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QUANTIFYING SOIL EROSION AND DEPOSITION RATES IN TEA PLANTATION AREA, CAMERON HIGHLANDS, MALAYSIA USING ^{137}Cs

(Pengiraan Kadar Hakisan Tanah dan Kadar Pemendapan di Kawasan Ladang Teh, Cameron Highlands, Malaysia Menggunakan ^{137}Cs)

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Abstract

The soil erosion and deposition in the hilly area is a great concern for the planters. In this study, the tea plantation was chosen to quantify the rates of soil erosion and deposition for it will provide information on the improvement of soil conditions and cost reduction of fertilizer consumption. The aims of this research are to determine the rate of soil erosion and deposition using environmental radionuclide, ^{137}Cs. Soil profile samples were collected by using scrapper plate and two cores soil sample were collected in the undisturbed forests area nearby. The ^{137}Cs activity concentration was measured using low background coaxial hyper pure germanium detector gamma spectrometer based on ^{137}Cs gamma energy peak at 661.66 KeV. The highest erosion rate using Proportional Models and Mass Balance Model 1 was found in point HE top area which is 52.39 t ha^{-1} yr^{-1} and 95.53 t ha^{-1} yr^{-1} respectively while the lowest at location HF top which is 4.78 t ha^{-1} yr^{-1} and 4.97 t ha^{-1} yr^{-1}. The deposition rate was higher in HF center which is 216.82 t ha^{-1} yr^{-1} and 97.51 t ha^{-1} yr^{-1} and the lowest at HE center which is 0.05 t ha^{-1} yr^{-1} for both models used.

Keywords: Soil Erosion, ^{137}Cs, Cameron Highlands, Gamma spectrometer

Abstrak

Hakisan tanah dan pemendapan di kawasan berbukit adalah satu kebimbangan besar bagi peladang. Dalam kajian ini, ladang teh di Cameron Highlands telah dipilih untuk mengira kadar hakisan tanah dan kadar pemendapan kerana ia dapat memberi maklumat mengenai pembaikpulihan keadaan tanah dan pengurangan kos penggunaan baja. Tujuan kajian ini adalah untuk menentukan kadar hakisan tanah dan pemendapan menggunakan radionuklid alam sekitar ^{137}Cs. Sampel profil tanah dipungut dengan menggunakan plat pengikis dan dua teras sampel tanah tidak terganggu telah diambil dari kawasan hutan yang berdekatan. Kepekatan aktiviti ^{137}Cs telah diukur dengan menggunakan latar belakang rendah pengesan germanium lampau tulen spektrometer gama berdasarkan tenaga gama ^{137}Cs puncaknya pada 661,66 keV. Kadar hakisan tertinggi menggunakan 'Proportional Model' dan 'Mass Balance Model 1' didapati di lokasi HE bahagian atas 52.39 t ha^{-1} yr^{-1} dan 95.53 t ha^{-1} yr^{-1} masing-masing manakala yang paling rendah di kawasan HF bahagian atas 4.78 t ha^{-1} yr^{-1}dan 4.97 t ha^{-1} yr^{-1} . Kadar pemendapan tertinggi di kawasan HF tengah iaitu 216.82 t ha^{-1} yr^{-1} dan 97.51 t ha^{-1} yr^{-1} dan paling rendah di HE bahagian tengah iaitu 0.05 t ha^{-1} yr^{-1} untuk kedua-dua model.

Kata kunci: Hakisan Tanah, ^{137}Cs, Cameron Highlands, Spektrometer Gama

Introduction

In hilly regions with swelling topography, the serious problem of soil degradation is the soil erosion that naturally occurred on cultivated lands. The problems not only on-site degradation as resulted from soil erosion but also off-site problems that occurred related to downstream sedimentation as well as surface and ground water pollution [1]. Every year, tones of soil are lost and cause reduction on crop production as well as pollution to rivers, lakes and other water bodies. Soil erosion that occurred due to natural process is usually does not cause much problem. It becomes a problem when human activity causes it to occur at much faster rate than under natural conditions. The exposure to soil erosion is dependent on a number of factors. The most common factors are the climate conditions of the area, the proportion of sand, silt and clay, sized particles in a particular soil, organic matter level, the length and slope of the field, amount of crop rotation and direction of cultivation. There is a need to explain, predict and quantify the soil erosion at all scales and accurately define the influence of local soil factors for the implementation of appropriate measures to control soil degradation including landslide and erosion. It is also a need to estimate the economic and environmental on-site and off-site impact of in-situ losing of surface soil with its nutrients and potentially polluting constituents [2].

