



10th International Conference

MINING AND ENVIRONMENTAL PROTECTION

09–12. September 2026., Sokobanja, Serbia

MINING AND ENVIRONMENTAL PROTECTION

PROCEEDINGS

Editor

Prof. dr Ivica Ristović

Sokobanja

09-12th September 2026.

FOREWORD

After the consultations with business entities in the field of mining and environmental protection, faculties and scientific institutes, an initiative for organizing a scientific meeting on mining and environmental protection was taken in 1996. The Faculty of Mining and Geology in Belgrade, CENTER FOR ENVIRONMENTAL ENGINEERING, have organized the First Yugoslav Conference with International participants held from 25th to 27th April 1996 in Belgrade, Serbia. 2nd International Symposium was held in Belgrade from 25th to 27th 1998. 3th Symposium was held in Vrdnik from 21st to 23rd May 2001, 4th International Symposium was held in Vrdnik from 23rd to 25th June 2003, 5th International Symposium was held in Vrdnik from 10 to 13 June 2015, 6th International Symposium was held in Vrdnik from 21st to 24th June 2017, and 7th International Symposium was held in Vrdnik from 25th to 28th September 2019.

Last two International Conferences were held in Sokobanja. Eight conference was held from 22nd to 25th of September 2021. and the ninth one from 24th to 27th of May 2023. In these years there were a lot of successes with international projects from whom conference gathered together a lot of international experience and collaborations.

Due to a range of organizational and external circumstances, the symposium was not held in 2025. On the basis of the conclusions made at the 9th Symposium MEP 2023 and great interest of domestic and foreign scientific and professional public, the Faculty of Mining and Geology in Belgrade, in cooperation with co-organizers (BERG FACULTY TU KOŠICE, SLOVAKIA, UNIVERSITY OF LJUBLJANA, FACULTY OF NATURAL SCIENCES AND ENGINEERING, SLOVENIA, GOCE DELČEV UNIVERSITY IN ŠTIP, NORTH MACEDONIA, GEOLOGICAL SURVEY OF SLOVENIA, LJUBLJANA, SLOVENIA, UNIVERSITY OF BANJA LUKA, FACULTY OF MINING ENGINEERING, PRIJEDOR, REPUBLIC OF SRPSKA, BOSNIA AND HERZEGOVINA, INSTITUTE FOR TECHNOLOGY OF NUCLEAR AND OTHER MINERAL RAW MATERIALS (ITNMS), BELGRADE, SERBIA, ASSOCIATION OF MINING AND GEOLOGY ENGINEERS, BELGRADE, SERBIA), shall organize the 10th International Conference Mining and Environmental Protection – MEP 2026.

Considering the overall work of the conference from 1996 until today, we are proud to celebrate this year the 30 years of work and existence of the International Conference on Mining and Environmental Protection – MEP. For all these years, about 800 scientific and professional papers in this field have been published in the Proceedings of the International MEP Conference, and about 1500 participants from the country and abroad have attended the conferences.

The previous Conferences were very successful and scientist and companies from many countries gathered to exchange information and research results. The objective of this Conference is to bring together engineers, scientists and managers working in mining industry, research organizations and government organizations, on development and application of best practice in mining industry in the respect of environment protection.

The Proceedings of the 10th International Conference on Mining and Environmental Protection contain 39 papers. Almost half of the papers are from abroad or have authors from different countries. At least a large number of authors and co-authors took part in the preparation of these papers. The papers were reviewed by Reviewers and Scientific Committee. Only high-quality papers were selected, from two side, one from the scientific basis and the second from point of view of applicability in resolving problems at the development of mining.

We are very grateful to the authors of the papers, who contributed to a great extent to the success of this meeting by having sent enough number of high-quality papers, and thereby made the work of the reviewers a pleasant one in respect of selecting the best quality papers. Also, we would like to thank all of the participants in the Conference, as well as the sponsors who helped and enabled us to hold such a great meeting.

Editor

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Publisher: University of Belgrade, Faculty of Mining and Geology, Belgrade, Serbia

For publisher: Prof. dr Aleksandar Cvjetić, Dean

Technical design: *M.Sc. Emilija Širadović
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Printed by: SaTCIP, Vrnjacka Banja, 2026.

Copies: 150

ISBN 978-86-7352-429-0

The publication of these Proceedings was approved by the Council of Faculty of Mining and Geology, University of Belgrade.

