DETERMINATION OF MEDIUM-TERM SOIL EROSION AND SEDIMENTATION RATES IN TWO SEASONS

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ABSTRACT

Studies on soil erosion and sedimentation rates in catchment areas in Peninsular of Malaysia using the Fallout Radionuclides (FRNs) as tracers are currently limited. This is due to the greater use of conventional methods in this study since then. However, the use of FRNs such as Cesium-137,^{137}Cs has proven to be used as tracers of soil movements that can complement interestingly more conventional approaches recently. Hence, this ^{137}Cs can be used for medium-term erosion and sedimentation rates at the site of the study for a long period of two seasons. Based on the results of the analysis, the dry season has given the soil erosion value at all sampling locations for different land use. The rate of soil erosion rate recorded varies from 9.59 t/ha^{-1}/y^{-1} to 47.83 t/ha^{-1}/y^{-1} respectively. This situation is quite different for analysis results for wet seasons, where analysis results are mixed with soil erosion rates and sedimentation. The wet season has given a slightly lower soil erosion rate than the dry season of varying values from 8.82 t/ha^{-1}/y^{-1} to 31.70 t/ha^{-1}/y^{-1} respectively. Only the wet season has given the results of sedimentation rates over the period of the study which is of varying value from -19.92 t/ha^{-1}/y^{-1} to -194.32 t/ha^{-1}/y^{-1} respectively. Overall, the wet season has given a higher sedimentation rate than the rate of soil erosion in the reference area at Frim Point of the whole data obtained during the study period. However, a more detailed study will be implemented in the future for reference data for catchment areas throughout Peninsular Malaysia.

Keywords: Erosion , Fallout Radionuclides (FRNs), Conventional, Dry season, Reference

INTRODUCTION

Soil erosion and sedimentation are one of the key environmental issues tropical ecosystems that may lead to loss of topsoil, a decrease of soil water capacity, soil fertility and also inhibit vegetation growth (Vásquez-Méndez et al., 2010). Knowledge of the interaction of geomorphologic drivers within a catchment in relation to soil erosion and land degradation has been developed by many studies around the world (Nyssen, et al., 2005). The potential for using environmental radionuclides for sediment source tracing has been recognized particularly a group of environmental radionuclides, namely, fallout radionuclides (FRNs). On the other hand, relating to this Walling *et al*., 2001. stressed the need for new approaches including the use of environmental isotopes" to obtaining the data required to establish a catchment sediment budget including soil erosion and sedimentation and suggested the potential for using environmental isotopes as tracers in erosion and sediment investigations has been increasingly recognized and exploited.

Meanwhile, the term "environmental isotopes" or fallout radionuclides (FRNs) is commonly used to refer to those isotopes which are commonly occurring and widely distributed in the environment or landscape and, whilst occurring at relatively low levels, are readily measurable. In most cases, they are of natural origin but in some cases they are man-made. One of the most frequently applied FRNs in soil erosion and sedimentation studies in catchment systems is ^{137}Cs. ^{137}Cs is an artificial or anthropogenic environmental radionuclide that can also classify as a fallout radionuclides. It has a half-life of 30.07 years and was released into the environment primarily as a result of the past testing of thermonuclear weapons during the mid-1950s to the early 1970s. The value of ^{137}Cs as a tracer lies in its rapid and strong adsorption by fine soil particles, particularly clay minerals and humic materials (Tamura, 1964; Bachhuber *et al*., 1982). The global ^{137}Cs fallout reached its peak of about 1963 and 1965 in the northern and southern hemisphere and fallout effectively ceased in the last 1970s. There was, however, some widespread regional fallout from ^{137}Cs associated with a Chernobyl accident in 1986, which affected adjacent areas in Europe and Asia.

Therefore,the post fallout redistribution of ^{137}Cs provides information on soil and sediment redistribution over the ca. 50 years since the late 1950s, although as indicated a Chernobyl input in 1986 can provide either additional opportunities or additional complications, depending on the relative magnitude of the Chernobyl input.

