Risk management of unexploded ordnance in the Republic of Serbia for environmental protection - Borovac case study

Ivan M. Potić[a], *Nenad* M. Komazec[b], *Ljiljana* M. Mihajlović[c], *Aleksandar* M. Milić[d], *Saša* T. Bakrač[e]

[a] Military Geographical Institute "General Stevan Bošković", Belgrade, Republic of Serbia,
e-mail: ivan.potic@vs.rs,
ORCID iD: https://orcid.org/0000-0002-0691-7675

[b] University of Defence in Belgrade, Military Academy, Belgrade, Republic of Serbia,
e-mail: nenadkomazec@yahoo.com,
ORCID iD: https://orcid.org/0000-0001-9227-118X

[c] University of Belgrade, Faculty of Geography, Belgrade, Republic of Serbia,
e-mail: ljiljana.mihajlovic@gef.bg.ac.rs, **corresponding author,**
ORCID iD: https://orcid.org/0000-0003-4022-8248

[d] University of Defence in Belgrade, Military Academy, Belgrade, Republic of Serbia,
e-mail: milickm5@gmail.com,
ORCID iD: https://orcid.org/0000-0002-2642-0340

[e] Military Geographical Institute "General Stevan Bošković", Belgrade, Republic of Serbia,
e-mail: sasa.bakrac@vs.rs,
ORCID iD: https://orcid.org/0000-0003-0211-3765

DOI: 10.5937/vojtehg71-44656; https://doi.org/10.5937/vojtehg71-44656

FIELD: geographic information systems, environmental management, risk management
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: Decades of dealing with unexploded ordnance (UXO) in some areas of the Republic of Serbia have confirmed that it presents a substantial hazard to the security of people, property, and the environment. Even though the terrain has been cleaned, various threats from difficult-to-find UXO components remain serious. Inadequate systemic solutions for UXO management can have significant harmful consequences.

ACKNOWLEDGMENT: The research reported in this paper was supported by Project 451-03-47/2023-01/200091 (Ministry of Science, Technological Development and Innovation of the Republic of Serbia) and written as part of Project 1.23/2023 (Ministry of Defence of the Republic of Serbia).

Methods: Based on the spatial distribution analysis and different UXO types and quantities, this article studies the effects of dangerous components of unexploded ordnance on human lives and the environment. Two different geospatial analyses were performed including the guidelines for risk management through risk elimination based on multiple criteria, the GIS, and the Remote Sensing analysis.

Results: Two different geospatial analyses resulted in the areas at high risk of remaining UXO.

Conclusion: The article significantly contributes to creating an environmental risk management strategy for UXO-contaminated regions. It presents an effective technique for addressing risk assessment challenges in such sites. The analysis considers both risk analysis and environmental protection options. Using the multi-criteria analysis and the GIS, it estimates the exposure of built structures, people, soil types, and plant species to UXO dangers in key locations. This paper serves as a guideline for environmental risk assessment.

Keywords: UXO, risk management, environmental protection, security, geospatial analysis.

Introduction

The Republic of Serbia has been facing the problem of unexploded ordnance (UXO)[1] remaining on its territory as a legacy of modern armed conflicts. Removing and destroying UXO should be considered a practical security task, as it entails reducing explosive ordnance and devices to a form in which they can no longer perform their intended lethal function. The detection and removal of UXO have become an increasingly urgent problem.

On the one hand, there is a need to reduce risks to the population and the environment from the explosion. On the other hand, the likelihood of unwanted accidents increase over time due to various physical and chemical processes in UXO, increasing the risk and possibility of extremely negative consequences on the environment and humans. The effects of UXO containing depleted uranium are not territorially or temporally limited; they cause far-reaching impacts on both friendly and hostile military and civilian targets, contaminating the air, land, and water, thus indirectly entering the food chain of living beings. Contamination extends to places that have not been directly impacted by armed conflicts. U-234, U-235, and U-238 are three isotopes of natural uranium that differ

[1] The widely established term unexploded ordnance (UXO) will continue to be used further on.

only in nuclear properties. Since uranium is a radioactive element, it emits atomic radiation when it decomposes in the environment. The chemical properties of depleted uranium (DU) are identical to those of natural uranium; however, it has much fewer isotopes than U-235 (0.2%) (McLaughlin et al, 2003). It is a low-level radioactive waste element as a by-product of uranium processing for nuclear reactors and weapons.

UXO does not contain only depleted uranium which was used during the bombing campaign against the Republic of Serbia in 1999 (Orlić, 2000). First and foremost, the impact of explosive charges (certain types of explosives) must be considered during detonation (explosion). The explosive charge compositions vary depending on the UXO manufacturer although they mainly contain highly destructive explosives (high explosives). TNT is the most common one; smaller charges may use more powerful explosives (such as tetryl) or other types (Cauderay, 1993). Explosive charges come in various weights depending on the type and function of a projectile (Orlić, 2000). Ammunition with higher explosive content harms technical equipment and results in more human resource losses. It does not only harm human health by inflicting physical damage (loss of limbs, loss of sight and hearing, etc.), but it also damages the environment by destroying pedological and geological substrates, causing ecological damage, and alike.

As a by-product of nuclear technology, depleted uranium is classified as low-level radioactive waste (Sahoo et al, 2004) and is mainly disposed of in specialized landfills. Since DU is increasingly used for military and civilian purposes, there is a significant increase in radiotoxicity and chemotoxicity to humans and the environment. Evaluating the depleted uranium impact implications on the environment and individuals is contentious (Orlić, 2000).

Representatives of Western countries' official military and state institutions reduce the potential for damage, stating that uranium is already present in the natural environment and that its increase due to weapons with depleted uranium is insignificant and geographically variable (Popovic et al, 2008). In contrast, non-official organizations, such as US military veterans' associations or environmental movements, often draw harsh conclusions (Popovic et al, 2008). One of the purposes of this research is to show possible acute and subsequent geospatial consequences for the environment using the multi-criteria GIS analysis.

Considering the time that has passed and the fact that the contaminated sites have been cleared for years, it is not likely that the national radioactivity monitoring would reveal substantial quantities of depleted uranium in the environment. Estimating the risk of unexploded ordnance to the environment, contamination, mobility, and the possibility of depleted uranium being absorbed into diverse inorganic or organic substrates is crucial for future research.

