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ESTIMATING THE SOIL EROSION AND DEPOSITION RATE USING ^{137}Cs TRACER METHOD IN THE CATCHMENT OF DRENOVA RESERVOIR (B&H)

by

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There are many limitations associated with traditional approaches to estimation of soil erosion and deposition rates. Recently attention has been focused on ^{137}Cs and successful usage of this isotope in soil erosion studies. This paper presents the results of measurements of ^{137}Cs in soil profiles which were sampled within catchments of Drenova reservoir. The proportional model and a simplified version of the mass balance model were used to estimate the mean soil loss or deposition redistributions rates. The aim of this study is to estimate the soil erosion and deposition rates using ^{137}Cs tracer model, as a support for the results obtained by empirical methodology.

Key words: soil erosion, soil deposition, ^{137}Cs concentration, ^{137}Cs inventory, catchments of Drenova reservoir

INTRODUCTION

Soil erosion is a serious environmental problem. In most cases, this process is caused by natural forces, but some human activities also notably contribute to soil erosion. Recently, there were many models for soil erosion estimation as well as deposition rate in the world, but the results of those models provided different possibilities for functional usage [1].

Traditional models are still widely applied in many countries, including Bosnia and Herzegovina. Empirical model of S. Gavrilović has been used in Bosnia and Herzegovina during the last 40 years [2-4]. This model resulted from experimental researches at the stations located in Bosnia and Herzegovina as well as on the territory of Former Yugoslavia. Due to an anthropogenic influence some significant changes have occurred in Bosnia and Herzegovina in the past. The civil war has caused serious consequences and made significant impact on the status and the structure of land usage. Hence, scientific attention is focusing on revision of the state and character of erosion processes, considering distribution of erosion processes in Bosnia and Herzegovina and its complexity which has been determined by specific physical geography conditions in which these processes occur. However, traditional methods, such as empirical method of S. Gavrilović and USLE method, used to estimate soil erosion and deposition rates, are time consuming in Bosnia and Herzegovina and the results obtained using these models, impose the need for appropriate validation.

Erosion and sedimentation rate estimations obtained by using the ^{137}Cs method have been reported by several authors and are in use in many countries, but this was a first attempt to apply this method on the territory of Bosnia and Herzegovina. Cesium – [137]Cs is a very good tracer for evaluating erosion processes, while since using this method to estimate soil erosion and deposition rates overcomes some of the limitations of the traditional methods [5]. [137]Cs measurements can be used as a basis for studying the spatial variability of soil loss magnitude and it can be used for identifying sediment sources as well [5-8]. [137]Cs is a fission product. It is a gamma emitter with energy of 661.6 keV and its half-life period is 30.02 years. These properties make ^{137}Cs isotope a valuable tracer for soil erosion in medium term. For the last 40 years, the fall-

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out of ^{137}Cs has been widely used as an environmental tracer for study of soil erosion [9, 10]. The method is based on the comparison of the ^{137}Cs inventories for sampling points with a reference point inventory.

The reference inventory represents the local undisturbed input fallout of [137]Cs. This means that for a reference site neither erosion nor deposition of soil occurred. In a place where soil erosion occurs, the ^{137}Cs inventory is lower then the reference inventory, but for soil deposition area, the ^{137}Cs inventory is higher then the reference inventory, so this comparison allows recognizing erosion and deposition areas [11-14]. To obtain quantitative estimation of soil erosion we used relationship which allows converting of ^{137}Cs data into erosion or deposition rate data [14, 15]. The successful application of the ^{137}Cs tracer model depends on the availability of reliable conversion models for converting measurement of ^{137}Cs in the soil erosion and deposition rate [16].

The aim of this study is to estimate the soil erosion and deposition rates for the field in the catchments of Drenova reservoir, and use of the ^{137}Cs tracer model to quantify soil erosion and deposition rates as a support for the results which are the product of use of empirical methodology [2-4]. These are preliminary investigations, in future studies; the number of sampling points will be higher, as well as the number of conversion models for soil erosion and soil redistribution. It is necessary to continue this preliminary investigations on more sampling sites in order to confirm the relationship between conversion models obtained by the measurements.

