Romanian Reports in Physics, Vol. 64, No. 1, P. 211–220, 2012

ASSESSMENT OF SEDIMENTATION RATE THROUGH THE USE OF ANTHROPOGENIC 137Cs RADIONUCLIDE*

A.M. BLEBEA-APOSTU[1,4], I. RADULESCU[1], R. MARGINEANU[1], I. IONITA[2], I.V. POPESCU[1,3]

[1] "Horia Hulubei" National Institute for Physics and Nuclear Engineering,
Email: anapostu@ifin.nipne.ro, romulus@ifin.nipne.ro
[2] "Alexandru Ioan Cuza" University of Iasi, Faculty of Geography and Geology,
Email: ion.ionita72@yahoo.com
[3] "Valahia" University of Targoviste, Faculty of Sciences and Arts, E-mail: ivpopes@valahia.ro
[4] University of Bucharest, Faculty of Physics

Received November 20, 2010

Abstract. A typical example of gamma spectrometry application using ^{137}Cs technique is related to the assessment of sedimentation rates in both the river floodplains and the reservoirs. The presence of ^{137}Cs in soil and sediments is mainly associated to the Chernobyl accident. This paper deals with the four sites within the Moldavian Plateau, namely: three reservoirs in the Moldavian Plain (Campeni-Miletin, Lungani-Albesti and Ciurbesti-Nicolina) and the alluvial plain of the Studinet River upstream of Corodesti within the Tutova Rolling Hills. Use of the ^{137}Cs technique has demonstrated a slow rate of sedimentation of 0.6–2.7 cm yr^{-1} at those reservoirs in the Moldavian Plain since 1986 and a high rate of aggradation of 4.3 cm yr^{-1} in the northern part of Tutova Rolling Hills. Excepting Miletin basin most of the catchments are small in area, usually under 5,000 ha. The significant difference of the sedimentation rates in those two areas of the Moldavian Plateau is resulting from the particular features of the landscape morphology and the geologic substratum. Thus, almost platte landforms developed on clayey layers are typically in the Moldavian Plain, while high hills on sandy layers are depicting the northern half of the Tutova Rolling Hills.

Key words: ^{137}Cs, erosion, sedimentation, gamma spectrometry.

1. INTRODUCTION

Many parts of the environment are strongly affected by accelerated erosion processes that lead to both soil and land degradation, [1]. In Romania, the accelerated soil erosion in association with land degradation represents a major problem that concerns on a long term the sustainable agriculture and the quality of the environment [2].

* Paper presented at the Annual Scientific Session of Faculty of Physics, University of Bucharest, June 18, 2010, Bucharest-Măgurele, Romania.

One consequence of the erosion processes is the transportation of the sediments in the reservoirs, subsequently these sediments accumulates upstream leading to a decrease of the water volume in the reservoir. These reservoirs fulfil essential functions such as: sources of the drinking water, irrigation water and fishery.

In addition, the rainfall pattern and the inadequate agricultural practices resulted in an increasing rate of land degradation. The higher erosion rate in the agricultural land determines the increase of the sedimentation rate in the reservoirs, too.

2. STUDY AREA

The Moldavian Plateau, located in Eastern Romania and covering about 27000 km^2 is one of the most severely eroded agricultural area in the country. Clayey-sandy Miocene-Pliocene layers with a gentle gradient of 7-8 m km^{-1} NNW-SSW have outcropped from sedimentary substratum [3]. The climate is temperate continental with a mean annual temperature of 8.0–9.8 ^{0}C. Average annual precipitation varies from about 460 mm at the lower elevation in the southern part to 670 mm in the central and north-western area with elevations up to 587 m. Natural vegetation cover was drastically changed by man during the last two centuries, especially. Mollisols and argiluvisols (forest soils) are among the most common soils and have been used for crop production. Main land use stratification is cropland 58%, pastures and meadows 16% and forest 13%. Under these circumstances, at present soil erosion, gullying, landslides and sedimentation have been recognized as the major important environmental threats. The total erosion is averaging 15–30 t ha^{-1} yr^{-1} [4].