Several research groups in Serbia have examined depleted uranium contamination, primarily through the Ministry of Education, Science, and Technological Development - funded scientific research programs, and, during remediation initiatives in southern Serbia, international cooperation has been achieved (Popovic et al, 2008). Since 2011, radioactivity management (owing to the environmental samples from the places where depleted uranium ammunition was used) has been mandated as part of the national monitoring program for radioactivity. Depending on needs, additional research should consider analytical techniques with higher sensitivity, such as high-resolution mass spectrometry and other more advanced physicochemical methods. Past analyses do not indicate significant deviations from natural variations in the uranium isotope content and ratios. The research might lead to a better understanding of the speciation and mobility of depleted uranium in the environment. Results that show the current or permanent threat of UXO can be obtained using the multi-criteria data analysis and GIS techniques. The effects of the endangerment of subsurface and surface water sources, soil, and other resources were derived based on the geo-ecological features of the studied area. The number of endangered residents can be estimated based on the facilities in the analyzed region at a specified distance from the contaminated sites (Popovic et al, 2008).

The term ‘unexploded ordnance’ is defined by the majority of experts in the field as "means equipped with military explosives that did not explode or function as intended, which includes military ammunition, anti-tank and anti-personnel mines, water mines, bombs, rockets, mortar shells, artillery shells, hand grenades or rocket-propelled grenades, and missiles or rocket-propelled grenades" (Landmine Action, 2002; The Geneva International Centre for Humanitarian Demining, 2019; Martin et al, 2019; Australian Government, Defence, 2020; Government of Canada, 2021).

Remote sensing is becoming an increasingly necessary and inescapable means of space data collection for military purposes. Along with monitoring and documenting the condition of diverse natural and social phenomena, all satellite primary missions and programs can effectively complete increasingly complex duties associated with military actions (Regodić, 2008). The GIS is critical for data management concerning geographic areas (environmental changes) and is one of the most promising research methodologies and information technologies.

Evelyn Pruit's (1960) definition of remote sensing was: "Remote sensing is a technique for acquiring data via systems that are not in direct physical touch with the event or item being studied" (Salomonson, 2014). GIS maps enable the integration and updating of vast volumes of data. This procedure is critical for safety purposes while testing for possible UXO.

Materials and methods

According to the research by the Demining Center of Serbia, it is estimated that the territory of the Republic of Serbia contaminated by UXO covers approximately 25 km^2 (Republika Srbija, Centar za Razminiranje, 2022). The area cleared of cluster bombs following international standards has grown to 11.6 km^2. Using the data on the sites effectively cleaned in the areas of Bujanovac (Table 1), Preševo (Table 2), and the airport complexes in the vicinity of Sjenica (Table 3), researchers may estimate the level of contamination and the probability of severe environmental impacts.

Table 1 – Overview of the UXO removed from the Bujanovac Municipality (Republika Srbija, Centar za Razminiranje, 2022)
Таблица 1 – Осмотр неразорвавшихся боеприпасов, вывезенных из муниципалитета Буяновац (Республика Сербия, Центр разминирования, 2022 год)
Табела 1 – Преглед неексплодираних убојних средстава уклоњених са територије општине Бујановац (Republika Srbija, Centar za razminiranje, 2022)

S.No.	Locality name	Area (km^2)	Type and quantity of means
1	„Borovac-3“ Bujanovac	0.102	BLU 97 -1 pc
2	„Borovac-4“ Bujanovac	0.109	BLU 97 -1 pc UXO (missile) -1 pc Fragment of KM -1 pc
3	„Turijska brda“ -Bujanovac	0.389	TMA -10 pcs Artillery shell fuzes-3 pcs RB - 1 pc 155 mm artillery shell -1 pc
4	„Bujanovac sever“ Bujanovac	0.276	PMA-2 -3 pcs Hand grenade M52P3 -1 pc
5	„Bujanovac sever“ Bujanovac	0.145	PMA-2 -5 pcs
6	„Bujanovac sever“ Bujanovac	0.071	PMA-1 -3 pcs PMR-2A -1 pc

7	„Bujanovac sever“ Bujanovac	0.114	PMA-2 -5 pcs RB -1 pc Mb bomb -1pc RB -1 pc
8	„Dobrosin“ Bujanovac	0.220	PMA-2 -6 RB -1 pc PMR-2A -3 pcs RB -1 pc
9	„Lučane“ Bujanovac	0.073	UXO -10 RB -1 pc 762 mm rounds -1.341 RB -1 pc
10	„TS Bujanovac – TS Berivojce“ Bujanovac	0.018	PMA -2 RB -1 pc
11	„Končulj-Singerit“ Bujanovac	0.199	PMA -20 RB -1 pc
12	„TS Bujanovac – TS Berivojce“ Bujanovac	0.002	////
13	„Končulj-Singerit 1“ Bujanovac	0.269	TMA-5 -1 pc RB 1 pc Projectiles for RRB M79 - 9 RB 1 pc Ammunition -1.577 RB -1 pc
14	Turijsko brdo	0.076	Anti-personnel mines -4 RB -1 pc
15	Bogdanovac 1	0.113	MK-4 -12 RB -1 pc
16	Bogdanovac 2	0.146	MK-4 -14 RB -1 pc
17	Jastrebac 1	0.114	MK-4 -13 RB -1 pc
18	Jastrebac 2	0.155	MK-4 -8 RB -1 pc
19	Karadnik	0.123	BLU97A/B -10 RB -1 pc UXO -5 RB -1 pc
20	Sebrat	0.176	MK-4 -36 RB -1 pc UXO -1pc RB -1 pc

21	Borovac 1	0.060	BLU97A/B -68 RB -1 pc UXO -15 RB -1 pc
22	Borovac 2	0.088	BLU97A/B - 28 RB -1 pc UXO -56 RB -1 pc
23	Bujanovac	1.179	PMA2 -14 RB -1 pc RB -1 pc RB -1 pc
24	Rafatova česma	0.092	Fragments of AB-6 RB -1 pc Fragments of UXO -5 RB -1 pc

Note: KM - cluster munition; RB, PMA2, BLU97A/B, MK -4, TMA, PMR-2A - different types of cluster bombs, AB - air bomb, MbM - mortar shell, UXO - unexploded ordnance

Over two decades after the bombing of Serbia, the issue of explosive remnants of war still exists. Even in the cleared areas, there is a chance that UXO will be detected. Such a situation presents an exceptional danger to both residents and employees (in construction of roads, housing, tourism, industrial and other infrastructure, etc.). Serbia faces numerous demining issues, and the pace at which they are resolved is contingent on the availability of financial funds for demining, among other things. Since 2002, the Demining Center has performed these functions primarily as an autonomous governmental entity but with significant assistance from foreign organizations and funders. Besides that, reconnaissance of areas suspected of being contaminated with cluster bombs, mines, and other UXO is being carried out to reduce the environmental threat. Additionally, demining projects are being created, and funds are being supplied for their execution. The quality of demining is monitored, international cooperation is conducted, international standards and agreements are implemented, etc. (Republika Srbija, Centar za razminiranje, 2022).

