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# Variation of $^{137}$Cs along the slopes of Mosna, Eastern Serbia

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**Abstract**

Fallout radionuclides (FRNs), e.g., $^{137}$Cs, $^{239+240}$Pu, $^{210}$Pb$_{ex,}$ and $^{7}$Be, have been successfully used to estimate soil erosion and deposition rates worldwide in the past few decades. The FRNs inventories can be converted to soil redistribution rates using different available conversion models. Among FRNs, artificial radionuclide cesium-137 is the most widely used as a tracer for soil erosion assessment. In this survey, the $^{137}$Cs measurements have been used to found patterns of cesium-137 along the slope transects located in the Mosna site (Eastern Serbia). A typical example of the vertical distribution of the $^{137}$Cs in an uncultivated soil was found. Patterns of downslope variation in $^{137}$Cs contents could be related to the field topography. Continuation of this research is important to provide insight into the potential of applying the $^{137}$Cs method for the assessment of soil erosion and deposition rates within a study site.

## 1. Introduction

Radioactive $^{137}$Cs is found globally in the environment due to fallout from atmospheric nuclear weapon tests (since the early 1950s with the peak in 1963) - bomb-derived $^{137}$Cs and nuclear power plant - NPP accidents in the more recent past (Chernobyl 1986 and Fukushima Daiichi 2011 accidents). The properties and particular features of $^{137}$Cs that have been explained in detail in numerous studies (Arata et al., 2016; FAO/IAEA, 2017; Mabit et al., 2008), indicate that $^{137}$Cs is an excellent tracer for studying soil erosion. The video demonstrating the cesium-137 method for soil erosion assessment is available at www.iaea.org/newscenter/multimedia/videos/studying-erosion-with-the-help-of-radionuclides (Producer: Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture). Over the past years, different models (such as *Proportional Model, Mass Balance Model I, II and III, Profile Distribution Model, Diffusion and Migration Model, Modelling Deposition and Erosion Rates with RadioNuclides,* etc.) have been developed for cultivated and uncultivated soils in order to convert fallout radionuclides - FRNs (such as artificial $^{137}$Cs and $^{239+240}$Pu, natural $^{210}$Pb fallout and cosmogenic $^{7}$Be) inventories into the soil redistribution rates (Arata et al., 2016; Walling et al., 2011). The $^{137}$Cs is the most widely used FRN soil tracer for soil erosion assessment (Ceaglio et al., 2012; Haciyakupoglu et al., 2005; Iurian et al., 2012, 2014; Theocharopoulos et al., 2003). Advantages and limitations of the $^{137}$Cs technique over traditional approaches can be found in the study of Mabit et al. (2008, 2013) and Walling et al. (2011).

Since erosion is one of the major sources of soil degradation and soil should be considered as a non-renewable resource and should be protected, determination of soil erosion rates is very important in order to design effective strategies for soil conservation. The recently applied RUSLE2015 model indicates the mean annual rate of soil loss in the EU erosion-prone lands of 2.46 t ha$^{-1}$ yr$^{-1}$, ranged from 8.46 t ha$^{-1}$ in Italy to 0.06 t ha$^{-1}$ in Finland (Panagos et al., 2015). According to erosion map of the Republic of Serbia (1966-1971), 86% of the total area of Serbia is endangered by soil erosion of

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various rates (Lazarević, 1983), available data in 2009 indicated that the ratio between individual erosion categories has changed (Lazarević, 2009). In recent years the use of $^{137}$Cs method is developing abruptly in Serbia, and results were published in different studies (Forkapić et al., 2019; Kalkan et al., 2020; Krmar et al., 2015; Petrović et al., 2016).

The present study was carried out as a preliminary survey to assess the feasibility of using the $^{137}$Cs to found patterns of soil movement along the slope transects located in the Mosna site (Eastern Serbia).

## 2. Study site

The Mosna site (Figure 1) is situated in the lower course of the Poreč River, in its narrowest part, between steep and high banks of the western slopes of Veliki Greben and the milder eastern slopes of Liškovac. From Mosna downstream, Poreč River begins to expand in the form of a funnel. That part of the mouth of Poreč River is the elongated funnel-shaped bay of the Đerdap Lake.