By 1960, the traditional agricultural system on slopes consisted in up-and-down hill farming. Most of the land was excessively split in small plots, each under one hectare in size. Since 1960, the awareness of soil erosion and adopting conservation practices has been increased. By the end of 1989 as much 0.9 million hectares, representing 71 percent of the agricultural land with erosion potential were adequately protected under different conservation practices. The Land Act no.18/1991 has caused the revival of the old traditional up-and-down hill farming.

Moldavian Plateau consists of three major units, namely: the Suceava Plateau located in the north-west, the Moldavian Plain and the Barlad Plateau. The Moldavian Plain, drained mainly by Jijia River, occupies the north-eastern part of the plateau, where a mild plain is underlying mostly by clayey Miocene layers. Its average altitude is about 150 m. The Barlad Plateau is the most typical unit covering around 8,000 km^2 and encompasses the following subunits: the Central Moldavian Plateau, the Falciu Hills and the Tutova Rolling Hills. The Central Moldavian Plateau is well known by some structural plateaus bounded by north looking cuestas. The Tutova Rolling Hills are lying in the southern area where sandy Pliocene layers are prevailing.

In this paper, the survey section for three reservoirs within Moldavian Plain and one in an alluvial plain located in the Tutova Rolling Hills are illustrated to emphasize changes in erosion and sedimentation rates.

3. MATERIALS AND METHODS

Among the many quantitative and qualitative assessment techniques of the erosion and sedimentation processes that occur in the environment, the ^{137}Cs method has the particularity of being less time consuming then the classical ones.

Measuring the specific activity of ^{137}Cs in soil and sediments sample constitute a typical example of gamma spectrometry application related to the assessment of sedimentation rates in both the river floodplains and the reservoirs. The presence of ^{137}Cs in soil and sediments is mainly associated to the Chernobyl accident. Careful investigations showed that a small amount of ^{137}Cs in soil is also due to the weapon testing fall-out before 1964.

The deposition of ^{137}Cs resulted from Chernobyl accident, are characterized of large variations on the entire Romanian territory, but also on Moldavian Plateau or even on smaller investigated areas of few km^2. One reason of the large variation of amount of ^{137}Cs on small area is wet deposition during May 1986 when low intensity rains in these areas occurred.

Once in contact with soil, ^{137}Cs is strongly associated within the clay particles of soil, which are carried by erosion and runoff from drainage areas to bodies of water.

In reservoirs, ^{137}Cs is readily adsorbed by suspended particles and presumably settle on the bottom. The total amount of ^{137}Cs in the sediments depends on many physical, geochemical and biological factors and processes in the aquatic environment, such as sedimentation rate, re-suspension, type of sediment etc.

It is also therefore unlikely that any large fraction of the ^{137}Cs would move from the bottom of reservoir, except through erosion of the sediment [5]. Once settled on the bottom, ^{137}Cs generally remain in the sediment. In time, the particles that have settled on the bottom are covered by new sediment layers and are gradually buried in deeper and deeper sediment layers. In favourable conditions, the deposited particles from undisturbed laminae in a stratigraphic sequence on the bottom, produces an archive recording the sediments' history of the reservoir.

In this case, the layer of sediments that contains ^{137}Cs turns to be the benchmark level and can be used effectively to provide a chronological measure of both the reservoir siltation and development of discontinuous gullies [5].

The later sediments, newer than 1986, have usually a lower content of ^{137}Cs than the benchmark level directly deposited, due to ploughing or gully erosion input that could have non-contaminated material from deeper strata.

The assessment of erosion and sedimentation rates can be performed by classical sedimentation surveys over many years, which involves repeated field measurements and, therefore, that is probably the most costly and time consuming method, but also by unconventional methods such as the use of radioactive isotopes as environmental tracers. From this point of view, using ^{137}Cs as environmental tracer is very important for several reasons, namely: relatively long half-life (30.14 years), strongly bound on clays or other sediments, relatively easy to be measured. Because fixed to the sediment fractions, soil mass movement involves ^{137}Cs with it. Direct deposits, from the Chernobyl brought measurable amounts of ^{137}Cs, practically for the next 100–150 years.

Measuring system. Quantitative determination of ^{137}Cs in sediment samples were done by high resolution gamma spectrometry. For these measurements we have used an ORTEC multichannel analyzer, which can also be used peripherally on a PC, with autonomous micro-processing unit.

