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SOIL EROSION IN THE RIVER BASIN ŽELJEZNICA, AREA OF BAR, MONTENEGRO

SUMMARY

According to the recently adopted general plan of protection against the harmful effect of waters for the period 2011–2017, the territory of the Municipality of Bar is a typical torrential area, with annual precipitation up to 2,000 mm. The conditions of pronounced slopes, as well as the specific geological and hydro-geological properties of the area, and the zone of the municipality between Mt. Rumija and the sea, in particular, result in a large number of quite pronounced torrents.

This paper presents part of the results of research on erosion processes in the coastal area of Montenegro for the region of Bar, which is intersected by several torrential watercourses, of which the most significant one is the Željeznica, which with its tributaries Rena and the Rikavac, flows through the very centre of the city and has a large influence on the use of the surrounding land.

The factors causing soil erosion, erosion forms and expansion and measures to protect against erosion and torrents were studied. Finally, the intensity of soil erosion and runoff for the basin of the River Željeznica was calculated using the computer-graphic method IntErO. The analyses indicated that there is a possibility for large flood waves to appear in the Željeznica river basin. According to Gavrilović classification, the value of the Z coefficient, 0.949, and the value of 1899 $m^3/km^2/year$ indicate that the river basin belongs to the category II destruction class. The strength of the erosion process is high. The findings indicate that it is a region of strong erosion.

Keywords: Soil erosion, river basin, water permeability, land use, precipitation, soil losses, deposition, runoff

INTRODUCTION

According to Lazarević (1996), Kadović (1999) and Spalević (2011), water and karst erosion have affected 13,135 km^2 or 95% of the total territory of Montenegro (13,812 km^2). Alluvial accumulation characterises the remaining area. Water erosion is the dominant form in terrain with high slopes due to complex physical and geographical conditions and reckless logging, which commenced in the time of the Venetian Republic (Đorović, 1975).

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The extent and the distribution of erosion depend on the specific pattern of physical and geographical factors. The major drivers of water erosion are intense rainfall, topography, low soil organic matter content, percentage and type of vegetation cover, inappropriate farming practices and land marginalisation or abandonment (Vukelic-Shutoska et al., 2011).

Bar encompasses a large area (598 km^2), but it is a complete natural entity in terms of geomorphology and climate. It spreads from the coast to the tops of Mt. Vrsuta (1,183 m), Mt. Rumija (1,595 m) and Mt. Lisanje (1,353 m). The river basins of Rikavac and Željeznica account for about 70 km^2.

Most of the study area is hilly-mountainous terrain, consisting mainly of Eocene flysch sediments in the lower and the central zone and of Triassic and Jurassic limestone, with plenty of detritus and traces of hornstones and other silicate ingredients in the central and higher zones.

The area is characterised mainly by crumbling geological substrate, which is prone to disintegration, and hilly and mountainous terrain strongly intersected by watercourses, with very pronounced relief dynamics at the water-source zones of the Rikavac, the Željeznica and their tributaries. This area is also characterised by high rainfall in the autumn–winter period. In many areas, the vegetation is very scarce or significantly denuded due to earlier intensive denudation. Under such conditions, intensive erosion has occurred, the extent of which has depended on the use of the land and on the status of the vegetation cover.

The dominant erosion form in this area is surface runoff, but more severe forms of erosion, such as rills, gullies and ravines, also occur frequently. The eroded soil becomes compacted and lacks a sufficient amount of nutrients and organic matter. The infiltration rates and water-storage capacity of the soil profile are reduced, and this, in turn, increases the overland flow and the erosion (Ristić et al., 2012). The erosion activities affect a large area of agricultural and forest land, in addition to roads and various commercial facilities and settlements. T he damage is vast and incalculable. The erosion has resulted in the loss of fertile land, the formation of patchy bare ground and the deposition of sterile alluvial deposits on fertile soils. It has also resulted in torrents, which have flooded roads and interrupted travel.

The purpose of this paper is to highlight the factors that trigger the erosion processes and to identify ways in which these can be alleviated; we also aim to illuminate the distribution of erosion forms and the harmful effects of this erosion, which is hindering the economic development of Bar.

MATERIALS AND METHODS

This research was funded by the Ministry of Science of Montenegro. Fieldwork was undertaken to collect detailed information on the intensity and the forms of the soil erosion, the status of the plant cover, the type of land use and measures contributing to the reduction or the alleviation of the erosion processes.

Morphometric methods were used to determine the slope, the specific lengths, the exposition and form of the slopes, the depth of the erosion base, the density of the erosion rills, the degree of rills and other relevant parameters.

Figure 1. Study area

We drew on the earlier pedological work of the Agricultural Institute in Podgorica (today, the Biotechnical Faculty) led by Đuretić, Fuštić who analysed the physical and chemical properties of all the Montenegrin soils during 1964 to 1988 including those in the study area. Furthermore, some pedological profiles were opened again in the last five years, and soil samples were taken for physical and chemical analysis. The granulometric composition of the soil was determined by the pipette method; the samples were prepared using sodium pyrophosphate. The soil reaction (pH in H_2O and nKCl) was determined with a potentiometer; the total carbonates were determined by the volumetric Scheibler method; the content of the total humus was determined by the Kotzman method; easily accessible phosphorous and potassium were determined by the Al-method and the adsorptive complex (y1, S, T, V) was determined by the Kappen method.

Many authors have discussed the possibility of using personal computers to develop thematic maps for use in landscape planning (Janjić et al., 1991). The importance of system-scale detection of erosion and deposition in assessing the transferability of findings from scaled laboratory and small field studies to larger spatial scales has also been emphasised (Stuart et al., 2003). Additionally, the use of computer-graphics methods in research on runoff and the intensity of soil erosion has been demonstrated in Montenegro (Spalević et al., 2007, 2007a, 2004, 2001, 2000, 2000a, 1999) and that methodology was used in the research on the Željeznica river basins of Bar.