The potential of soil erosion is measured by determination of radionuclide (tracer) content and related the information to the long term history of its formation. The measurement of^{137}Cs is to derive soil erosion rates for two reasons, its long live period with regard to human scale, added to a strong advection to soil particles, and has formed a universal soil erosion tracer after precisely known the fallout episode [3].The nuclear weapon tests during the 1950s and 1960s have afforded an effective and valuable means for studying erosion and deposition within the landscape appropriate to it related with the worldwide fallout of ^{137}Cs which can be used to study the different types of soil erosion and sedimentation in different positions and periods, particularly in the northern hemisphere where atomic deposition was three times as greater as in the southern hemisphere [4]. The Chernobyl accident in 1986 was also another source of radioactive ^{137}Cs. It provided a new source of ^{137}Cs deposition in Europe and Western Asia [5].^{137}Cs was released into the atmosphere and afterward redeposit on the earth surface via precipitation. Because of its 30 years half life, the relative alleviate of detection of the strong gamma rays that it emit, and its strong adsorption on clay and organic particles, the ^{137}Cs serves as a useful tracer for determining long term mean annual rates of soil erosion or deposition [6].

The calculations involved conversion of data set of ^{137}Cs activity concentration into soil erosion or deposition rates unit in tone per hectare per year. In reviewing the variety of models to be used for this study, a vital distinction can be made between cultivated soils and soils under permanent pasture or rangeland, which are uncultivated and effectively undisturbed. The need for this distinction relates to the vertical distribution of the ^{137}Cs inventory in the soil profile [7]. The ^{137}Cs method is frequently based on a comparison of calculated inventories (total activity per unit area) at individual sampling points with an equivalent estimate of the inventory representing the cumulative atmospheric fallout input (reference inventory) at the site [8]. From the selected models, the erosion rate values are calculated that relate soil loss with radio-cesium loss and must consequently; show a specific isotope concentration profile at that point. This inherent assumption is, there exist a specific profile of ^{137}Cs in the soil because erosion itself decreases the overall amount of the radioisotope links to its depth distribution. As a result, application of different models to the same experimental value of total cesium inventory may give very dissimilar erosion rate values [9]. In this paper, the study area was carried out in cultivated soils and the theoretical calibration model selected for data interpretation were Proportional Model and Mass Balance Model 1; which was found to be suited for data interpretation of the generated ^{137}Cs from this study.

Study Area

The study area for this research is in Cameron Highlands, Pahang, Malaysia. It is a small district located at North West of Pahang in the upper left corner inside the Pahang state. The place is situated on the main mountain range of Peninsular Malaysia. Cameron Highlands count roughly 71,000 hectare of lands where 79 percent is still forested which makes 21 percent developed. Specific location is the tea plantation area near Tanah Rata and forest nearby, around 1387 m above sea level. Cameron Highlands is one of the places with the cruel soil erosion in Malaysia. Because of overdevelopment, landslides, soil erosion will occur during heavy raining and lastly river contamination. The specific study area was in agricultural area where it is the second major land used after forestry with 16.4 percent of the total land area [10]. It is one of the areas with high altitude in Malaysia thus; the chance to receive fallout of ^{137}Cs radionuclide is relatively high. The ^{137}Cs contamination is positively correlated with altitude, so the upland, most susceptible sites, is mostly contaminated too [11]. This paper presents the study of soil erosion and deposition rates using environmental radionuclide ^{137}Cs as s tracer. The global positioning system (GPS) as shows in Table 1 was used to record the details information on sampling locations. The sampling locations (three slopes and two forests) are shown in Figure 1.