However, the repeated reference to war remnants must not obscure the reality that some areas are also contaminated with ammunition dispersed and buried after explosions in manufacturing units and warehouses or burglaries into ammunition depots. Quantities of unexploded ordnance (whether in warehouses or dispersed) are not the data that may be made widely accessible. The given data is accessible to selected structures to carry out important projects for the clearance of UXO from the designated sites. As a result of these findings, there is a reasonable assumption that different forms of UXO are, after fires and explosions at military storage and manufacturing units (in the cities of Paraćin, Kraljevo, Vranje, and Čačak), currently being discovered outside military facilities over an area of about 13.5 km^2.

Table 2 – Overview of the UXO removed from the Preševo Municipality (Republika Srbija, Centar za Razminiranje, 2022)
Таблица 2 – Осмотр неразорвавшихся боеприпасов, вывезенных из муниципалитета Прешево (Республика Сербия, Центр разминирования, 2022 год)
Табела 2 – Преглед неексплодираних убојних средстава уклоњених са територије општине Прешево (Republika Srbija, Centar za razminiranje, 2022)

No.	Locality name	Area (in km^2)	Type and quantity of means
1	Buštranje	0.205	KM -48 pcs
2	Buštranje - Đeren	0.148	KM-9 pcs
3	Šatkin Vir	0.129	fragments of KM
4	Šatkin Vir 1	0.100	KM-2 pcs
5	Šatkin Vir 2	0.032	KM-1 pc AB -1 pc
6	Reljan Brezovčani	0.244	KM-25 pcs UXO -6 pcs
7	Šatkin Vir 3	0.118	fragments of KM
8	Pečeno - school	0.088	///
9	Cerevajka 1	0.165	MbM -1 pc
10	Cerevajka 2	0.106	MbM -2 pcs Fragments of KM-4 pcs

Note: KM - cluster munition, AB - air bomb, MbM - mortar shell, UXO - unexploded ordnance

Table 1, Table 2, and Table 3 list the UXO types reported in the Preševo, Sjenica, and Bujanovac zones. A total of 4.232 km^2 was cleaned in the Bujanovac area. In the municipality of Preševo, the demining procedure covered 1.334 km^2 of the territory. In the municipality of Sjenica, the region around the airport complex was cleaned during the last four years.

NATO forces launched approximately 15,000 large projectiles on the territory of the former Yugoslavia (Bozanic et al, 2018). Unguided and guided air bombs and missiles from various combat systems amounted to approximately 25,000 tons, with 1,660 cluster bombs, dispensaries containing about 330,000 cluster bombs and more than 50,000 pieces of depleted uranium ammunition (Pamučar et al, 2011). Depleted uranium is radioactive, a health hazard, and a persistent contaminant of the environment. Several hundred locations were bombed during the NATO air raids in 16 municipalities in Serbia, not including Kosovo and Metohija (City of Niš - Mediana and Crveni Krst, Kraljevo, Brus, Preševo, Bujanovac, Kuršumlija, Raška, Gadžin Han, Tutin, Sjenica, Čačak, Vladimirci, Knić, Stara Pazova, and Sopot) (Pamučar et al, 2011; Bozanic et al, 2018).

Table 3 – Overview of the UXO removed from the areas of the airport complex in the Sjenica region (Republika Srbija, Centar za Razminiranje, 2022)
Таблица 3 – Осмотр неразорвавшихся боеприпасов, вывезенных с территории аэродромного комплекса в регионе Сьеница (Республика Сербия, Центр разминирования, 2022 год)
Табела 3 – Преглед неексплодираних убојних средстава уклоњених са подручја аеродромског комплекса у региону Сјеница (Republika Srbija, Centar za razminiranje, 2022)

No.	Locality name	Year	Type and quantity of means
1	The airport in the region of Sjenica	2018.	Cluster bomb-29 pcs
2		2019.	Cluster bomb-71 pcs Cluster bomb booster-3 pcs 88 mm artillery shell -1 pc
3		2020.	Cluster bomb-72 pcs Air bomb MK-82 -1 pc 80 mm artillery shell -1 pc

Table 4 – Remaining cluster ammunition in the Bujanovac Municipality (Republika Srbija, Centar za Razminiranje, 2022)
Таблица 4 – Оставшиеся кассетные боеприпасы в муниципалитете Буяновац (Республика Сербия, Центр разминирования, 2022 год)
Табела 4 – Преостала касетна муниција у општини Бујановац (Republika Srbija, Centar za razminiranje, 2022)

No.	District	Municipality	Populated place	Name of the suspected area	Number of suspected areas	Size of the suspected area (km^2)
1	Pčinjski	Bujanovac	Borovac	Borovac 5	1	0.281
IN TOTAL					1	0.281
The remaining mine problems in Bujanovac						
No.	District	Municipality	Populated place	Name of the suspected area	Number of tsuspected areas	Size of the suspected area (km^2)
1	Pčinjski	Bujanovac	Dobrosin	Dobrosin 1	1	0.028
2	Pčinjski	Bujanovac	Končulj	Tuštica	1	0.144
3	Pčinjski	Bujanovac	Ravno Bučje	Đorđevac	1	0.390
IN TOTAL					3	0.562

The study emphasizes the municipality of Bujanovac since it is an area that, according to the most recent official data from the Serbian Demining Center, is primarily contaminated with UXO and demands special attention (Table 4).