There are a number of empirical valuation methods that may contribute to that assessment. These methods involve several steps: data acquisition, model specification and estimation (Madureiraa et al., 2011). We used the program package **Int**ensity of **Er**osion and **O**utflow - IntErO (Spalević, 2011) in this research. This program is an integrated, more modern second-generation version of the program „Surface and Distance Measuring" (Spalević, 1999) and the program "River basins" (Spalević, 2000). We used this program to obtain data on forecasts of maximum runoff from the basin and the intensity of the soil erosion.

RESULTS AND DISCUSSION

Physical-geographical characteristics and erosion factors

Position and relief. The area of Bar under research is located from the Bay of Bar to the tops of Mts. Rumija, Lisinja and Vrsuta, and belongs mainly to the basis of the Rikavac and the Željeznica. In lower elevations, steeper terrain rises from the coast only along the hill of Volujica (228 meters above sea level). The rest of the area under research is located in the Barsko polje (Bar Field) and the level terrain along the river Željeznica.

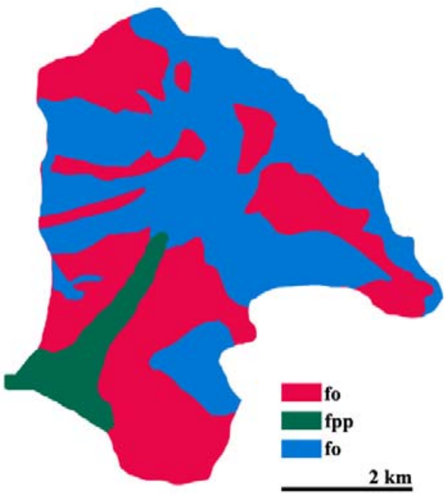
The plain continues with mild slopes with terraces and olive groves, with steep and very steep slopes of surrounding mountain massifs occurring occasionally. The rounded relief forms with terraces are situated at the borders of the Barsko Field from Zaljevo to Sustaše, in Jankovići and Zupci. There are not many places along the Montenegrin coast that are as steep and as broken as the area above the Old Bar to the tops of Mts. Rumija and Lisinja.

The Rikavac and its tributaries Vruća River and the Bunar, as well as their own tributaries have intersected this part of the area to such an extent that it is still inaccessible and without the roads. The watercourses break through shorter and longer gorges from the villages of Turčini, Mali and Veliki Mikulići, situated in the zone of flysch sediments and faults, all the way to the Old Bar. In the basin of the Željeznica, the steeper slopes can be found around its source, below Sutorman, around the source of its tributaries Banduka and Velja river and other occasional watercourses collecting the water from below the tops of Čukurel (1119 meters above sea level), Široka strana (1185 meters above sea level), Kunor (999 meters above sea level), Čorotaj (976 meters above sea level), Čugagolin (1297 meters above sea level), Mala Rumija (1468 meters above sea level) and Velika Rumija (1595 meters above sea level).

The relief of the hilly-mountainous terrain in the area of Bar is characterised by many steep slopes from which the water runs off and flows quickly, which is favourable for triggering the soil erosion process.

The ridges of Mts. Rumija and Lisinje, as well as those between them - Kulumrija, Kunteljat, Mrljika, Buval, Mukoval and others have become completely denuded, which is also the case in the gorges of the watercourses. From such areas, absorption of rainfall waters is minimal; the water runs off quickly into the watercourses, causing strong torrents.

The Montenegrin coastal zone is a narrow strip (max. 15 km in width) bordering the Adriatic Sea, with alternating sedimentary and volcanic rocks and areas of limestone and dolomite (Radulović and Radulović, 1997). In the geological structure of the area under research, according to Mirković et al. (1978), in addition to the quaternary sediments, there are large areas of limestone from the Triassic, Jurassic and Cretaceous periods, which, together with dolomites, are pure only in the highest ridges of the Mts. Rumija and Lisinje. In other, lower parts, they are accompanied by marl and breccias limestone, followed by hornstones, marl and rarely sandstone.



fp: *very permeable rocks;*
fpp: *medium permeable rocks;*
fo: *poor water-permeable rocks*

Figure 2: Structure of the the river basin according to the permeable products from rocks

The flysch formations of the Triassic period where sandstone, marl and claystone can be found occur from Šušanj to Zupci, below Sutorman, around Tudjemil, from Sustaše to the Old Bar and around Ljumetići and Veliki Mikulići.

Eocene flysch is most frequently found along the borders of the Barsko Field, from Šušanj to Dobre Vode, from Tudjemili along the valley of the Velja river to the Markov Kamen and from Mali Mikulići to Dobri Do and Veliki Mikulići and around Velembus.

Eruptive andesite rocks occur occur occasionally from Gornji Šušanj to the Željeznica and Crni Krš, and only as small patches along the valley of the Velja river.