MATERIALS AND METHODS

Study area

The study area selected for the investigation is a small agricultural valley in the catchments of Drenova reservoir. The study area is 0.61 km^2, and it is located near town Prnjavor, Bosnia and Herzegovina (44º49'42"N 17º31'13"E).

Average annual rainfall for the study area is 850 mm, and the average annual temperature is 10.4 ºC. Soil samples were collected on three sites in july of 2011. These are preliminary investigations conducted in order to estimate soil erosion and deposition rates using ^{137}Cs tracer model in some of the catchments on territory Bosnia and Herzegovina. Previous researches of this study area were using S. Gavrilović and USLE empirical erosion model. Within the previous research, a bathymetric survey was conducted and examined to estimate radioactivity and sediment deposition rate of the Drenova reservoir [17-19].

Method – sampling and measurements

The first step was to select adequate, undisturbed reference site where neither erosion nor deposition has taken place. At this reference site (the first sampling point) the representative undisturbed ^{137}Cs samples were taken from surface to this depth of 49 cm. This soil depth is divided in 7 samples each of 7 cm height. The representative undisturbed ^{137}Cs samples were taken from the site which is flat, and hasn't been cultivated during the last 50 years. The first sampling site was at 287 m above sea level, (44°47'38"N 17°37'07"E). The second was taken from cultivated area and this sample was divided in 7 cm^{-1} increments. The second sample sampling site was on at 211 m above sea level, (44°47'39" N 17°36'52" E).

The third sample was taken from depositional cultivated site, and this sample was divided in 7 cm increments. Third sampling site was at 175 m above sea level, (44°47'47"N 17°36'40"E). The vertical distribution of ^{137}Cs in the samples was determined by gamma spectrometry measurements at the Laboratory of Nuclear Physic, Faculty of Sciences, Novi Sad, Serbia. Soil samples were dried at 105 °C to a constant mass. After that all mechanical contaminants, mainly small rocks and peaces of plant material were removed. Dried soil samples were mechanically fragmented and homogenized to fine powder. Prepared soil samples were packed in cylindrical measurement vessels 62 mm in height and 67 mm in diameter. Typical mass of the samples was between 200 and 300 g. Activity concentrations of gamma emitting radionuclides were determined by the method of low-level gamma spectrometry. Measurement time of these samples was 70 000 s. Two high resolution HPGe detectors were used. First of them, produced by CANBERRA has had nominal efficiency of 36% and resolution of 1.79 keV.

The detector was operated inside the 12 cm thick lead shield with 3 mm Cu inner layer. Second one, germanium detector was extended range ORTEC GMX type detector (10 keV-3 MeV) with nominal efficiency of 32% and resolution of 1.9 keV. The detector was shielded with the cylindrical 12 cm thick lead shield. The five 0.5 m 0.5 m 0.05 m plastic veto detectors, produced by SCIONIX surrounded the lead shield. The veto plastic scintillators and Ge detector were operated in anticoincidence mode thus all events simultaneously detected in by any veto and Ge detector were rejected. The active shield reduces the integral background by factor 3 in the energy range from 50 to 2800 keV [20]. Through CANBERRA type pre-amplifiers and amplifiers the signals were connected to multichannel analyzer MCA with two analog to digital converters with 8192 channels. MCA was directly connected with PC in which measured spectra were stored and analyzed. The gamma spectra were acquired and analyzed using the Canberra Genie 2000 software.

The program calculates the activity concentration of an isotope from all prominent gamma lines after peaked background subtraction. All measurement uncertainties are presented at 95% confidence level. That means that probability of errors in repeated measurements of the same sample would be less than 5%.