Research area

The research area is in the Bujanovac municipality near Borovac, the regional Južna Morava River and the JUG military base. The area encompasses 87.05 km^2 and is located within UTM 34n 555335.402, 4690210.743 and 564706.827, 4699481.616 coordinates. Three analyses have been performed within this area (Fig. 1). Borovac is a settlement in Serbia in the municipality of Bujanovac in the Pčinja district. According to the 2011 census, its population was 166 people (Republika Srbija, Republički zavod za statistiku Srbije, 2023). In 2002, there were 214 inhabitants. According to the 1991 census (before the bombing), the population was 267. It is essentially an adult population. Only 44 homes have remained in the community, fewer than in the previous census (61 in 2002), and the average number of people per household is 3.77 (Republika Srbija, Republički zavod za statistiku Srbije, 2023). Serbs predominantly populate this village, and a reduction in the number of residents was seen in the past three censuses. During the air raids on Serbia in 1999, Borovac was heavily bombed. In certain instances, using depleted uranium led to the relocation of the inhabitants on a large scale, and some were directly or indirectly killed.

Input data

The current situation with UXO (types and quantities) in the Republic of Serbia can be discovered through the multi-criteria data analysis. The content of the documents was examined based on national and international legal regulations concerning UXO risk management. The comparison method demonstrates the crucial distinction in comprehending the need for protection and adequate risk management of residual UXO containing depleted uranium. The GIS analysis is fundamental in the areas with such a significant time and space framework in which this study is conducted. The spatial dispersion of harmful consequences on environmental and human health is not depicted.

Different sets of geospatial data were used to perform a spatial analysis of the potential diffusion of the extension of the UXO impact on the environment:

- Digital Elevation Model (DEM): A DEM with 4.4 m vertical accuracy (Tadono et al, 2016) and 22.45 m spatial resolution was chosen as elevation data. The initial data for completing a hydrographic analysis to extract watersheds and watercourses was the JAXA ALOS Global Digital Surface Model AW3D30 (Eorc.Jaxa, 2019). TauDEM 5.3 (Tarboton et al, 2015) was used for a terrain analysis to delineate watersheds and extract watercourses.

- Land Cover is created using multispectral satellite imagery: Sentinel 2 satellite imagery was downloaded from Copernicus Sci-Hub (Copernicus, 2020) to create a land cover map using the Dzetsaka classification plugin (Karasiak, 2016) in QGis (QGIS, 2022). The research used Sentinel 2 S2B MSIL2A 20210913T093029 N0301 R136 T34TEN 20210913T114013 cloud-free imagery collected on September 13th, 2021. Satellite data was analyzed and classified using 10m red, green, blue, and near-infrared bands. The Random Forest machine learning algorithm classified five classes from satellite imagery: developed, barren, forest, pastures, and planted/cultivated areas. The Random Forest supervised classification necessitates the creation of a comprehensive and precise training zone selection for each class (Mas & Flores, 2008; Duro et al, 2012; Potić & Potić, 2017; Potić et al, 2017). Regression is used as a pixel-based supervised learning task to model and predict variables where numerical true ground values are provided for the research area. Regression trees (decision trees) are used to classify satellite data, iteratively separating the dataset into distinct branches and maximizing the information gained to understand nonlinear correlations. The Random Forest classifier classifies data with high accuracy using classification trees. The accuracy assessment is performed by generating the error matrix in the Semi-Automatic Classification Plugin (Congedo, 2021) in QGis (QGIS, 2022), which is provided as a table that compares reference data (i.e., ground truth data) with map information for several sample areas to ensure the quality of the classification (Congalton & Green, 2019). Twenty randomly selected points are obtained for each class to finalize the accuracy assessment. Overall accuracy is the ratio of correctly classified samples to total sample units (Congalton & Green, 2019). The Kappa analysis is a discrete multivariate technique for detecting whether two error matrices differ statistically (Plackett, 1976; Congalton & Green, 2019). High-resolution imagery from Google Earth Pro (Google Earth, 2020) and downloadable Sentinel 2 colour and false-colour composites were used to ensure the quality of the accuracy evaluation points.
- Google Earth Pro (Google Earth, 2020) was used to collect additional data, with all watercourses enclosed by a 1-kilometer buffer zone around four UXO locations corrected and updated. Furthermore, the same software is used for digitizing topographic labels and all buildings within a 1-

kilometer buffer zone. The buffer zone for building collection was created as a 1-kilometer 3D distance from the main four UXO drainage streams.

Results

The first analysis for the entire research area consists of delineating watersheds, creating streams and drainage paths from four UXO locations (Fig. 1), and performing a land cover (LC) classification (Fig. 2). When of adequate quality, groundwater is a resource initially considered in all water supply evaluations to settlements. However, subsurface waters have a very tight relationship with surface waters, and they most commonly share their fate in quantity and quality. Significantly, when soil is contaminated with UXO and drainage systems contain contaminating particles (for example, depleted uranium), they affect groundwater quality and, belonging to multiple catchments, go to other watersheds. Therefore, risk assessment and environmental management (land and water) are crucial. Groundwater and surface water contamination are long-term concerns, mainly if we are talking about increasing water radioactivity.

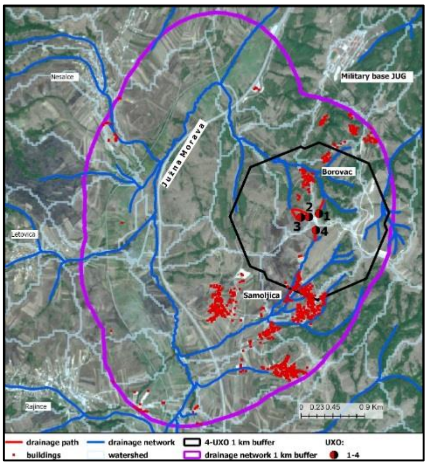

Figure 1 – Research area (source: Sentinel 2 (ESA, 2020) and Google Earth Pro (Google Earth, 2020)
Рис. 1 – Область обследования (источник: Sentinel 2 (ESA, 2020) и Google Earth Pro (Google Earth, 2020)
Слика 1 – Подручје истраживања (извор: Sentinel 2 (ESA, 2020) и (Google Earth, 2020)

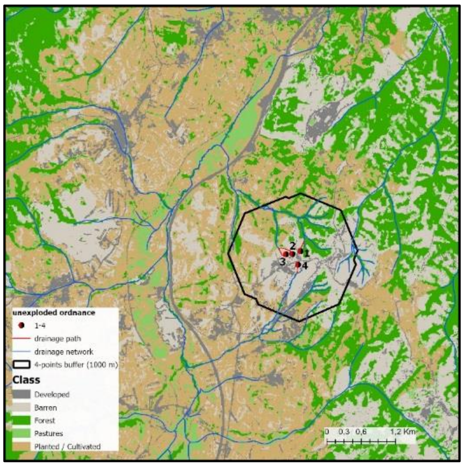

Figure 2 – Land cover of the research area
Рис. 2 – Земляной покров области обследования
Слика 2 – Земљишни покривач подручја истраживања

The land cover analysis (Fig. 2) results (Table 5) revealed that planted/cultivated areas dominate the research area, accounting for more than 33% of the total area, followed by forest and barren classes, each accounting for more than 20%. Both the developed class and the pasture class account for less than 10% of the total area (Table 5).

