THE INFLUENCE OF CULTIVATION SYSTEM ON DISTRIBUTION PROFILE OF ^{137}Cs AND EROSION / DEPOSITION RATE

Nita Suhartini

Pusat Aplikasi Tehnologi Isotop dan Radiasi - BATAN

Jl. Cinere Pasar Jumat Kotak Pos 7002 JKSKL, Jakarta 12070, Indonesia

Email : s-nita@batan.go.id

ABSTRACT

^{137}Cs radiogenic content in the soil can be used to estimate the rate of erosion and deposition in an area occurring since 1950's, by comparing the content of the ^{137}Cs in observed site with those in a stable reference site. This experiment aimed to investigate the influence of cultivation type on distribution profile of ^{137}Cs and distribution of erosion and deposition rate in cultivated area. A study site was small cultivated area with slope steepness <10^{o} and length 2 km located in Bojong – Ciawi. For this purpose, the top of a slope was chosen for reference site and three plot sites were selected namely Land Use I that using simple cultivation, Land Use II that using simple cultivation with ridge and furrow, and Land Use III using machine cultivation. The results showed that cultivation could make a movement of ^{137}Cs to the deeper layer and ridges and furrows cultivation system could minimized an erosion process. The net erosion and deposition for land Use I, II and III were -25 t/ha/yr , 24 t/ha/yr and -58 t/ha/yr, respectively.

Keywords : Erosion and deposition, environmental radioisotope, ^{137}Cs

INTRODUCTION

Indonesia is an agrarian country which agrarian sector is a dominant supporting of livelihood. Becauce of disharmonised deforestation and agriculture system, the eosion occurred and caused the degradation of soil fertility. Today, erosion is become a major land degradation problems in Indonesia, because it could decrease the agriculture production and also landuse management. Erosion in the steep slope can bring sediment materials in the footslopes. To minimized erosion, it need control to the cultivation land and because of the the many limitations associated with traditional techniques, the use of environmental radionuclides as alternative approach could be used to documenting rates of erosion and sedimentation distribution. Some environmental radioisotopes that have been used in erosion study are ^{210}Pb, ^{137}Cs and ^{7}Be to estimate a long-term (~ 100 yrs), mid-term (~ 40 yrs) and short-term (<30 days) average soil distribution rates and pattern, respectively [11].

The use of environmental radioisotope ^{137}Cs has attracted increasing, because it affords a valuable means of assembling spatially distributed information on medium term (ca 40 yrs) rates of soil erosion and deposition on the basis of a single site visit to the study area for sampling. Recently, the use of ^{137}Cs has been successfully applied in a wide range of environments in many different area of the word, such as America, United Kingdom and

Australia [8]. ^{137}Cs in soil could be used as tracer because it is easy to identified so that its dynamics could be monitored.

^{137}Cs is a fallout product of nuclear weapons testing carried out in the late 1950's and early 1960's. During this time significant levels of ^{137}Cs were produced via the following decay chain [7] :

$$^{137}\mathrm{I}\ ^{-\hat{a}}\ ^{137}\mathrm{Xe}\ ^{-\hat{a}}\ ^{137}\mathrm{Cs}\ ^{-\hat{a}}\ ^{137m}\mathrm{Ba}\ ^{-\tilde{a}}\ ^{137}\mathrm{Ba}\ \text{(stable)} \quad (1)$$

^{137}Cs is produced at a relatively late stage after a nuclear explosion and can remain in the atmosphere for approximately ten years. It is washed out of the atmosphere by rain and n deposited on the earth's surface. On reaching the earth's surface, ^{137}Cs becomes rapidly and firmly adsorbed on the surface soil and can therefore used as a tracer of soil redistribution. The ^{137}Cs technique is based on a comparison between the ^{137}Cs inventories measured at eroded and deposited sites in the landscape and the local reference ^{137}Cs inventory that is normally established by sampling at a long-term undisturbed site. Negative (-) values are indicative of erosion and positive (+) values reflect deposition. The ^{137}Cs techniques can be used in the identifying the spatial distribution of erosion and deposition in the landscape, and affords a fast and economical way of estimating the results of soil redistribution occurring over the last 35 – 40 years. Both soil loss and deposition can be estimated their spatial units.

