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USING ENVIRONMENTAL RADIONUCLIDE, ^{137}Cs TO INVESTIGATE SOIL RE–DISTRIBUTION IN AN AGRICULTURAL PLOT IN KALUMPANG, SELANGOR, MALAYSIA

Zainudin Othman[1] and Wan Ruslan Ismail[2*]

[1]Department of Geography and Environmental Studies, Faculty of Humanities and Social Sciences, Universiti Pendidikan Sultan Idris, 35900 Tanjung Malim, Perak
[2]Geography Section, School of Humanities, Universiti Sains Malaysia, 11800 USM, Penang

*Corresponding author: wruslan@usm.my

Owing to the limitations associated with traditional methods of measuring rates of soil erosion, the fallout radionuclide Caesium-137 (^{137}Cs) technique has been increasingly used in recent years as an alternative approach to estimate rates of soil erosion and soil redistribution in both cultivated and non-cultivated areas. A preliminary study has been conducted using the environmental isotope ^{137}Cs to assess the feasibility of applying this method on Malaysian soils in order to provide a retrospective estimate of medium-term soil erosion rates within the catchment area over the past years. The study plot is situated in Kalumpang Agriculture Station, 90 km northeast of Kuala Lumpur. The site is being used for light agricultural activities and the study area is covered by local fruit trees, shrubs and light bushes. Soil samples for ^{137}Cs analysis were collected at the study and reference sites using a steel core and sampling frame. A local reference inventory for ^{137}Cs is 551 ± 27.6 Bq m^{-2}. The average soil erosion rate estimated using an empirical Proportional Model is 1.69 t ha^{-1} $year^{-1}$. The proportional model of He and Walling is considered more suitable for the study site than the empirical model of Ritchie and McHenry. The minimum rate of erosion from the proportional model was estimated at 17.6 t ha^{-1} $year^{-1}$, while the maximum rate of deposition on the plot was estimated at 4.6 t ha^{-1} $year^{-1}$. The mean for soil re-distribution was 5.7 ± 4.24 t ha^{-1} $year^{-1}$. The nett erosion of the slope found by integrating all data was estimated to be 5.42 t ha^{-1} $year^{-1}$. This study provides a significant contribution to the growing literature on this technique especially from this part of the world.

Keywords: soil redistribution, ^{137}Cs, proportional model, Kalumpang, Malaysia

INTRODUCTION

Soil erosion which is one of the most challenging processes faced by human beings poses a major environmental problem worldwide. Soil erosion is the removal of soil particles by wind and running water, and each year, 75 billion metric tonnes are removed from the continent via these means (Pimentel et al., 1995). Soil erosion can be evaluated by a number of methodologies such as erosion plots, erosion pins and sediment yields. However, all these methods are constrained to certain site conditions, apart from being labour intensive (Peart, Ruse and Hill, 2006).

Owing to the many limitations associated with traditional approaches mentioned above, scientists have had to find alternative approaches to measure soil erosion by using environmental radionuclides fallout (Stocking, 1987; Loughran, 1989). They are called environmental radionuclides because they are common occurrences and they are widely distributed in the environment. They have become part of the world's ecosystem as they have remained in the environment for a long time (Katcoff, 1958). They are found at a relatively low level and are readily measurable in the soil (Walling, 2006; McHenry and Ritchie, 1977; Loughran, Elliott and Campbell, 1982; de Jong, Begg and Kachanoski, 1983).

One particular radionuclide which happens to be the most commonly used element in radionuclide tracing is Caesium-137 (^{137}Cs). There are other useful elements and these include lead (^{210}Pb) and berrylium (^{7}Be) (Walling, 2004). ^{137}Cs is a man-made radionuclide (with a half-life of 30.12 years) present in the global fallout of debris resulting from the testing of nuclear weapons in the atmosphere during the middle years of the twentieth century. The maximum rate of ^{137}Cs fallout from atmosphere was recorded in 1963 (Zhang et al., 2008) and reached the earth's surface primarily in association with precipitation (Wallbrink, Olley and Murray, 1994).

The fallout radionuclide possesses one particular property that makes it an effective tracer in soil erosion research. This is because upon reaching the earth's surface, ^{137}Cs becomes firmly adsorbed in surface soils and sediment particles in most environments and any subsequent lateral redistribution that occurs primarily reflects erosion and sedimentation (Collins and Walling, 2004). ^{137}Cs can be detected dating from the mid-1950s particularly clay minerals (Singh and Gilkes, 1990; Sutherland and de Jong, 1990; Ritchie and McHenry, 1990).

^{137}Cs measurements could be used to estimate a medium term of erosion and sedimentation (i.e., about 40 years) based on a single site visit (cf. Walling and Quine, 1995; Walling, 1998; Walling et al., 2002). Over the past decade, the

^{137}Cs approach, for example, has been successfully applied in a wide range of environments in many different areas of the world (Ritchie and McHenry, 1990; Walling, 1998; Ritchie and McCarty, 2003). Such work has included a number of studies in Africa, where ^{137}Cs measurements have been used to quantify soil redistribution in both the field and catchment scale areas in Lesotho (Walling and Quine, 1992). They have also been used to study local patterns of soil erosion in Niger (Chappell et al., 1998) and to investigate rates of soil loss and soil redistribution in areas of commercial and communal farming in Zimbabwe (Quine, Walling and Mandaringana, 1993) and southern Zambia (Collins et al., 2001).

The fallout has been used as an indicator of soil erosion and to determine its sediment deposition status. As mentioned earlier, the fallout radionuclide can become locally and uniformly deposited on the soil and adsorbed in soil particles. Inventories of ^{137}Cs at a study site will be carried out in this research. Sites without any net soil loss or gain should have ^{137}Cs inventories that reflect the amount of ^{137}Cs fallout minus the loss due to radioactive decay. The level of ^{137}Cs at an undisturbed site provides a reference value for assessing ^{137}Cs loss and gain and the associated degree of erosion and deposition within an area. Sites having ^{137}Cs inventories less than the reference value can be considered as eroded while sites having more than the reference value can be regarded as depositional (Loughran, 1989; Walling and Quine 1992). Moreover, using ^{137}Cs measurements with existing models has made it possible for soil redistribution rates to be calculated in the medium term (Walling and Quine, 1991; Zapata and Garcia-Agudo, 2000).

