed by sub-basin 8 with 2166.9 m^3/year of eroded sediment, sub-basin 26 with 3295.2 m^3/year of eroded sediment, sub-basin 29 with 3996.5 m^3/year of eroded sediment and sub-basin 7 with 6701.8 m^3/year of eroded sediment. All the other sub-basins have their contributions, according to the values given in Table 4, to the total amount of eroded material for the Vjosa River Basin.

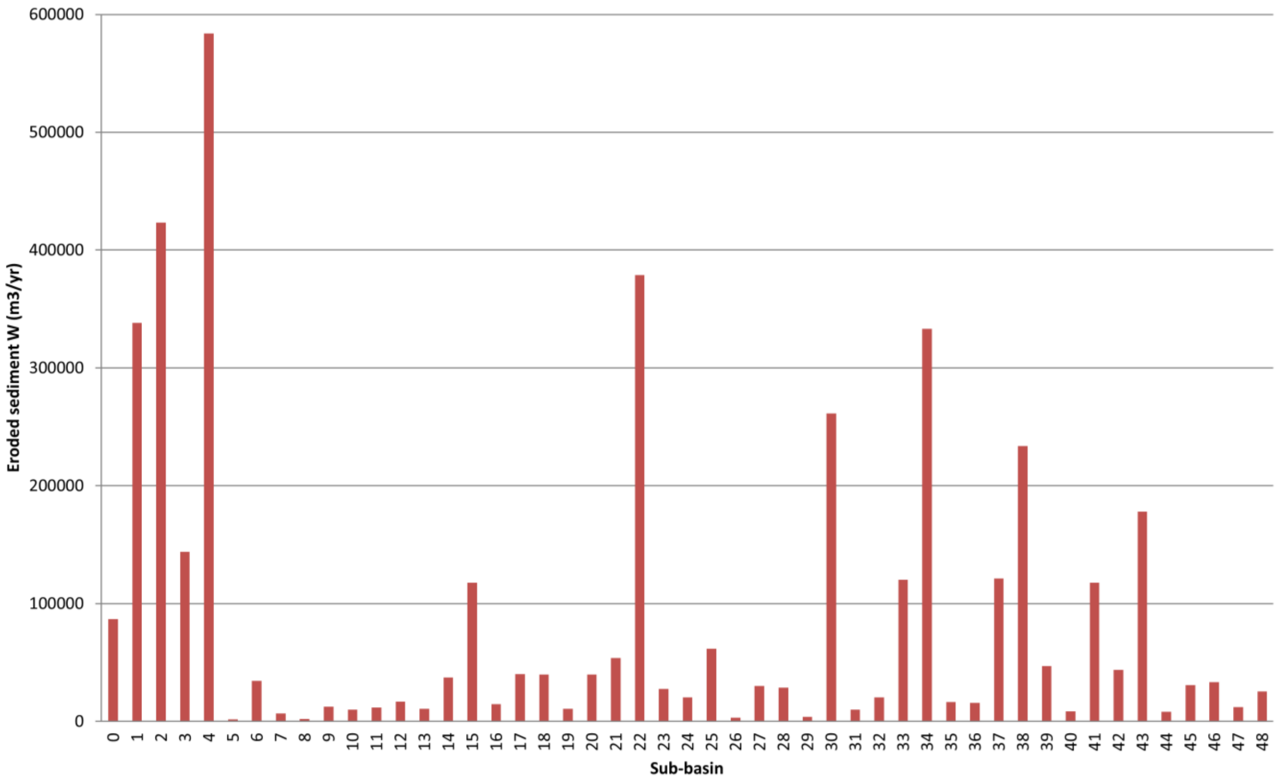

Figure 7. The quantity of eroded sediment W for each sub-basin of the Vjosa River Basin.

Based also on the equation used to calculate the eroded sediment W, the parameters which mostly affect this value are the surface S and the erosion coefficient Z. Sub-basin 4, with the largest amount of eroded material, has the highest erosion coefficient and has the biggest surface (S = 290.3 km^2). According to the sensitive analyses performed by Dragicevic et al. [37], there are two parameters that affect the amount of eroded sediment W, the coefficient of soil erodibility ***y*** and the land cover coefficient *x* (values in Table 2). Sub-basin 4 has the highest value of land cover coefficient (0.7) but not the highest for the coefficient of soil erodibility (0.8). Sub-basin 34 has the highest value of the coefficient of soil erodibility (0.9), but the amount of eroded material is not the largest because this sub-basin has a smaller land cover coefficient and surface compared to sub-basin 4. Sub-basin 5 has the lowest value for soil erodibility (0.1) and land cover coefficient (0.2), as reflected in the result of the eroded material.