All Papers in Proceedings are reviewed.

This Proceedings was published with the financial assistance of the Ministry of Science, Technological Development and Innovations of Republic of Serbia.

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<https://doi.org/10.46793/MEP26.223D>

ANALYSIS AND RISK ASSESSMENT FROM FLOOD WAVE OF THE "OTINJA" DAM – ŠTIP

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Abstract: *This paper presents an analysis of the flood wave and an assessment of its associated risks for the "Otinja" Dam in Štip. The flood-wave analysis was conducted for a critical scenario involving the outflow of water from the reservoir through an opening in the dam body. Additionally, the paper presents the maximum discharge rates at characteristic cross-sections of the flood wave downstream of the dam on the Otinja River, extending down to the village of Sfilari (after its confluence with the Bregalnica River). The risk assessment of the flood wave was carried out by defining the consequences of flooding in the event of a dam failure—based on the loss of human life and environmental damage, as well as the probability of their occurrence—using a computer model developed in GIS.*

Keywords: *analysis, assessment, risk, flood wave, dam.*

1. INTRODUCTION

Dams represent vital hydrotechnical structures because they enable the accumulation, regulation, and rational use of water resources for various purposes, such as water supply, irrigation, flood protection, industrial water use, recreation, and energy needs. However, in addition to their functional and economic value, dams are also structures where potential damage or failure can cause serious consequences in the downstream area. Therefore, the issue of their safety is addressed not only from a structural perspective, but also through the analysis of potential hazards, consequences, and risk levels in the event of their failure.

The modern approach to dam safety is based on the concept of risk management [2]. In such an approach, it is not sufficient only to assess whether a dam is stable at a given moment; it is also necessary to examine potential failure mechanisms, the probability of their occurrence, and the damage that could arise if a failure were to occur. Risk for dams represents a combination of hazard and consequences, i.e., the possibility of a certain unfavorable event occurring and its impact on people, material goods, infrastructure, and the environment.

The risk management process for dams begins with risk assessment, continues with the evaluation of its acceptability, and, if necessary, concludes with the implementation of risk reduction and control measures. This approach forms the foundation for modern safety management of hydrotechnical structures.

Global experience shows that absolute safety in dams does not exist. Historical cases of incidents and failures indicate that the causes of damage can be diverse: overtopping, internal erosion, foundation weaknesses, structural deficiencies, operational errors, extreme hydrological conditions, or seismic impacts. Hence, dam safety should not be perceived as a static category, but as a continuous process of monitoring, assessment, and risk management [2].

The subject of this paper is the analysis of a flood wave caused by a potential failure of the "Otinja" Dam in Štip. It is an embankment rockfill dam with a central clay core, constructed on the Otinja River, a right tributary of the Bregalnica River. The location of the dam (Figure 1) is of particular significance because

it is situated immediately upstream of the city of Štip, meaning that a potential flood wave could affect the urban area in a very short time. This makes the analysis of possible scenarios and the assessment of consequences exceptionally important from the perspective of technical safety, risk management, and population protection [1].

2. BASIC DATA ON THE DAM, RESERVOIR, WATERSHED, AND DOWNSTREAM RIVER VALLEY

The "Otinja" Dam is an embankment rockfill dam with a central clay core, constructed on the Otinja River, a right tributary of the Bregalnica River. The dam is located immediately upstream of Štip and approximately 2.5 km upstream of the confluence of the Otinja River with the Bregalnica River. The reservoir is intended for recreation, flow augmentation during low-water periods, provision of industrial water, and supplemental emergency water supply [1]. The geometric elements of the dam are important for the analysis of a potential breach, as the dam type and its geometry influence the formation of the opening, the duration of the breach, and the volume of water that can suddenly discharge into the downstream area.

The parameters presented in Table 1 show that this is a dam with a significant height and structural volume. From the perspective of flood-wave analysis, the height of the dam, the riverbed elevation, and the geometry of the dam body are particularly important, as they influence the potential energy of the stored water and the potential discharge dynamics in the event of a breach.

The watershed determines the amount of water that reaches the reservoir through precipitation and surface runoff. In a flood-wave analysis resulting from dam failure, the watershed is not considered separately from the reservoir, because inflows from the watershed can compound the outflow through the breach.