The fallout distribution over the globe is shown in Figure 1. The fallout in the equatorial region is minimal and ^{137}Cs fallout in Malaysia was reported to be of low quantity from the low intensity nuclear test in the southern hemisphere, northern hemisphere and the tropics. Earlier studies in Malaysia, for example by Lowe (1978) who had taken soil samples from the peak of Malaysian mountain ranges found that the average ^{137}Cs radioactivity was 5 Bq/g and the range was 0.37 Bq/g–24 Bq/g. Lowe (1979) also showed that ^{137}Cs radionuclides were also found in fishes from the Strait of Malacca ranging from 14–35 pCi/kg (see Table 1). He agrees with Francis and Brinkley (1976) who pointed out that these radionuclides could enter the food web via the sediment transported in suspension in rivers.

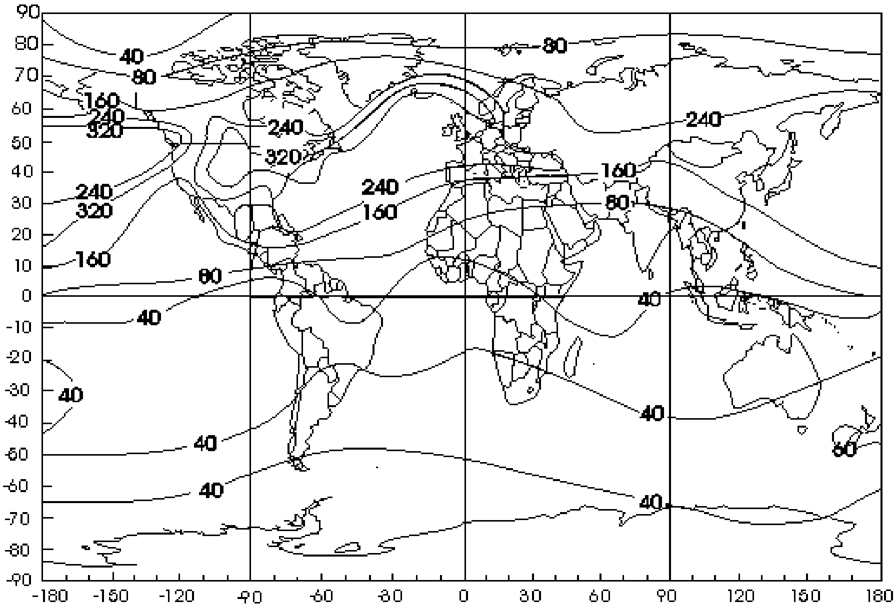

Figure 1: The distribution of global inventory ^{137}Cs originated from nuclear test (in mBq/cm^2), estimated for 1996

Source: United Nation Scientific Committee on Effects of Atomic Radiation, UNSCEAR, (1969)

Table 1: Radioactivity of ^{137}Cs found in fishes in West Malaysia

Sample	pCi/kg wet ^{137}Cs	pCi/kg dry ^{137}Cs	Weight of fish/shrimp (kg)	Location
Round scad	9.2 ± 1.2	35.7 ± 4.7	0.20	Straits of Malacca
Shrimp (*P. parapeneosis*)	3.1 ± 1.4	13.0± 6.6	0.05	Straits of Malacca
Shrimp (*P. metapeneaus*)	3.0 ± 1.4	14.0 ± 6.6	0.05	Straits of Malacca

Source: Lowe (1979)

The measurements of ^{137}Cs have been used in investigation of water induced soil erosion in a wide range of environments because generally, the ^{137}Cs concentration declines exponentially with depth in undisturbed soil profiles. The ^{137}Cs depth distributions were described by the simple profile-shape model which was widely used for estimating soil losses (Zhang, Higgitt and Walling, 1990; Walling and Quine, 1991).

This paper presents an attempt to use ^{137}Cs tracing technique to investigate the soil erosion and soil redistribution on a slope at Kalumpang Agriculture Station, Selangor, Malaysia. The objectives of this paper are: (1) to determine the ^{137}Cs

reference inventory in the study area by combining direct field measurement and modeling estimation; (2) to estimate the erosion and deposition rates on different slope locations using two different models; (3) to compare overall outputs of the different models.

STUDY SITE

The Experimental Plot

The experimental plot chosen for this study is at the Kalumpang Agricultural station (3° 38'N, 101° 34'E) in Selangor which is about 90 km Northeast of Kuala Lumpur (Figure 2a). This site was chosen because the plot is relatively "undisturbed." It is also suitable because we postulate that the rate of erosion is undergoing natural erosion. This is also shown by the reference inventory at an undisturbed site which is described in the methodology section. The site faces west and lies at an altitude of approximately 70–80 m above sea level (Figure 2b).