The geologic structure of the wider area around Mosna involves Proterozoic crystalline shales, Cambrian green shales with peridots, gneiss, and granite and gabbroid rocks of Deli Jovan Mountain. Devonian and Carboniferous sediments, volcanogenic-sediment series, Hercine-age granitoid, and Permian red sandstones were identified. In the broader area around the Mosna site, there is a significant distribution of Jurassic and Cretaceous sediments (andesites, dacites, pyroclastic rocks), Paleogene series of coal, plutonic rocks and Neogene and Quaternary sediments (Bogdanović, 1977).

From Miroč Mountain in the north (the highest peak Veliki Štrbac, 768 m) to the Popadija saddle (428 m) in the south, climatogenic reddish and darker (due to the presence of shale-derived materials) ore soils were identified (Milić, 1976; Petrović, 1974). These soils are formed by complex pedogenetic processes, denudation, and by drifting of Danube sediments. Their rubification occurred during the Pliocene under the influence of a subtropical climate. During the Würm, there was some accumulation of the loess and its mixing with other alluvial fragments during the flooding of the alluvial planes (Milić, 1976; Petrović, 1974).

According to the erosion map of Serbia (Lazarević, 1983), the study site is affected by medium erosion, and all the soil profiles are located within this soil erosion class.

## 3. Soil sampling and analytical methods

Soil profiles were taken during the summer of 2016 along two parallel transects to determine the distribution of $^{137}$Cs within the soil profile. Soil samples were collected every 5 cm up to the depth of 30 cm at 11 spots along both transects. Soil samples were dried, homogenized, sieved through a 2 mm sieve, loaded into a Marinelli beaker and weighed for $^{137}$Cs analysis. Soil samples were analyzed for $^{137}$Cs using an HPGe gamma-ray spectrometer. The specific activity of $^{137}$Cs was determined from its gamma-ray line at 661.6 keV, and $^{137}$Cs content of the soil samples was expressed as specific activity (Bq kg$^{-1}$). Soil properties (sand (0.05-2 mm), silt (0.002-0.05 mm), and clay (<0.002 mm) content, dry bulk density, particle density, and total porosity) were analyzed using standard procedures (Blake and Hartge, 1986; Rowell, 1997). OriginPro and Minitab were used for statistical analysis of data.

