Research article

Development of Erosion Risk Zones in the Skopje Region, Republic of North Macedonia

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Abstract The project "Erosion Study and Action Plan for the City of Skopje" was initiated by the administration of the City of Skopje, as well as the expert community, after a catastrophic flood event occurred in August 2016 in the Skopje region, resulting in the loss of 22 lives and causing immense damage and losses. According to Article 135 of the Law on Water: "On the basis of technical documentation, the state administrative body competent for environment, the council of the municipalities of the City of Skopje and the water management enterprises for their respective areas, shall determine the boundaries of both the erosive area and the area endangered from erosion, and specify the measures and the activities pertaining to the protection of land from erosion and regulation of torrents." Based on this legal framework, a methodology was developed to define the actual and potential erosive areas. The starting point was the creation of an erosion map using the Erosion Potential Method, in which all identified erosive areas were considered and analyzed. To define the erosion risk, the erosion map was overlaid with critical infrastructure, inhabited areas, and main transport infrastructure. In the Skopje region, 5,874 ha of actual erosion risk areas and 36,332 ha of potential erosion risk areas were delineated as part of the Action Plan. The Action Plan proposed administrative measures and technical work, including prohibited and obligatory activities specific to actual and potential erosive areas.

Keywords soil erosion, erosion risk, erosive area, areas affected by erosion

INTRODUCTION

Soil erosion has occurred throughout geological time. However, inappropriate human activities can significantly accelerate these processes. Soil erosion by water is a widespread problem throughout Europe, with the southern and southeastern regions being particularly prone to water erosion. In some areas, erosion has reached an irreversible stage, whereas in others, it has practically ceased owing to the complete loss of soil. Almost 7.7% of the total annual soil losses in Europe originate from the Western Balkan countries (Albania, North Macedonia, Serbia, Montenegro, Bosnia and Herzegovina, and Kosovo), and the average erosion intensity in the region is 2.42 times higher than the European average. Soil erosion is widespread across the Balkan Peninsula and represents one of the most significant environmental challenges (Blinkov et al., 2022).

The project "Erosion Study and Action Plan for the City of Skopje" was initiated by the administration of the City of Skopje and the expert community after a catastrophic disaster occurred in August 2016 in the Skopje region, resulting in the loss of 22 lives and causing immense damage to the city. According to Article 135 of the Law on Water, "On the basis of technical documentation, the state administrative body competent for environment, the council of the municipalities, of the City of Skopje and the water management enterprises for their respective areas, shall determine the boundaries of both the erosive area and the area endangered from erosion, and specify the measures and the activities pertaining to the protection of land from erosion and regulation of torrent.”. Based on this legal provision, a methodology was developed to define the actual and potential erosive areas.

In this context, Actual erosion risk area (Erosive area) refers to land already affected by active erosion processes, where the surface soil layer is degraded and may lead to significant social, economic, environmental, and other impacts. Potential erosion risk area (Area endangered by erosion) is land where visible signs of erosion are not yet present, but which is susceptible to erosion due to improper land use, agricultural practices, or forestry activities. In such areas, intense erosion processes can be initiated, leading to serious social, economic, environmental, and other consequences.

OBJECTIVE

Since the Law on Water, under the section “Harmful Effects of Water, ” prescribes, in general terms, the delineation of actual and potential erosion risk areas, the specific procedure and methodology for developing these zones was not defined. Therefore, this study describes the steps taken to develop erosion risk zones. The main objective of this study was to develop a methodology for erosion risk zoning in the Skopje region.

METHODOLOGY

The study area is situated in the Skopje region, Republic of North Macedonia. Skopje is the capital of the country, and a significant portion of the national economy is concentrated there. Almost half of the population is present in the city on either a permanent or impermanent basis. According to the latest census in 2021, Skopje has a population of 526,505 permanent residents. Most of the country’s critical infrastructure is located in the capital.

Source of map of Europe: https://www.worldatlas.com/geography/how-many-countries-are-in-europe.html

Fig. 1 Location of the Skopje region within the Republic of North Macedonia and in the broader context of Europe

The Skopje region is characterized by a diverse and complex relief, primarily forming a large basin shape with a high peripheral zone and a low central area. The high peripheral parts of the valley are formed by the surrounding mountains: Skopska Crna Gora (north), Zeden mountain (west), Vodno mountain (central part 1,066m above sea level - a.s.l.), and the Jakupica mountain massif to the south (2,540 m.a.s.l.). The Skopje Valley lies at an average altitude of 220-340 meters a.s.l., oriented in a northwest-southeast direction, and covers a surface area of 361 km^2.