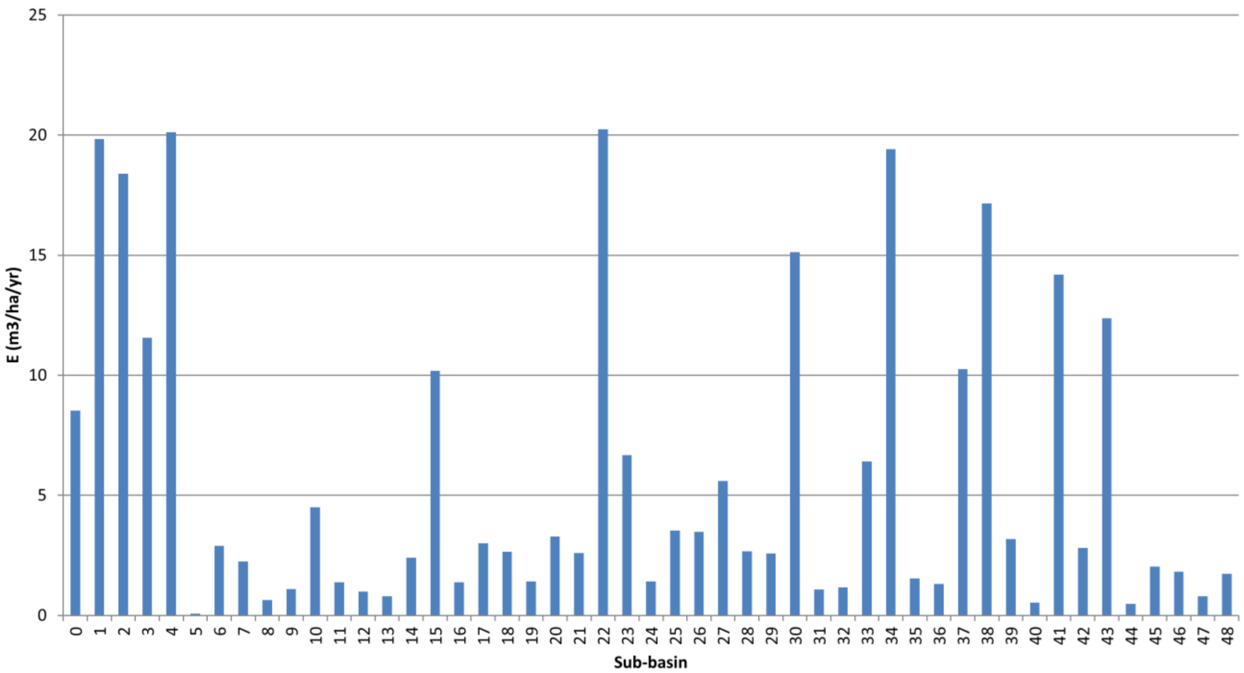

Figure 8. The quantity of specific eroded sediment E for each sub-basin of the Vjosa River Basin.

In this study we calculated also the specific eroded sediment values *E*. As can be seen in Table 4 and Figure 8, sub-basin 22 has the largest amount of eroded sediment per hectare per year (20.24 m^3/ha/year), followed by sub-basin 4 (20.11 m^3/ha/year), sub-basin 1 (19.84 m^3/ha/year), sub-basin 34 (19.41 m^3/ha/year) and sub-basin 2 (18.38 m^3/ha/year). Sub-basin 5 has the smallest amount of eroded sediment per hectare per year (0.07 m^3/ha/year). As explained previously, the specific eroded sediment is calculated as a report of the amount of eroded material and the surface of each sub-basin. It can be seen that the results for the specific eroded sediment (E) are not in the same order as those for the eroded sediment (W), due to the fact that even the surfaces of the sub-basins do not follow that order. Considering the results obtained by the calculations of specific eroded sediment (E) of the Vjosa River Basin, it is evident that the sub-basins 4 and 22 are the only sub-basins with very high erosion risk. Sub-basins 1, 2, 3, 15, 30, 34, 37, 38, 41 and 43 shows high erosion risk, while sub-basins 0, 23, 27 and 33 show moderate erosion risk, and all the other sub-basins show low or very low erosion risk.

Appling Eqs 4 and 5 of the EPM, the sediment delivery ratio and sediment yield were calculated for the entire Vjosa River Basin. The results of these calculation are a delivery ratio of 0.55 and a sediment yield of 2326917 m^3/year. This amount is deposited in different parts of the Vjosa River Basin, mainly in the sub-basins where the land cover coefficient, the altitude above sea level and the pronounced slopes are combined with their highest values.

4. Conclusions

In this study, the application of the Erosion Potential Method was proposed for the Vjosa River Basin, as an appropriate method for the Albanian situation. The Erosion Potential Method provides an estimate of the amount of sediment production, the erosion coefficient, the sediment yield, specific eroded sediment and the erosion intensity and risk. EPM was applied to 49 sub-basins of the Vjosa

River Basin in Albania. The overall sediment production in the Vjosa River Basin is 4230759 m^3/year, the mean specific eroded sediment is 6.53 m^3/ha/year, and the overall real sediment production is 232917 m^3/year. The major contributors in all the results obtained for the sediment production and the real sediment production are the sub-basins 1, 2, 4, 22 and 34. The erosion coefficient Z of each sub-basin was calculated, and it varies between 0.01 (sub-basin 42) and 0.71 (sub-basin 4). According to the Gavrilovic classifications, 2% of the study area shows heavy erosion (II erosion category), with 8% medium erosion (III erosion category), 18% slight erosion (IV erosion category) and 72% very slight erosion (V erosion category).

The Erosion Potential Method is feasible for the area chosen in this study. The application of this methodology can be extended in other country areas that need to be evaluated. Information gained from the results of this study can serve to update the data regarding erosion of the Vjosa River. Further, this information can be used by the national and local authorities to establish new strategies for Vjosa River Basin protection.

Conflict of interest

The authors have no conflicts of interest to declare.

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