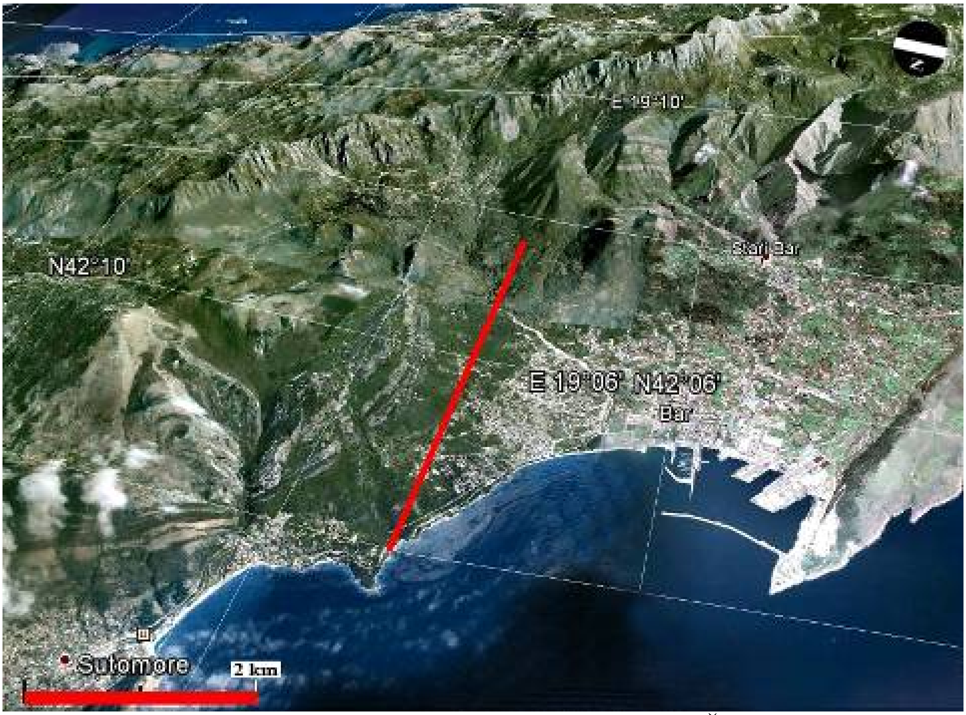


Figure 3: View of the City Bar and River Basin Željeznica

Figure 4: Cross-section Ratac – Zupci

Quaternary sandy-gravel sediment fills the Barsko Field, while detritus (rock creep, scree) is numerous and frequent under the Sutorman and Rumija and at the south-western side of the Lisinje, where there are numerous gullies and ravines.

The diverse composition of the geological substrate and the soil formed on this substrate, are not, for the most part, resistant and are prone to erosion where the area is not protected by adequate vegetation cover. In places where the terrain is free from vegetation, runoff is intensive. This terrain is also characterised by the formation of rill erosion, gully erosion and other forms of deep erosion. The arrival of torrents erodes the very substrate and results in fretting away, causing frequent slides of the soil and the substrate. The deep erosion occurs most frequently in the flysch terrain and in areas containing loose detritus material, such as those on the slopes of Lisinje. The intersection of gullies and ravines is quite frequent in the limestone substrates, particularly on the slopes.

Climate: Mediterranean countries are especially vulnerable to desertification, as they have to deal with a highly variable climate and human pressure on the land (Beguería et al., 2008; White et al., 1997). The climate of Bar is determined by the proximity of two large water areas (the Adriatic Sea and the Lake of Skadar) and the Rumija mountain massif. It is characterised by long, warm and dry summers and mild and rainy winters. The mean monthly maximum temperatures in July and August are 23.3°C, and the minimal temperature in January is 8.8°C.

Basic data on Bar's climate needed for calculation of soil erosion intensity and runoff are presented in the Table l and 2.

Table 1. Mean monthly temperature and mean monthly precipitation for the period 1948–2012 (°C)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Bar	8.8	8.9	10.2	12.4	17.6	21.1	23.3	23.3	20.1	15.9	14.3	11.5	15.6

Table 2. Maximal monthly precipitation in a 24 h period for 1948–2012 (mm)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Max 24 h	181	157	81	80	114	78	87	122	224	88	135	136	1483

The level of torrential rain (hb) was 123.5 mm. The average annual rainfall was in the range of 1,391. The standard deviation for the average annual rainfall was 234 mm. The maximum annual rainfall was 1,862 mm; the minimum annual rainfall was 948 mm.

All climatic elements are relevant for occurrence of erosion and rainfall brought by southern wind in particular. Petković (1995) concluded that the structure of annual precipitation and runoff plays a very important role in the process of production of erosion material in smaller basins. More intensive rainfall, corresponding to higher daily quantities, cause significant erosion production of material in the basin. On the other hand, torrential watercourses, caused by intensive rainfall in the basin play a fundamental role in the annual transport of sediment. The annual precipitation sum (Bar 1489 mm) is growing from the sea towards the Mt. Rumija and other mountains and the Lake of Skadar (Virpazar, 2311 mm).

Rainfall distribution is not even, as most of it falls from September to April (133-186 mm by months). For the rest of the year, the quantities are significantly lower. However, the characteristic is heavy rainfall that lasts for several days and the showers in particular, which in both cases is favourable for erosion and torrential floods. The rain with strong intensity and their destructive power can to some extent be illustrated by the information that on September 2 and 3, 1990, 227 mm of rain fell over 24 hours in the Old Bar; in one hour only, 117 mm/m^2 of rain or 1.95 mm/min fell on that occasion. Such rainfall is very dangerous due to sudden runoff and soil erosion.

Vegetation. Recent studies discuss (Brandt and Thornes, 1996; Geeson et al., 2002; Hill et al., 2008; Hooke, 2006; Kosmas et al., 1997; Le Houérou, 1989), and sometimes question (Butzer, 2005; Grove and Rackham, 2001), the magnitude of land degradation and desertification in the Mediterranean basin, the human responses, and the linkages with land use and cover (LUC) changes. Vegetation plays and important role in improving the soil quality, reduction of runoff and reduction in loss of soil (Zha et al. 1992; Tompson et al. 2005), that is, in increasing the infiltration capacity and reduction of soil erodibility (Zigler and Giambelluca 1998; Bochet et al. 1999). It alleviates the destructive force of rain drops and their effect on soil. Plants pose an obstacle to the flow of water down the slope, so more water is absorbed by the soil, and one part of it is used by plants for their own needs. Thus, less water runs off the slope, and in such cases it usually does not cause erosion and it reaches brooks and rivers clear (Šarić, T. et al. 1999).