The Skopje valley is a very dry area, receiving an average annual rainfall of around 500 mm, with a highly uneven distribution. Recent climatic changes have led to several extreme rainfall events during the spring-summer period, increasing the risk and vulnerability to rain-related natural hazards. Most of the lower-altitude areas exhibit semi-arid characteristics, while in the higher southern altitudes, annual rainfall exceeds 1000mm. The annual temperatures range from 1ºC to 14ºC (Aksoy et. al., 2020).

The soil properties of the study area are diverse. The valley is dominated by fluvisols (12% of the total area). Other soil types present in the hilly and mountainous areas include rendzic leptosols (14.5%), complex of cambisol, humic eutric, and umbric regosol (16.5%), complex of vertisol, chromic luvisol on saprolite, regosol (7%), and cambisol (7%) (Filipovski, 2017).

The geological structure is also diverse and includes marl clay, sand and gravel (13%), alluvium (12.8%), marble, muscovite double mica gneiss (10.4%), muscovite gneiss (9.6%), quartz-sericite and biotite schists (8.2%), conglomerate, sand, marl, and claystone (8.1%), conglomerate, sand, claystone and massive limestone (7.7%) and marble (7.3%) (Dumurdzanov et al., 2004; Stafilov et al. 2019). Regarding land cover, nearly half of the study area is covered with forest and forest land (49.3%), 33% is arable land, 6% grasslands, and 6% is artificial land (EEA, Corine land cover 2018). The methodology for the development of erosion risk zones in the Skopje region consisted of several steps.

Development of Soil Erosion Map

There are many methodologies used for soil erosion estimation. Blinkov and Kostadinov (2010) provide a review of the applicability of various models for different usage scenarios, including EUROSEM, USLE, PESERA, KINEROS, WEP, WEPP and EPM.

The Erosion Potential Method (EPM) was developed in the Balkan region, south Serbia, which has climatic conditions very similar to those in North Macedonia. Therefore, the model was well-adapted to the study area. Moreover, the EPM can predict sediment transport and deposition because it was calibrated using measurements of deposited sediments in existing reservoirs.

$$Z = \gamma . Xa . (\varphi + \sqrt{I_{sr}}) \quad (1)$$

Where Z is the coefficient of erosion by Gavrilovic (dimensionless), γ the reciprocal value of soils/rocks resistance on erosion processes, Xa the protection of the basin under natural conditions and after erosion control, φ the coefficient of visible processes of erosion and Isr the mean slope of the basin.

The EPM (developed by Gavrilovic) was originally designed to be used with hardcopy maps, and the mapping process itself was carried out on a basin level. With the advent of GIS tools and the availability of a wide range of geographic data (Corine LC/LU, soil maps, geology maps, elevation data-DEM, etc.), the mapping process has evolved and can now be conducted on much smaller mapping units.

Although these datasets are often of good quality, the production scale should be carefully considered, and the data may need to be reclassified according to the classes defined in the methodology section. The use of a global dataset is recommended due to their transferability and the comparability of the results across regions (Minchev, 2015).

The input parameters used for the EPM were as follows: national soil map (scale 1:50,000); land cover: Corine LC/LU 2018 (developed by the European Environmental Agency, scale 1:100,000), later improved using visual photo-interpretation of aerial imagery with a spatial resolution of 0.3 m (2009) and Google Earth imagery; and DEM spatial resolution of 5 m.

After preparing the input parameters in the office, the study team conducted several field visits to assess the visible erosive processes (φ). Field observations were used to refine the existing data, after which the final erosion map was produced.

The methodology has been validated several times in many research publications, where sediment transport was validated with water reservoir sedimentation (Minchev, 2015; Minchev et al., 2023).