The objective of this experiment was to analys the influences of cultivation system to the vertical distribution of ^{137}Cs in soil and distribution of erosion and deposition rate in small cultivated areas. A small communal cultivated area in Bojong – Ciawi was selected as study area (see Fig.1).

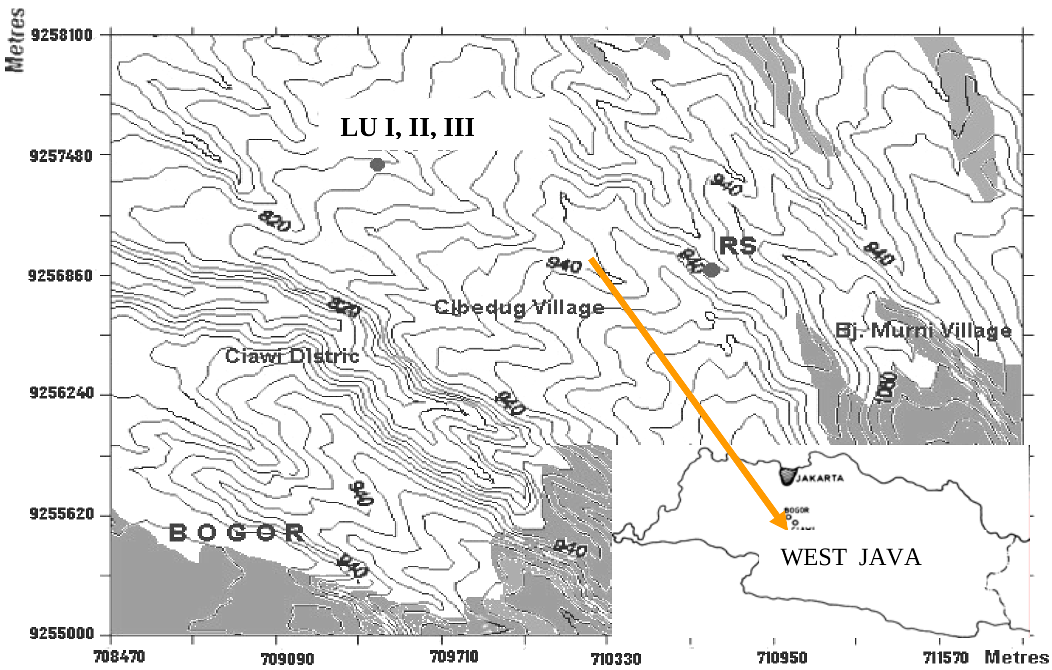

Fig.1 Map of study area in Bojong – Ciawi - Bogor

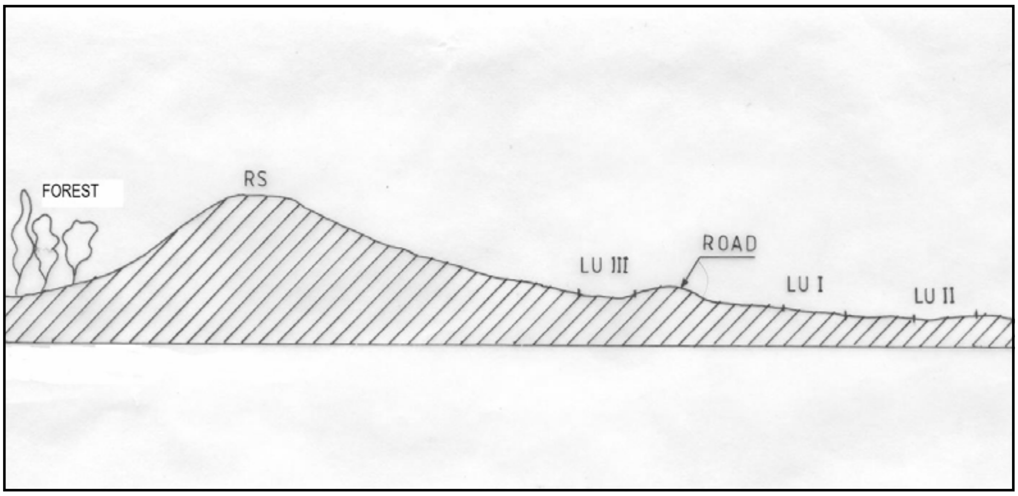

Fig. 2. Location of Lang use I, II and III to the refernce site at study area

It has a slope steepness of about 10°, and a slope length of about 2 km. The slope is divided into plots, and planted with different crops. The top of this slope was chosen as the reference site. This site is flat, open and erosion is minimal, and it was used as a cultivated area since 1949 to 1976. For application of the ^{137}Cs technique, three small sites were selected, namely Land use I (15 m x 25 m), Land use II (17,5 m x 20 m) and Land use III (40 m x 50 m). Land use I is about 1000 m distance from the reference site, with a slope steepness of 8.5°, and planted with corn, and rotation with cassava. Land use II is located about 1300 m from the reference site, and consists of 12 ridges and 14 furrows. The slope steepness of this plot is 3.25° parallel to furrows and 2.8° perpendicular to furrows, and planted with peanut, cassava and corn in rotation. Land use III is lpcated about 800 m from the reference site, with slope steepness of 14°. This site is cultivated by using machine and planted with chilli and corn in rotation. The location of land use I, II and III to the reference site can be seen in Fig.2.

METHOD

Material and Data analysis

Steel core tubes with internal diameter 10 cm and 6.9 cm were used to collect a penetration soil to depth of 100 cm with depth incremental of 10 cm, and bulk samples to depth of 40 cm, respectively. For distribution of erosion and deposition rate, 24 core soil samples were taken from land use I in a grid of 15 x 25 m, with a 5 m distance between the points. From Land use II, 54 core soil samples were taken from a grid of 17.5 x 20 m. Soil samples were taken every 3 ridges and 4 furrows normal to the slope, and at interval of 3.5 m parallel to the ridge and furrow. In land use III, 30 core soil samples were taken in a grid of 40 x 50 m, with a distance between each point of 10 m. The soil samples were brought to the laboratory in PATIR – BATAN, to be preparation.

