

Research Article

Karst Regions of Montenegro and Environmental Degradation and Remediation

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Abstract

Montenegro is an area of vast mountain ridges and terrain, deep and narrow river valleys, and only a small number of low-level planes. In its total area, with just over 90% share, the area over 200 meters above sea level dominates. Hilly and mountainous areas of 200 - 1000 meters above sea level cover about 35% of the territory. The mountainous region of 1000-1500 meters above sea level covers about 45%, while the highest parts of the mountains over 1500 meters above sea level accounts for about 15% of the territory. Below 1000 m above sea level is approximately 45% of the territory, in which about 15% are areas up to 500 meters above sea level and 29% of the area of 500 - 1000 meters above sea level. The territory of over 1700 meters above sea level qualifies as a very high mountain, and thus, in terms of the development of restrictive category area covers about 8.5% of the area. Karst in Montenegro covers more than 75%. Here, deep karst (Holokarst) is represented, followed by Jure-type karst, and shallow karst is the least present, with about 12% of total karst. Karst is most strongly pronounced in the mountainous area from Orjen via Lovcen to Rumija. High mountain karst covers the Central Zone of Montenegro, and shallow karst is represented in the northeastern zone towards the Serbian border.

Keywords

Karst, Ecology, Development, Mountain, Karst Area, Glacier Karst, Tourism Development Potential

1. Introduction

Old Montenegrin karst plateau, as the southernmost part of the Dinaric karst area, rises above the coast, including parts of Old Montenegro, Rudinice and Banjane, and is territory of both the municipality of Cetinje and the Niksic western parts of the municipality, as well as parts of coastal municipalities of Herceg Novi, Kotor and Bar. This large limestone - dolomite surface, with an average altitude of 800 – 1000 meters, sloping from the west and northwest (the area of Herzegovina, above which it steeply rises), in the southeast, gradually descends to the Skadar depression and valley of the Zeta River,

where it disappears. The valley of the River Crnojevica and several short watercourses at the foot of the coastal mountain range, facing the lake, in Crmnica and the Nudolska River to the west, deeply bury the high plateau, contributing to its horizontal complexity.

Most prominent landforms are coastal mountain ridges, which are separated from this surface coast, as well as the mountains, Pusti Lisac, Veliki Garac, Njegos etc., which are in both the interior and the outskirts.

The whole plateau is an area called Ljuti krs - holokarst

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with fully developed surface and underground forms of relief and specific hydrographic. Waterless end, scarcity of land, nakedness of significant parts of the area and the harsh conditions of communication, both internally and with neighboring areas, strongly impact the living conditions of the area and its relatively low population density.

On the other hand, the agricultural overpopulation related to the fields, valleys and other sites that offer more conditions for the development of mostly small subsistence-farming on small plots, and, to some extent, the development of animal farming, has long been a major cause of permanent migration from these areas. It is still happening today, despite the significant changes, particularly in terms of improving traffic conditions. The result is a tendency, gradual or continuous, to leave relatively numerous villages and contrast, the concentration of the centers, which, in the case of Cetinje show the first signs of saturation.

The Dinara mountain system (Dinarides) is the largest chain of limestone mountains in Europe. In its geographical distribution, the Dinarids spread from the Soca River in the northwest to the river Drim in the southeast, including the central mountain range in Southeastern Europe. The Dinarides are decorated with rich flora and fauna, a high degree of endemism, habitat diversity, and geomorphologic forms. Limestone, as geological substrate, allows the formation of a number of morphological forms - caves, sinkholes, gorges and canyons, subterranean rivers, karst fields, caves, and others that contribute significantly to the diversity of the Dinarides, classifying it as one of the centers of biodiversity in the Mediterranean. [5] Important determinants are diverse vegetation of karst, a sprawling complex of natural forests, populations of mammals including the beasts, cave fauna, etc. [2] The results show that other factors that need to be taken into account, when considering measures for the conservation of biodiversity, are the socio-economic circumstances and demographic situation of depopulation of mountain areas as one of the possible factors threatening biodiversity. In September, 1991, at the solemn session of the National Assembly, Montenegro was declared an ecological state. [10] The idea of the ecological state carries the response to the challenges of the time, and its implementation is a key element in the overall program formulation development directions of Montenegro.