The most widespread forests on this area (Mijović, 1998) are thickets of manna ash (*Fraxinus ornus*), oriental hornbeam (*Carpinus orientalis*), downy oak (*Quercus pubescens*), hop hornbeam (*Ostrya carpinifolia*) and turkey oak(*Quercus cerris*). They are followed by the coppices of downy oak, turkey oak, hop hornbeam and oriental hornbeam. The coniferous trees account for about 20% of the area and the species present include Aleppo pine (*Pinus halepensis*), Black pine (*Pinus nigra*), Maritime pine (*Pinus pinaster*) and Cypress(*Cupressus sempervirens*). High forests include also smaller areas of degraded beech forests, forests of Turkey oak and Downy oak with older cultures of Aleppo pine and Cypress.

The total share of deciduous trees in state forests (Turkey oak, Downy oak, beech, manna ash, oriental hornbeam, locust and other) in the total wood volume is 78%, while coniferous trees make 22% of the total volume. In forests with proprietary rights deciduous species are present, while coppices of Downy oak, Turkey oak and Hop hornbeam prevail.

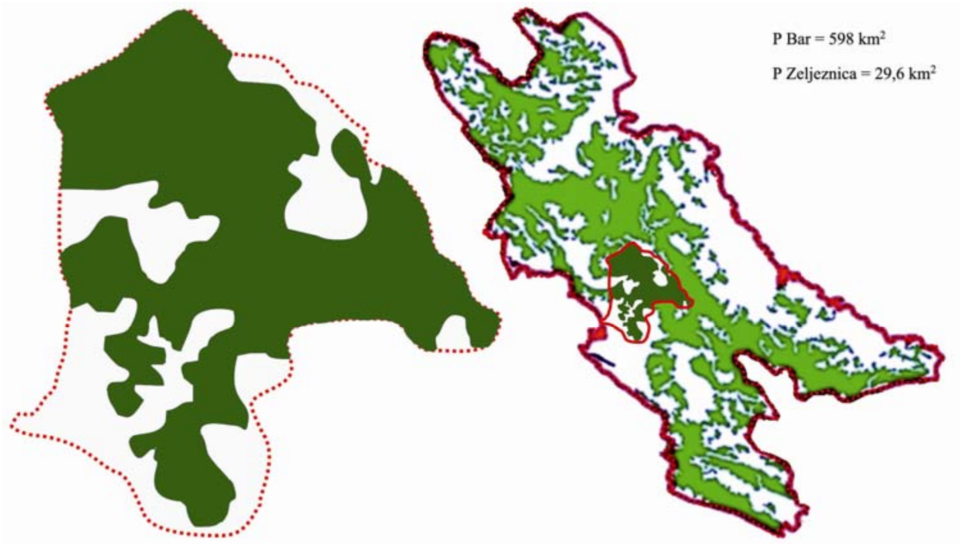


Figure 5: Land cover – forests in the studied area

The land cover data were derived from satellite imagery. Figure 5 indicates the amount of land cover with forests in the area of Bar and in the watershed of the River Željeznica. These data, together with official statistics from the MONSTAT (Statistical office of Montenegro) were used to characterise the watershed, evaluating the intensity of runoff and soil erosion.

In the Rikavac and Željeznica basins, low forests, thickets and pastureland prevail. The forests are mainly of low density and degraded in many places, so their protective role has been reduced. Runoff and gullying, characteristic of this region with its bare ground and pastures also occur in the forest–thicket zone. The denuded vegetation cover has no protective function, with resulting surface runoff and more intensive gullying and torrent erosion. In the study area, this can be seen at the source of the Velja and Vruća rivers, in particular, around the Markov Kamen, then above the Mali and Veliki Mikulići, around the Dobri Do and below the Srednji Vrh (1,292 m). Gullying here is often accompanied by landslides and rock falls in Mali and Veliki Mikulići, Tudjemili, Lumetići and Turčini. Reforestation with black pine was carried out before in the study area around Markov Kamen, Dobri Do, the southern slopes of Djerinac and elsewhere. This has alleviated the erosion processes in some parts. Reforestation with black pint had a major positive effect in the district of the village Stari Zupci, resulting in the development of a natural forest-thicket. This process was supported by reduction in livestock numbers in this region.

The northern slopes of the Djerinac and the southern slopes of the Sutorman, from Tudjemil and Zupci to the rocky ridges of the Mt. Rumija, are covered by a good forest canopy and thickets. Therefore, they are subject to only sporadic erosion. There are numerous gullies at the west side of the Kneževo hill. The Gradac hill and Crni Krš are almost completely bare; the same situation is found on the highest limestone ridges of the Rumija, Plat, Mala and Velika Vrsuta. Below these ridges and cliffs generated by faults, the vegetation is scarce and changes into the forest-thicket at the base. Therefore, erosion processes are quite pronounced.

Olives dominate the periphery of the Barsko Field, where the terrain is terraced, while the terrain not in terraces is either under forest or thicket. Such vegetation cover and meadows between and within the olive grows provide good protection of the soil against erosion. Thus, deep forms of erosion are rare here, and runoff is less pronounced, except in some smaller ridges around Velembus, Sustaše and Velji Brijeg.