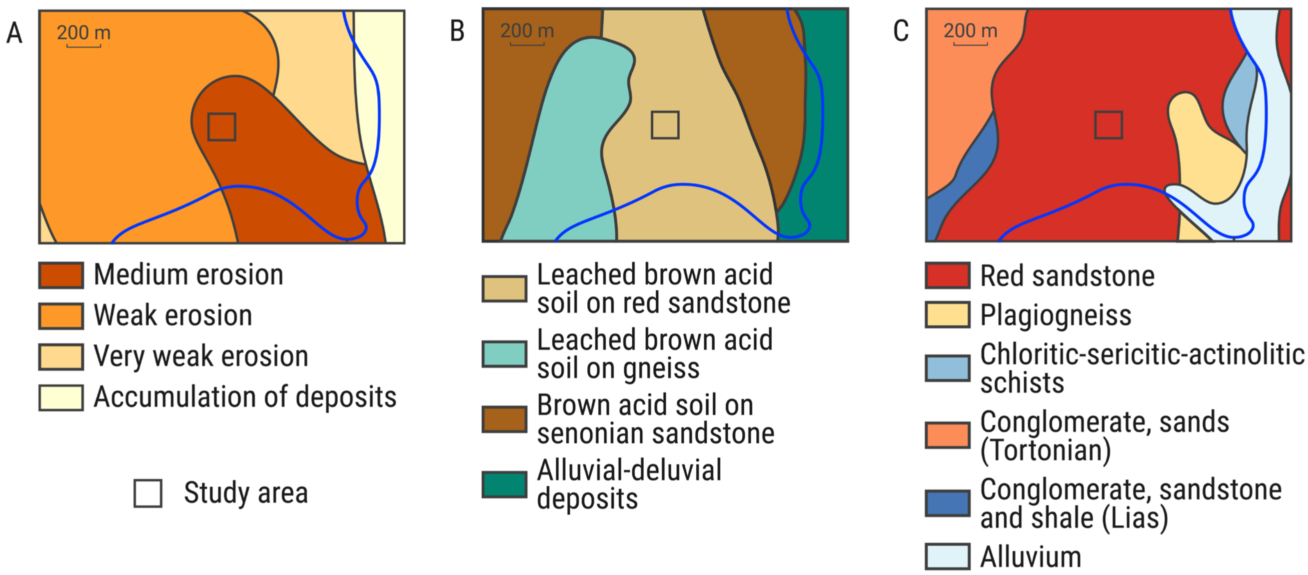


**Figure 1.** Erosion, soil, and geology maps of the study area and its surroundings.

## 4. Results and discussion

The $^{137}Cs$ specific activities in the studied surface soil layers showed a wide range of values (from 14.3 to 357 Bq kg$^{-1}$ in the 0-5 cm layer and from b.d.l. to 304 Bq kg$^{-1}$ in the 5-10 cm layer) (Figure 2), which indicate that study site is affected by Chernobyl fallout. Histogram of the $^{137}Cs$ specific activities in studied soils is presented in Figure 2. According to available data before the Chernobyl accident, the $^{137}Cs$ specific activities were below 5 Bq kg$^{-1}$ in the soils of Serbia (Popović and Spasić-Jokić, 2006). After the Chernobyl accident, the different survey reported a wide range of the $^{137}Cs$ specific activities in soils of different regions of Serbia (Bikit et al., 2005; Dragović et al., 2012; Dugalic et al., 2010; Janković-Mandić et al., 2014).

The vertical distribution of the $^{137}Cs$ in soils of a study site is presented in Figure 3. A typical example of the vertical distribution of the $^{137}Cs$ in an uncultivated soil was found, its activity decreases exponentially with soil depth, about 94% of the total activity was found in the top 15 cm (Figure 3). This indicates that the study site has not been cultivated since 1986, when the main input of $^{137}Cs$ into the landscape occurred. Constant decrease of $^{137}Cs$, but with different configurations, in soil profiles collected along the transect was found in the study of Iurian et al. (2012), according to the authors this may be due to percolating water, growth conditions of microflora or biotic interactions within the soil. Different soil horizons may have different soil characteristics, which can influence the degree of retention and migration of $^{137}Cs$ through the profile (Nimis, 1996).

Descriptive statistics of $^{137}Cs$ specific activities and soil properties of studied soils are given in Table 1. According to the USDA soil textural classification, most samples belonged to the silty loam textural class.

Data transformations have been performed prior to analysis to obtain a normal or near-normal distribution. The one-way ANOVA test results indicate that for most of the variables there is statistically significant difference in average values between at least two of the sampling locations or at least two soil depths (Table 2).