In the laboratory, all soil samples were air dried, weighed, and disaggregated. Each air dried soil sample was sieved through a 1 mm sieve inorder to separate the fine soil from the > 1 mm fraction. A representative sub samples of the fines (ie 500 g) was put into the plastic marinelli beaker for determination of ^{137}Cs. The ^{137}Cs activity was measured by gamma spectrometry at 661 keV with a minimum counting time of 50000 s.

Based on the concentration obtained from gamma spectrometry, erosion and deposition rate of each point was calculated by using formula [9] :

Mass Balance Model 2

(i)

where :

A(t) = cumulative ^{137}Cs activity per unit area (Bq/m^2)

R = erosion rate ($kg/m^2/yr$)

d = cumulative mass depth representing the average plough depth (kg/m^2)

= decay constant for ^{137}Cs (yr^{-1})

I(t) = annual ^{137}Cs deposition flux ($Bq/m^2/yr$)

= percentage of the freshly deposited ^{137}Cs fallout removed by erosion before being mixed into the plough layer

If an exponential distribution for the initial distribution of ^{137}Cs fallout at the surface of the soil profile can be assumed, Ã can be expressed as :

(ii)

Where ã is the proportion of the annual ^{137}Cs input susceptible to removal of ^{137}Cs by erosion, and H (kg/m^2) is the relaxation mass depth (limit of cultivation depth by hand) of the initial distribution of fallout ^{137}Cs in the soil profile.

The rate of erosion and deposition in each plot was estimated using GRID modeling tools provided by Surfer software. The study plot has been divided into cells with an area of 3 m x 3 m. This model had been developed for a spatially distributed sediment delivery that has been applied to catchments ranging in size from several kilometers to several hundred square kilometers [6].

RESULT AND DISCUSSION

Vertical Distribution Profile of ^{137}Cs

Samples collection of ^{137}Cs vertical distribution and distribution of erosion/deposition were done during 2002 until 2003. Profile of ^{137}Cs vertical distribution for reference site, land use I and land use II can be seen at Figure 3.