Over the last few decades, there have been many publications that have described the various uses of ^{137}Cs in soil erosion study (e.g.Ritchie &McHenry, 1990; Walling and Quine, 1990; Walling and Quine, 1993; Zapata, 2002: Ritchie *et al*., 1974). In addition to its use to estimate medium rates of soil loss, ^{137}Cs has also had been found to be effective as a diagnostic property in sediment source fingerprinting studies (e.g. Wallbrink *et al*., 1998; Motha *et al*., 2003) and it has been widely used as a sediment tracer (Ritchie & McHenry, 1990; Zapata, 2002). It has also been used as a tracer for studying atmospheric processes (Feely *et al*., 1989; Dibb, 1990; Todorovic *et al*., 1999). Lakes have been incorporated into several sediment budget studies involving ^{137}Cs, since the radionuclide affords a useful means of establishing the recent chronology for a sediment core.Therefore, the collection of sediment cores provides a basis for reconstructing past catchment sediments dynamics (Owens *et al*., 1997).

Therefore, ^{137}Cs is widely used to estimate medium-term (50 years) mean annual soil erosion and deposition rates with the assumption that land use and erosion rates have remained essentially constant over this period. Meanwhile, the use of natural fallout of $^{210}Pb_{ex}$ has been extended from the sediment dating application to provide a method of estimating for longer term (100 years) of soil and sediment redistribution studies. Therefore, the long and medium-terms soil erosion by using $^{210}Pb_{ex}$ and ^{137}Cs radionuclides are estimated as average erosion/sedimentation rate according to each land use in the catchment and the rates are normally expressed in tonne/hectare/year. Most areas the catchment indicates soil being eroded at almost the same rate for all land use. Land activities such as agriculture, timber extraction and planting is being fully exploited during the dry season. Occasional rain impacted on the disturbed soil will mobilize sediment to downstream. Even though the estimation using $^{210}Pbex$ are suitable for a longer term, land use activities in the catchment indicate soil being eroded at about the same rate but slightly lower than the rates given the ^{137}Cs tracer during the dry season. The study paper is prepared to determine the rate of soil erosion and sedimentation in the land use diversity range between wet and dry seasons using ^{137}Cs, a medium-term tracer.

MATERIAL AND METHODOLOGY

Soil sampling and preparation of samples

A total of 50 soil core and sediment sample were collected from The Timah Tasoh reservoir (6°36'N and 100°14'E) is located approximately 13 km north of the Kangar town near the Thailand border during the dry and wet seasons. The soil and sediment samples were collected using a metal corer and and integrating suspended trap samplers of the type described by Philips *et al*. (1993) and Russell *et al*. (2001). Meanwhile, the reservoir has a mean surface area of 13.33 km^2 and a storage capacity of about 40 million m^3. The reservoir receives inputs from two main rivers, the Tasoh and Pelarit, which have a combined area of 191 km^2 and supply approximately 97 million m^3 of water into the reservoir annually. The Tasoh River consists of two main sub-catchments, the Jarum River and the Chuchuh River, respectively. The area surrounding the reservoir and its upstream catchments include mainly agriculture such as rubber, paddy, sugar cane and timber plantations (fig. 1). Urbanization and some infrastructural development that involved land clearing activities were observed to take place in the catchment area. Such activities in the vicinity of the Padang Besar town influenced the sediment discharge of the Jarum River. Similarly, the Pelarit River catchment includes the area of agricultural land, quarrying and urbanization. Before samples are ready for counting using gamma spectrometry, all samples were dried using an oven at 45 - 60 ºC for a few days gently disaggregated. Then, dried samples were then fine grinded and sieved at 2 mm using a sieve before the samples transfer and packing into the 250 ml Marinelli beaker for ^{137}Cs analysis (fig.2).