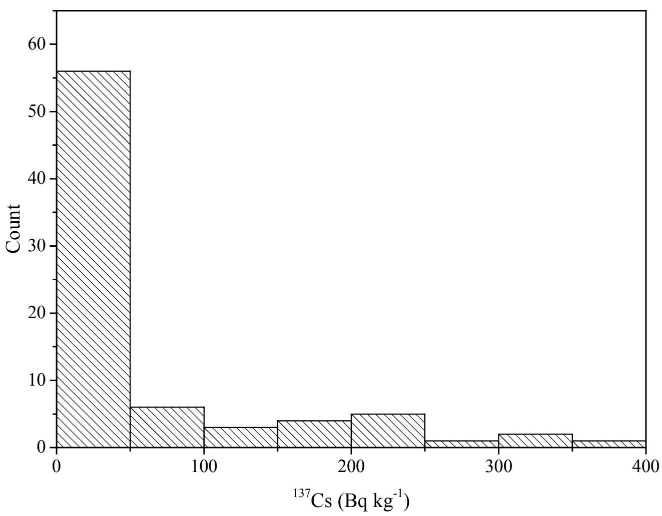


**Figure 2.** The histogram of the $^{137}Cs$ specific activities (Bq kg-1) in soil samples from the study site.

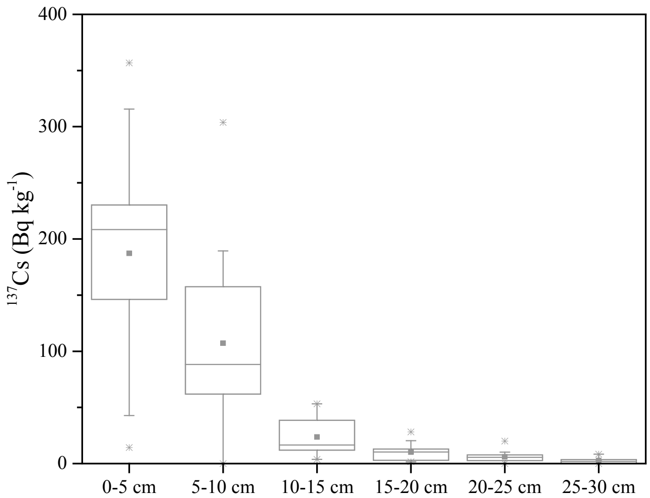


**Figure 3.** Mean depth profile of the 137Cs in soils from the study site.

**Table 1.** Basic descriptive statistics for $^{137}Cs$ specific activities and soil properties.

| Parameter | Mean | St. Dev. | Coef. Var. (%) | Min | Median | Max | Shapiro -Wilk (Sig.) |
|---|---|---|---|---|---|---|---|
| $^{137}Cs$ (Bq kg$^{-1}$) | 56.2 | 88.1 | 157 | b.d.l. | 12.7 | 357 | 0.000 |
| Sand (0.05-2 mm) (%) | 15.6 | 5.6 | 35.9 | 9.10 | 13.9 | 34.7 | 0.000 |
| Silt (0.002-0.05 mm) (%) | 66.7 | 7.24 | 10.9 | 49.2 | 69.3 | 79.4 | 0.001 |
| Clay (<0.002 mm) (%) | 17.7 | 7.21 | 40.7 | 9.20 | 15.3 | 37.1 | 0.000 |
| Particle density (g cm$^{-3}$) | 2.59 | 0.03 | 1.29 | 2.52 | 2.59 | 2.65 | 0.011 |
| Bulk density (g cm$^{-3}$) | 1.51 | 0.16 | 10.6 | 1.12 | 1.52 | 2.02 | 0.025 |
| Total porosity (%) | 41.7 | 5.75 | 13.8 | 23.5 | 41.3 | 55.9 | 0.025 |

b.d.l. below detection limit.

**Table 2.** One-way ANOVA test results for 137Cs and soil properties with soil depth and location.

| Variable | Source of variation | F-value | Sig. |
|---|---|---|---|
| $^{137}Cs$ (Bq kg$^{-1}$) | Depth | 25.2 | 0.000 |
| | Location | 1.70 | 0.087 |
| Sand (0.05-2 mm) (%) | Depth | 0.18 | 0.970 |
| | Location | 6.37 | 0.000 |
| Silt (0.002-0.05 mm) (%) | Depth | 4.08 | 0.003 |
| | Location | 8.29 | 0.000 |
| Clay (<0.002 mm) (%) | Depth | 5.58 | 0.000 |
| | Location | 6.77 | 0.000 |
| Particle density (g cm$^{-3}$) | Depth | 21.7 | 0.000 |
| | Location | 2.05 | 0.033 |
| Bulk density (g cm$^{-3}$) | Depth | 5.10 | 0.000 |
| | Location | 4.17 | 0.000 |
| Total porosity (%) | Depth | 4.20 | 0.002 |
| | Location | 4.23 | 0.000 |