Soils: The fact that soil properties always have an effect on the intensity of erosion has been generally accepted and confirmed in the work of Baver (1972), Lazarević (1975) and Pavićević (1968), among others. Those studies paid particular attention to the types of soil and their properties, with particular focus on their propensity towards erosion.

The soil cover of the area of Bar is quite heterogeneous. According to Djuretić et al. (1966) and Fuštić et al. (2000), alluvial talus soils dominate the Barsko Field. These are replaced by Terra Rossa and brown soils in the Volujica, formed on various substrates, while limestone-dolomite Cernozem occurs in limestone ridges and slopes of Lisinje, Rumija, Sutorman and Vrsuta, with detritus also in Rendzina soils.

Brown soils (cambisols) are most frequently found in the hilly-mountainous area of Bar, where the erosion process is the most intensive. These soils are largely on the flych and limestone substrate that have been significantly silicified (hornstone, claystone, breccia and similar) with marl and other ingredients. Thus, they are containing a larger share of silt and clay and exhibit lower water permeability. As a result of such features and properties, when humid they swell, disperse and are prone to runoff after each rain event. As they are situated on an impermeable substrate, their ability to accumulate and retain water is small, except in terraces, milder slopes and under-preserved vegetation. Fast runoff of water on the surface and strong gushes cause runoff and the formation of rills, gullies, ravines, torrents and landslides.

The limestone dolomite Cernozem and Terra Rossa are mainly shallow soils, quite loose in the surface layer. As a result, they are not able to retain a large quantity of water following abundant rainfall. For that reason, those soils are prone to eolic and water erosion. The strong north wind quickly dries the soils and strong showers rinse them off the surface quickly. In this way, the shallow layer of the soil disappears, and the terrain becomes a rocky and bare area without soil or vegetation, which is typical not only of the area of Bar, but the Montenegrin coastal area as a whole.

The alluvial talus soils of the Barsko Field and the lower elevations of the watercourse valleys are prone to relocation, particularly at times of torrential activity when large amounts of erosion deposits are produced. The regulation of the Rikavac and the Željeznica has slowed down these watercourses and protected the soil. As a result, the soils along their banks have been cultivated intensively.

Erosion forms and distribution: Water-induced soil erosion is the result of the complex effect of a whole group of factors. In their research, Baver (1972), Martinović (1974), Lazarević (1975), Ćirić (1975), Zaslavskӳ (1979), Čurović et.

al. (1999), Spalević et al. (2000a), Fuštić and Spalević (2000), Spalević et al. (2001) and Spalević (2011) showed that the erosion intensity is always influenced by the properties and the use of soil, increasingly so in the anthropogenous period of their evolution. Over the last thirty years, anthropogenic factors have significantly increased the pressure on agricultural and on forest land, leaving behind only scarce vegetation, which eventually results in serious degradation and loss of fertile soil (Lee at al., 2006).

The coastal zone has recently experienced intensive tourism. Bar has become overcrowded and building has occurred on the steep hill slopes, which has had an impact on agriculture, the availability of groundwater and the environment in general (Nyssen et al., 2012). Many other factors have influenced the development of erosion processes in the territory of Bar. As a result, there are very few locations in Montenegro with such extensive erosion.

Massive surface runoff of soil results in denudation of slopes, followed by the occurrence of numerous gullies, ravines and landslides. Surface or runoff erosion has taken place in all the soils on the slopes, with the effect that this erosion is most pronounced on the steep slopes with scarce or denuded vegetation cover.

The steep slopes in the hinterland of Bar, the low resistance of the soils and substrate free from vegetation facilitate fast runoff when it rains and provide a favourable setting for putting erosion material into motion. This contributes not only to surface erosion, but also to deep forms of erosion. Such erosion is typified by the bare ridges and the slopes in the Lisinje, Mrljika, Buvalo, Mukoval, Trolj, Kulumrija and Kunteljat regions and on the highest ridges in the Rumija, Sutorman and Vrsuta regions. Rock creep is present in these locations, as well as pronounced erosion. The renewal of soil in such terrain will be a long-term process.

The renewal of soil and vegetation in the study area will be slow because of quite developed rill erosion in the flysch terrain, where, in addition to the soil, a part of the geological substrate more than ten metres in depth has been removed. Such terrain can be found in the village of Ljudjemili, in the river source basin of the Velja and Vruća rivers and around Male and Velike Mikulice. To support faster renewal of the vegetation and slow down the erosion processes, biological protection measures need to be applied, together with technical ones, notably by using shoulders and ditches to partition water fluxes at the land surface. These would prevent fast runoff and transport of erosion material. They would further support reforestation and the renewal of grass, shrubs and trees.

The expansion of ravines in the village of Tudjemili is accompanied by rock falls and landslides; these affect part of the arable land from the adjacent terraces on the right bank of the Velja River. Bar to Sutorman-Virpazar road is endangered by the erosion deposition during the torrential flows of the Velja River. No protection measures have been undertaken at this location so far, despite the fact that the erosion processes endanger an area of about 20 ha. The application of both technical and biological protection measures is necessary for this site.

The intensity of erosion and the percentage of affected areas are given in Table 3.