Table 1. Basic parameters of the dam and reservoir, [1]

Parameter	Value
Dam type	Rockfill, with a central clay core
Riverbed elevation	305.20 m a.s.l.
Height above terrain	32.00 m
Crest width	7.00 m
Base width	157.70 m
Normal water level elevation	334.00 m a.s.l.
Maximum water level elevation	335.40 m a.s.l.
Volume at normal water level	3,130,000 m ³
Maximum volume	3,400,000 m ³
Discharge – flood $T = 10.000$ yr.	152.00 m ³ /s

According to the project documentation, the watershed area of the Otinja River is 43.8 km², and the mean altitude is 670 m a.s.l. For the analysis, a flood wave with a return period of $T = 10.000$ yr., i.e., a probability of $p = 0.01\%$, was adopted, which is customary for hydro systems with an embankment dam and a settlement located immediately downstream of the dam [1].

The downstream river valley determines the propagation, height, and velocity of the flood wave. In the case of "Otinja", the dam is located approximately 0.3 km upstream of Štip. The initial part of the valley has relatively steep banks and an approximately triangular cross-section, with a longitudinal slope of about 2.5%. At the entrance to the city, the channel transitions into a regulated rectangular channel with a width of about 25 m and a height of about 3 m, and through the urban area, the river has a length of about 2 km and a slope of 1–2% [1]. A critical point in the valley is the constriction near the Hisar fortress, because a local increase in the water level can occur there. After exiting Štip, the Otinja flows into the Bregalnica River, where the wave spreads into a wider river valley. From a risk perspective, the section through Štip and the constriction near the Hisar fortress are the most important, because hydraulic conditions there coincide with the exposure of population and infrastructure.

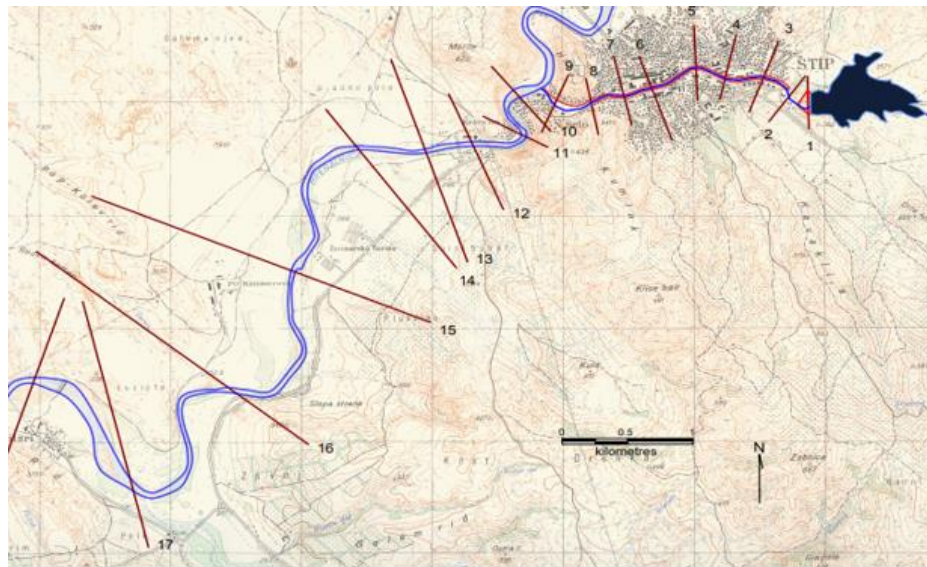


Figure. 1. Downstream river valley for the propagation of the catastrophic flood wave (cross-sections, structures, and settlements) [1]

Figure 1 shows the downstream river valley through which the catastrophic flood wave would propagate in the event of a failure of the "Otinja" Dam. It illustrates the spatial arrangement of the valley relative to the city of Štip and its further propagation toward the valley of the Bregalnica River.

3. ANALYSIS OF THE FLOOD WAVE UPON DAM FAILURE

The complete mathematical model for the hydraulic analysis of the catastrophic wave comprises three functional modules [1]:

- 1) a module for simulating the dam failure, i.e., temporal and geometric description of the breach development;
- 2) a module for calculating the resulting outflow hydrograph;
- 3) a module for simulating the downstream propagation of the flood wave in the river valley.