The ORTEC program package has been used to process the gamma spectra and for the presentation of the results. In general, the program functions used for analysis are the energy resolution calibration; searching, localizing, identification of peaks, calculating total, net areas and uncertainties by fitting the spectra with appropriate functions and displaying the measured results.

The gamma spectrometry system has to be calibrated in energy when identifying the radionuclides contained in the samples. For the energy calibration, isotopes such as ^{60}Co, ^{137}Cs, ^{40}K (more than 2 peaks) are used (see Table 1).

The MAESTRO software can assess, depending on the existing database, to which isotope the analyzed peak corresponds. For peaks that do not appear in the software database, gamma lines tables are utilized (*e.g.* LBNL/LUND Table of Radioactive Isotopes [6]).

For quantitative determination of ^{137}Cs in sediment samples it is necessary to have a relative efficiency calibration too. For efficiency calibration throughout the entire energy range (40–3000 keV), at least 7 peaks are drawn and the geometry of the sample has to be identical or resemble closely the reference. The isotopes in Table 1 can be used when determining the efficiency calibration curve for different geometries.

Table 1

Isotopes used for efficiency and energy calibration, energy gamma-lines with their decay probability, the half-life

Radionuclide	Energy (keV)	Decay probability	T1/2 (year)
^{40}K	1460.80	0.1100	$1.277 \cdot 10^9$
^{54}Mn	834,840	0.9997	0.86

Table 1 (continued)

^{57}Co	122,06	0.8560	0.74
	136,47	0.1068	
^{60}Co	1173,23	0.9986	5.27
	1332,50	0.9998	
^{137}Cs	661,6	0.8510	30.14
^{241}Am	59,53	0.3600	432.20
^{152}Eu	121,78	0.2837	13.54
	244,69	0.0753	
	344,28	0.2657	
	778,90	0.1297	
	964,05	0.1463	
	1112,08	0.1354	
	1408,02	0.2085	

The specific activity of ^{137}Cs in the sample is calculated using the equation:

$$A = \frac{An}{T_a \cdot m \cdot \varepsilon \cdot \eta}, \quad (1)$$

where: A – specific activity [Bq/kg]; A_n – net area of analysed peak [counts]; T_a – acquisition time [s]; M – mass [kg]; ε – efficiency; η – decay probability.

When the specific activity is lower then the minimum detectable activity then this later quantity is calculated and presented using the equation:

$$\text{MDA} = \frac{2.73 + 4.65\sqrt{A_t}}{T_a \cdot m \cdot \varepsilon \cdot \eta}, \quad (2)$$

where: MDA – minimum detectable activity [Bq/kg]; A_t – total area of the analyzed peak [counts].

Sample preparation. Soil and sediment samples were manually collected in 2008–2009 from four sites, three reservoirs within the Moldavian Plain and one in an alluvial plain within Tutova Rolling Hills. In all sites, the increment sampling was 5 cm and the depth was variable up to 170 cm depth (Fig. 1).

Subsequently, the samples were dried, sieved and placed in plastic Marinelli beakers where the weighted mass varied between 500 g and 700 g. The acquisition time varied between 10 000s and 80 000s.

Fig. 1 – Hand sampling site in the Ciurbesti-Nicolina reservoir on February 13, 2008. The sediment samples were taken up to 80 cm depth with an increment of 5 cm.

4. RESULTS AND DISCUSSIONS

The depth distribution of ^{137}Cs in sediments was analyzed with a sum of Gauss and Boltzmann distributions:

$$y = A_2 + \frac{A_1 - A_2}{1 + \mathrm{e}^{\frac{x - x_0}{\Delta x}}} + \frac{A}{\mathrm{w}\sqrt{\frac{\pi}{2}}}\mathrm{e}^{-2\frac{(x-x_c)^2}{w^2}}, \tag{3}$$

where A_1, A_2, x_0, Δx, A, w, x_c are parameters obtained from the fit by minimizing χ^2.

This sum of functions was chosen to reconstruct the profile of ^{137}Cs deposition from 1986 and 1963 (with the Gauss distribution) and the later deposition of the mixed agricultural land (plough land) with lower and relatively constant content of ^{137}Cs (Boltzmann distribution).

From Moldavian Plain the selected sites for this paper were: Ciurbesti – Nicolina, Campeni – Miletin and Lungani – Albesti.