Table 5 – Land cover report for the entire research area
Таблица 5 – Отчет о земляном покрове по всей территории обследования
Табела 5 – Извештај о земљишном покривачу за целокупно подручје истраживања

Class	Pixel Sum	Percentage %	Area (km^2)
1 developed	67094	7.71	6.71
2 barren	183244	21.05	18.32
3 forest	247794	28.47	24.78
4 pastures	79705	9.15	7.97
5 planted/cultivated	292627	33.62	29.26
Total	870464	100	87.05

The classification data's reliability is assessed by calculating the confusion matrix, followed by an overall accuracy and a discrete multivariate technique - Kappa analysis (Congalton & Green, 2019) (Table 6). The forest class is the only one which is 100% accurately classified. All other classes have some misclassifications, which leads to an overall accuracy of 84.28% and a Kappa hat classification of 0.79, which is a substantial result (Table 6).

Table 6 – Confusion matrix (pixel count)
Таблица 6 – Матрица путаницы (количество пикселей)
Табела 6 – Матрица конфузије (број пиксела)

Value\Classified	1	2	3	4	5	Total ground truth points to the class
1 developed	18	1	0	0	2	21
2 barren	2	16	0	0	3	21
3 forest	0	0	20	0	0	20
4 pastures	0	0	0	17	0	17
5 planted/cultivated	0	3	0	3	15	21
Total	20	20	20	20	20	100

Overall accuracy [%] = 84.28 Kappa hat classification = 0.79

All drainage paths belong to the Južna Morava River watershed, a regional drainage network. Therefore, the second performed analysis was to determine the number of buildings within a 1-kilometer 3D distance buffer zone (19.13 km^2) from four UXO locations with drainage paths directly connected to the drainage network (Fig. 1). The total number of 801 buildings is collected in the second analysis in the broader zone of UXO impact.

The third, more focused analysis spans 3.62 km^2 by encircling a 1-kilometer 3D distance buffer zone around four UXO locations (Figs. 1- 8). The total number of buildings within this 3D distance buffer zone is 168 (Fig. 3).

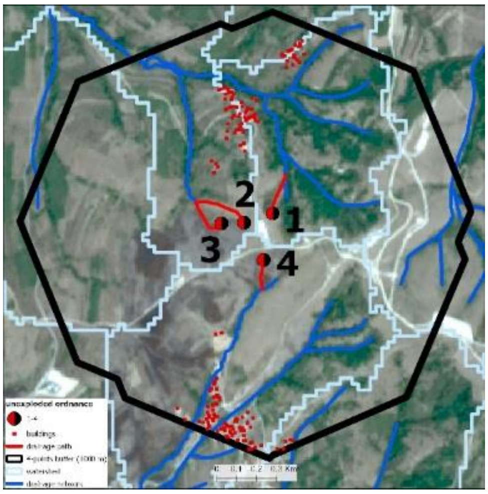

Figure 3 – Four UXO areas with a 1 km buffer zone, source: Sentinel 2 (Copernicus, 2020)
Рис. 3 – Четыре местности под неразорвавшимися боеприпасами с буферной зоной протяженностью 1 км, источник: Sentinel 2 (Copernicus, 2020)
Слика 3 – Четири подручја под неексплодираним убојним средствима са бафер зоном од 1 km (Copernicus, 2020)

The first selected UXO location is within a 1 km 3D distance buffer zone encompassing 79 buildings. The minimum building distance from UXO is 355.44 m, while the maximum distance from UXO is 980.56 m. The mean distance from UXO is 637.26 m (Fig. 4).

The second selected UXO location is within a 1 km 3D distance buffer zone and counts 86 buildings, where the closest one is 309.98 m from UXO. The farthest building is 982.96 m away. The mean building's distance from UXO is 683.89 m (Fig. 5).

The third selected UXO location is within a 1 km 3D distance buffer zone that counts 79 buildings, where the closest one is 258.61 m away from UXO. The farthest building is 978.79 m away. The mean building's distance from UXO is 665.97 m (Fig. 6).

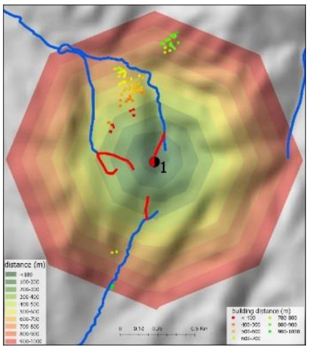

Figure 4 – UXO area 1 with a 1 km buffer zone and buildings within the zone
Рис. 4 – Местность 1 под неразорвавшимися боеприпасами с буферной зоной протяженностью 1 км и сооружениями внутри зоны
Слика 4 – Подручје 1 под неексплодираним убојним средствима са бафер зоном од 1 km и објектима унутар зоне

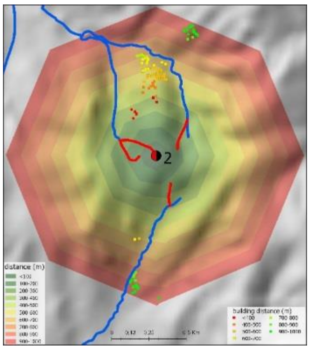

Figure 5 – UXO area 2 with a 1 km buffer zone and buildings within the zone
Рис. 5 – Местность 2 под неразорвавшимися боеприпасами с буферной зоной протяженностью 1 км и сооружениями внутри зоны
Слика 5 – Подручје 2 под неексплодираним убојним средствима са бафер зоном од 1 km и објектима унутар зоне