Conversion models

There are many relations to for obtaining quantitative estimations of soil erosion and deposition from ^{137}Cs measurements. Usually to obtain the quantitative value of soil erosion from ^{137}Cs measurements the initial input of fallout of ^{137}Cs has to be known. This input may be obtained for the study area by relatively simple measurements of ^{137}Cs in soil at places with no erosion or deposition. The main idea of using ^{137}Cs measurements to study soil erosion is a comparison of the ^{137}Cs inventory for the investigated places with the local ^{137}Cs initial input. All approaches can be divided into two groups: empirical relationships and theoretical models. Empirical equation was established to explain the relationship between ^{137}Cs loss and soil erosion. This approach demands simultaneous measurement of ^{137}Cs loss from erosion plots and soil loss [21, 22]. Usually the relationship between soil loss and ^{137}Cs loss is exponential [14, 23-25].

The simplest theoretical model is the proportional model witch establishes a direct proportionality between soil loss and amount of ^{137}Cs removed from the soil.

The proportional model is the most commonly used theoretical model for estimating soil erosion rates from ^{137}Cs measurements of cultivated soils. The proportional models were summarized by [14]. The equation for this model can be written as follows

$$Y = \frac{B d X}{100 T} \quad (1)$$

where Y [tha^{-1}] is the mean annual soil loss per year, B [kgm^{-3}] – the bulk density of the soil, d [m] – the depth of the plough layer, T [year] – the time elapsed since initiation of ^{137}Cs accumulation, and X – the percentage of reduction in total ^{137}Cs inventory, defined as

$$X = \frac{A_{\text{ref}} - A}{A_{\text{ref}}} \cdot 100 \quad (2)$$

A_{ref} [Bqm^{-2}] is the local ^{137}Cs inventory and A [Bqm^{-2}] – the measured ^{137}Cs inventory at the sampling point.

To calculate the total amount of ^{137}Cs per unit area, the ^{137}Cs concentrations [Bqkg^{-1}] are converted into area activity [Bqm^{-2}] by the equation [26]

$$^{137}\text{Cs}_{\text{inventory}} = \sum_{i=1}^{n} C_i BD_i D_i \quad (3)$$

where ^{137}Cs inventory [Bqm^{-2}] is the total area activity, i – the sampling depth, n – the maximum number of sample depth with detectable ^{137}Cs, C_i [Bqkg^{-1}] – the activity concentration per unit mass for depth i, BD_i [kgm^{-3}] – the dry bulk density for depth i, and D_i [m] – the depth increment for sample i.

To overcome the limitations of the proportional model, the Mass balance model was proposed by Kachanoski and de Jong, [14, 15, 27]. In 1990, a simplified version of the mass balance model was published by Zhang *et all*. [28]. A site with a total ^{137}Cs inventory A [Bqm^{-2}] less then the local reference inventory A_{ref} [Bqm^{-2}] is assumed to be an eroding site, while sites with inventories higher than the reference inventory are assumed to be depositional sites. According to this model, for an eroding site ($A < A_{\text{ref}}$) the mean annual soil loss rate can be expressed as follows

$$Y = 10 \, dB \left[1 - \left(1 - \frac{X}{100} \right)^{\frac{1}{t - 1986}} \right] \quad (4)$$

where t – 1986 is the time elapsed since the year 1986 when there was a significant fallout of ^{137}Cs in our region due to the Chernobyl nuclear power plant accident.

For a depositional site ($A > A_{\text{ref}}$), assuming a constant depositional rate R in kg per m^2 per year or convert in t per ha per year at the site (sampling), the sediment depositional rate can be estimated from ^{137}Cs concentration of the deposited sediment $C_d(t')$ [Bqkg^{-1}] according to

$$R = \frac{A_{\text{ex}}(t) - A_{\text{ref}}}{\int_{1986}^{t} C_d(t') \, e^{-\lambda(t - t')} dt} \quad (5)$$

where $A_{\text{ex}}(t)$ [Bqm^{-2}] is the excess ^{137}Cs inventory of the sampling point over the reference inventory in year t (defined as measured inventory less local reference inventory), $C_d(t')$ [Bqkg^{-1}] – [137]Cs concentration of deposited sediment in year t', and λ [year] – decay constant for [137]Cs.