Figure 2 shows the vertical distribution of ^{137}Cs based on 16 sediment samples within the Nicolina-Ciurbesti reservoir associated to a drainage area of 3,791 ha.

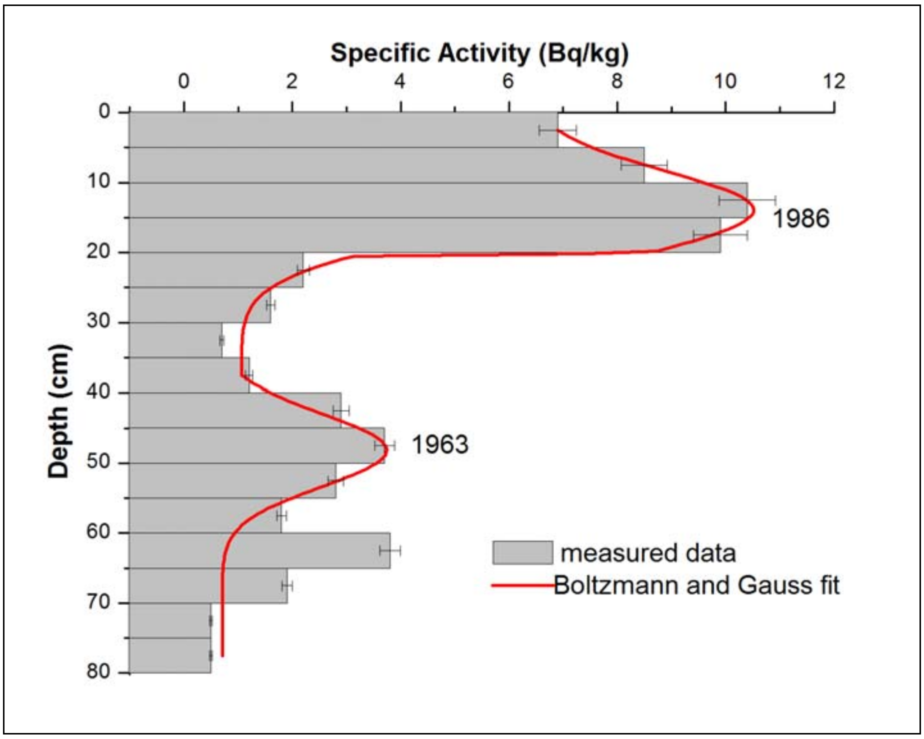

Fig. 2 – Depth profile of ^{137}Cs in the Ciurbesti-Nicolina reservoir. The measured data (gray boxes) are fitted with a combination of two Gauss functions and a Boltzmann function (red line), which results a good estimation of the 1986 and 1963 position of the peaks.

Here it is noticeable that the sedimentation rate over the period 1986–2008 has a very low value of 0.63 cm yr^{-1} due to both clay substratum which is more resistant to soil detachment and less precipitation. If looking at the previous rainier period, 1963–1986, the sedimentation rate is more than double (1.55 cm yr^{-1}).

The Miletin catchment, upstream of Campeni reservoir, has an area of 32,811 hectares, representing 48.3% of the total. In that site a number of 33 sediment samples were collected down to 170 cm depth. According to the ^{137}Cs depth distribution Fig. 3 illustrates that the values of sedimentation rates are close to each other, 1.40 cm yr^{-1} over 1963–1986 under natural conditions and 1.81 cm yr^{-1} over the period 1986–2008 under flood controlling reservoir.

The Albesti basin downstream the junction between Albesti and Goesti rivers, where the Lungani reservoir is located, has an area of 5,068 ha representing 92.6% of the total. A number of 20 sediment samples were collected in that reservoir up to 100 cm depth as shown in Fig. 4.