Defining Erosion Hot Spots

General erosion hotspots were defined using the erosion map. Only locations with the most severe erosion processes, the II and III erosion categories, were considered. These erosion hotspots express the on-site effects of erosion. However, to account for the off-site effects of erosion, the identified hotspots overlapped with the river network and land cover data, including critical infrastructure. The sediment produced from these hotspots, through the stream network, is transported downstream and can reach the main riverbed and impact settlements, road and railway networks, agricultural land, or reservoirs. Depending on the type of land cover impacted, the risk was classified into risk severity categories. The highest risk is assigned to critical infrastructure (hospitals, government institutions, schools, and embassies). Next in line were the inhabited areas, which were classified according to the number of inhabitants impacted. The third severity risk is the transport infrastructure, which was classified depending on the road category (highway highest – local road lowest). The lowest risk ranking was assigned to agricultural land.

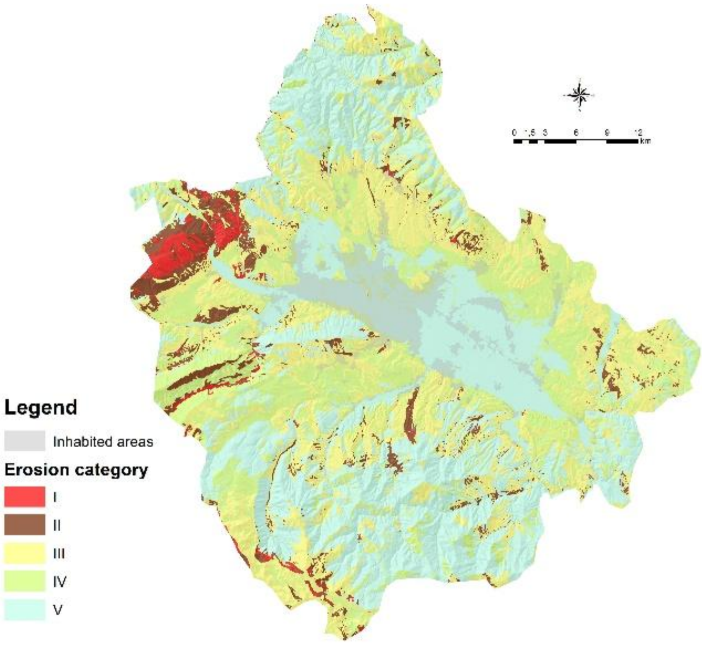

Fig. 2 Erosion map of the Skopje region

Development of actual and erosion risk areas: In order to define the actual erosion risk areas, the classified land cover risk areas overlapped with the highest erosion categories. Finaly the resulting polygons were simplified into meaningful erosion risk areas, discarding the remnant polygons which were under the area threshold.

Defining erosion hot spots: General erosion hotspots were identified from the erosion map. Only locations with the most severe erosion processes (categories I, II, and III) were considered. These erosion hotspots represent the on-site effects of erosion.

To consider the off-site effects of erosion, the identified hotspots were overlaid with the river network and land cover data, including critical infrastructure. Sediment produced in these hotspots is transported downstream via the stream network, potentially reaching the main riverbed and impacting settlements, road and railway networks, agricultural land, and reservoirs.

Depending on the type of land cover impacted, the erosion risk was classified into risk-severity categories. The highest risk was assigned to critical infrastructure (e.g., hospitals, government institutions, schools, and embassies). The next level of risk included inhabited areas, which were further classified based on the number of inhabitants impacted.

The third risk level was assigned to transport infrastructure and classified according to the road category (with highways representing the highest risk and local roads the lowest). The lowest risk rank was assigned to agricultural land.

Development of actual and erosion risk areas: To define the actual erosion risk areas, the classified land cover risk areas were overlaid with the highest erosion risk categories. Finally, the resulting polygons were simplified into meaningful erosion risk areas by discarding remnant polygons that fell below the area threshold.

Development of potential erosion risk areas: Potential erosion risk areas were delineated using what-if scenarios. These areas are defined as future risk zones in the event of significant disturbances or where erosion-related disasters have been recorded in the past. One example is Vodno Mountain, located to the south of the most densely populated part of Skopje. Prior to the 1950s, Vodno Mountain was completely barren and lacked tree cover. After every rainfall, the base of the mountain is regularly flooded by torrential streams. In 1951, a fatality was recorded due to such an event. In the early 1950s, large-scale afforestation efforts were undertaken. Currently, the inhabited areas at the foot of the mountain are of high economic value, and the slopes of Vodno Mountain are under intense urbanization pressure. For this reason, Vodno Mountain was designated as a potential erosion risk area to safeguard the existing "protective forest."