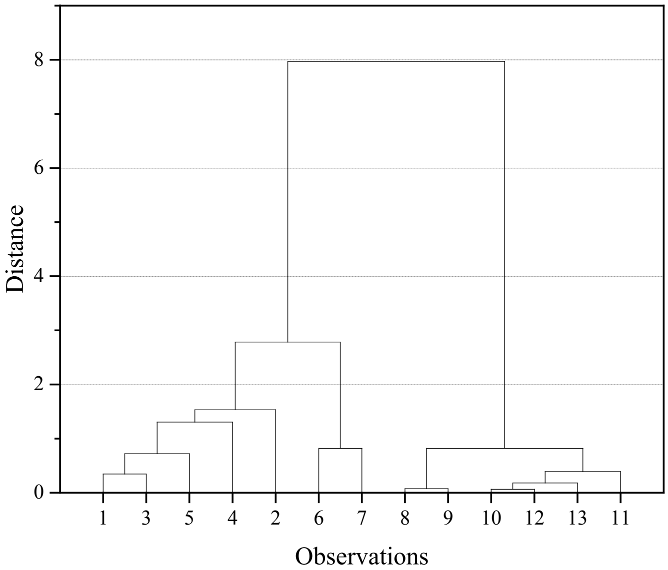


**Figure 4.** Dendrogram derived from the hierarchical cluster analysis

The cluster analysis using Ward's method and squared Euclidean distance was applied to obtain a dendrogram illustrating similarities between soil profiles (Figure 4). Two main clusters are distinguished - the first one contained soil profiles collected from the first transect. In the second cluster, soil profiles collected from the second transect are grouped.

In the area affected by Chernobyl fallout, some of the variability may reflect an initially non-uniform distribution of Chernobyl fallout, i.e., irregular distribution of rainfall during the short period after the accident in the landscape due to factors influencing the meso- and micro-scale variability in rainfall distribution (IAEA, 2014). According to Navas and Walling (1992), high spatial variability of $^{137}$Cs can be mainly attributed to the distribution of vegetation cover along with the micro- and meso-topography, which control the small-scale redistribution of $^{137}$Cs.

Along the transects, the downslope variations of $^{137}$Cs activities show similar patterns in the upper part of the slope (Figure 5). The $^{137}$Cs activity decrease from hilltop locations to locations at the mid of the slope (Figure 5). From the middle of the slope at Transect I, there is a sudden increase of $^{137}$Cs activity and then a decrease at the bottom of the slope, while at Transect II, there is a small increase of $^{137}$Cs at the bottom of the slope. Patterns of downslope variation in $^{137}$Cs activities could be described by field topography. Before started sampling, we were assured by the landowner that the land had never been used for agriculture before. But, according to the topographic map from 1971, most of the sampling locations are within an area classified as the orchard. There was no evidence about it on the field in the time of sampling and obtained vertical distribution of $^{137}$Cs in soil profile confirmed that the land had not been cultivated since the main fallout $^{137}$Cs occurred in 1986. According to the literature data (FAO/IAEA, 2017), the undisturbed site can be found at the hilltop, the eroded site is common at the mid-slope position, and the deposition site occurs at the bottom of the slope. The existence of eroding areas downside the slope due to the morphological pattern of the field was reported in the study of Iurian et al. (2012). The close relationship between erosion rates and variations in vegetation cover density was found in the study of Porto et al. (2001).

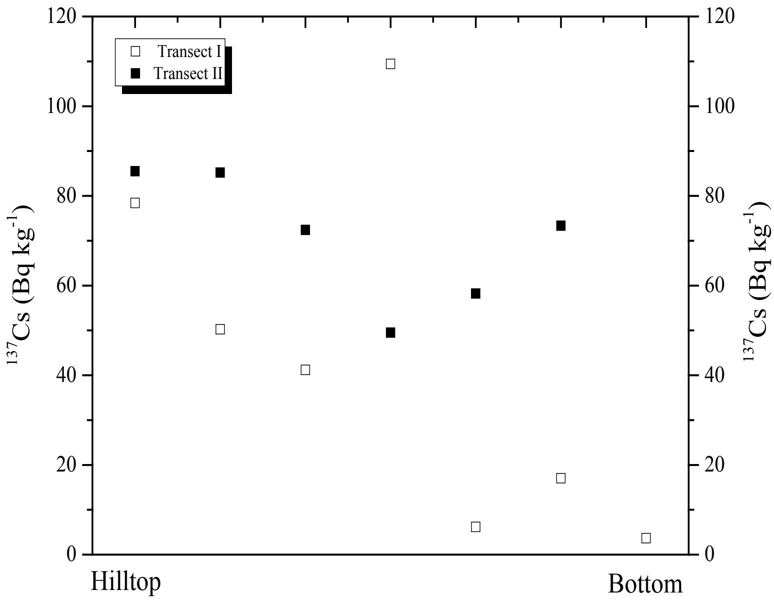


**Figure 5.** Distribution of $^{137}$Cs along the slope transects.

## 5. Conclusion

In order to improve soil conservation strategies, the search for additional methods for soil erosion assessment showed that fallout radionuclides (FRNs), especially $^{137}$Cs, can be used as a soil erosion tracer. This preliminary investigation provides insight into the possibility of using $^{137}$Cs as soil erosion tracers within the study site. To obtain quantitative estimates of soil erosion/deposition rates from $^{137}$Cs measurements, using different conversion models, in further investigations, the reference site should be identified, and additional samples should be collected within the study site following the grid approach.