2. The Position of Montenegro

Montenegro is located in Mediterranean Europe, in the center of the Balkan Peninsula. It borders Serbia in the northeast. The eastern border is with Kosovo and Albania. To the west, it borders Croatia and Bosnia. Its coastal position improves the quality status of Montenegro. Montenegro's sea route provides the shortest link to the south of Italy and the Mediterranean countries, as well as the Atlantic Ocean and the Suez Canal. It provides a number of advantages, especially in the field of tourism and maritime economy. Montenegro has an almost perfect deltoid shape. It covers an area of 13,812

square kilometers with, according to the census of 2023, 623.633 inhabitants. Given its economic characteristics, it can be treated as an agricultural country, but, in the secondary and tertiary sector, there is a large number of people. The capital city is Podgorica, which has about 179.505 inhabitants. [15] Therefore, there problems of centralization, land reclamation, and the concentration of population in the capital city, since it is home to nearly 1/3 of the country's population. [9]

The aridity of the region, shortage of arable land, the barrenness of significant parts of the area and the harsh conditions of communication, both internally and with neighboring areas, strongly affects the living conditions of the area and its relatively low population density. On the other hand, the agrarian overpopulation related to the fields, valleys, and other sites that offer more conditions for the development of mostly small subsistence farming on small plots of land, and, to some extent, the development of animal farming, has long been a major cause of permanent migration of people from this area. So, it is today, despite the significant changes, particularly in terms of improving traffic conditions. The result is a tendency, gradual or continuous, to leave relatively numerous villages depart from the concentration of the centers, which, in the case of Cetinje shows the first signs of saturation space.

Montenegro is a vast area of mountain ridges and surfaces, deep and narrow river valleys, and only a small number of low planes. In its total area, with just over 90% share, it dominates the area above 200 meters above sea level, where, hilly and mountainous areas of 200 - 1000 meters above sea level cover about 35% of the territory, a mountainous region of 1000 to 1500 meters above sea level about 45%, while the highest parts of the mountains over 1500 meters above sea level account for about 15% of the territory. About 45% of the territory is below 1000 meters above sea level, where about 15% are areas up to 500 meters and 29% of the area is 500 - 1000 meters above sea level. The territory over 1700 meters above sea level is very high mountainous terrain, and thus, in terms of the development of restrictive category area covers about 8.5% of the area. Old Montenegrin karst plateau, as the southernmost part of the Dinaric karst area, rises above The Coast, including parts of Old Montenegro, Rudine and Banjani, ie. Territory of the municipality of Cetinje, Niksic western parts of the municipality, as well as parts of coastal municipalities of Herceg Novi, Kotor and Bar. This large limestone - dolomite surface, with an average altitude of 800 - 1000 m, sloping from the west and northwest (Herzegovina, above which rises very steeply), in the southeast, gradually descends to the Skadar depression and Zeta River valley, where it then vanishes. The valley of the Crnojevica River and several short watercourses foot of the coastal mountain range, facing the lake, in Crmnici and Nudolska River to the west, deeply burying the high plateau, contribute to its horizontal dissection. The most prominent landforms are ridges of coastal mountains, which separate this surface from the coast and the mountains Pusti Lisac, Veliki Garac and Njegos in the

interior and the perimeter. The whole plateau is an area called Ljuti Karst- holokarst with a fully developed surface and underground forms of relief and specific hydrographic. [14]