The result in Fig.3 showed that reference site (Fig. 3 A) has maximum value of ^{137}Cs concentration at layer of (0 – 10) cm, then the value decrease sharply at layer of (10 – 20) cm and insignificantly increase until the layer of (40 – 50) cm. This vertical distribution of ^{137}Cs profile has formed because of cultivation process. Before 1978, this reference site was used as cultivation plot, afterwards it uncultivated from 1978 to 2003, and during uncultivated period, it was grown over with elephant grass. In this plot, ^{137}Cs has distributed until the depth of (70 – 80) cm, because the deeply elephant grass roots and high annual rainfall (> 2500 mm/yr) had been brought ^{137}Cs into the deeper layer. The result in Figure 3 B (land use I) showed that maximum value of ^{137}Cs was at layer of (0 – 10) cm and decrease with a deeper layer, because land

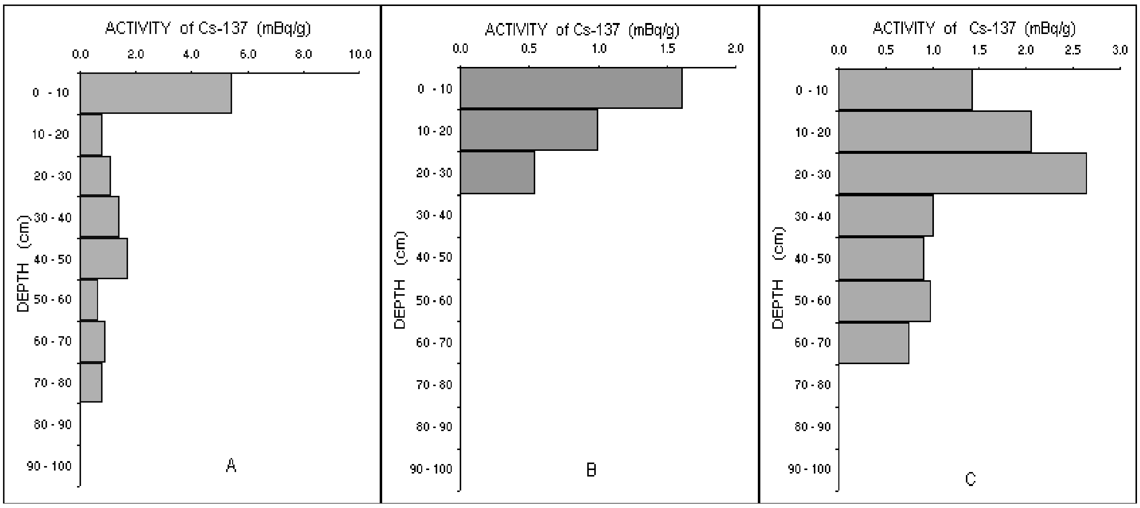

Fig.3. Vertical distribution of ^{137}Cs at Reference site (A), Land Use I (B) and Land use II (C) (sources : 5)

use I has shallow cultivation by hand and ^{137}Cs moves up and down only at the depth of 10 cm.. Land use I has shallow vertical distribution of ^{137}Cs caused of simple cultivation by hand and sometimes it left bare without any plant. ^{137}Cs vertical distribution profil of land use I is similar with undisturbed site's distribution profile, wherein a maximum of ^{137}Cs concentration at surface layer and the ^{137}Cs concentration decrease exponential on the increase of a depth. Figure 3 C (land use II) showed that maximum value of ^{137}Cs at layer of (20 – 30) cm, and flat distribution until a layer of (60 – 70) cm. This profile of ^{137}Cs distribution has formed due to the ridges and furrows cultivation system which is the position of ridge and furrow always changes related to the season. Because of the cultivation, ^{137}Cs moves up and down into the depth of 30 cm (a maximum depth of furrows), and a runoff that collected in the furrows caused ^{137}Cs at the bottom of furrows distributed to the deeper layer.

Distribution of erosion and deposition rate

The average value for the reference inventory obtained from this study site is (261 ± 37) Bq/m^2 based on 16 cores and 1 scraper plate. In the plots field (land use I, II and III), erosion has been ongoing during 24 years (1978 – 2002) because cultivation started in 1978. To calculate the erosion and deposition rate of individual sampling point using MBM2 with data set for a relaxation depth (H) value of 40 kg/m^2 and proportion factor (ã) value of 0.85. The result of individual sampling point in Table 1 showed that most of points in Landuse I and III have (-) sign, and in Landuse II has (+) sign. It indicated that erosion had been occurred in plot of landuse I and III, and deposition had been occurred id landuse II. The results could be seen in Table 1. Based on the data from Table 1, erosion and deposition rates of each plots was estimated by using SURFER program and the result of erosion and deposition rate of each plots could be seen in Table 2.