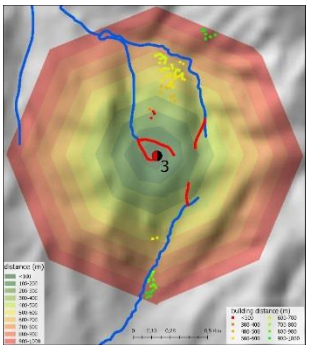

Figure 6 – UXO point 3 with a 1 km buffer zone and buildings within the zone
Рис. 6 – Местность 3 под неразорвавшимися боеприпасами с буферной зоной протяженностью 1 км и сооружениями внутри зоны
Слика 6 – Подручје 3 под неексплодираним убојним средствима са бафер зоном од 1 km и објектима унутар зоне

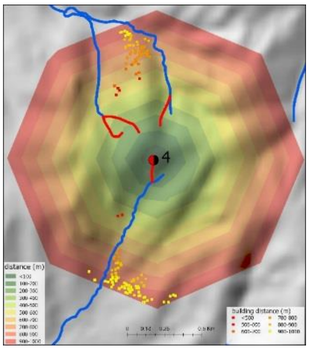

Figure 7 – UXO point 4 with a 1 km buffer zone and buildings within the zone
Рис. 7 – Местность 4 под неразорвавшимися боеприпасами с буферной зоной протяженностью 1 км и сооружениями внутри зоны
Слика 7 – Подручје 4 под неексплодираним убојним средствима са бафер зоном од 1 km и објектима унутар зоне

There are 131 buildings in a 1 km 3D distance buffer zone, the closest of which is 469.38 m from UXO in the fourth UXO location. The farthest building is located 996.43 m away. The mean distance between buildings and UXO is 843.24 m (Fig. 7).

The land cover (Fig. 8) report (Table 7) for the area within four UXO 1 km buffer zones reveals that the dominant class in the area is the barren land with 43.5 % area coverage, followed by the planted/cultivated area (~ 23%) and forests (17.5%).

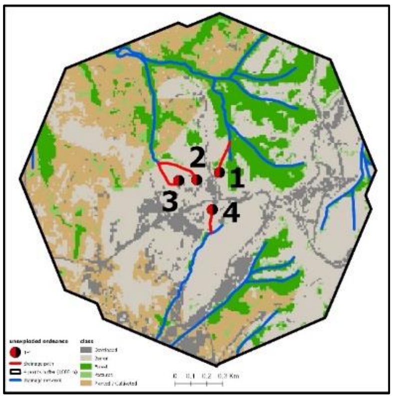

Figure 8 – Land cover of four UXO areas within a 1 km buffer zone
Рис. 8 – Земляной покров четырех местностей под неразорвавшимися боеприпасами в пределах 1-километровой буферной зоны
Слика 8 – Земљишни покривач четири подручја под неексплодираним убојним средствима у оквиру бафер зоне од 1 km

Table 7 – Land cover report for four UXO areas within a 1 km buffer zone
Таблица 7 – Отчет о земляном покрове четырех местностей под неразорвавшимися боеприпасами в пределах 1-километровой буферной зоны
Табела 7 – Извештај о земљишном покривачу за четири подручја са неексплодираним убојним средствима у оквиру бафер зоне од 1 km

Class	Pixel Sum	Percentage %	Area (km^2)
1 developed	3871	10.69	0.39
2 barren	15765	43.54	1.58
3 forest	6341	17.51	0.63
4 pastures	1900	5.25	0.19
5 planted/cultivated	8328	23.01	0.83
Total	36205	100	3.62

Discussion

The usage of the word UXO is commonly connected with the threats presented by anti-personnel and anti-tank mines set during war events and the deployment of engineering units (Pamučar et al, 2011), as well as the repercussions they cause left behind after armed conflicts. There are generally mine-explosive barrier records with accurate locations for these explosive devices. However, cluster bombs also constitute a significant and genuine hazard. The method they are deployed (dispersion of bomblets from various delivery canisters or missiles) results in a vast scattering zone whose borders are not simple to find and designate. Simultaneously with landing on uneven terrain or owing to the surrounding vegetation, there is an extra dispersion of explosives, further increasing the contaminated area. A variety in their looks (colour) and detonators (which are activated in a specific way), unable their trouble-free clearance /demining. Furthermore, damage to UXO causes the delay of the intended "self-destruction - self-sterilization" thus producing an extension of the period of its destruction capabilities. The preceding section describes the sites where soil decontamination was applied but also indicates the regions where the hazard persists to a considerable degree. Gamma-ray spectrometry techniques have been developed to determine the uranium content of surface samples of the soil contaminated with depleted uranium (Sahoo et al, 2004). This approach may estimate contaminated surface soil samples' natural and depleted uranium content and the depleted uranium activity ratio of 235U/238U (Vukanac et al, 2010). It would be necessary to do such analyses to improve everyday life of the local population.

Geoecological aspect

The use of depleted uranium is contentious and has been the subject of international discussion (UN Institute for Disarmament Research, 2008). When it comes to contamination and degradation of the environment, it can be said that uranium and depleted uranium are isotopically very similar, chemically radioactive heavy metals that are dangerous to humans in four ways (Fairlie, 2009):

- as a toxic heavy metal,
- as a chemical carcinogen,
- as an endocrine disorder agent, and
- as an carcinogenic radiation agent.

Another difficulty is with bombs, grenades, and projectiles buried in the ground for many years and whose detonators and primary explosive charges have become "dormant." They can be activated due to an external effect (earthquakes, landslides, excavation of building foundations, increased temperature due to fire, etc.). In addition to fatal consequences for the population (as the most significant loss), there are long-term psychological consequences for the people, water pollution, disabling of water and electricity supply installations, damage to road infrastructure, damage to health systems, and significant economic consequences.

After conducting a multi-criteria study of the described area, it was determined that in addition to the cultivated land cover (33 % - Fig. 2, Table 5), this area contains 21.05 % of the total infertile land. The barren soil is essentially the most contaminated. In the 18.32 km^2 area, there is an enhanced danger to human life and health. Such locations are appropriately referred to as zones of low security. The same is typical for forest-covered places (28.46 %). In this part of Serbia, the population depends on exploiting wood mass, so the existing danger of UXO endangers their primary economic activity. The removal of UXO is complicated in the forest area due to the area relief, lack of visibility, and other obstacles. Pastures cover only 7.97 km^2, but it is not an immeasurable area where cattle and people can be endangered as well as other wild animals that live or feed there. Additionally, pastures are crucial regions for honey production, medicinal plants harvesting, and more. Increased radioactivity in these locations has a direct effect on human health degradation.