Table 3. Distribution of erosion in the area of Bar

Power of destruction	Erosion process intensity	Area
I	Excessive	13%
II	Strong	35%
III	Medium	24%
IV	Low	15%
V	Very low	13%

Measures of protection against erosion and floods. Effective soil and water conservation programmes require the concentration of resources on limited areas (Vrieling et. al, 2006). Reforestation with black pine in the river source area of the Velja and Vruća rivers and the Rikavac (elevation 562) contributed to reduction or alleviation of erosion activity in some areas. However, erosion is still quite pronounced in the mountain pass close to the road Bar-Sustaši-Mali and Veliki Mikulići. To the north from the elevation 562, ravines and gullies are up to ten meters in length. They are somewhat less pronounced around the water source Kucino, to the south-east from Dobri Do towards the Veliki Mikulići village. Many ravines and gullies have intersected the flysch sediment and detritus and they can be found also in the area from Ljuti Krš to the highest tops of the Mt. Rumija (1595 m). In this part of the terrain, the eastern slopes are made of laminated marl and breccia limestone, the terrain is dotted with oak trees, but, due to strong erosion processes, in some parts the terrain has developed into the bare rocks.

The hydrographic network of the area consists of the rivers Željeznica, Rikavac and Rena.

The Željeznica flows in the north-western part of the Barsko Field. The waters of numerous water sources and brooks flowing down from Vrsuta, Sutorman and Rumija flow into this river. The most significant and the largest tributaries are the Velja river, 4.6 km in length, Dumezića brook and the Rena, which, after regulation, became a tributary of the Željeznica.

Figure 6: Floods caused by river Rena on January 25, 1955

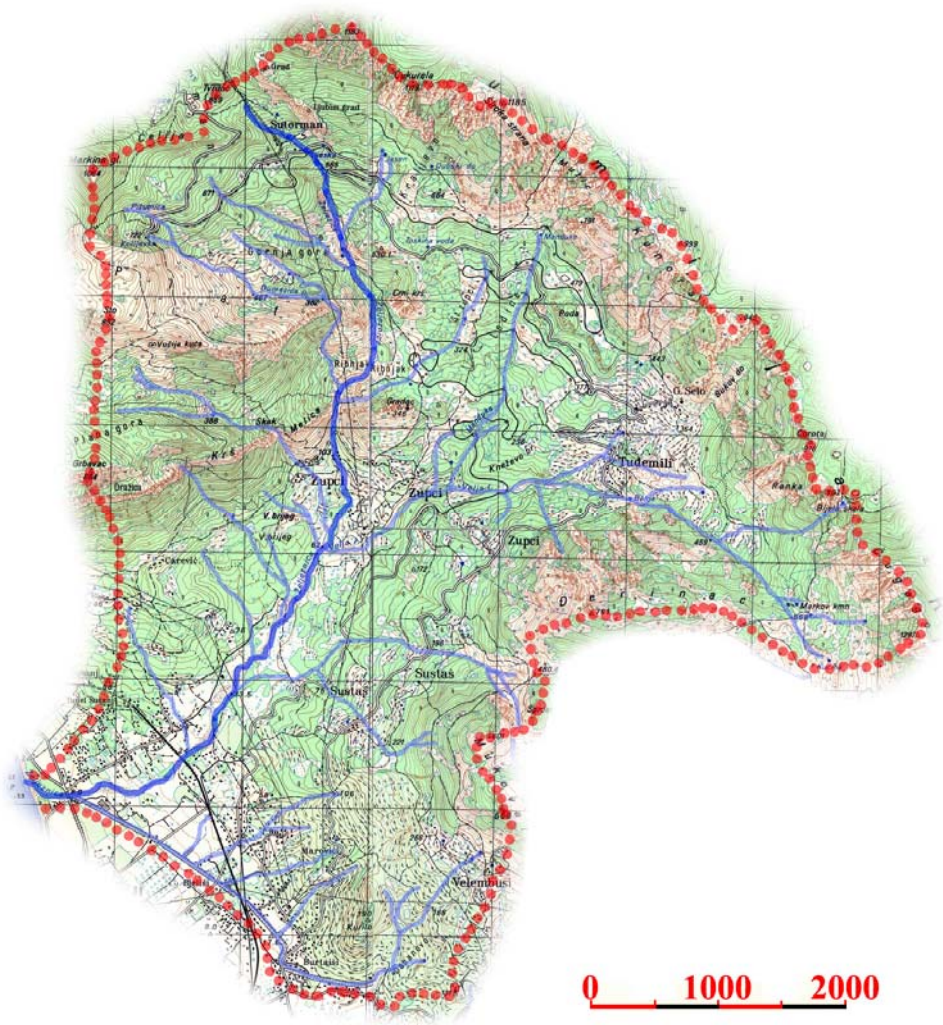


Figure 7. The Željeznica river basin

In the upper part of its basin, the Željeznica and its tributaries, in particular, the River Velja, have steep riverbed slopes. They flow through flysch and karst sediments and limestone formations that the Željeznica has carved a small gorge into above the village of Zupci.

A very dynamic and broken relief with many steep slopes, which are the result of the warping of geological layers, as well as intensive degradation and denudation of the substrate and the soil, facilitates the occurrence and development of torrents. The torrents carry the erosion material down and deposit it along along the valleys' slopes, mainly in the Željeznica valley in the village of Zupci to the mouth.

Figure 8. The village of Zupci, showing the upper part of Željeznica river basin

Large blocks of rocks can be found in the river bed, which shows the great energy of this river. Downstream of the confluence with the Velja river, the Željeznica has carved out a bed in the porous and sandy material. In some places, the bed is as wide as 150 metres as a result of meandering and relocation of the bed. During times of high water levels, this river moves significant quantities of erosion material into the surrounding land in the valley.

The regulation of the Željeznica bed was undertaken in response to strong torrential flows, floods and danger to the existing buildings. According to Zdravković (1996), the regulation was done in phases, first along the Belgrade–Bar railway line and then along the main road from Bar to Ulcinj. The work included covering the bottom and the sides of the bed (with broken stone in cement mortar), constructing chutes, cascades, downstream aprons and retention compartments, which were built about 400 metres upstream from the bridge on the Belgrade–Bar railway. No work was undertaken in the zone where the river flows into the sea.