Table 1. Erosion and deposition rate of individual sampling point estimates obtained From the sampling grid in land use I , Land use II and land use III

No.	Land Use I		Land Use II				Land Use III	
	^{137}Cs Activity (Bq/m²)	Eosion/ deposition (t/ha/yr)	^{137}Cs Activity (Bq/m²)	Erosion/ Deposition (t/ha/yr)	^{137}Cs Activity (Bq/m²)	Erosion/ Deposition (t/ha/yr)	^{137}Cs Activity (Bq/m²)	Erosion/ deposition (t/ha/yr)
1	199	-24	135	-55	384	48	386	79
2	188	-29	176	-33	510	98	30	-243
3	260	0	350	38	235	-9	60	-164
4	232	-10	425	69	153	-45	314	38
5	278	7	331	30	386	41	135	-72
6	148	-51	363	43	243	-6	227	-15
7	121	-70	405	61	260	0	271	7
8	137	-58	270	4	291	9	177	-42
9	203	-22	301	17	167	-37	131	-76
10	206	-21	266	2	302	16	172	-45
11	232	-10	307	15	488	91	155	-57
12	170	-39	283	7	427	66	295	29
13	212	-19	349	30	358	39	62	-161
14	301	15	362	34	415	61	176	-43
15	154	-48	424	55	316	22	333	45
16	143	-54	309	16	310	16	197	-30
17	230	-11	557	99	372	37	46	-195
18	121	-70	231	-10	359	33	24	-269
19	308	17	260	0	362	34	57	-170
20	259	-1	283	7	439	60	193	-33
21	193	-27	386	39	282	7	69	-149
22	221	-15	284	7	230	-10	444	74
23	258	-1	188	-27	323	19	277	6
24	173	-37	318	21	260	0	197	-30
25			366	39			263	1
26			297	13			99	-108
27			301	15			217	-20
28			439	70			260	0
29			446	73			260	0
30			435	68			260	0

Note: (-) : indicative of erosion process, and (+) : indicative of deposition process
(sources : 4)

Table 2. Result of Mean erosion and deposition and net erosion for landuse-I, II and III

	Erosion/depositin Rate (t/ha/yr)		
	Mean Erosion	Mean deposition	Net Erosion and deposition
Land Use I	-25	0	-25
Land Use II	-3	27	24
Land Use III	-62	4	-58

(Sources : 4)

The calculation of mean and net erosion rate for land use I that showed in Table 2 was -25 t/ha/yr, and -25 t/ha/yr respectively. Figures 4 showed the erosion and deposition contour maps for land use I produced using surfer software, and explained the erosion occurred over most of the plot. This site is cultivated by hoelike tool, and is kept flat after cultivation. The fine soil at this site is easy remove to the lower point by water erosion, because sometime this site was unplanted and kept in flat condition. This site has net erosion more than -10 t/ha/yr and according to Wischmeier and Smith (1978), the value of 10 t/ha/yr is the maximum soil erosion tolerance rate, and it suggest that land use I has serious erosion over 24 years [10].

Landuse II is characterized by a ridges and furrows system, where the depth of the furrows is 30 cm. The conversion models can not be applied for traditional cultivation using ridges and furrows, since the calculation of erosion and deposition assumes a flat terrain. To convert the ^{137}Cs inventory of ridges and furrows to equivalent values for a flat surface, the ^{137}Cs concentration value (Bq/kg) for each point was multiplied by bulk density (kg/m^3) and initial depth plough (m) prior to ridge formation. From 54 sampling points, this site has