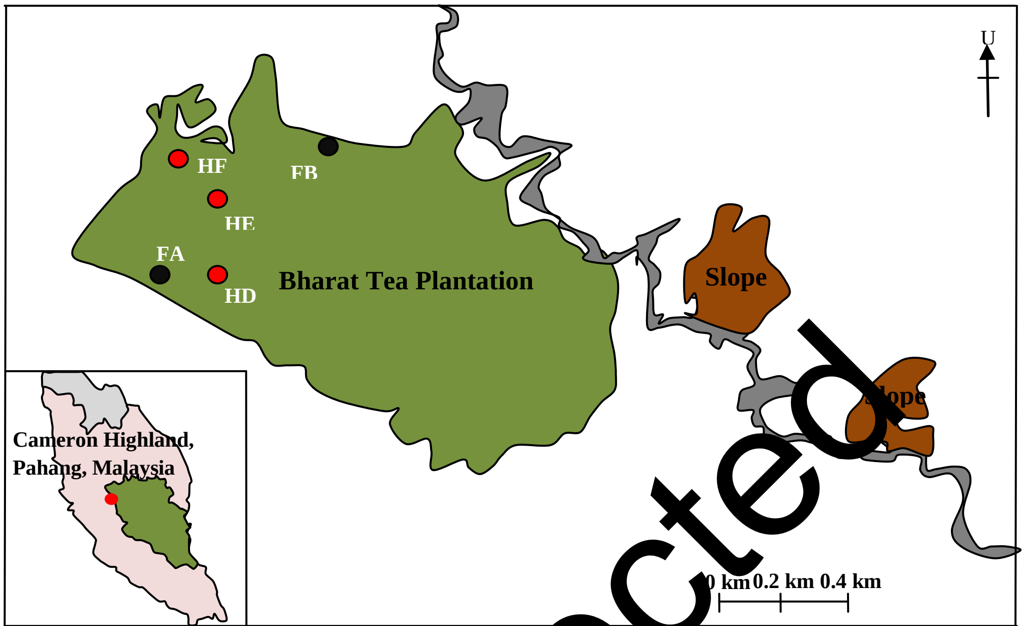


Figure 1: Maps of the study location in the tea plantation area. Inserted map shows the state of Pahang, Malaysia

Table 1: The locations for composite and profile soil samples

Code	Locations	Elevation (m)	Description
HD	N 04^0 27.145' E 101^0 21.600'	1340	Top of the hill
	N 04^0 27.135' E 101^0 21.595'	1329	Center of the hill
	N 04^0 27.[illegible]05' E 101^0 21.580'	1322	Bottom of the hill
HE	N 04^0 27.24[illegible]' E 101^0 21.560'	1391	Top of the hill
	N 04^0 27.27[illegible]' E 101^0 21.573'	1316	Center of the hill
	N 04^0 27.290' E 101^0 21.597'	1266	Bottom of the hill
HF	N 04^0 27.283' E 101^0 21.441'	1387	Top of the hill
	N 04^0 27.312' E 101^0 21.487'	1330	Center of the hill
	N 04^0 27.313' E 101^0 21.514'	1297	Bottom of the hill
FA	N 04^0 27.064' E 101^0 21.523'	1330	Undisturbed flat area
FB	N 04^0 27.438' E 101^0 21.728'	1308	Undisturbed flat area

Materials and Methods

Sampling and sample preparation

The soil samples were collected from three hilly areas of the tea plantation covering top, center and bottom of each hills-top namely HD, HE and HF, respectively (Figure 1 and Table 1).The soil from two undisturbed forests which are FA and FB were collected for reference inventories. For each of the sampling point, bulk and soil samples of various depth (2 cm each layer) were taken. The specially designed scrapper plate with PVC pipe 40 cm long and 15.2 cm diameter was used for depth profile sampling and this device enable for quantitatively obtaining layer of 2 cm interval of the soil depth profile. Whist a bulk samples were collected using hand auger with 15 cm long for soil basic parameter tests. The soil samples were kept each in polyethylene bags and transported back to the UiTM laboratory in Shah Alam. The samples were taken to the laboratory for oven dried at 60^{o}C until constant weight, then ground using Fritsch pulverizer (400 rpm rotational speed, 2 repetitions, 5 minutes) in agate bowl and ball and sieved through 250 µm sieve. About 150 g of samples was kept and sealed properly in the plastic container of 6 cm diameter and 4 cm height.

Measurements

Gamma spectrometer measurement was carried out using low background hyper pure coaxial germanium (p-type) detector. It is linked to a multi-channel digital analyzer system from EG & G, ORTEC. The gamma peak resolution at 1332 keV^{60}Co was 1.82 keV and relative efficiency of 25 % with energy range from 40 keV to 10 MeV. The ORTEC Gamma Vision^{TM} Version 6.07 software was used for the spectra analysis and processing [12]. All the samples were counted at 28800 second live time and the spectrum was analyzed using Gamma Vision software for energy peak at 661.66 keV of ^{137}Cs. The efficiency calibration of the detector was made using secondary standard made up of UO_3 and KCl matrix in the same geometry as the sample [12].The spectrometer efficiency at 661.66 keV obtained from an efficiency calibration curve (12) was used to calculate the absolute activity concentration of ^{137}Cs in the soil using the Equation 1,

$$A_{Ei} = \frac{N_{Ei}}{\varepsilon_E \times t \times \gamma_d \times M_s} \qquad (1)$$

A_{Ei} = Activity concentration (in Bq/kg)
N_{Ei} = Net peak area of a peak at energy E
ε_E = Detection efficiency at energy E
t = Counting live time
γ_d = Number of gammas per disintegratio of this nuclide for a transition at energy E
M_s = Mass in kg of the measured sample