The Rikavac develops from the rivulet Bunar and Majelika that flows into it under Buval hill. The source of the Rikavac consists of several brooks flowing under the Mala Rumija, above Mali Mikulići. These flow through smaller gorges to Old Bar. The Rikavac watercourse has been integrated into the structure of the settlement it flows through, from Old Bar to Polje.

The source of the Vruća river, the left and the largest tributary of the Rikavac, is in the flysch under the Rumija. Downstream from the Veliki

Mikulići, it flows through limestone and dolomites in a deep gorge 400–800 m long. The Rikavac is 9.4 km, and the tributaries to the Vruća river are 7 km. The beds of both rivers, as well as their tributaries, are quite steep in the area around the Old Bar, often with rapids and cascades, so their narrow beds are quite deep.

The terrain is similar to that of the Željeznica, but the slopes are even steeper and include broken relief and substrate and soil that are not resistant and, therefore, prone to erosion, resulting in very strong torrential activity. In addition to the mechanical erosion, which produces an enormous quantity of erosion material in the Rikavac Basin, chemical erosion of the underlying carbonate rocks is quite pronounced.

The works on the Rikavac were carried out on several occasions since the 1950s, but their extent has not been sufficient to significantly alleviate the erosion processes, particularly around the water source and in the central part of the basin. Most of the works were carried out in the lower part of the flow, downstream the Old Bar, where the regulation of the bed across the Barsko Field and the tunnel through the hill of Volujica (1,150 m in length) moved the point where it flows into the sea from the Pristan into the open sea. As a result, the erosion material is no longer spread throughout the Barsko Field by floods, which used to occur regularly before the draining of the marsh pond (that Bar is named afterr), the construction of the Port of Bar and the urban settlement.

Zdravković (1996) underlined that in the lower part, in the section from the Bridge of Mijovići to the Tunnel (520 m), the Rikavac is fully regulated. In the section from the Bridge of Mijovići to the main Bar–Ulcinj road, steps were taken to protect the slopes of the bed (covered). Five cascades were built, as well as a number of consolidation cross-ties. However, over time, all these measures have been significantly damaged by high waters.

The bed of the Vruća river was regulated by constructing a concrete bed (520 m in length) to protect the Primorka plant.

In the upper part of the basin, four antierosion compartments (all made of stone in cement mortar) were built on the Rikavac and the Vruća rivers, 2–5 m in height, but currently, all of these are filled with erosion material. The lateral foundations of two compartments have also caved in.

We used the software IntErO to process the input data required for calculation of the soil erosion intensity and the maximum outflow.

(A)symmetry coefficient (0.84) indicates that there is a possibility for large flood waves to appear in the river basin.

The value of the G coefficient was 1.69. This indicates that there is high density of the hydrographic network. The value of average river basin decline was 28.72%. This indicates that in the river basin prevail steep slopes. The value of the Z coefficient was 0.949; the real soil losses per square kilometre per year were 1899 $m^3/km^2/year$. According to Gavrilović classification this indicates that the river basin belongs to the category II destruction class. The strength of the erosion process is high. The findings indicate that it is a region of strong erosion.

A complete report for the Željeznica river basin is presented in Table 4.

Table 4. Part of the IntErO report for Željeznica river basin

Input data:	**Symbol**	**Value**	**Units**
River basin area	F	29.57	km²
Natural length of the main watercourse	Lv	7.62	km
The shortest distance between the fountainhead and mouth	Lm	5.72	km
The total length of the main watercourse with tributaries	ΣL	49.84	km
River basin length measured by a series of parallel lines	Lb	9.9	km
The area of the bigger river basin part	Fv	21.03	km²
The area of the smaller river basin part	Fm	8.54	km²
The lowest river basin elevation	Hmin	0	m
The highest river basin elevation	Hmax	1297	m
A part of the river basin with a very permeable rocks	fp	0.48	-
A part of the area consisted of medium permeable rocks	fpp	0.08	-
The area consisted of poor water permeability rocks	fo	0.44	-
A part of the river basin under forests	fs	0.49	-
The area under grass, meadows, pastures and orchards	ft	0.25	-
Bare land, plough-land and ground without grass vegetation	fg	0.26	-
The volume of the torrent rain	hb	123.5	mm
Average annual air temperature	t0	15.6	°C
Average annual precipitation	Hgod	1391	mm
Types of soil products and related types	Y	1.2	-
River basin planning, coefficient of the river basin planning	Xa	0.7	-
Numeral equivalents of visible erosion process	φ	0.59	-
Results:	**Symbol**	**Value**	**Units**
Coefficient of the river basin form	A	0.65	-
Coefficient of the watershed development	m	0.4	-
Average river basin width	B	2.99	km
(A)symmetry of the river basin	a	0.84	-
Density of the river network of the basin	G	1.69	-
Coefficient of the river basin tortuousness	K	1.33	-
Average river basin altitude	Hsr	405.76	m
Average elevation difference of the river basin	D	405.76	m
Average river basin decline	Isr	28.72	%
The height of the local erosion base of the river basin	Hleb	1297	m
Coefficient of the erosion energy of the river basin's relief	Er	177.04	-
Coefficient of the region's permeability	S1	0.69	-
Coefficient of the vegetation cover	S2	0.75	-
Energetic potential of water flow during torrent rains	2gDF^½	485.21	m km s
Maximal outflow from the river basin (incidence 5 years)	Qmax	106	m³/s
Maximal outflow from the river basin (incidence 10 years)	Qmax	130	m³/s
Maximal outflow from the river basin (incidence 20 years)	Qmax	168	m³/s
Maximal outflow from the river basin (incidence 25 years)	Qmax	184	m³/s
Maximal outflow from the river basin (incidence 50 years)	Qmax	204	m³/s
Maximal outflow from the river basin (incidence 100 years)	Qmax	232	m³/s
Temperature coefficient of the region	T	1.29	-
Coefficient of the river basin erosion	Z	0.949	-
Production of erosion material in the river basin	Wgod	154042	m³/year
Coefficient of the deposit retention	Ru	0.365	-
Real soil losses	Ggod	56160	m³/year
Real soil losses per square kilometer per year	Ggod/km²	1899	m³/km²/year