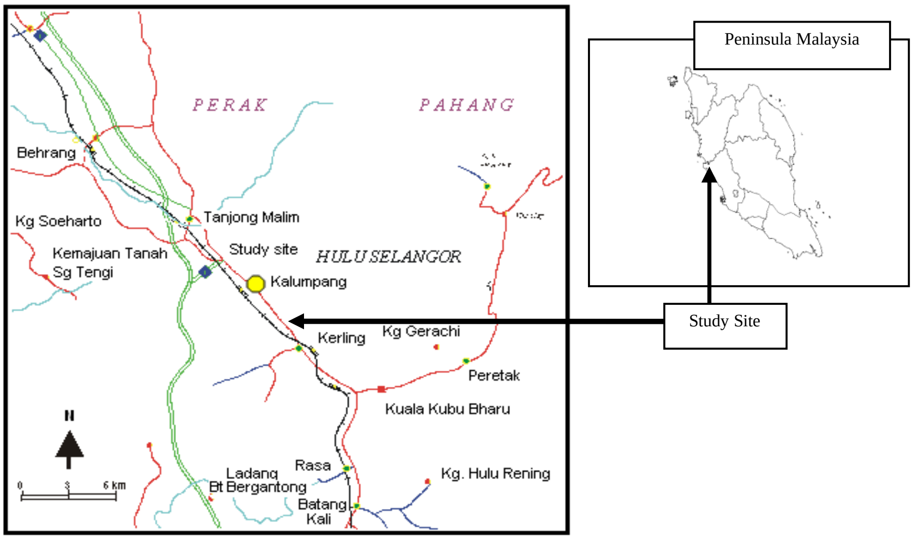

Figure 2a: Study site and the Kalumpang area in Selangor

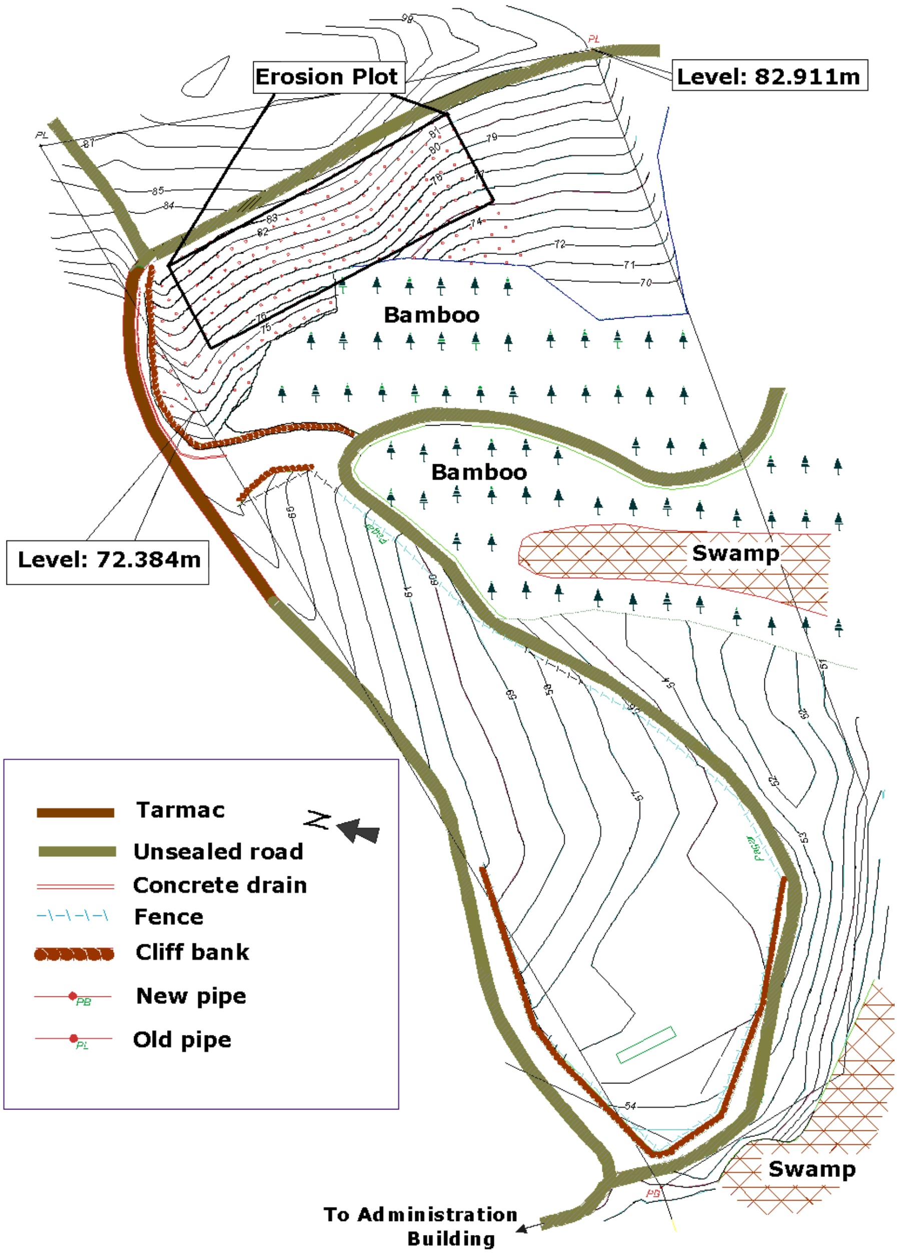

Figure 2b: The location of the studied erosion plot at the Kalumpang Agriculture station

The Kalumpang Agricultural Station is dedicated to agricultural planning and research. The station was established in 1981. The experimental slope chosen for the study has been planted with durian fruits (*Durio Zabathinus*) in 1990. There were 12 durian trees spacing 20 meter apart with shrubs and light bushes in between the trees (Figure 3), covering an area of 55 hectares. For the purpose of this study, sampling was limited to three hectares only.

Figure 3: Slope at the study site at Kalumpang, Selangor, Malaysia

The underlying geology of the area comprises interbedded sandstone and shale or sandy shale, which has weathered to produce soils of the Bungor Series. The Bungor Series is a member of the clayey, kaolinitic isohyperthermic family of the Typic Paleudults. Soils of the Bungor Series show very little variation and they have colours that range from strong brown, brownish yellow to yellowish brown. Textures range from fine sandy loam to fine sandy clay loam to clay. Clay content seldom exceeds 50% and coarse sand always dominates the fine sand. The latter seldom exceeds 20%. Structures are weak to moderate medium with fine sub-angular blocky while consistence is friable to firm with depth (Guan, 1992).

Climate

The area experiences an equatorial climate classified as rainforest climate Af_i according to Köppen's classification (Kotteki et al., 2006). In this regard, the average annual air temperature is over 24^{o}C with high humidity between 80%–90% and annual rainfall of 2,850 mm (1951–1985). Two distinct wet periods with a higher than the mean monthly rainfall occur in April–May and September–November. The first peak is associated with the intermonsoon month of April and the Southwest monsoon, while the second peak is associated with the second intermonsoon in October and the Northeast monsoon season (Nieuwolt, 1982).

Most of the precipitation occurs during the period of May–October while dry periods are from January–February and Jun–July each year. However, rainfall at Kalumpang is higher from January–March but it declines in April and May and peaks again in October. Figure 4 shows the average monthly rainfall at Kalumpang for 1999–2000 compared to the long term average distribution for 45 years (1951–1995) at Tanjung Malim Meteorological Station (Latitude 3^{o} 47' N Longitude 101^{o} 28' E; 42.7 meters above sea level), located about 6 km to the north of the study site.