RESULTS AND DISCUSSION

The figure below shows the delineated actual and potential erosion risk areas in the Skopje region, North Macedonia. It can be observed that most of these risky areas are located in close proximity to inhabited areas.

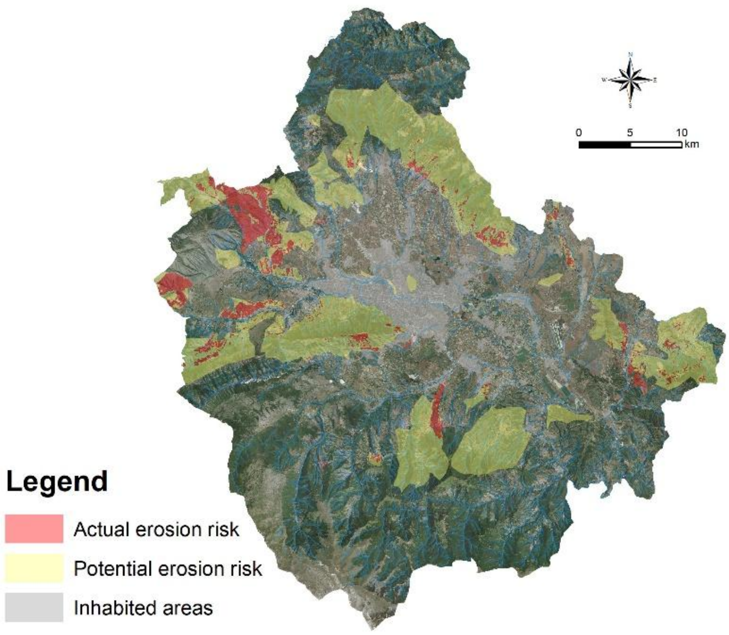

Fig. 1 Actual and potential erosion risk area in the Skopje region

The final step was to prescribe activities that would not exacerbate erosive processes in the identified erosion risk areas. These activities were categorized by the mainland-use sectors that influence erosion processes.

The first priority is to implement measures that address the enabling environment, including institutional roles and management instruments, which will form the foundation for and serve as preparatory steps toward more technical measures. In parallel, as the legal and regulatory framework is established and organizational structures and institutional capacities are developed, technical measures will be implemented in a structured "learning-by-doing" approach.

Technical measures for erosion and torrent control were organized into the following areas: Protection from erosion on agricultural land; Protection from erosion in forest and semi-natural areas; Protection from erosion in small streams; Protection from erosion on artificial land; Reduction of hazard severity; Increase of torrent bed conveyance capacity; Reduction of sediment transport, and Reduction of exposure to risk. Depending on the erosion risk level and expected type of erosion, a set of administrative measures was proposed to mitigate erosion. Experience shows that the best results are achieved through the following sector-specific administrative measures.

Agriculture: Prohibition of plowing on steep terrain (in accordance with the Law on Agricultural land); Prohibition on plowing perpendicular to the slope; Prohibition of grazing on degraded pastures; Obligation to practice contour plowing; Obligation to convert degraded arable land into meadows or forests; Obligation to rehabilitate degraded pastures; Obligation to convert perennials into vineyards or orchards.

Forestry: Prohibition of clear -cutting; Prohibition of grazing in forest; Ban on collecting foliage for fodder; Obligation to afforest barren lands; Obligation to designate protective forests and implement appropriate silvicultural measures; Obligation to practice sustainable forest management, with erosion controls as guiding principle.

Urbanism, construction, mining: Prohibition of urbanization in erosion-prone areas; Obligation to implement urban green infrastructure; Obligation to develop urban green areas in accordance with erosion control principles; Obligation to conduct sustainable planning and responsible execution of mining and metallurgical activities, with mandatory preparation and adherence to the "Plan for protection from erosion and sediment deposition on mining and metallurgical surfaces".

In the Skopje region, 5,874 ha of actual erosion risk areas and 36,332 ha of potential erosion risk areas were delineated. Within the Action Plan, both administrative measures and technical interventions—including prohibited and obligatory activities—were proposed separately for the actual and potential erosion areas.

CONCLUSION

The main motive for preparing this paper was to develop a methodology for erosion risk zoning. The resulting map of actual and potential erosion risks provides an outline of the erosion-prone areas. If municipalities want to implement these zones for operational purposes, they should be further defined at the cadastral level and officially proclaimed through a municipal rulebook.

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