CONCLUSION

Many factors have influenced the development of erosion processes in the territory of Bar. The most significant factors are the area's climate, relief, geological substrate and pedological composition, as well as the condition of the vegetation cover and the land use.

The area's climate is characterised by high precipitation, with the maximum annual rainfall being 1,862 mm. The average annual rainfall ranges between 1391 ± 234 mm. The level of torrential rain (hb) is 123.5 mm, with showers lasting several days. The daily maximum rainfall is 224 mm.

The relief and the associated pronounced dynamics in the hilly-mountainous area of Bar encourage the development of the erosion processes. Bar is characterised by large altitudinal differences within a small area. These contribute to fast runoff and the removal of erosion material down the very steep slopes and narrow and deep valleys of the watercourses. They give rise to gorges due to the lithological composition of the substrate.

The lithological composition of the rocks means that they are not resistant to erosion processes and that they are favourable to the development of runoff and, in certain locations, in-depth erosion, which is accompanied by the occurrence of ravines, gullies and landslides. All these features are favourable to the occurrence of torrential floods.

The land use and the condition of the vegetation covering the hilly-mountainous area of Bar is very unfavourable from the viewpoint of soil erosion. Pastures and degraded forest prevail. In many places vegetation has been destroyed, and their protective role has been diminished. Only the terraced terrain, under the olives and grass, is not prone to intensive erosion. The terraces are still well maintained.

Surface erosion is the most common type of erosion. It develops in soils on the slopes. It is most noticeable on the substrate of limestone and dolomites. Ravines and gullies, as well as landslides, occur frequently. The rills, ravines, gullies and torrents characteristic of the flysch terrain and the loose substrate are most frequently found around the sources of the watercourses.

The distribution of the erosion by destruction category covers the following areas: category I (excessive erosion) 1007 ha; category II (strong erosion) 2755 ha, category III (medium erosion) 1856 ha, category IV (low erosion) 1179 ha, category V (very low) 1007 ha, **Total:** 7833 ha. Analyses indicate that there is a possibility for large flood waves to appear in the river basin of Željeznica.

The value of the Z coefficient was 0.949; the real soil losses per square kilometre per year were 1899 $m^3/km^2/year$. According to Gavrilović classification that indicate that the river basin belongs to the category II destruction class. The strength of the erosion process is high. The findings indicate that it is a region of strong erosion.

After World War II, significant attention was paid to the fight against soil erosion. Aforestation was undertaken, and numerous structures were constructed in the beds of the watercourses. Some of the most significant measures taken involved the regulation of the beds of the Rikavac, the Rena and the Željeznica through the Barsko Field. These measures eliminated the floods and protected the roads and some buildings and settlements. The antierosion works in the basins of the watercourses have alleviated the effects of erosion to some extent. However, erosion processes still cause significant damage in this region.

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EROZIJA ZEMLJIŠTA NA PODRUČJU BARA, CRNA GORA

SAŽETAK

Upravo usvojeni opšti plan zaštite od štetnog dejstva voda opštine Bar za period 2011-2017 definiše da je teritorija barske opštine tipično bujično područje sa prosječnom godišnjom količinom padavina do 2.000 milimetara. U uslovima izrazite nagnutosti terena, te geoloških i hidrogeoloških osobenosti tog područja, posebno dijela opštine između Rumije i mora, to za posljedicu ima pojavu velikog broja vrlo izrazitih bujica.

U radu se prikazuje dio rezultata istraživanja erozionih procesa Crnogorskog primorja. Površina istraživanog područja iznosi iznosi oko 78km^2. Područje Bara presijeca nekoliko vodotokova bujičnog karaktera, a hidrografski i hidrološki najznačajniji su Željeznica, Rena i Rikavac, koji protiču kroz najuže gradsko jezgro i imaju veliki uticaj na korišćenje okolnog zemljišta.

Proučeni su faktori koji prouzrokuju eroziju, erozioni oblici i njena zastupljenost, kao i dosada preduzimane mjere zaštite od erozije i bujica. Na kraju je, primjenom računarsko-grafičke metode IntErO urađen proračun intenziteta erozije zemljišta i oticanje za sliv rijeka Željeznice. Analize ukazuju da u rečnom slivu Željeznica postoji mogućnost za stvaranje velikih poplavnih talasa. Utvrđeno je da je ovo sliv sa velikom gustinom hidrografske mreže u kome preovladavaju strme padine. Vrijednost koeficijent erozije sliva, Z, od 0.949 kao i vrijednost stvarnih godišnjih gubitaka zemljišta od 1899 m^3/km/god ukazuje, prema klasifikaciji Gavrilovića, da rečni sliv Željeznice pripada II kategoriji razornosti. Jačina erozionog procesa je jaka, a prema tipu vladajuće erozije u pitanju je dubinska erozija.

Kijučne riječi: Erozija zemljišta, rečni sliv, vodopropusnost, korišćenje zemljišta, padavine, gubici zemljišta, taloženje, oticaj.