RESULTS AND DISCUSSION

Vertical and horizontal distribution of [137]Cs. The results of gamma spectrometry measurements of ^{137}Cs activity concentrations in soil samples for three sampling points are presented in tab. 1. The total area inventories for each sampling site were calculated from ^{137}Cs activity concentrations according to eq. (3). The percentage reductions in total ^{137}Cs inventory relative to reference ^{137}Cs inventory were estimated using eq. (2).

The values of ^{137}Cs activity concentrations for the reference site (the first sampling site-point) show exponential distribution through the vertical soil profile, confirming that this soil was undisturbed. At the second sampling point, the ^{137}Cs concentrations in soil samples are lower relative to values measured on the reference point indicating soil erosion (fig. 1). For the

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Table 1. Bulk density of the samples, measured ^{137}Cs concentrations and the ^{137}Cs inventories at the sampling points S_1, S_2, and S_3

Sample	Sample depth [cm]	Bulk density [kgm^{-3}]	[137]Cs [Bqkg^{-1}]	[137]Cs inventory [Bqm^{-2}]	X reduction percentage [%]
S_{1-1}	0-7	1175	71.6 2.1		
S_{1-2}	7-14	1182.5	38 1.6		
S_{1-3}	14-21	1175.5	16.9 0.8		
S_{1-4}	21-28	1205	4.1 0.3	11002.16	0
S_{1-5}	28-35	1247	<0.8		
S_{1-6}	35-42	1278	<0.8		
S_{1-7}	42-49	1364.5	0.94 0.21		
S_{2-1}	0-7	1160	46.0 2.1		
S_{2-2}	7-14	1247.5	18.5 1.0		
S_{2-3}	14-21	1259	3.1		
S_{2-4}	21-28	1260	<0.9	6024.94	45.24
S_{2-5}	28-35	1183.5	<1.3		
S_{2-6}	35-42	1318	<1.2		
S_{2-7}	42-49	1341	<1.1		
S_{3-1}	0-7	1056.5	85 4		
S_{3-2}	7-14	1068.5	63.1 2.7		
S_{3-3}	14-21	1143.5	15.7 0.9		
S_{3-4}	21-28	1159	1.9 3.4	12778.89	−16.15
S_{3-5}	28-35	1193.5	<1.5		
S_{3-6}	35-42	1200	<1.4		
S_{3-7}	42-49	1218.5	<1.4		

third sampling site ^{137}Cs activity concentrations are higher than the local reference, sediment has accumulated (fig. 1). This is the result of soil deposition process on depositional cultivated site. The ^{137}Cs depth distribution conformed to profiles reported for undisturbed-reference and disturbed-depositional cultivated sites by literature [7, 29, 30]. The depth of the plough layer was estimated to be 35 cm which is the mean height of coulter.

Soil loss-soil erosion and soil deposition redistributions rates. There is a wide array of conventional models to estimate erosion/sedimentation rates such as the empirical USLE and S. Gavrilović model. The ^{137}Cs tracer method has been widely applied in a variety of locations throughout the world by several research groups to document soil erosion and sedimentation rates at the catchment scale [16, 28-31]. The proportional model (eq. 1) and a simplified version of the mass balance model (eqs. 4 and 5) were used to estimate the mean soil loss-soil erosion and soil deposition redistributions rates. The calculated redistribution rates are presented in tab. 2.

Proportional model (PM) yielded the value 9.19 t per ha per year for annual soil loss on sampling site S_2. The value calculated for the third sample site (depositional cultivated site) by using the proportional model was 2.50 t per ha per year, but in this case we have depositional process, and this is the value of depositional rate. Using the simplified version of the mass balance model (SMBM) the calculated values of annual soil loss and soil deposition for the same sam-

pling site differ by a factor of 4. The annual soil loss-erosion rate for the study area calculated, using the S. Gavrilović's model, is 9.89 t per ha per year, and 8.74 t per ha per year calculated by USLE method [17, 18]. In a comparative approach it was found out that calculated results significantly varied between different conversion models (PM and SMBM).