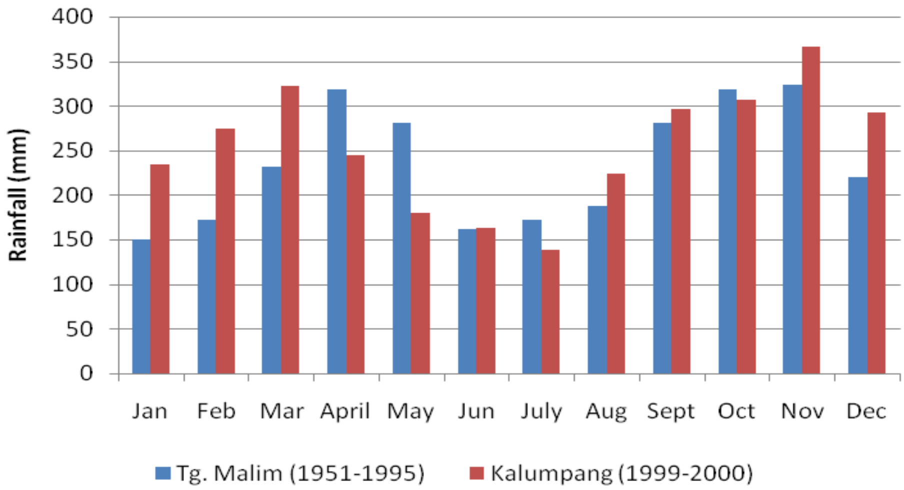

Figure 4: Average monthly rainfall distribution at Kalumpang station and Tanjung Malim Meteorological Station

Source: Malaysian Meteorological Services, pers.comm.

METHODS

Sampling Strategy

Point inventory at study site

To establish the spatial variability of soil ^{137}Cs point inventories at the study site in response to soil redistribution, soil samples were collected at three sampling locations, A (upslope), B (mid-slope) and C (downslope). In this study, individual slope transects were employed because the site is characterised by a simple topography. A total of 40 samples were collected for an initial survey. Sample collection involved the use of either a steel core or sampling frame and scraper plate (Campbell, Loughran and Elliott, 1988). Samples were collected from the upslope to the downslope at 10 m intervals. At each sampling location, a 200 × 500 mm steel frame was placed on the soil surface and hammered into the soil. A scraper plate was used to slice off soil in 20 mm increments to a depth of 400 mm. The steel core (id: 96 mm, length: 300 mm) was used to collect samples from the vicinity of the sampling point for comparison and statistical analysis. Soil samples were dried and analysed for ^{137}Cs using high-resolution gamma-ray spectroscopy (Ritchie and McCarty, 2003; Owens and Walling, 1996).

Reference inventory at undisturbed site

The basic premise for ^{137}Cs in soil erosion investigations is that the point inventories of ^{137}Cs can be directly compared to a reference inventory at an undisturbed site which reflects the total cumulative input of ^{137}Cs less radioactive decay (Owens and Walling, 1996). The establishment of local reference inventory is therefore an important requirement when using ^{137}Cs technique in estimating rates of soil erosion. Samples collected for a reference inventory should be taken close to the study site which has not experienced any disturbance since 1953, or soil erosion or deposition since 1953. It must have a minimal slope angle with full vegetation cover of grass or similar vegetation all year. A suitable site was chosen for the ^{137}Cs local reference inventory. The reference site were located at Kalumpang (3° 38'N; 101° 34'E) which receives an average annual rainfall (1951–1985) of 2850 mm (Figure 4). The soil at this location is classified as the Bungor Series, with bulk density of 1.48 g/cm^3 (Guan, 1992).

Laboratory analysis

After collection, soil samples were dried overnight at 60°C, sieved through a 2 mm mesh (to remove stones and to ensure a constant sample density and geometry). They were then placed in Marinelli beakers and assayed for ^{137}Cs activity using HPGe (EG&G ORTEC) co–axial detector coupled with a multi-channel analyser at the Malaysian Nuclear Agency laboratory. All samples were counted for 50,000 seconds to take into account low ^{137}Cs activity in the soil. The detector was calibrated with a radionuclide standard (mixed radionuclides as chloride solid incorporated in 1.0 litre plastic container with density approximately 1.0g/cm^3). The net count rate under the ^{137}Cs photopeak at 662 keV was measured to determine the ^{137}Cs concentration of the sample.

The ^{137}Cs inventory of the sample was calculated from the equation given by Walling and Quine (1993):

$$CIS = \frac{(CASS \times FW)}{HSA} \qquad [1]$$

where;

CIS = ^{137}Cs inventory of the sample (Bq/m^2)
CASS = ^{137}Cs activity of the sub-sample (Bq/kg)
CFW = the corrected weight of the fine (<2 mm) fraction of the sample (kg)
HSA = horizontal surface area of the sample (m^2)

$$CIS = \frac{CCSS}{SSW} \qquad [2]$$

where;

CIS = ^{137}Cs inventory of the sample (Bq/m^2)
CCSS = ^{137}Cs content of the sub-sample (Bq)
SSW = weight of the sub-sample (kg)

All ^{137}Cs inventories are reported within 2σ or at 95% confidence level.

RESULTS

Distribution of ^{137}Cs Within the Soil Profile at an Undisturbed Site

One undisturbed reference site was also selected at Kalumpang Agricultural Station. The depth distribution of ^{137}Cs at this reference site location was examined to obtain background information on the behaviour of fallout ^{137}Cs within the soil and to assist with the interpretation of the ^{137}Cs inventories. The total reference inventory value at Kalumpang was 551 ± 27.6 Bq m^{-2} and the depth distribution of ^{137}Cs within the soil profile is shown in Figure 5, with depth expressed as the cumulative mass depth. This reference value is in close agreement with existing estimates of the global fallout of ^{90}Sr data compiled by Larson (1985) of about 526 Bq m^{-2} at latitude band 0°–10° in the Southern hemisphere (Walling and Quine, 1995). The inventory value was about three to four times lower than those found in Europe e.g., in Italy (Porto et al, 2003) and Turkey (Haciyakupoglu et al., 2005); China (Lu and Higgit, 2000) and Australia (Loughran et al., 1988) as shown in Table 2. The inventory value, however, doubled the value recorded in Zimbabwe by Owens and Walling (1996).