Bearing in mind the text size limitation, this paper will analyze only the module for simulating the downstream propagation of the flood wave in the valley of the Otinja River. The movement, i.e., propagation of the flood wave along the river valley of the Otinja River, was simulated using a computer simulation, yielding the results presented in Figures 2 and 3.

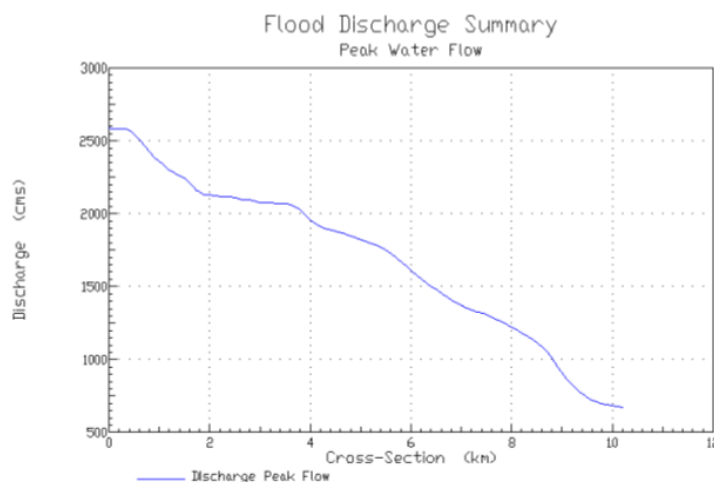


Figure. 2. Peak discharges DPF [m^3/s] as a function of stationing S [km]

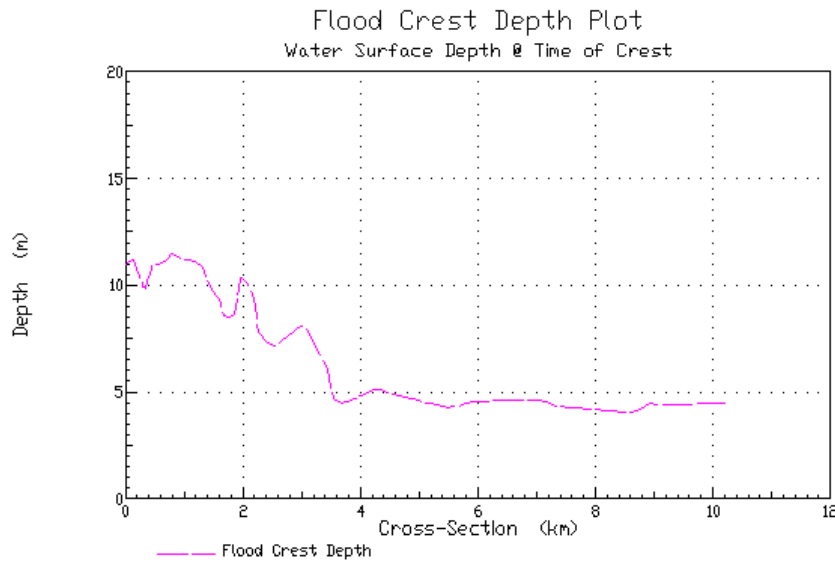


Figure 3. Peak water levels (Peak Depth [m]) as a function of stationing S

Regarding the destructive power of the flood wave caused by the potential failure of the dam, it can be noted that the maximum discharge of the catastrophic wave—for the analyzed variants under the critical scenario—at the dam cross-section at stationing $S = 0+000$ is approximately $2,600 \text{ m}^3/\text{s}$ (Figures 2 and 3). Along the reach of the regulated riverbed of the Otinja River through Štip up to cross-section No. 8 – "Hisar" at stationing $S = 1+950$, the peak of the wave attenuates to approximately $2,200 \text{ m}^3/\text{s}$. The first reach of the Bregalnica River, from the confluence of the Otinja River to cross-section No. 13 at stationing $S = 3+910$, is characterized by a negligible reduction in the peak discharge value, which decreases to $2,100 \text{ m}^3/\text{s}$. Due to the substantial widening of the Bregalnica river valley downstream from cross-section No. 13, a significant reduction in the wave's destructive power and a decrease in the maximum discharge can be expected. This is confirmed by the numerical analysis, which shows that at cross-section No. 17 at stationing $S = 8+920$, the maximum discharge is reduced to approximately $950 \text{ m}^3/\text{s}$. At cross-section No. 18 at stationing $S = 10+200$, immediately downstream of the village of Sofilari, the maximum discharge drops to approximately $650 \text{ m}^3/\text{s}$.