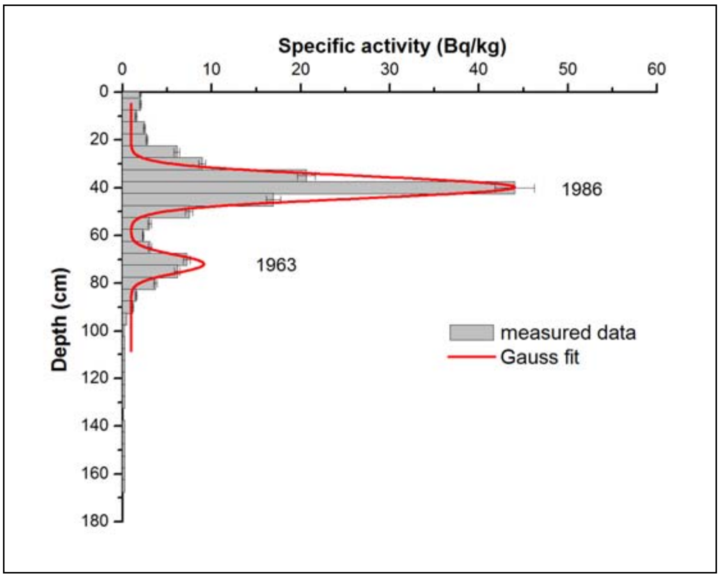

Fig. 3 – Depth distribution of ^{137}Cs in Campeni-Miletin reservoir. The measured data (gray boxes) are fitted with a combination of two Gauss functions (red line), that give a good estimation of the 1986 and 1963 position of the peaks.

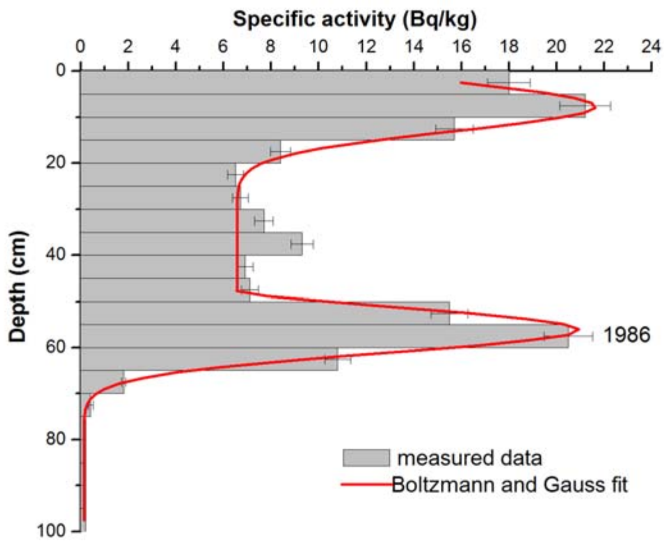

Fig. 4 – Depth distribution of ^{137}Cs in Lungani-Albesti reservoir. The measured data (gray boxes) are fitted with a combination of two Gauss functions and a Boltzmann function (red line), which results a good estimation of the 1986 and 1963 position of the peaks.

The Lungani-Albesti reservoir presents a different variation of ^{137}Cs depth profile, meaning that in the first 15–17 cm of sediments the amount of ^{137}Cs is at the same level as the one obtained from the 1986 deposition. The first peak clearly occurs at 50–55 cm (20.5 $Bq\cdot kg^{-1}$) and it is connected to the Chernobyl accident of April 1986, while the second is related to the present-day revival of the up-and-down hill farming [7]. However, since 1986 the mean sedimentation rate is 2.66 cm yr^{-1} but the 1963 ^{137}Cs peak could not be observed within the 100 cm depth profile.

In the Tutova Rolling Hills the selected site was the floodplain of the Studinet River upstream of the Corodesti Village. The associated drainage basin has an area of 3,402 ha and a length of only 13 km. From that site a number of 30 sediment samples were collected up to 150 cm depth and the depth distribution of ^{137}Cs is shown in Fig. 5.