The different erosion rates estimated using the proportional model and the simplified version of the mass balance model indicate several limitations of these models. Generally, results of proportional model are closer to the results of the conventional models, because the proportional model is a less sensitive model than the simplified version of the mass balance model [32]. It is necessary to continue this preliminary investigation on more sampling sites in order to confirm the relationship between conversion models obtained by the measurements. Thus, in contrast to empirical models (S. Gavrilović´s and USLE models), ^{137}Cs tracer model is the clearest quantitative method. Namely, the intensity of accumulation with the USLE model is very difficult to quantify and Gavrilović´s model gives only assessment based on subjective field observations. Hence, use of the ^{137}Cs tracer model would explain the specific soil erosion or deposition rate in the study area better than the conventional (empirical) models [33]. In future studies, it is planned to take samples of the soil in 1   1 km or 100 m   100 m grid, and then compare the intensity of erosion in the basin on the basis of other methods that are in use.

Figure 1. Location of study area

Table 2. Soil loss-soil erosion (S₂) and soil deposition redistribution rates (S3)

Sample site	PM model – Y [tha^{-1} per year]	SMBM model – Y [tha^{-1} per year]
S_2	9.19	123.75
S_1	2.50	23.47

CONCLUSIONS

The objective of the use ^{137}Cs tracer model technique in this work is to quantify soil erosion and deposition rate in the catchments of Drenova reservoir. Two conversional methods were used in order to estimate the annual soil loss or gain on the basis of ^{137}Cs activity concentrations in soil samples taken at depth of 49 cm and divided in 7 cm increments. Measurements were performed by low level gamma spectrometry method.

Results provided by usage of ^{137}Cs tracer model technique in to quantify soil erosion and deposition rates in the catchment of Drenova reservoir show that this methodology gives reliable calculations. First PM gives the erosion rate of 9.19 t per ha per year for the sampling site S2, which is very close to value 9.89 t per ha per year calculated by empirical model of S. Gavrilović, and 8.74 t per ha per year calculated by USLE method. This good agreement will encourage future use of ^{137}Cs tracer model technique and proportional method on this cultivated region, especially when there is a need for prompt studies and calculations of soil erosion and deposition rates as a support for the implementation of soil conservation programs, sustainable agricultural exploitation and environmental protection. Using ^{137}Cs tracer model technique in the future will require more sampling points in order to confirm these relations between models and evade errors caused by non ideal distribution of the radioisotope, especially its concentration and distribution on cultivated areas.
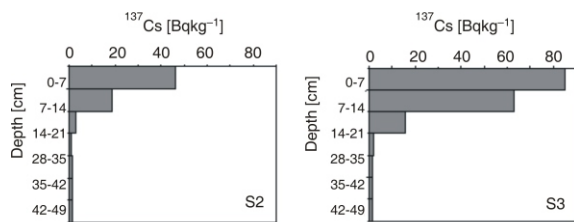
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Figure 2. Depth distribution of ^{137}Cs activity concentrations for sampling sites S$_2$ and S$_3$

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**ПРОЦЕНА ЕРОЗИЈЕ ЗЕМЉИШТА И ИЗНОСА АКУМУЛАЦИЈЕ
КОРИШЋЕЊЕМ [137]Cs ТРАСЕР МЕТОДА У СЛИВУ
АКУМУЛАЦИЈЕ ДРЕНОВА (БИХ)**

Постоје многа ограничења повезана са традиционалним приступима процене ерозије и износа акумулације. У новије време пажња је усмерена на [137]Cs и успешно коришћење овог изотопа у студијама о ерозији земљишта и акумулацији материјала. У овом раду су приказани резултати мерења [137]Cs у земљишту профила који су узорковани у сливу акумулације Дренова. Пропорционални модел и поједностављена верзија модела биланса масе коришћени су за процену губитка земљишта и износа акумулације. Циљ овог истраживања је процена ерозије земљишта и износа акумулације користећи [137]Cs као трасер, и то као проверу и подршку резултатима који су добијени коришћењем емпиријских метода.

Кључне речи: ерозија земљишта, акумулација, [137]Cs концентрација, [137]Cs инвентар, слив акумулације Дренова