4. METHODOLOGY OF RISK ASSESSMENT

4.1. GIS-based spatial exposure assessment

A GIS-based spatial exposure assessment was conducted to quantify the land-cover and population elements located within the downstream flood-wave corridor of the Otinja Dam. This analysis was designed as a complementary spatial assessment to the existing hydraulic flood-wave analysis, rather than as a replacement for the hydraulic modelling itself. The official flood-risk assessment identifies a potential operational-phase dam-failure scenario capable of generating a catastrophic downstream flood wave. Accordingly, the reported inundation extent, flood-wave arrival times, and times to maximum water level were used as the spatial and temporal basis for the subsequent GIS-based exposure assessment [3].

The spatial basis for the exposure analysis consisted of the mapped flood-wave extent downstream of the Otinja Dam. The original flood-wave maps were georeferenced in QGIS and used to digitize the potentially inundated area. The mapped corridor was then divided into four downstream flood-risk zones, following the spatial progression of the flood wave from the dam toward the Otinja River valley, the confluence with the Bregalnica River, and the downstream area near Sofilari. Each zone was attributed with a hazard class, mapped area, flood-wave arrival time, and time to maximum water level. These zones formed the vector layer used for all subsequent spatial overlay and zonal statistics. The final zone attributes included four hazard categories: extreme, very high, high, and moderate-high, with flood-wave arrival times ranging from 7.8 minutes in the most upstream zone to 101 minutes in the downstream zone. Land-cover exposure was assessed using the ESA WorldCover 2021 product available in Google Earth Engine. The ESA WorldCover 2021 v200 dataset provides a global land-cover map for 2021 at 10 m

spatial resolution, derived from Sentinel-1 and Sentinel-2 data, and includes 11 thematic land-cover classes [5]. The WorldCover raster was clipped to the flood-risk zones and reclassified into the land-cover classes present within the study area, including built-up land, cropland, grassland, tree cover, bare/sparse vegetation, and permanent water bodies. For each flood-risk zone, class-based area statistics were calculated by combining the categorical land-cover raster with pixel-area information. The resulting land-cover exposure metrics were reported in hectares and as a percentage of the corresponding zone area.

Population exposure was estimated using the WorldPop Global Project population dataset in Google Earth Engine. The WorldPop dataset provides gridded estimates of residential population, with population counts disaggregated to approximately 100 m grid cells using census-based data and dasymetric modelling methods , [6]. For this study, the 2020 WorldPop population layer for North Macedonia was selected and clipped to the flood-risk zones. Zonal population sums were calculated using the native WorldPop projection to avoid artificial inflation or distortion of population totals during raster resampling. The resulting values were rounded to whole persons for reporting and were expressed both as absolute exposed population and as a share of the total exposed population within the mapped flood-wave corridor.

All zonal statistics were processed in Google Earth Engine and exported as tabular outputs for further review and integration into the manuscript. The flood-risk zones, land-cover exposure layers, and population exposure raster were then imported into QGIS for cartographic preparation. QGIS was used to prepare publication-ready maps showing the spatial distribution of flood-risk zones, exposed land-cover classes, and relative population exposure within the mapped flood-wave corridor.

This workflow provides a reproducible spatial framework for linking the official flood-wave hazard corridor with exposed land-cover and population elements. The results should be interpreted as an exposure assessment, not as a direct estimation of casualties, structural damage, or economic losses. Such impact estimates would require additional information, including flood depth, flow velocity, building footprints, infrastructure vulnerability, evacuation capacity, and demographic vulnerability.

5. RESULTS

5.1 GIS-derived flood-risk zones and flood-wave timing

The GIS-derived flood-risk zones downstream of the Otinja Dam show a clear spatial progression of the potential flood-wave corridor from the dam area, through the Otinja River valley, toward the confluence with the Bregalnica River and the downstream area near Sofilari (Figure 4). The mapped flood-risk corridor was divided into four zones according to the downstream propagation of the flood wave and the associated hazard characteristics. These zones provide the spatial basis for interpreting both the timing of the flood wave and the subsequent land-cover and population exposure patterns.