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## References

Arata, L., Meusburger, K., Frenkel, E., A'Campo-Neuen, A., Iurian, A. R., Ketterer, M.E., Mabit, L., Alewell, C., 2016. Modelling Deposition and Erosion rates with RadioNuclides (MODERN) - Part 1: A new conversion model to derive soil redistribution rates from inventories of fallout radionuclides. J. Environ. Radioact. 162-163, 45-55.

Bikit, I., Slivka, J., Čonkić, Lj., Krmar, M., Vesković, M., Žikić-Todorović, N., Varga, E., Ćurčić, S., Mrdja, D., 2005. Radioactivity of the soil in Vojvodina (northern province of Serbia and Montenegro). J. Environ. Radioact. 78, 11-19.

Blake, G.R., Hartge, K.H., 1986. In: Klute, A., Ed. Methods of Soil Analysis. Part 1 - Physical and Mineralogical Methods, 2nd Edition, Soil Science Society of America, Madison, pp. 363-382.

Bogdanović, P.O., 1977. Geology of northerneast Serbia (stratigraphy, magnetism, tectonics and metallogeny). Institute for Geological, Hydrogeological, Geophysical and Geotechnical Research - Geological Institute (in Serbian).

Ceaglio, E., Meusburger, K., Freppaz, M., Zanini, E., Alewell, C., 2012. Estimation of soil redistribution rates due to snow cover related processes in a mountainous area (Valle d ' Aosta, NW Italy). Hydrol. Earth Syst. Sci. 16, 517-528.

Dragović, S., Janković-Mandić, Lj., Dragović, R., Đorđević, M., 2012. Natural and man-made radionuclides in soil as sources of radiation exposure. In: Radiation Exposure: Sources, Impacts and Reduction Strategies. Balenovic, D., and Stimac, E., (Eds.) New York: Nova Science Publishers, Inc. pp. 1-42.

Dugalic, G., Krstic, D., Jelic, M., Nikezic, D., Milenkovic, B., Pucarevic, M., Zeremski-Skoric, T., 2010. Heavy metals, organics and radioactivity in soil of western Serbia. J. Hazard. Mater. 177, 697-702.

FAO/IAEA, 2017. Use of $^{137}$Cs for soil erosion assessment. Fulajtar, E., Mabit, L., Renschler, C.S., Lee Zhi Yi, A., Food and Agriculture Organization of the United Nations, Rome, Italy. 64p.

Forkapić, S., Kalkan, K., Marković, S., Bikit-Šreder, K., Mrđa, D., Lakatoš, R., Samardžić, S., 2019. Soil erosion rate assessment based on the activity of $^{137}$Cs on Titel loess plateau. XXX Symposium of the Radiation Protection Society of Serbia and Montenegro. pp. 103-109.

Haciyakupoglu, S., Ahmet Ertek, T., Walling, D.E., Fatih Ozturk, Z., Karahan, G., Evren Erginal, A., Celebi, N., 2005. Using caesium-137 measurements to investigate soil erosion rates in western Istanbul (NW Turkey). Catena, 64, 222-231.

IAEA, 2014. Guidelines for Using Fallout Radionuclides to Assess Erosion and Effectiveness of Soil Conservation Strategies, IAEA TECDOC No. 1741. 215 p.

Iurian, A.R., Begy, R., Cătinaş, I., Cosma, C., 2012. Results of medium-term soil redistribution rates in Cluj county, Romania, using $^{137}$Cs measurements. Procedia Environ. Sci. 14, 22-31.

Iurian, A.R,, Mabit, L., Cosma, C., 2014. Uncertainty related to input parameters of $^{137}$Cs soil redistribution model for undisturbed fields. J. Environ. Radioact. 136, 112-120.