Following the confirmation that ammunition containing U-236 with depleted uranium (DU) was used during the NATO air campaign in Serbia in 1999, concern was expressed about the possibility that other nuclides from the nuclear fuel cycle, especially transuranium nuclides, could be present with this type of ammunition. Numerous tests have been performed, and many papers have been published. For example, in an article entitled "Actinide Analysis of a Depleted Uranium Penetrator from a 1999 Target Site in Southern Serbia," published in the Journal of Environmental Radioactivity (2003), McLaughlin et al published the results of the analyses of uranium and plutonium from the target location in southern Serbia (McLaughlin et al, 2003). The results of that and many other works confirmed the presence of trace plutonium in the penetrator, the highest concentration of plutonium ever reported in the Balkans.

After military operations, most UXO (or their fragments) containing depleted uranium remained underground in specific geomorphological and geochemical environments exposed to local climatic conditions. The distribution, mobility, and/or fixing of depleted uranium in the contaminated soil varied according to the geological and pedological surroundings, vegetation type, and climatic factors. Corrosion products of depleted uranium and other contaminating particles associated with UXO fluctuate over time depending on the extent of their geochemical fractionation. It is an assumption that has been validated in several studies. At around 150 mm from the source, the concentration of depleted uranium decreases to 1% of its original value (Radenković et al, 2008).

Moreover, the danger of UXO activation varies by season and during dry and rainy periods. The ability to transfer contaminated material over various environmental mediums signals an infinite hazard to the living world. Human epidemiological research has shown that exposure to low and moderate radon concentrations may cause up to 14% of malignant tumours. Due to the radiation in the soil, animals living in subterranean cavities are exposed to more significant amounts. Over the years, numerous dose-effect models have been created to evaluate the dangers to individuals and the environment (Ćujić et al, 2021).

Studies of the mobility and geo-fractionation of depleted uranium in the soil have shown that depleted uranium may be very mobile under substantial contamination conditions and intensive ion exchange with the environment. Furthermore, as previously mentioned in the study, the decomposition rate is also soil-dependent, mainly for Fe and Mn oxides and carbonate substrates in the soil (Popovic et al, 2008).

In the past few decades, the southern part of Central Serbia has undergone significant ecological changes, including depopulation as a social factor (Potić et al, 2022), where the natural process of ecological revitalization due to population ageing and emigration is taking place, and forest areas are expanding. Due to the growth and spread of vegetation on uncultivated surfaces, it will become more challenging to clean and remediate that area over time (Mihajlović et al, 2014).

Risk management of unexploded ordnance

One risk assessment method is insufficient for UXO locations. The UXO risk assessment procedure requires creating civil-military collaboration to develop alternative approaches. The initial step might be prioritizing UXO cleanup areas. This data type is beneficial for allocating financial and non-financial resources, such as equipment and personnel. A full description or geoecological investigation of UXO-contaminated regions would be the second stage in risk assessment (risk assessment for specific locations). With this approach, quantifiable data on the possible harm to individuals living around the UXO location (as shown in Figs. 1 - 8) and local ecosystems may be supplied.

Location data is often unavailable and wildly inaccurate. Using remote sensing allows the creation of at least a rough database with the most endangered locations. However, detailed information is necessary for data collection to establish UXO risk management correctly. Two sources of risk at UXO sites must also be considered: the risk of explosion and environmental contamination from ammunition components flushed into water and soil. These two types of threats are significantly different. The first leads to immediate consequences for a man or his material environment; in contrast, the consequences of permanent exposure to ammunition are chronic impairment of the quality of life.

The presence of 33% arable land (Table 5) indicated significant agricultural activity and increased people's mobility and daily activities in the vicinity of UXO. According to the 2011 census, this region had 166 people living in 44 homes. Such a demographic distribution would suggest an equal number of potential UXO victims.

At only four notable locations where the Serbian Center for Demining confirmed the presence of UXO, there are 801 built structures: houses, shops, schools, food storage facilities, warehouses, garages with mechanization for agricultural surface processing, and fuel depots, among others. Without security measures over an extended period, it is logical to presume that this area poses an enhanced security risk. Given the unknown and unexpected composition of UXO, the threats to the environment, groundwater and surface water, soil, and air, and the long-term impacts on living organisms' DNA, it is deemed essential to affirm environmental risk management.

Risk assessment methods can define the level of danger to people, property, and the environment in an area and establish priorities and courses of action. It is necessary to determine the factors and levels of risk to develop a UXO risk management system. Such a system would provide a strategic advantage over the area's level of vulnerability. Specifically, applying various (physical, educational, economic, etc.) measures would lower the risk of endangering people, property, and the environment. This claim is supported by the fact that the problem of UXO has the characteristics of a "long shadow" of a crisis, i.e., a problem arises quickly, while its consequences remain for a long time in the future. Therefore, developing an adequate methodology for risk assessment and a risk management strategy in this area is paramount.

Conclusion

Besides unexploded ordnance left behind after the 1999 bombing campaign on the territory of former Yugoslavia, there is also UXO left from World Wars I and II and still buried in the ground. The data on the mentioned amounts is not accessible except in the circumstances encountered during particular land excavation works. Afterwards, the problem of UXO intensifies, but it does not move away from stating the problem and demanding that it be solved. The frequent reference to UXO in the ground inadvertently covers the issues of our waterways which are also contaminated with unexploded ammunition. Contamination levels considerably impact planning and decision making when choosing safe locations for crossing an area while undertaking different activities (Bozanic et al, 2018).

Combining physical and chemical procedures and analyses may help decision making on the cleanup plan for depleted uranium-contaminated military sites. It is vital to consider establishing radioactive monitoring in such a location and others where UXO is an issue. Such surveillance must be genuine, radiological surveillance must be reasonably valid, and unprofessional groups or people cannot conduct it. In Serbia, such monitoring is undertaken by the Department of Radiation and Environmental Protection of the Institute of Nuclear Sciences in Vinča, Belgrade (Krneta Nikolić et al, 2014).