Figure 1: The land use activities around the Timah Tasoh catchment area

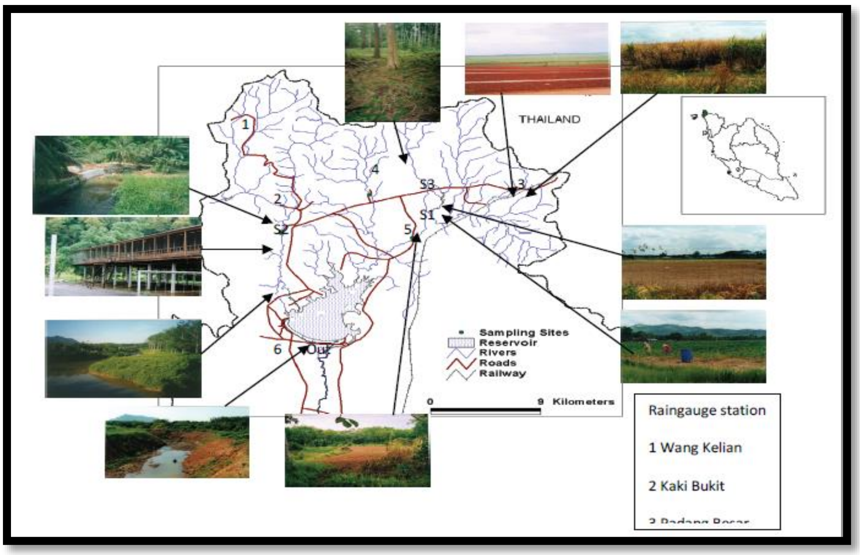
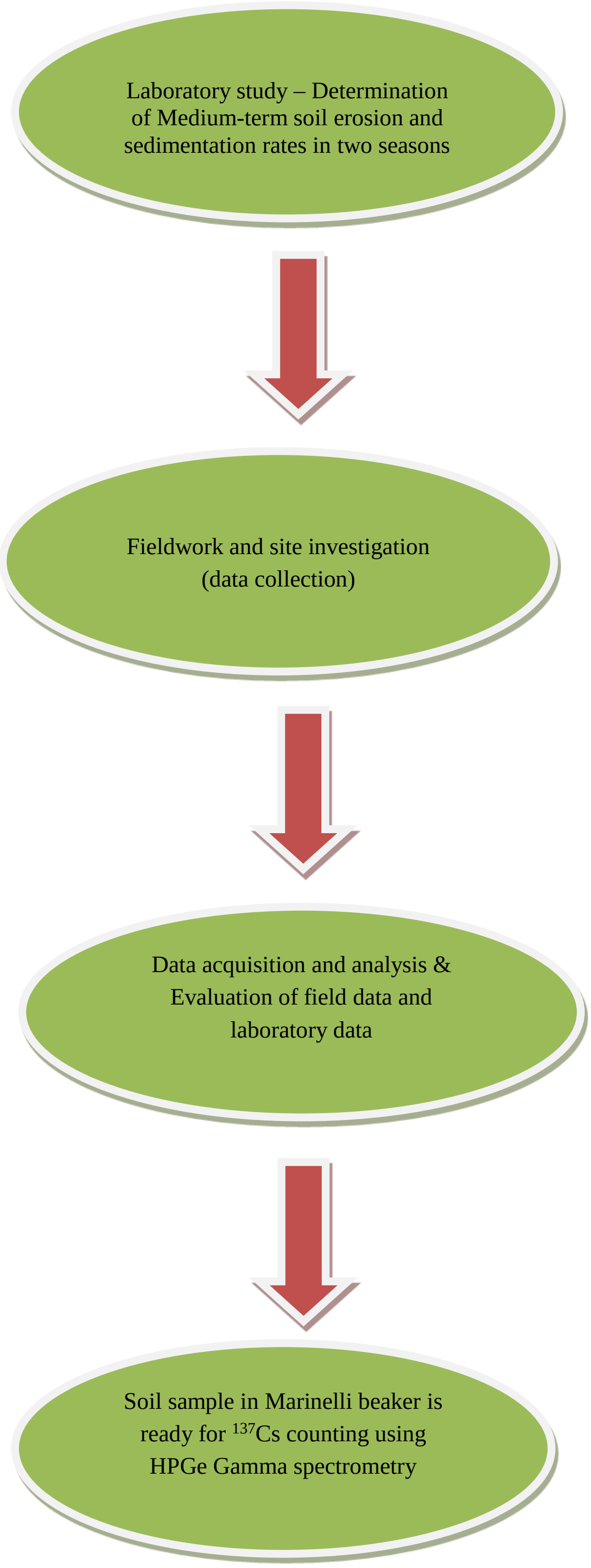


Fig. 2 Flow chart Measurements of 137Cs in soil sample radioactivity



Measurements of ^{137}Cs radioactivity in soil and sediment sample

Measurements of ^{137}Cs will be carried-out by using gamma spectrometry utilizing high-purity Germanium (HPGe) detector with relative efficiency of 28%. The detector will be calibrated for the selected measuring geometries and different soil densities by standard calibration samples. The gamma spectra are analyzed using dedicated computer software provided by the manufacturer. Due to expected low ^{137}Cs concentrations in the samples, the count time will be set to long counting hours (>20 h) per sample, in order to achieve a measurement precision of better than 10% at the 95% level of confidence. Walling and Quine (1993) noted and suggested that more counting time were needed to detect the fallout activity from all samples such as ^{137}Cs and commonly in the range of 29000 to 55000s because of the low activity in the fallout samples.The ^{137}Cs detection limit for this measuring time is estimated to be approximately 0.3 Bq/kg for the Marinelli geometry.