Janković-Mandić, Lj., Dragović, R., Đorđević, M., Đolić, M., Onjia, A., Dragović, S., Bačić, G., 2014. Spatial variability of $^{137}$Cs in the soil of Belgrade region (Serbia). Hemijska Industrija 68, 449-455.

Kalkan, K.S., Forkapić, S., Marković, S.B., Bikit, K., Gavrilov, M.B., Tošić, R., Mrđa, D., Lakatoš, R., 2020. The application of $^{137}$Cs and $^{210}Pb_{ex}$ methods in soil erosion research of Titel loess plateau. Open Geosciences - De Gruyter 12, 11-24.

Krmar, M., Velojić, M., Hansman, J., Ponjarac, R., Mihailović, A., Todorović, N., Vučinić, M., Savić, R., 2015. Wind erosion on Deliblato (the largest European continental sandy terrain) studied using $^{210}$Pbex and $^{137}$Cs measurements, J. Radioanal. Nucl. Ch. 303, 2511-2515.

Lazarević, R., 1983. The erosion map of Serbia 1: 500000-Interpreter. Belgrade: Institute of Forestry and Wood Industry.

Lazarević, R., 2009. Erosion in Serbia. Belgrade: Želnid.

Mabit, L., Benmansour, M., Walling, D.E., 2008. Comparative advantages and limitations of the fallout radionuclides $^{137}$Cs, $^{210}$Pbex and $^{7}$Be for assessing soil erosion and sedimentation. J. Environ. Radioact. 99, 1799-1807.

Mabit, L., Meusburger, K., Fulajtar, E., Alewell, C., 2013. The usefulness of $^{137}$Cs as a tracer for soil erosion assessment: A critical reply to Parsons and Foster (2011). Earth-Sci. Rev. 127, 300-307.

Milić, S.Č., 1976. River watersheds as elements of the relief of Eastern Serbia. Serbian Geographical Society - Special Issues,Vol. 42. Belgrade.

Navas, A., Walling, D.E., 1992. Using caesium-137 to assess sediment movement on slopes in a semiarid upland environment in Spain. Erosion, Debris Flows and Environment in Mountain Regions (Proceedings of the Chengdu Symposium). IAHS Publ. no. 209. pp.129-138.

Nimis, P.L., 1996. Radiocesium in plants of forest ecosystems. Studia Geobot. 15, 3-49.

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L., Alewell, C., 2015. The new assessment of soil loss by water erosion in Europe. Environ. Sci. Policy 54, 438-447.

Petrović, J., 1974. Karst of Eastern Serbia. Serbian Geographical Society - Special Issues, Vol. 40. Belgrade.

Petrović, J., Dragović, S., Dragović, R., Đorđević, M., Đokić, M., Zlatković, B., Walling, D.E., 2016. Using $^{137}$Cs measurements to estimate soil erosion rates in the Pčinja and South Morava River Basins, southeastern Serbia. J. Environ. Radioact. 159, 71-80.

Popović, D., Spasić-Jokić, V., 2006. Consequences of the Chernobyl disaster in the region of the Republic of Serbia. Vojnosanit Pregled 63, 481-487.

Porto, P., Walling, D.E., Ferro, V., 2001. Validating the use of caesium-137 measurements to estimate soil erosion rates in a small drainage basin in Calabria, Southern Italy. J. Hydrol. 248, 93-108.

Rowell, D.L., 1997. Bodenkunde. Untersuchungsmethoden und ihre Anwendungen, Berlin: Springer.

Theocharopoulos, S.P, Florou, H., Walling, D.E., Kalantzakos, H., Christou, M., Tountas, P., Nikolaou, T., 2003. Soil erosion and deposition rates in a cultivated catchment area in central Greece, estimated using the $^{137}$Cs technique. Soil Till. Res. 69, 153-162.

Walling, D.E., Zhang, Y., He, Q., 2011. Models for deriving estimates of erosion and deposition rates from fallout radionuclide (caesium-137, excess lead-210, and beryllium-7) measurements and the development of user-friendly software for model implementation. In: Impact of Soil Conservation Measures on Erosion Control and Soil Quality. IAEA-TECDOC-1665. IAEA, Vienna. pp. 11-33.