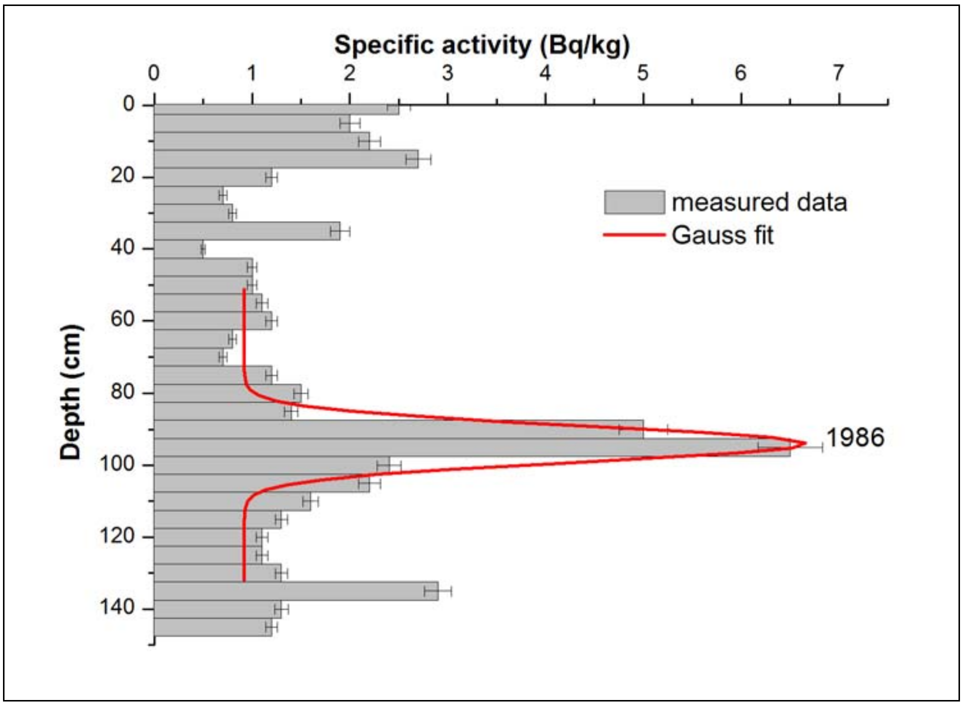

Fig. 5 – Depth distribution of ^{137}Cs in Corodesti alluvial plain. The measured data (gray boxes) are fitted with a Gauss function giving a good estimation of the 1986 position of the peak.

The mean sedimentation rate in the Corodesti floodplain is 4.30 $cm\cdot yr^{-1}$, considerable higher than in the other investigated sites as is given in Table 2.

Table 2

The average sedimentation rates in all four investigated sites calculated on two intervals 1963–1986 and 1986–2008

Site	Sedimentation rate [cm yr^{-1}]	
	1963–1986	1986–2008
Ciurbesti-Nicolina reservoir	1.55 ± 0.09	0.63 ± 0.18
Campeni-Miletin reservoir	1.40 ± 0.09	1.81 ± 0.09
Lungani-Albesti reservoir		2.66 ± 0.09
Corodesti alluvial plain		4.30 ± 0.20

5. CONCLUSIONS

^{137}Cs proved to be a useful radioactive tracer for assessing both erosion and sedimentation rates. Taking into account its relatively long half-life it is possible to determine such erosion/sedimentation rates over the last 50 years.

The sedimentation rate within Tutova Rolling Hills is much higher than in the Moldavian Plain because of higher relief, sandier geologic layers and severe eroded soils.

It was also shown that depth distribution of ^{137}Cs in recently reservoir sediments as for Lungani-Albesti was triggered by the significant changes in land management practices.

REFERRENCE

1. K. G. Renard et al., *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)*, United States Department of Agriculture, Agriculture Handbook, No 703, 1997.
2. I. Ionita, R. Margineanu, C. Hurjui, *Assessment of the reservoir sedimentation rates from ^{137}Cs measurements in the Moldavian plateau*, Acta Geologica Hispanica, **35**, 2000, 357–367.
3. I. Ionita, *Gully development in the Moldavian Plateau of Romania*, Catena, **68**, 2006, 133–140.
4. Motoc M., *Ritmul mediu de degradare erozionala a solului in R. S. Romania* (Mean rate of the soil degradation by erosion in Romania), Buletinul Informativ al A.S.A.S., No. 13, Bucharest, 1983, pp. 47–65.
5. E. Ilus, R. Saxen, *Accumulation of Chernobyl-derived ^{137}Cs in bottom sediments of some Finnish lakes*, J. Environ. Rad., **82**, pp. 199–221 (2005).
6. http://ie.lbl.gov/toi.html.
7. I. Ionita, R. M. Margineanu, *Application of ^{137}Cs for measuring soil erosion/deposition rates in Romania*, Acta Geologica Hispanica, **35**, 311–319 (2000).