The magnitude charge in the gamma spectrometry crystal detector is directly related to the energy emitted from the gamma rays by the sample. Most of the γ-ray removed from the sample of the detector was absorbed and subsequently lost during processing between the detector and the sample, which is the release of γ-ray loses all energy by producing electron pulses (Blake *et al.*, 2000). The electron pulses is producing from the radioactivity emitted samples are amplified by pre-amplifiers as voltage pulses into the multi-channel analyzer. The Multi-channel analyzer as function of sorted the pulses output from the multi channels into the counting systems, whereas the transfer emits γ-ray pulses into the amount of counts to be processed and displayed in the screen of the gamma spectrometry (Blake *et al* ., 2000).

Meanwhile, the ^{137}Cs concentrations or activity from the samples was calculated using equation as below:

$$A = \frac{N}{\varepsilon . p_{\gamma} . m . t} \qquad (1)$$

where N was the net count under the peak of 662 keV gamma line energy that characterized ^{137}Cs (in counts), ε was the efficiency of the detection system for the 662 keV gamma line energy (in counts.$Bq^{-1}.s^{-1}$) obtained from equation (1), p_{γ} was the absolute probability transition for 662 keV keV gamma line for ^{137}Cs .Meanwhile, m and t were the mass and time of counting in minutes or second for ^{137}Cs can be found in soil and sediment almost everywhere on the landscape. After collection, it can be measured in term of concentration (Bq/kg) using Gamma-ray spectrometry.

Meanwhile, the conversion of concentration into FRNs inventory, A are as follows:
A = CMS (Bq/m^2)
Where;
C = FRNs activity concentration of the sample (Bq/kg),
M = total dry mass of the collected soil core (kg),
S = cross-section of the sampling corer (in m^2), which two types of inventories will be used for comparing;

- Reference inventory
- Sample inventory

By comparing the sample inventory and reference inventory and by using a conversion model, soil erosion rate can be estimated and normally expressed in ton/hectare/year (t/ha/y). The conversion model used in this study is the Proportional Model (Walling *et al.,* 2002). The model is based on the premise that ^{137}Cs fallout inputs are completely mixed within the plough or cultivation layer and that the soil loss is directly proportional to the reduction in the ^{137}Cs inventory due to loss of soil from the soil profile, since the beginning of ^{137}Cs accumulation or the onset of cultivation.

The proportional model used to estimate soil erosion rate in tonnes/hectare/year is based on the premise that ^{137}Cs fallout inputs are completely mixed within the plough or cultivation layer and that the soil loss is directly proportional to the reduction in the ^{137}Cs inventory due to loss of soil from the soil profile, since the beginning of ^{137}Cs accumulation or the onset of cultivation, whichever is later. Thus, if half of the ^{137}Cs input has been removed, the total soil loss over the period is assumed to be 50% of the plough depth. The model can be represented as follows:

$$Y = 10 \frac{BdX}{100TP}$$

Where:
Y = mean annual soil loss (t/ha/yr);
d = depth of the plough or cultivation layer (m);
B = bulk density of soil (kg/m^3);
X = percentage reduction in total ^{137}Cs inventory (defined as (*A*ref-*A*)/*A*ref×100);
T = time elapsed since the initiation of ^{137}Cs accumulation or the commencement of cultivation, whichever is later (w/yr);
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 for erosion (P=1).