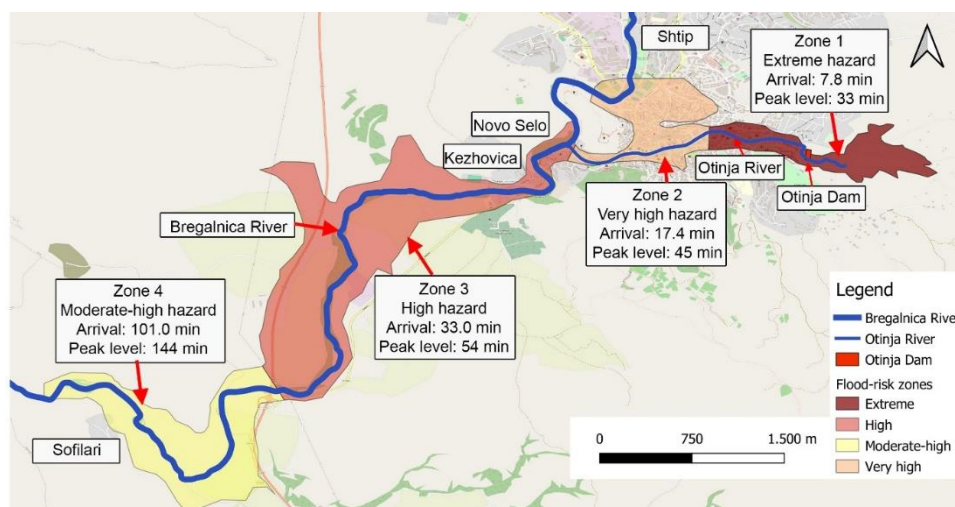


Figure 4 GIS-derived flood-risk zones downstream of the Otinja Dam, showing the spatial progression of the potential flood-wave corridor from the dam area toward the Otinja River valley

The total GIS-derived flood-risk area covers approximately 4.98 km². Zone 3 represents the largest part of the mapped corridor, with an area of 2.455 km², corresponding to 49.3% of the total flood-risk area. Zone 4 covers 1.324 km², or 26.6% of the total area, while Zone 2 covers 0.694 km², or 13.9%. Zone 1 is the smallest zone, covering 0.508 km², or 10.2% of the total mapped flood-risk area. Although the upstream zones are smaller in spatial extent, they are more critical in terms of flood-wave timing.

5.2 Land-cover exposure

The land-cover exposure analysis indicates a clear spatial differentiation of exposed surface types within the GIS-derived flood-risk zones (Figure 5). The ESA WorldCover 2021 classification shows that the flood-wave corridor includes a combination of built-up land, cropland, grassland, tree cover, bare/sparse vegetation, and permanent water bodies. This spatial pattern is important because the potential consequences of flooding differ substantially between urbanized areas, agricultural land, semi-natural surfaces, and areas along the river corridor.

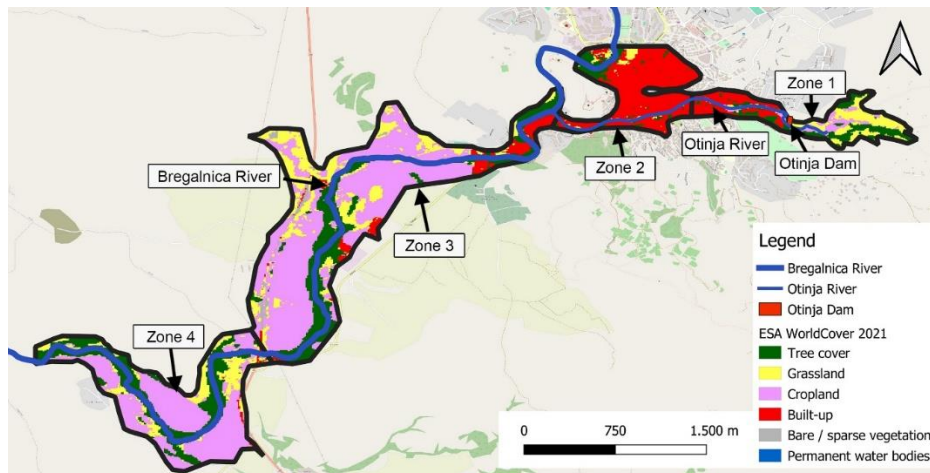


Figure 5. Land-cover exposure inside the GIS-derived flood-risk zones downstream of the Otinja Dam, derived from ESA WorldCover 2021

The most pronounced built-up exposure is observed in Zone 2, where built-up land represents the dominant land-cover class. In this zone, 55.26 ha of built-up area are located within the flood-risk corridor, corresponding to 79.64% of the zone area. This result identifies Zone 2 as the main urban exposure hotspot within the mapped flood-wave corridor.