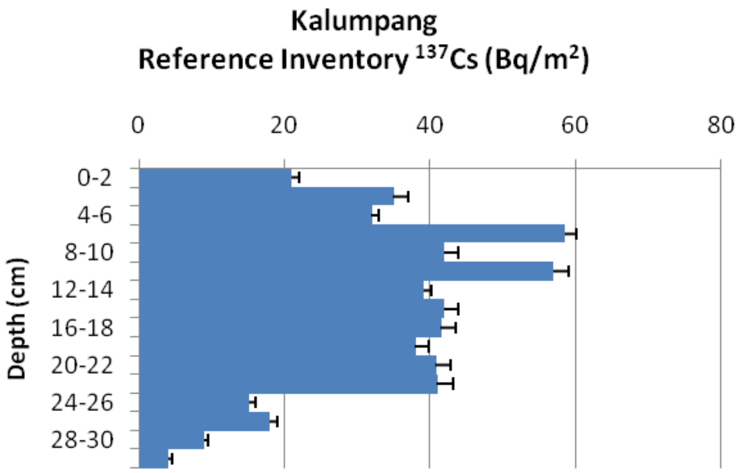

Figure 5: Reference inventory values at Kalumpang, Selangor

Table 2: The ^{137}Cs inventory values for some locations as a comparison with Malaysian values

Location	Caesium-137 Inventory (Bq m^{-2})	Source
Kalumpang, Malaysia	551	This study
Italy	2033–2088	Porto et al., 2003
Western Istanbul, Turkey	1620	Haciyakupoglu et al., 2005
Eastern Istanbul, Turkey	1104	Haciyakupoglu et al., 2005
Australia	860–1140	Loughran et al., 1988
Devon, England	2374	Owens and Walling, 1996
Zimbabwe	236.8	Owens and Walling, 1996
Woodland, China	2127–5092	Lu and Higgit, 2000
Paddy, China	1824–2158	Lu and Higgit, 2000

The results show that essentially ^{137}Cs was sorbed, and the degree of sorption was independent of soil horizon. There is a decline in ^{137}Cs activity with increasing depth and more than 70% of the total inventory occurs in the top 160 mm, indicating that downward translocation is minimal. ^{137}Cs downward movements in an undisturbed soil profile includes diffusion and migration processes. ^{137}Cs diffusion in soil is the process that the ^{137}Cs movement is caused by the concentration pressure in the ion or molecule form which means that the nuclide is only able to move from high concentration to low concentration by diffusion. ^{137}Cs migration in soil is the process that the ^{137}Cs downward movement is caused by transportation of mediums, such as the adsorbed solid particles and the dissolved fluids and it means that the nuclide is able to move either from high concentration to low concentration or from the low to the high (Zhang et al., 2008).

The profile distribution of ^{137}Cs in soil systems has a tendency to decrease towards the deeper layers. Meanwhile the forest floor remains the main reservoir for Caesium even years after fallout. On the basis of the estimated factor of accumulation (FA), Zhiyanski et al. (2008) concluded that the type of vegetation is a factor influencing the vertical distribution of ^{137}Cs in the soil system and they found that spruce forests have higher retention capacity to deposited Caesium. Other factors that could modify the Caesium distribution in soils are the human activities in forests and implemented sylvicultural practices.

Distribution of ^{137}Cs Within the Soil Profile at the Study Site

Three inventory sites A, B and C were chosen to represent the upslope, midslope and the toe slope. Figure 6 (a, b and c) shows the depth profiles of ^{137}Cs within the soil at the study site. In an undisturbed condition, we would expect that the ^{137}Cs found in cultivated soils at locations, A, B and C, is uniformly distributed throughout the soil layer to a depth of about 340 mm. However, we found that the site has been disturbed in the past.

Site A (Figure 6a), located at coordinate (–14567.9E, 52097.5N) or local coordinate (80 m, 24 m), is 84 m above sea level. The slope of the surface is about 4^{o} with some patches of plant cover. Visual observations indicate that this site has been disturbed for agriculture. The chances of all ^{137}Cs distributed throughout the column are high. The total values of ^{137}Cs inventory at site A is 139.60 ± 17 Bq/m^2, which is lower than the total reference inventory of 551 Bq/m^2 at Kalumpang (Figure 5) indicating that the samples have been disturbed. Without any disturbance, the maximum depth profiles of ^{137}Cs could have been around 38 cm depth as shown in Figure 5. The disturbance has caused the soil profile of about 2 cm at site A to move towards the base slope. This is shown by the high ^{137}Cs values at site A at the 4 cm depth in Figure 6a.

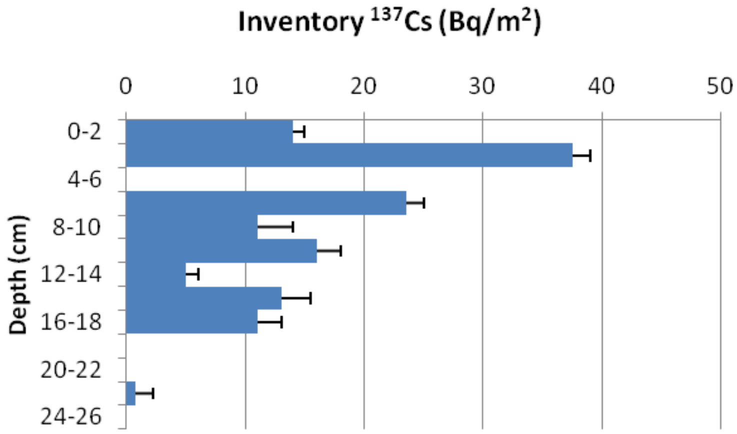

Figure 6a: Sample inventory at station A on the erosion plot. The elevation is 84 m a.s.l; slope 4^o patches of grass

Site B, on the other hand, located at coordinate (–14567.9E, 52097.5N) or local coordinate (80 m, 24 m) is 80 m above sea level (Figure 6b). The slope of the surface is about 4^o with some form patches of plant cover. Visual observations indicate that this site has been disturbed for agriculture. The chance that all ^{137}Cs are distributed throughout the column is high. The total values of ^{137}Cs inventory at site B is 442 ± 25 Bq/m^2 and this amount is 30% less than the reference inventory. Depth profile of the ^{137}Cs in Figure 6b shows that the inventory distribution is only limited to the upper 28 cm of the profile. The upper portion of the soil has been removed depicting the highest inventory at depth 12–14 cm layer while the maximum inventory for reference site is at layer 8–10 cm (Figure 5). Thus location B has experienced a sediment removal of about 8 cm of soil with ^{137}Cs content towards the lower foot slope. At the same time, site B also received 2–4 cm of soil from the upper portion of the studied slope.