RESULTS AND DISCUSSION

Overall, the analysis results for both seasons during the study period are shown in Table 1 and Table 2. From these two tables the results of varying analysis between the two seasons for all sampling locations. The dry season has provided soil erosion rate to all sampling locations of varying values varies from 9.59 $t/ha^{-1}/y^{-1}$ to 47.83 $t/ha^{-1}/y^{-1}$ respectively. Different for wet seasons, where both indicators for soil erosion and sedimentation rates have provided varying analysis values. The rate of soil erosion and sedimentation has given the values from 8.82 $t/ha^{-1}/y^{-1}$ to 31.70 $t/ha^{-1}/y^{-1}$ and from -19.92 $t/ha^{-1}/y^{-1}$ to -194.32 $t/ha^{-1}/y^{-1}$ respectively. The Pelarit-mid (sediment) has given the highest soil erosion rates throughout the dry season compared with another location sampling, 47.83 $t/ha^{-1}/y^{-1}$ respectively. Such incidents do not occur in Bukit Manik where the lowest erosion rates have been recorded throughout the dry season, 9.59 $t/ha^{-1}/y^{-1}$ respectively. These two significant differences in value can be seen from inventory differences that have been recorded. The lower the inventory value in the sampling location the higher the soil erosion rate recorded is shown in Table 1. This situation can be seen as a whole for the value of inventory and the rate of soil erosion is directly proportional to each other. Consequently, the correlation r-value for both of these parameters is greater than 0.89.

The wet season has provided both soil erosion and sedimentation rates throughout the study period. This condition does not apply to the dry season due to several factors such as the amount of rainfall received is less and the frequency of rain falls during the dry season compared to the wet season as shown in Table 2. The wet season has given the highest sedimentation rate throughout the study period in the undisturbed -Bulk Frim Point,-194.32 $t/ha^{-1}/y^{-1}$ respectively. Meanwhile, Bulk Ladang Tebu 1 provides the lowest sedimentation rates for the whole of both seasons, -19.92 $t/ha^{-1}/y^{-1}$ respectively. Both of these significant differences in the highest and lowest sedimentation rates are due to plant type factors in the sampling location. For example, the FRIM point is a teak tree growing area more than 30 years old, causing large leaves to cause rain to reach the ground. This has resulted in lower soil erosion when compared to sedimentation in the wet season. Similarly, the location sampling area for Bulk Ladang Tebu 1, where long, tapered leaves and irregular sugarcane areas have caused rainwater to completely fall to the soil surface easily. And this has resulted in higher soil erosion rates and frequent occurrences compared to sampling location having a large size of leaves and regular planting activities. Although some of these factors seem so simple and concise, they have given a high impact value to soil erosion rates and sedimentation.

Table 1 Medium-term soil erosion rate during at different land use (dry season) estimated using ^{137}Cs

Sampling Location	Activity (Bq/Kg)	Inventory (Bq/m^{-2})	Erosion/sedimentation rate (t/ha/yr)
SgChuchoh(Post Flood)	1.95	8.42	29.22
Titi Kg Sahabat	2.82	12.18	20.41
Bukit Manik	3.89	16.80	9.59
AlorDalam 5 (Mixed Crop)	1.29	5.57	35.89
FeldaRimba Mas (Upper Sungai Jarum)	1.79	7.73	30.83
Sungai KwangRua	1.18	5.10	37.01
SgJarum	2.01	8.68	28.61
Rimba Mas(nearbridge Kg Felda)	0.94	4.06	39.43
Pelarit-upper (Sediment)	0.27	1.17	46.21
Pelarit-mid (Sediment)	0.11	0.48	47.83
Chuchoh(Sediment)	0.53	2.29	43.58
Sungai Telintong (Sediment)	0.14	0.60	47.53

Kg Pak Omar	1.97	8.51	29.01
Pelarit-Lower (Sediment)	0.21	0.91	46.82
Confluence of SgJarum and SgManik	0.18	0.78	47.12
Anak Sg Jarum (Upper)	0.70	3.02	41.86
AnakSgJarum (Lower)	0.21	0.91	46.82
Mata Air	0.57	2.46	43.18
Jarum 2	0.17	0.73	47.22
Sungai KwangRua (upper)	0.61	2.64	42.77
Tasoh	0.37	1.60	45.20

Table 2 Medium-term soil erosion rate during at different land use (wet season) estimated using ^{137} Cs