5.3 Population exposure

The population exposure analysis provides an estimate of the number of people located within the GIS-derived flood-risk zones downstream of the Otinja Dam (Figure 6). Based on the WorldPop 2020 gridded population dataset, the total estimated exposed population within the mapped flood-wave corridor is approximately 1,759 people. These values should be interpreted as spatial exposure estimates derived from gridded population data, rather than as exact counts of potentially affected individuals.

The highest estimated population exposure is observed in Zone 3, where approximately 729 people are located within the flood-risk corridor, representing 41.4% of the total exposed population. Although Zone 3 is classified as a high-hazard zone rather than the most severe hazard class, it covers the largest mapped area and includes the largest absolute number of exposed people. This indicates that downstream zones with broader spatial extent may contribute substantially to total population exposure, even when the flood-wave arrival time is longer than in the upstream zones.

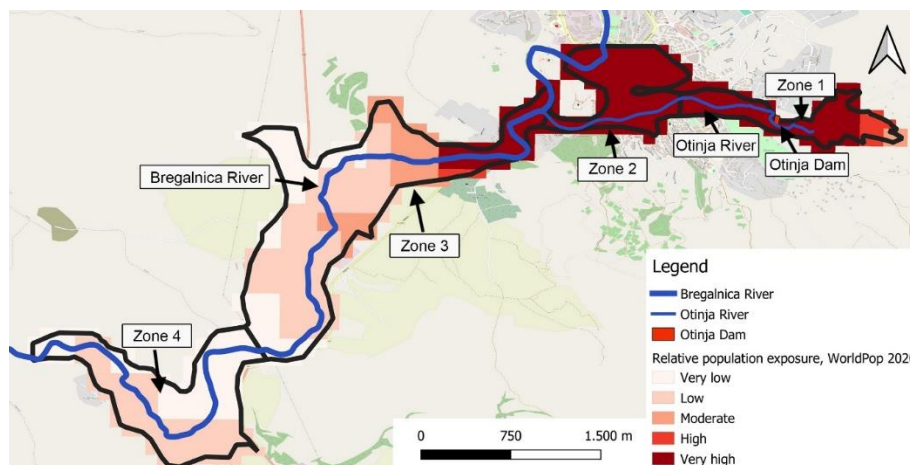


Figure 6 Estimated population exposure inside the GIS-derived flood-risk zones downstream of the Otinja Dam, derived from the WorldPop 2020 gridded population dataset

Population exposure cannot be interpreted only from population counts, but must be assessed together with flood-wave timing, hazard intensity, land-cover characteristics, and the spatial distribution of exposed settlements.

6. CONCLUSION

The integrated exposure results indicate that flood-risk management downstream of the Otinja Dam should be spatially differentiated according to flood-wave timing, land-cover exposure, and population distribution. The very short arrival times in Zones 1 and 2 show that the available response window would be limited in the event of a dam-failure scenario. Therefore, emergency planning should not rely only on reactive warning after failure detection, but should include pre-defined evacuation routes, automatic warning systems, institutional coordination, and regular public-awareness activities.

Zone 2 requires particular attention because it represents the main urban exposure hotspot, combining very high hazard, dominant built-up land, substantial population exposure, and short flood-wave arrival time. In this zone, priority should be given to population protection, rapid warning dissemination, evacuation feasibility, access-road assessment, and protection of critical infrastructure.

The downstream zones require a broader exposure-management perspective. Zone 3 contains the largest estimated exposed population and the largest cropland exposure, while Zone 4 has the longest flood-wave arrival time and considerable agricultural exposure. This indicates that potential consequences would not be limited to urban areas, but could also include agricultural damage, disruption of rural infrastructure, and impacts on local economic activities.

Overall, the GIS-based exposure assessment shows that risk management should not be based only on inundation extent or hazard class. A more effective approach requires the combined interpretation of flood-wave timing, built-up exposure, agricultural exposure, exposed population totals, and the spatial distribution of exposed settlements, allowing emergency measures to be targeted to the specific characteristics of each zone.

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