Site C located at the coordinate (–14585.6E; 52087.8N) or at local coordinate (80 m; 4 m) at 76 m a.s.l. (Figure 6c). The slope of the surface is 7^o, covered with grass with little erosion scar on the water path. The total values of ^{137}Cs inventory at site C is 269 ± 23 Bq/m^2 and this amount is 60% less than the reference inventory. Owing to its location near to the foot slope, location C should have accumulated more sediment and the inventory is expected to be higher than at location A and B. However, the inventory is not that high, also there is a thinning in the sediment layer at this site compared to the reference site. Because of its location near the base of the slope there is a possibility that ^{137}Cs has been removed or transported downslope out of the study plot thus making it difficult to ascertain the soil redistribution at this site C.

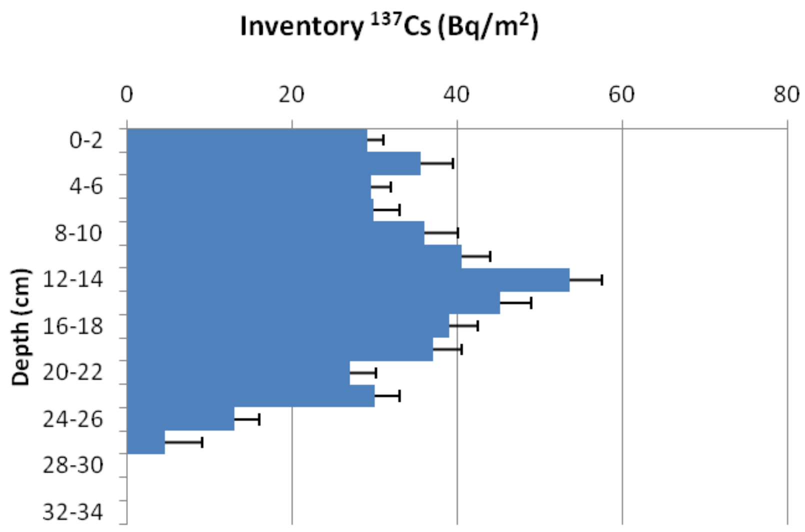

Figure 6b: Sample inventory at location B on the erosion plot. The elevation is 80 m a.s.l; slope 4^o, covered with grass

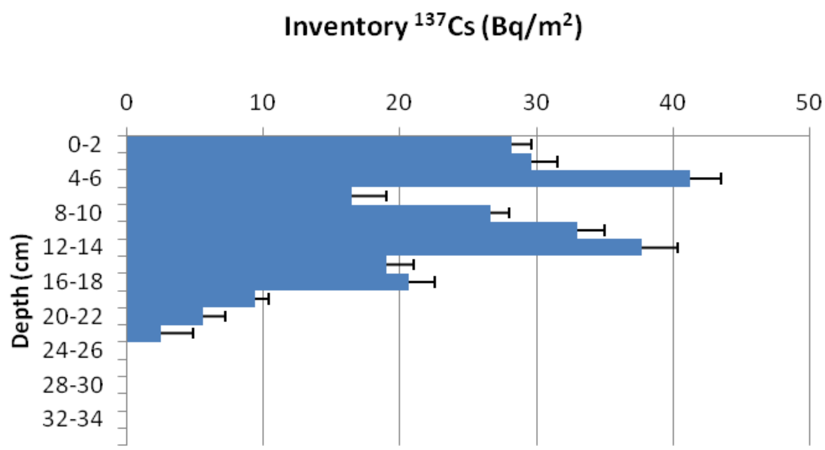

Figure 6c: Sample inventory at location C on the erosion plot. The elevation is 76 m a.s.l; slope 7^o, covered with grass, little erosion scar on the water path

In general, the inventories along the transect show a decrease in ^{137}Cs inventory at the upper part of the slope, an increase in the middle portion of the slope and decrease at the bottom of the slope. However, the ^{137}Cs inventories are evidently lower than the local reference inventory and this suggests that some erosion or soil removal has occurred.

The bulk ^{137}Cs inventory on the erosion plot

Bulk sampling was also carried out to obtain the distribution of ^{137}Cs in grids to cover the whole slope besides the reference samples A, B and C. A total of 220 bulk samples were collected using auger on the plot covering the upper slope, middle slope and the foot slope. The slope was divided into grid of 8 rows by 21 columns, and samples were collected at an interval of 4 meters. The slope run downslope from column 80 to column 0 and across slope from row 28 to row 0. ^{137}Cs concentration on the whole slope of the erosion plot range from 148 to 287 Bq/kg and changing these values into ^{137}Cs inventories, it ranged from 176 to 469 Bq/m^2 with a mean inventory of 381.5 Bq/m^2 (Figure 7). Table 3 shows the bulk samples collected at seven locations on the study slope site to get the average reference inventory. The average inventory of the site was 421.6 Bq/m^2.

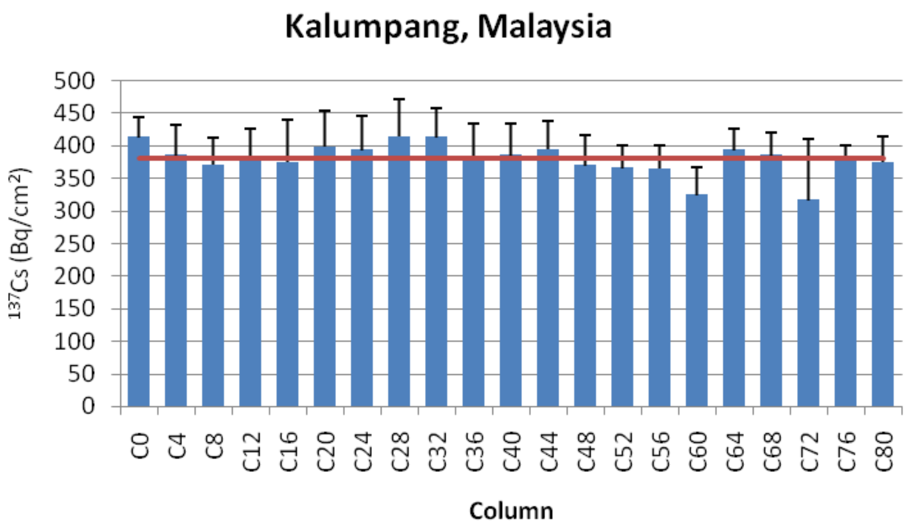

Figure 7: The average and standard deviation of the ^{137}Cs activity for each column along the slope in the study plot

The pattern of Cs distribution on the slope was established based on Kriging algorithm which is used to interpolate the contour lines passing through all points having similar ^{137}Cs inventory. The interpolation process produced an iso-inventories contour for ^{137}Cs differentiated by the difference in the colour shown in Figure 8. The distribution of the inventories clearly shows that there was a reduction in ^{137}Cs on the study slope. There was no loss of ^{137}Cs in high quantity that could be associated with transporting agent. The low ^{137}Cs concentration on the foot slope was due to deposition of ^{137}Cs shown by darker colours.