Sampling Location	Activity (Bq/Kg)	Inventory (Bq/m^{-2}	Erosion/sedimentation (t/ha/yr)
Frim 3 (Near SgChuchoh)	0.34	17.13	8.82
Bulk Felcra (LubokSireh 1)	0.25	12.66	19.29
Bulk Frim 1(16 cm)	0.26	14.2	15.68
Bulk LadangTebu	0.29	15.99	11.49
Bulk Upper Pelarit 1	0.34	17.04	9.03
Bulk Kg Melayu Pak Omar 2	0.68	34.58	-32.03
Bulk LadangTebu 1	0.58	29.41	-19.92
Frim Point(Undisturbed)-Bulk	2.04	103.88	-194.32
Bulk FelcraLubokSireh 3	0.15	7.36	31.70
Bulk Cow Feed Lot 2	0.69	36.38	-36.25

Note: (-ve) sigh shows rate of sedimentation

However, other factors also need to be taken into consideration such as soil types and rocks in sampling locations. Already naturally, areas with rocky soil will experience low soil erosion rates and sedimentation due to the small quantities of soil. However, other factors also need to be taken into consideration such as soil types and rocks in sampling locations. Naturally, rocky areas will experience low soil erosion and sedimentation due to the low quantities of soil covering the surface of the earth. This can be seen in both sampling locations at Bukit Manik and Bulk Upper Pelarit 1, giving the lowest value of soil erosion rates for both seasons, 9.59 t/ha^{-1}/y^{-1} to 9.03 t/ha^{-1}/y^{-1} respectively. This is because both of these areas are covered with rocks and only a few lands cover this study area. For the correlation of the wet season between the inventory and the rate of soil erosion is almost similar to the dry season. However, the r-value is slightly lower compared to the dry season, 0.72. Whereas, the higher the inventory value, the higher the sedimentation rate as recorded in Frim Point (Sediment) -Bulk. This can be seen against the value of r for the correlation between the two parameters is 0.93.

Meanwhile, previous studies as reported by Zullyadini *et al.*,(2013) at the same study site have shown that the total annual erosion of the cliffs at Sungai Tasoh is the highest at 348.76 tonnes (1.38%), Sungai Pelarit Hilir is 25.64 tonnes (0.68%), Sungai Jarum is 55.45 tonnes (0.55%), Sungai Chuchuh is 12.58 tonnes (1.18%) and Sungai Pelarit Hulu is 17.41 tonnes (0.27%). However, these prior values are not much different from the results of this study. This situation is evident, where Timah and Tasoh are still two major contributors of mud and sediment entering the catchment area for both seasons. The rate of soil erosion and sedimentation in this study is still considered to be very small in value compared to under cultivation over large cropland areas in the United States and from lands that were brought into production during the last century in the northeastern China, 6 Mg ha^{-1} yr^{-1} and 15 Mg ha^{-1} yr^{-1}, each respectively (Mark A.N. *et al*., 2017).

CONCLUSION

The rate of soil erosion rate for dry season recorded varies from 9.59 t/ha^{-1}/y^{-1} to 47.83 t/ha^{-1}/y^{-1} respectively. This situation is quite different for analysis results for wet seasons, where analysis results are mixed with soil erosion and sedimentation rates. The wet season has given a slightly lower soil erosion rate than the dry season of varying values from 8.82 t/ha^{-1}/y^{-1} to 31.70 t/ha^{-1}/y^{-1} respectively. Only the wet season has given the results of sedimentation rates over the period of the study which is of varying value from -19.92 t/ha^{-1}/y^{-1} to -194.32 t/ha^{-1}/y^{-1} respectively. Overall, the wet season has given a higher sedimentation rate than the rate of soil erosion in the reference area at Frim Point of the whole data obtained during the study period. However, the overall results of soil erosion and sedimentation from this study are not much different as the results of the analysis have been reported by Zullyadini *et al.,* (2013) at the same site. This situation is evident, where Timah and Tasoh are still two major contributors of mud and sediment entering the catchment area for both seasons.Hence, proposals for reducing soil erosion rates and sedimentation are like land conservation practices by local authority that are widely used, and in particular the utilization of agricultural land and crops, have been found to be effective in reducing erosion rates. However, a more detailed study will be implemented in the future for reference data for catchment areas throughout Peninsular Malaysia although some of the constraints of the study such as the limited number of gamma spectrometry and the relatively short time of counting due to the relatively large number of samples from other projects. As the final conclusion, this study has proven that ^{137}Cs can be used as a medium-term tracer for soil erosion and sedimentation rates studies in catchment areas and its surroundings for both seasons.

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