The article contributes significantly to creating a strategy for environmental risk management in regions contaminated by UXO. The paper provides an example of an effective technique for resolving risk assessment issues experienced by the Army in UXO locations. Not only does it present a suitable risk analysis, but it also considers numerous environmental protection possibilities. It is feasible to calculate the number of structures and people, soil kinds, plant types, and others exposed to UXO dangers based on the key spots using the multi-criteria analysis and the GIS. This paper is one of the guidelines for environmental risk assessment.

Since the UXO issue in the observed region has not been resolved for the last two decades and based on the findings of this paper's analyses, it can be stated that the UXO problem in this area will persist and continue to threaten the safety of people and property. Consequently, establishing a UXO risk management plan and a methodology for risk assessment following strategic guidelines is paramount. The findings of this paper's analyses unequivocally reveal the level of risk to people, property, and the environment with a detrimental long-term effect on this region. Appropriate risk assessment and UXO risk management would contribute to slowing down the UXO detrimental consequences in all aspects.

Future studies should identify the criteria for zoning UXO-contaminated regions based on threats to people, property, and the environment. The findings of the analyses presented in this article may be used as a foundation for establishing the criteria and methodology and then estimating the danger of UXO. According to the same approach, it is conceivable to do comparable analyses for other areas and the whole territory of the Republic of Serbia, therefore resolving the issue of UXO risk management and laying the groundwork for more effective protection of people's property and the environment.

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Управление рисками, связанными с неразорвавшимися боеприпасами, в Республике Сербия в целях защиты окружающей среды – исследование случая Боровац

Иван М. Потич[а], *Ненад* М. Комазец[б], *Лиляна* М. Михайлович[в], *Александр* М. Милич[б], *Саша* Т. Бакрач[а]

[а] Военно-географический институт имени генерала Стевана Бошковича, г. Белград, Республика Сербия

[б] Университет обороны в г. Белград, Военная академия, г. Белград, Республика Сербия

[в] Белградский университет, географический факультет, г. Белград, Республика Сербия, **корреспондент**

РУБРИКА ГРНТИ: 81.93.03 Методология оценки вероятности аварий, катастроф, стихийных бедствий и их последствий. Оценка риска,
34.35.51 Антропогенные воздействия на экосистемы,
20.23.25 Информационные системы с базами знаний.
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: После нескольких десятилетий борьбы с неразорвавшимися боеприпасами (НРБ) в некоторых районах Республики Сербия обнаружено, что они все еще представляют значительную опасность для населения, имущества и окружающей среды. Несмотря на то, что местность была разминирована, все еще стоит серьезная угроза от труднодоступных частей неразорвавшихся боеприпасов. Несоответствующие системные решения в управлении неразорвавшимися боеприпасами могут повлечь за собой серьезные негативные последствия.

Методы: В данной статье изучается воздействие частей НРБ на население и окружающую среду на основании анализа пространственного распределения различных видов и количества НРБ. Были проведены два различных геопространственных анализа, а также разработаны рекомендации по управлению рисками с помощью многокритериального устранения рисков, анализа ГИС и дистанционного зондирования.

Результаты: Было проведено два различных геопространственных анализа, в результате которых осуществлена классификация территории с высоким риском от неразорвавшихся боеприпасов.

Выводы: Данная статья вносит значительный вклад в создание стратегии управления экологическими рисками на местности, загрязненной неразорвавшимися боеприпасами. Такой тип стратегии является эффективным методом для решения проблемы оценки риска на местности с неразорвавшимися боеприпасами. В статье также обсуждается анализ рисков и меры по охране окружающей среды. С помощью многокритериального анализа и ГИС оценивается степень риска для населения, имущества, типов почвы и растительности от воздействия НРБ. Данная статья представляет собой руководство по оценке экологических рисков.

Ключевые слова: Неразорвавшиеся боеприпасы, управление рисками в кризисных ситуациях, охрана окружающей среды, безопасность, геопространственный анализ.

Управљање ризиком од неексплодираних убојних средстава у Републици Србији у функцији заштите животне средине – студија случаја Боровац

Иван М. Потић[а], *Ненад* М. Комазец[б], *Љиљана* М. Михајловић[в], *Александар* М. Милић[б], *Саша* Т. Бакрач[а]

[а] Војногеографски институт „Генерал Стеван Бошковић", Београд, Република Србија

[б] Универзитет одбране у Београду, Војна академија, Београд, Република Србија

[в] Универзитет у Београду, Географски факултет, Београд, Република Србија, **аутор за преписку**

ОБЛАСТ: географски информациони системи, менаџмент животне средине, управљање ризицима
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: После вишедеценијског решавања проблема са неексплодираним убојним средствима у неким областима Републике Србије, она још увек представљају знатан ризик по безбедност људи, имовине и животне средине. Иако је терен знатно очишћен, постоје озбиљне претње од компоненти које се тешко проналазе. Неадекватна системска решења за управљање овим средствима могу изазивати веома велике последице.

Методе: На основу анализе просторне дистрибуције различитих типова и количина неексплодираних убојних средстава, у чланку се проучавају ефекти ових компоненти на људске животе и животну средину. Извршене су две различите геопросторне анализе, а укључене су и смернице за управљање ризиком путем елиминације ризика на основу више критеријума, ГИС анализа и даљинске детекције.

Резултати: Две различите геопросторне анализе резултирале су класификацијом области које су под високим ризиком од преосталих неексплодираних убојних средстава.

Закључак: Чланак значајно доприноси стварању стратегије управљања еколошким ризицима у регионима контаминираним неексплодираним убојним средствимаОна представља ефикасну технику за решавање изазова процене ризика на тим просторима . У раду се разматрају и анализа ризика и опције заштите животне средине. Користећи вишекритеријумску анализу и ГИС, процењује се изложеност структуре, људи, врста земљишта и биљних врста опасностима које неексплодирана убојна средства изазивају на кључним локацијама. Овај рад служи као смерница за процену еколошког ризика.

Кључне речи: неексплодирана убојна средства, менаџмент кризних ситуација, заштита животне средине, сигурност, геопросторна анализа.

Paper received on / Дата получения работы / Датум пријема чланка: 24.05.2023.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 30.11.2023.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 01.12.2023.