Table 3: Locations and amount of bulk samples collected to determine the reference inventory.

Location	Coordinate (Easting)	Coordinate (Northing)	Inventory (Bq m^{-2})	Average Inventory (Bq m^{-2})	Number of sample
1	–14562.6	52095.6	473; 459	466.0	2
2	–14564.2	52099.0	463; 427	445.0	2
3	–14564.5	52105.4	468; 417	442.5	2
4	–14565.1	52107.6	217; 265	241.0	2
5	–14566.7	52111.6	437; 481	459.0	2
6	–14567.2	52115.9	479; 419	449.0	2
7	–14568.4	52115.3	488; 398	443.0	2
Average				421.6	

From the inventory we found that the study plot is experiencing ^{137}Cs loss by as much as 16% compared to the reference inventory. Most of the sampling points on the slope have a lower inventory compared to the reference inventory. Only eight sampling points on the foothill have values greater than the reference inventory.

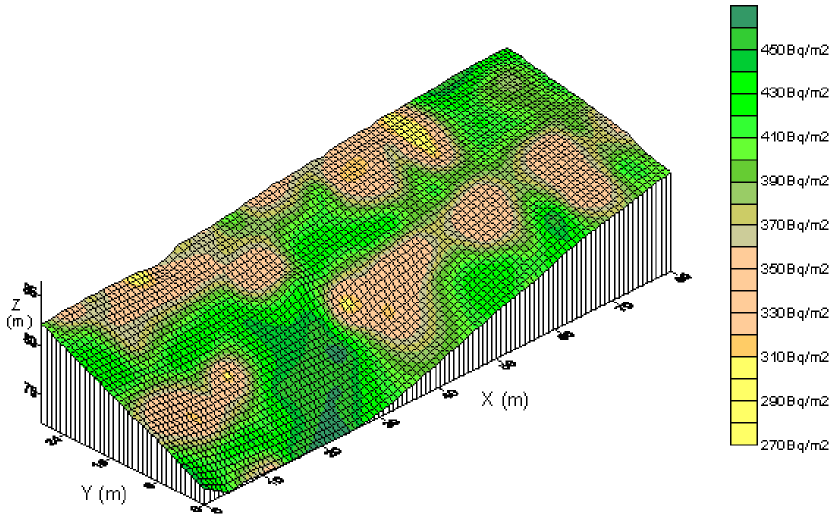

Figure 8: Contours for the ^{137}Cs inventory on the erosion plot

There was no clear relationship between the ^{137}Cs content and the distance crossing the slope. Generally, the ^{137}Cs inventory at transect 0 meter, 16 meter and 32 meter from initial point is controlled by the topography. This is verified visually due to the presence of heaps of soil and mount in a N–NW orientation

(Figure 8). This mound could have been produced during tree planting and there was also some form of depressional surfaces that could have been developed by concentrated water flows eroding the upper part of the slope (Figure 8).

Spatial Inventory of ^{137}Cs on the Erosion Plot

Figure 9 shows the pattern of inventory losses and gain in ^{137}Cs on the studied slope. Only 40% of the slope experienced an increase in the ^{137}Cs concentration while the rest are losses. Most of the deposition occurred at the base of slope showing that ^{137}Cs from the upslope is washed down from the upslope and transported down to the mid slope and base slope. Besides rainfall, other factors such as topography of the slope determined the pattern of soil re-distribution shown in Figure 9. The nature of micro relief of the surface and the rate of infiltration into the soil at the time of radioactive fallout also influence the soil redistribution, and Loughran et al. (1988) has pointed out that micro erosion process is the main factor that causes the variability of inventory and it is unavoidable.

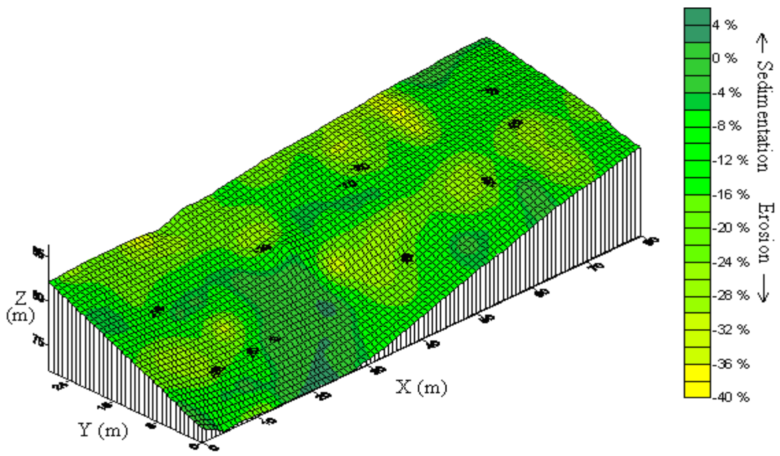

Figure 9: Pattern of erosion and deposition of sediment based on the ^{137}Cs pattern of inventory gain and loss

Estimation of Soil Erosion Rate at Cultivated Slope by Empirical Model

Quantifying ^{137}Cs loss/gain in soils has provided a method to quantify soil redistribution. Also mass balance models have been relatively reliable in soil erosion research. A few mass balance models have been proposed (Martz and de Jong, 1987; Walling and He, 1999; Yang et al., 1998). Erosion rates at

Kalumpang Agriculture Station were estimated using an empirical Proportional Model (He and Walling, 1997). The model can be expressed as:

$$Y = 10\frac{BdX}{100TP} \quad [3]$$

where;

Y	=	mean annual soil loss (t/ha/yr)
d	=	depth plough or cultivation layer (0.01 m)
B	=	bulk density of soil (1480 kg m^{-3})
X	=	% reduction in total in total ^{137}Cs inventory ($(A_{ref} - A)/A_{ref}$ x 100)
T	=	elapsed time since initiation of ^{137}Cs accumulation (year)
A_{ref}	=	local ^{137}Cs reference inventory (Bq/m^2)
A	=	measured total ^{137}Cs inventory at the sampling point (Bq/m^2)
P	=	particle size correction factor (clay = 1.0)

The empirical model developed by Ritchie and McHenry (1975) was based on soil erosion plot study for three years. There is insufficient data since three years is relatively too short a time to get the whole content of ^{137}Cs into a depth of 20 cm tillage depth.