Exogenous forces, the geological evolution, have made Montenegro very disaggregated and specific. This is evident in parts of the undersea terrain (below level 0.00 m) to high mountain ranges that rise to over 2,522 meters above sea level. Montenegro (13,830 km²) is divided by valleys and canyons of the deep and over 1000 m: Moraca (with tributaries Cijevna, Mala Rijeka and the Mrtvica); Komarnica (with its tributaries); Tara (with tributaries Draga, Susica, Selecka river, Stitarica, Plasnica); Cehotina, Lim and Ibar. This orographic complexity is complicated: Zeta Skadar and Bjelopavlicka depression and fields in karst of Montenegro. Such a surface indentation area is of significant influence on the possible-probable natural hazards, because the complexity itself, a carrier of some natural hazards. Geological settings, Montenegro and its topographical, geomorphologic, hydro geological and engineering geological characteristics carry certain risks - risks to man and its goods. This risk is caused by high mountainous slopes, canyons and gorges. Over time, such a steep slope leads to the destruction and disintegration of rock masses which build these very steep slopes. When parts of the surface soil on the slopes and along the canyon, become heavier than the bond strength of the masses with its chamber, it comes to mass movement down the slope. It is often difficult to predict the time, place, speed of movement and quantities of initiated rocky material. Sometimes, these movements are quiet and relatively slow, and other times they are current and the amount of displaced material causes considerable damage, sometimes costing people's lives. [12]

Such landslides occurred in the Bar field basin in the 1970s: Ratac landslides along roads Sutomore-Bar; Macuga and Baljinima in the Crmnica fields basin; landslides along the railway route through the terrain constructed from flysch sediments below Ostrog beams; landslides near the monastery Moraca which have claimed human lives, and others. Current tumble rock masses are common and cause rockslides. It is necessary remember the yellow beams on the road Budva - Mrcevo, Platije, Crkvine etc. The hilly and mountainous terrain, make up the areas from which fast sink or swell where the atmospheric deposits for the basis of erosion occur. This process accelerates erosion, dredging, cutting and sliding. This is a field which is of significant impact on the environment - the organization of life. Institution for floods and remediation for the study of such processes used to exist in Kotor, but they stopped working decades ago.

Montenegro belongs to the Mediterranean seismic area and its coastal part of the zone 9-10° degrees, 8-9° degrees middle, north to 7° degrees, and north-east to 8° degrees MC scales, and this is its big development and unfavorable environmental condition. Seismicity of the territory is reflected in the production of such disasters causing slowdown of economic development, as well as physical hazards endangering people's lives.

3. Geomorphological Structures as a Factor of Development

Relief of Montenegro is very unfavorable for the performance and construction of all types of communication. On the coast, there is not enough space to build good roads. Other territories are unfavorable for the use and development of transport routes which make up about 30% of the territory. The other part of the country's communication is unbuildable and useless. Dissection of relief causes difficulties in the construction and operation of the power network, telephone communications, gas pipeline and oil pipeline, as well as in the transmission of television images, audio, and internet communications. Most suitable for the construction of the horizontal or slightly inclined surfaces are those slopes up to 2° degrees. In Montenegro there are very few such areas. They make up 8% of the territory. Conditional suitability for construction is on slopes of 2-7° degrees, and these areas account for 12% of the territory of Montenegro. Very difficult construction is on slopes of 7-12° degrees, which is also 12% of the territory. This means that 66% of the territory of Montenegro is unsuitable for the construction of facilities and infrastructure, not consistent with the law of gravity. Relief of Montenegro is very diverse, and as such, is very attractive to tourism. Montenegro is primarily a mountainous country. As such it is of interest to hikers and climbers. It is characterized by eight very attractive canyons. As a country of karst, Montenegro is very rich in attractive surface, underground facilities, and caves. In its territory, there is the deepest cave in the Balkans (Vjetrena jama) and one of the longest caves (Djavalji virovi in Bijelo Polje). Caves are not only impressive but also very attractive for visitors. [3] In Montenegro, there are about 3,500 caves as the surface makes the richest country in the world. The chances are excellent for the use of these facilities for water supply, because only there you can find water for cities in karst areas. Caves serve as important shelters and storages, good wine cellars, facilities for the production of mushrooms, and finally, as tourist attractions. In Montenegro, 32 natural mineral materials from over 700 sites are known: economic valorization is significant because of coal, lead, zinc, bauxite supplies, architectural and construction (decorative) stone, technical construction stone, gravel and sand. [8] Although a small number of natural mineral resources in Montenegro come to economic valorization, some of them (technical construction stone, gravel and sand) appear in dozens of sites. The process of economic evaluation of mineral resources threatens the environment in all its aspects (land, water, air). This growing trend of vulnerability is in accordance with the achieved level of economic valuation. Geological studies have assessed the devastation of nature, mainly, to smaller spaces, outside of urban areas, including overburdening, shallow drilling, excavations, and the access time for equipment (drill rigs, compressor). Exploitation of the surface makes a significant pollutant of the karst environment. The intensity of pollution depends largely