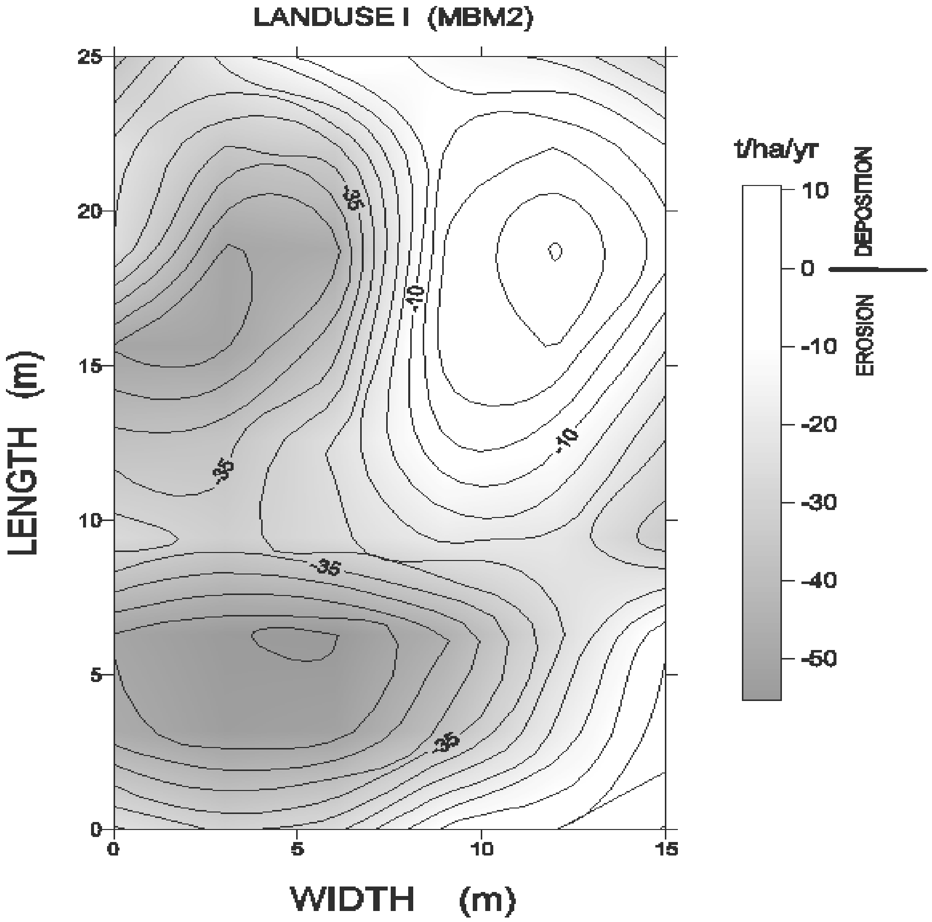

Fig.4. Erosion and deposition contour map for land use I based on data obtained using MBM2 (source : 5)

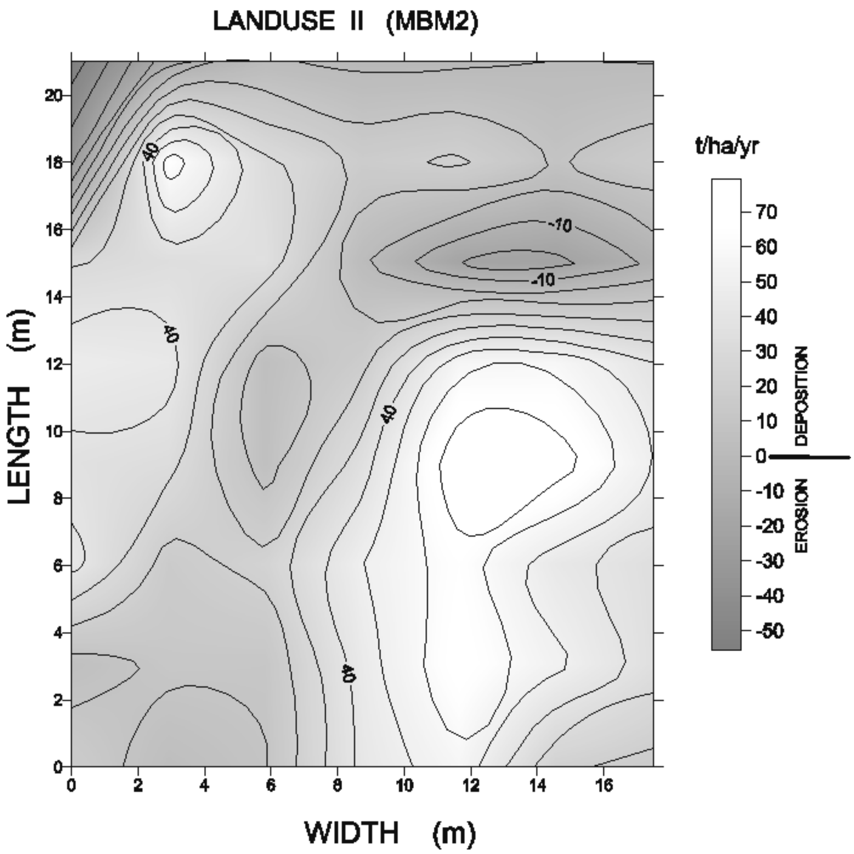

Fig.5. Erosion and deposition contour map for land use II based on data obtained using MBM2 (source : 5)