From the model, the mean annual soil loss at upslope (A), intermediate slope (B) and foot slope (C) was estimated at 2.56 t ha^{-1} $year^{-1}$, 0.80 t ha^{-1} $year^{-1}$ and 1.71 t ha^{-1} $year^{-1}$, respectively, while the average of soil erosion was 1.69 t ha^{-1} $year^{-1}$. The soil redistribution based on the Proportional Model was a little lower than those estimated using Ritchie and McHenry's (1975) empirical equation. The pattern of soil redistribution (Figure 10) on the soil erosion plot is almost similar to those given by empirical model where almost 95% of the study plot is eroded (–ve values). The rest of the area is deposition. This model takes into account the depth of tillage and sediment enrichment. In this case the sediment enrichment factor is made to equal to 1 as suggested by Owens et al. (1997).

The minimum rate of erosion from this model was estimated at 17.6 t ha^{-1} $year^{-1}$ while the maximum rate of deposition on the plot was estimated at 4.6 ton/ha/year. The mean for soil re–distribution was 5.7 t ha^{-1} $year^{-1}$ with a standard deviation of 4.24 t ha^{-1} $year^{-1}$. This is much higher than the erosion rate of 2.5 t ha^{-1} $year^{-1}$ estimated using similar techniques from a communal cultivation in Zambia (Collins et al., 2001).

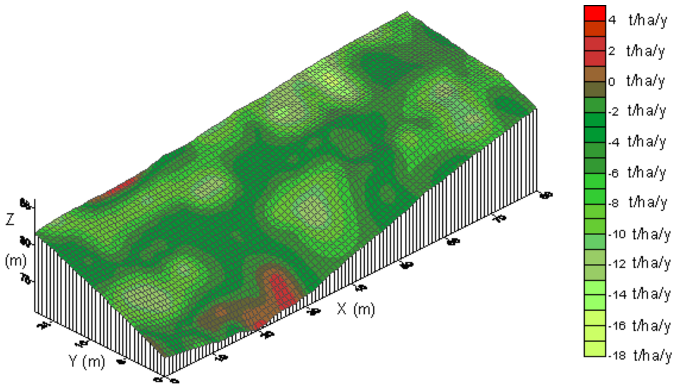

Figure 10: Pattern of soil redistribution produced by the proportional model on the studied plot slope in the study area

The proportional model gave a lower estimation of soil redistribution, i.e., four times lower than the empirical model (Ritchie and McHenry, 1975). This proportional model is considered more suitable at the study sites than the empirical model because it takes into consideration the depth of tillage. The empirical model, on the other hand, uses the direct relationship from soil erosion plot. The depth of tillage is the most important factor in the loss of ^{137}Cs. This thus affects the soil redistribution.

Table 4: Estimation of nett erosion based on the fixed transect

Transect (meter)	0	1	2	3	4	5	6	7
Number of grid point, *T*	12	19	20	20	20	20	20	20
Number of negative values, *n*	9	15	20	20	20	20	20	17
Number of positive values, *p*	3	4	0	0	0	0	0	3
Eroded area *(*n*/*T*)	12.00	12.63	16.00	16.00	16.00	16.00	16.00	13.60
Amount of erosion, *E*	–2.55	–5.54	–14.72	–14.56	–6.37	–12.11	–16.32	–15.11
Mean erosion *E*/*n*	–0.28	–0.37	–0.74	–0.73	–0.32	–0.61	–0.82	–0.89
Gross erosion *E*/*T*	–0.21	–0.29	–0.74	–0.73	–0.32	–0.61	–0.82	–0.76
Area of deposition, *(*p*/*T*)	4.00	3.37	0.00	0.00	0.00	0.00	0.00	2.40
Amount of deposition, *D*	4.04	3.17	0.00	0.00	0.00	0.00	0.00	8.65
Mean deposition, *D*/*n*	1.35	0.79	0.10	0.10	0.10	0.10	0.10	2.88
Gross deposition, *D*/*p*	0.34	0.17	0.00	0.00	0.00	0.00	0.00	0.43
Net erosion = Gross erosion – Gross deposition	–0.55	–0.46	–0.74	–0.73	–0.32	–0.61	–0.82	–1.19

Note: * cumulative area of erosion (–ve) or deposition (+ve) at that particular transect

Estimating Net Erosion and Deposition

The estimation of net erosion or deposition on the experimental plot was done by integrating data using grid where each grid point was assumed to represent an equal area. Data from each grid was integrated (Table 4) to get the total erosion (E), deposition (D), gross erosion (E/T) and gross deposition (D/T), and nett erosion and nett soil deposition. Erosion was shown to dominate the whole experimental plot. The nett erosion of the slope found by integrating all data was estimated to be 5.42 t ha^{-1}year^{-1}.

CONCLUSION

The study has attempted to use the ^{137}Cs technique to estimate net rates of soil loss on an agricultural sloping farmland in our equatorial climate. We have successfully estimated the soil re-distribution rate of the study area, and compared and tested two types of models converting ^{137}Cs inventory to soil redistribution rate. The mean ^{137}Cs local reference inventory value was 551 ± 27.6 Bq m^{-2} from the undisturbed site at Kalumpang. Two main factors induce the soil loss at location A (upslope), location B (intermediate slope) and location C (footslope) that is through water erosion due to surface runoff and human activity in the past. The proportional model is considered more suitable at the study sites than an empirical model. The minimum rate of erosion from the proportional model was estimated at 17.6 t ha^{-1} year^{-1} while the maximum rate of deposition on the plot was estimated at 4.6 t ha^{-1} year^{-1}. The mean for soil re-distribution was 5.7 t ha^{-1} year^{-1} with a standard deviation of 4.24 t ha^{-1} year^{-1}. The proportional model estimates the soil loss at 4 times lower than those estimated from the empirical model. The findings from this study provide a significant contribution to the growing literature on the use of such techniques. The results obtained in this preliminary investigation confirm the potential for using ^{137}Cs measurements to estimate erosion and deposition rates in the study area despite the low counts of radioactivity in this region.

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