on the type of raw mineral materials, methods, and exploitation capacity. The greatest impact of exploitation on the land is due to overburdening and mining of mineral substances. When agricultural land is being destroyed, the residents move out, roads and waterways relocate, and springs disappear. Tailings degrade the natural environment. Work machinery in the open pits creates noise, dust, fumes, vibrations and tremors, it leading to the destruction of habitats for animals and birds, deforestation, and creation of waste water. Facilities of exploitation-settlements, workshops, services, roads, fuel and lubricants, and bio-waste deteriorate environmental conditions in the complex operation. Preparation and primary processing leaves the great mass of waste (tailings). Some striking examples are the red mud of the Aluminum Plant Podgorica and flotation tailings of lead-zinc mine hollow rocks in Brskovo (since repaired). At the Aluminum Plant - Podgorica, toxic red sludge in the basins, are the leftovers of the refining of red bauxite. [7]

Most watercourses, springs, lakes and the sea belong to an unpolluted water environment. However, certain activities (like utilities) environment pollutes some water areas. The problem with accurate and substantiated assessment of water quality is an insufficient number of measurement stations for analysis of chemical water pollution, as well as very few for bacteriological analysis, which provide precise evaluation of saprobes. There is also no permanent data on groundwater quality. According to the observations and occasional measurements, the following can be performed. All watercourses in the upper part of the basin, and the entire river network basins of Piva, Tara, Cijevne, Mala Rijeka are generally first class. All streams in the basin from Moraca to Zlatina are first category of quality. The river Lim and its tributaries to Berane, Ibar to Rozaje, Cehotina to Pljevlja also have first category of quality. The river Lim has second, occasionally third quality class from Berane, especially from Bijelo Polje. Moraca, downstream of the capital, has second class quality, and occasionally fourth class of water quality. Tara is downstream from Kolasin to the Ravnjak during the summer months in the second category, and occasionally, in the third. Cehotina is downstream from the town to Graca, usually in third and, fourth class. Vezisnica (Cehotina tributary in Pljevlja) is consistently in the fourth class. Crnojevica river water is polluted by waste water from Cetinje, and periodically has third class of water quality. Zeta, downstream from the Niksic, has second or third class, and periodically fourth class. Lake water in Montenegro is, in most cases, first class. Exceptions are the Skadar Lake waters up to the confluence with the river Moraca, which is third and periodically the fourth class. Otherwise, the waters of all lakes are in the first category of quality. [4]

3.1. Pollution and Problems of Karst land Devastation

The most important forms of destruction and land degra-

dation are erosion, industrial and municipal pollution, destruction of mining pits, construction of settlements and infrastructure, and flooding. On the other hand, the land can be a significant source of environmental pollution. With rising dust in the air, suspended particles go into the water and contaminate it. Pesticides and other chemicals, micro-organisms and viruses are due to land in the water and air. [7] When it comes to the degradation and devastation of karst, then we should specify the following problems:

- 1) Taking fertile land for unplanned construction of most tourist complexes along the coast, partly on tourism activated mountains;
- 2) Taking fertile land for unplanned construction around big cities, primarily industrial centers, and most of the suburban area of Podgorica, Niksic, and partly Cetinje and Bijelo Polje;
- 3) The occupation and destruction of fertile land for surface mining of bauxite mines stone, gravel, clay, etc.
- 4) Covering the land and its contamination of municipal waste landfills in the vicinity of almost all settlements, such as waste red mud and the like;
- 5) Water soil erosion over large areas, especially in areas where there is a high level of rainfall, steep slopes, and erodible surface;
- 6) Soil erosion by wind, especially in the flysch zone and the zone of Paleozoic shales;
- 7) Chemical degradation due to excessive use of agrochemicals;
- 8) Soil contamination with lead and mineral oil around the roads and around the warehouse transformer oil /KAP/, large substations and power distribution systems, and storage of petroleum products. [11]