^{137}Cs inventory values ranging from 135 Bq/m^2 to 557 Bq/m^2 (see Table 1), and most of sampling points have ^{137}Cs inventory more than the reference site value. The mean and net deposition based on individual sampling point calculated using MBM2 for this site was estimated to be 27 t/ha/yr and 24 t/ha/yr, respectively (see Table 2). The result showed that the site is accumulating ^{137}Cs from the upper site, because it located at the lowest point, and by changing the position of ridges and furrows, movement of soil beyond the site can be avoided. The results provided by MBM2 model conversion show that erosion at this site is minimized by using ridges and furrows Figures 5 provide erosion and deposition contour map of landuse II, and show that some erosion occurred at the top of site.

Landuse III which is located above landuse I is cultivated using a machine with a plowing wheel diameter of 60 cm. The depth plough at this site is 30 cm, and the depth of sampling was 40 cm. From Table 1 showed that the ^{137}Cs inventory values at this site were in the range 24 Bq/m^2 to 444 Bq/m^2 for 30 sampling points. Most of the sampling points have ^{137}Cs inventory values less than the reference site value. Based on the soil redistribution rates of individual sampling point provided by MBM2 model conversion, the mean and net erosion rates for this site were -52 t/ha/yr and -58 t/ha/yr, respectively.

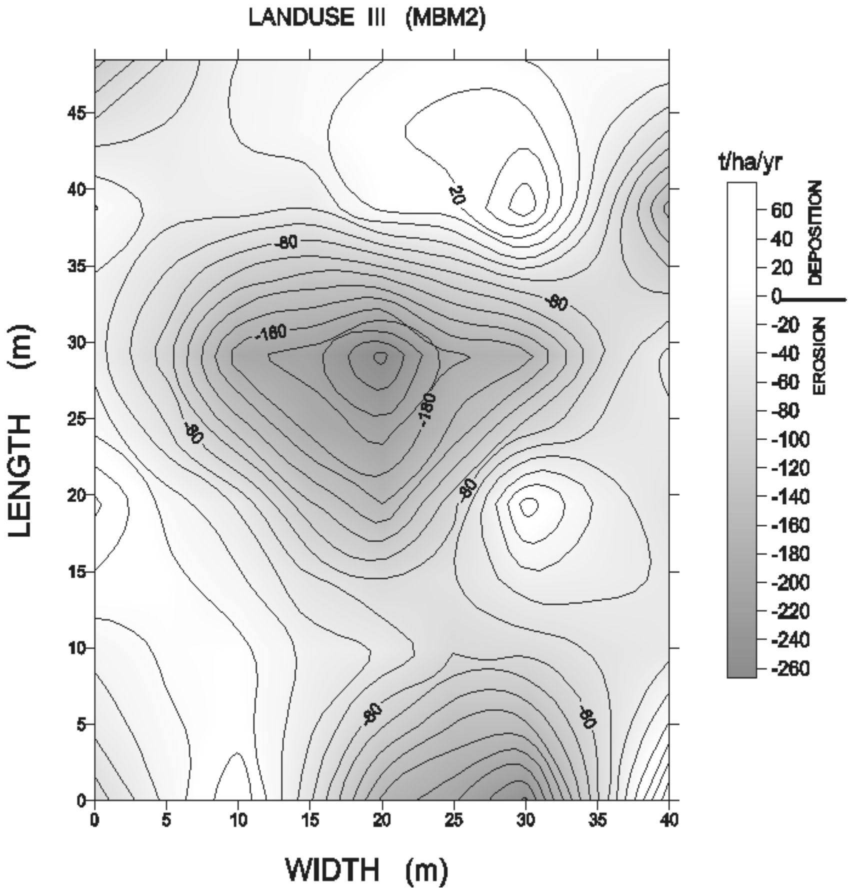

Fig. 6. Erosion and deposition contour map for land use III based on data obtained using MBM2 (source : 5)

This plot has high erosion rate because calculation using ^{137}Cs method based on activity of ^{137}Cs in soil, and machinery cultivation in this plot caused some soil loss carried over to the wheels. Figures 6 provide the contour map of erosion and deposition rates for landuse III obtained using the MBM2 conversion model, and showed that the highest erosion occurred in the middle of the site.

From Fig. 4 to 6 and Table 2 showed that Land use I has high erosion, because this plot was kept flat, and sometime it was unplanted. Land use III has high erosion that could be the outcome of intensive annual cultivation processes and machinery cultivation. The high annual rainfall rate, especially in a wet season, is a main cause for the high erosion in this area.

CONCLUSION

The investigation showed that cultivation of the land had influenced the movement of ^{137}Cs to a deeper layer in the soil profile, and vertical distribution of ^{137}Cs in this cultivation site was more than 30 cm.

The estimate of mean and net erosion based on the soil redistribution rates of individual sampling point provided by MBM2 for landuse I are -25 t/ha/yr and -25 t/ha/yr respectively. The mean and net deposition provided by MBM2 for landuse II are 27 t/ha/yr and 24 t/ha/yr, respectively. The mean and net erosion for landuse III are -62 t/ha/yr and -58 t/ha/yr, respectively. Net erosion rates in landuse I and III are very significant, and it suggest that those sites have serious erosion. In landuse II, movement of soil to the lower site is avoided by changing the position of the ridges and furrows. To obtain more valuable information about ridge and furrow system, an investigation of spatial soil redistribution in some plots using this system should be done for the next case.

ACKNOWLEDGEMENTS

This study was supported by the International Atomic Energy Agency (RAS-05/39) – Vienna, and National Atomic Energy Agency – Indonesia. The author wish to thanks these institutions for their support. Discussion with prof. Prof. R . Loughran as IAEA expert concerning the method and his comments have prove invaluable. The author wish to thanks to Prof. D.E. Walling and Dr. Y.S. Zhang from the Geography Dept.- University of Exeter – United Kingdom concerning to the discussion of conversion models. The author also wish to thanks to technicians in Sedimentology Laboratory – PATIR-BATAN, concerning the their helping in sampling and preparation sample.

REFERENCES

Dibyosaputro, S. 2005. “Muatan Suspensi Total dan Laju Sedimentasi Sungai Kayan di Kabupaten Bulungan, Kalimantan Timur”. *Forum Geografi*, Vol. 19, No. 2, Desember 2005. Hlm 103-114.

Elliott,G.L., Loughran., R.J., and Campbell,B.L., 1992, Appl.Radiat.Isot. A41, p.1 – 1

He, Q., and Walling,D.E., 2003, Hydrol. Process, 17, p 901 – 916

Loughran, R.J., Elliott, G.L., and Campbell, B.L., 1993, Appl. Geogr.,13,p.109 – 188.

Porto,P., Walling,D.E., and Ferro,V., 2001, J of Hydr., 248, p.93 – 108.

Ritchie,J.C., and McHenry, J.R., 1990, J.Environ. Qual., 19, p.215 – 233

Suhartini,N., Country Report of RAS/5/039, Mid-Term Meeting of IAEA, Jakarta, 2003

Suhartini, N., Laporan Tehnis, BATAN, 2004.

Wahyu Santosa, Langgeng. 2005. “Identifikasi Kerusakan Lahan dan Cara Penangananya di Zona Perbukitan Baturagung Kabupaten Gunung Kidul”. *Forum Geografi*, Vol. 19, No. 1, Juli 2005. Hlm 30-54.

Walling, D.E., 1998, IAEA – TECDOC, 1028, p.39 – 62

Walling,D.E., Collins,A.L., and Sichingabula,H.M., 2003, Geomorphology, 52,p.193 -213

Wischmeier, W.H., and Smith,D.D., 1978, Predicting rainfall losses: A guide to conservation planning, Agri.Handbook, vol.537, USDA, Washington, DC, p.58

Zapata, F., 2002, Handbook or The Assessment of Soil Erosion and sedimentationUsing Environmental radionuclides, Kluwer Academic Publishers, Netherlands, p.1–16.