Changing the use of agricultural land happens usually to the detriment of the land and agricultural production. Conversion of land results from the impact of various economic, socio-political and natural factors. Deagrarization and depopulation of large expanses has led to many parcels of arable land abandoned and neglected. Many of the fences that protected cultural spaces (parcels) of land were destroyed. Weeds and vegetation take sometimes very intensively used land.

3.2. Tourism in Montenegro and the Karst Issues

Tourism in Montenegro has long been one of the central categories of economic development plans, relying on exceptional natural conditions, and in the meantime tourism infrastructure, accommodation facilities, and other ancillary services have been developed. Montenegro's tourism industry has close to 100,000 beds, of which about 30% are in the basic accommodation. The coastal region accounts for 95% of available capacity, while in the mountain, despite the extraordinary natural beauty, climate and solid ski facilities (tracks, ski lifts, etc.) only about 3% of total beds are located. The coefficient of tourist functionality (about 150 beds per

1000 inhabitants) is higher than in most developed tourist countries of Europe, which should be another indicator that emphasizes the tourism development orientation and distinct tourism potential and character of Montenegro. However, economic performance and development progress remain below expectations. The results and the contribution of the tourism industry in Montenegro have for years ranged only 5-7%. This indicates many unexploited opportunities and weaknesses in this sector. [3, 6]

Considering Montenegro's natural and anthropogenic potentials, there are significant opportunities for tourism valorization and creating space for the development of numerous attractive types of tourism. In recent years, several types of tourism have been gaining momentum across the country, including active tourism, particularly in the northern region, where tourism in post-industrial towns such as Mojkovac offer an increasing focus on cultural tourism and the presentation of cultural heritage. Notably in Kotor, cruise tourism, as well as rural tourism, has become increasingly prominent within households of the northern countryside.

Although it relies mostly on natural and environmental quality of tourist sites and the total area of Montenegro, tourism has direct and indirect negative implications for the conservation and protection of the environment and natural resources. In addition to the problems of waste and other forms of pollution brought by the seasonal concentration of a large number of people in a confined space, there are also significant indirect adverse impacts and effects on Montenegro ecology. Thus, for example, increased interest in the construction of individual residential buildings on the coast or in the most attractive locations within or near national parks has resulted in construction practices that degrade spatial quality beyond the basic postulates of controlled urbanization.

Tourism affects the growth of transport services and, consequently that, in the circumstances, reinforces negative environmental implications. The development of trade is also largely induced by the development of tourism and the needs of the tourism industry. Thus, for example, logistics solutions in retail have very significant environmental dimensions. A good choice of location for distribution centers reduces transport destinations and associated pollution and can accelerate the development of trade and its infrastructure without major environmental disturbances. It is obvious that the tourism potentials of Montenegro are not exploited and economically valorized in the best way. Indirect impact of tourism on the development of other sectors of the economy is increasingly prominent. [13]

3.3. Municipal Waste and Karst Issues

The concentration of population along the Montenegrin coast and other municipal centers has increased overall spending. Industrial and manufacturing facilities were built near the area of concentrated population influx. This led to an increase in municipal and industrial waste (solid, liquid and

gaseous). It did not follow the construction of modern landfills for solid waste; for waste water or devices to prevent uncontrolled releases of gases from industrial installation are. Waste of space Pljevlja basin (municipal, power plants, and cement factories) has visibly affected and affects the environment of the area. Similarly, the waste in the Berane valley, which was largely reduced after the cessation of pulp and paper production, has also impacted the environment. Municipal and industrial waste in the area of the Niksic field is carried by contaminated water clear and influential in the water Zeta and Morace rivers including Skadar Lake. Municipal waste and scrap have contaminated water wells in Crnojevica River area. This waste has contributed flooding in the field, burying the main chasm, waste is reduced karst porosity along the underground stream influent water. Also, waste along the Montenegrin coast has a significant adverse impact on the environment as well. The impact of the exploitation of mineral resources, such as lead-zinc ore mining Brskovo - Mojkovac and "Suplja stijena" - Gradac left permanent traces by the exploitation of their excavations in the ground and dumps on the ground. [4, 13]

Exploitation of white and especially red bauxite also left a permanent mark. These traces are visible through the surface and underground excavation and relocated overlying materials (for detection of bauxite deposits). Red bauxite exploitation in the basin of Niksicka Zupa has affected the environment by the bauxite dust and pollution of groundwater. Exploitation of coal in the Berane and Pljevalja basins have left visible traces in underground facilities (Berane) and Pljevaljska large surface excavations (with depth - sloped terrain and over 100 m at Potrljica) and downloaded the deposit overlying rock masses in the area of Jagnjila (millions of tons). These works have impacted the groundwater regime so that the former spring horizon Kutlovac - Tvrdas - Podstranac down to lower elevations due to excavation, removing and waste rock masses of roof coal. Contact Neogene sediments, which are carriers of coal, with Triassic rock masses containing - worn and vented groundwater fissured karst aquifer is nearly vertical. [16] Relying Triassic rock masses in the Neogene sediments excavated disappeared underground water rinsed and expanded groundwater flows toward the former spring horizon and decreased rock masses so that the water to the mainland stood out and stand out over time - exploitation in all lower elevation. [11, 12]

This caused the appearance, approximately parallel to the edges of the pit, the cracks in the limestone hillside (long and over 10 m) along which (stepped toward mine) drops carbonate rock mass. Exploitation of bentonite on Pastrovskoj mountain and brick clays in the Tivat field, Bjelopavlice River Valley Plasnica - Kolasin Beranska Pljevalja basin left traces of these works in an excavation in the ground. Exploitation of ornamental and building stone materials are visible in many micro-locations around municipal centers along the roads and elsewhere in the field. [3] In all municipal centers throughout Montenegro, there was a quarry in which the exploitation of

construction and/or decorative stone took place. Decorative stones in the Bjelopavlicka plain and its surroundings are now exploited in several locations. Some of those most highly visible examples are excavations in Visocica. (The exploitation of this material was carried out for building and construction for well-known remains of historic Duklja settlement on the Moraca coast). Likewise, there are no water-courses in Montenegro from which the bedrock has not been exploited and which is not exploited for alluvial sand-gravel sediment. Sediments moraines and glacial fluvial have been exploited, particularly for roads and construction in general. [1, 3]

4. Conclusion

Environmental protection procedures and revitalization in the earlier built capacities are based on the basis of the strictest European environmental criteria, standards, and norms with carefully elaborated program purification of pollutants in the industry, thus controlling input and processing of materials, protection and recharge in agriculture and waste water control. The essential process of developing an environmental state will lead in the direction of improvement of the ecological basis of constructed facilities to the development of new facilities and other structures that fully meet the environmental standards, in which case the location of new, environmentally sustainable programs will be carried out in accordance with the general scheme of distribution of natural resources of the country. Exploitation of white and especially red bauxite leaves permanent marks. These traces are visible through the surface and underground excavation and relocated to rocky overlying material (for detection of bauxite deposits). The economic situation in Montenegro is characterized by the transition and some implications for the environment. [17] It can be compared with the situation in other Central and Eastern European countries. To implement the concept of sustainable development of the ecological state from the standpoint of environmental taxation of great importance is the choice of access to economic instruments, including eco-compensation due to pollution, according to the principle of "polluter pays".

Abbreviations

M	Meter
etc.	Et Cetera
i.e.	Id Est
MC scales	Medvedev-Sponheuer-Karnik Scale
KAP	Aluminium Plant Podgorica
Dinarides	Dinara Mountain System
km ²	Square Kilometer
°	Degress

Conflicts of Interest

We declare that we have no conflict of interest.

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