The minimum detectable activity (MDA) of this low background gamma spectrometer at 661.66 keV was 0.03927 Bq/kg calculated using the Equation 2 [13];

$$MDA = \frac{(4.65\sqrt{N+3}}{ET} \qquad (2)$$

N = background count
T = counting time
E = counting efficiency

The theoretical calibration model used were the Proportional Model and Mass Balance Model 1 to obtain erosion and deposition rate, Y, t ha^{-1} yr^{-1}, as shown in the Equation 3 and 4 below [14];

$$Y = 10\,\frac{BdX}{100TP} \quad (3)$$

d = depth of the plough or cultivation layer (m)
B = bulk density of soil (kg m^{-3})
T = time elapsed since initiation of ^{137}Cs accumulation (yr)
P = particle size correction factor
X = percentage reduction in total ^{137}Cs inventory (defined as $[(A_{ref} – A)/A_{ref}]$ x 100].
A_{ref} = local ^{137}Cs reference inventory (Bq m^{-2})
A = measured total ^{137}Cs inventory at the sampling point (Bq m^{-2})

$$Y = 10\,\frac{dB}{P}\left[1 - \left(1 - \frac{X}{100}\right)^{t-1963}\right] \quad (4)$$

d = depth of the plough or cultivation layer (m)
B = bulk density of soil (kg m^{-3})
t = time elapsed since initiation of ^{137}Cs accumulation (yr)
P = particle size correction factor
X = percentage reduction in total ^{137}Cs inventory

Results and Discussion

Properties of soil

Results in Table 2 show that soil in tea plantation study sites are acidic with pH value lower than six with an average of 4.07. The trend shows that higher elevation has lower soil pH. Lower pH will help ^{137}Cs ions to move freely and being washed easily by the rain water runoff. Also, low pH level may result in lack of some basic elements such as Ca, Mg, K, N, in the soil [14]. Results of bulk density are in the range between 1.23 – 1.69 gcm^{-3}. Bulk density is usually included to evaluate tillage and crop management effects on soil quality. Soil compaction increases bulk density and decreases pore volume. At constant water content, compaction increases the proportion of soil pores filled with water as average pore size decreases. This can lead to aeration stress and changes in biological processes. If bulk density becomes too high, it can limit plant root growth [15]. This density is related to the soil texture in the location itself. Soil texture in the study site is sandy clay loam soil particles. This soil texture directly affects the porosity of soil, which in turn, determined its water-retention, flow characteristic and nutrient-holding capacity. Heavy clay soils normally have higher percentage of smaller pores and higher water holding capacity. On the other hand, sandy soils have relatively higher percentage of larger pores with water holding capacity under relatively dry conditions.

Soil organic matter plays an important role in determining the fertility and productivity of soils. This may be especially true in tropical areas where nutrient poor, highly weathered soils are often managed with few external inputs [17]. Results of organic matter content were in the range of 8.84 – 10.46 % which means lower than 10 %. This organic matter was dependent on the amount of the living organisms in that soil that consumed humus. The highest content of that humus or dead materials, the value of the organic matter also increases.

^{137}Cs vertical profile

Figure 2 to 5 showed the vertical profile of ^{137}Cs activity concentrations in study area. Generally, there are two patterns are observable, one from the depth of 0 cm to about 18 cm and the other from 20 cm until 30 cm. In location HD (Figure 2 (a, b and c)), the upper pattern shows ^{137}Cs activity concentrations increase downward to the depth of 15 cm. This is similar to location HE (Figure 3c) and HF (Figure 4c) at the bottom locations. The ^{137}Cs activity concentrations increase downward to the depth of up to 20 cm. Zhiyanski and co-workers concluded that 80% of the ^{137}Cs from the Chernobyl is located within the upper 15 cm of soils [18]. These would happened because the surface of soil was wash out by rainfall thus erosion occurs makes the surface soil loss their original ^{137}Cs fallout as compared the ^{137}Cs present in the depth profile of soil. Thus, make the ^{137}Cs measured in the depth was high activity as compared in the surface of soil. The locations itself have more farmers activity such as plough make the soil surface of the study area had low ^{137}Cs activity concentration. However, in location HE (Figure 2a) and HF (Figure 4b) at top and center of the hills, the ^{137}Cs activity concentration was high in the surface soil layer but declining in activity level since subsurface soil layer down to the depth of 20 cm. This trend is basically in agreement with the result of study in other countries [19] as reported in literature. This finding signified that the ^{137}Cs is having characteristic that is strongly adsorbed on the surface of soil particles; thus enable as tracer of soil movement during events such as soil erosion and landslide.

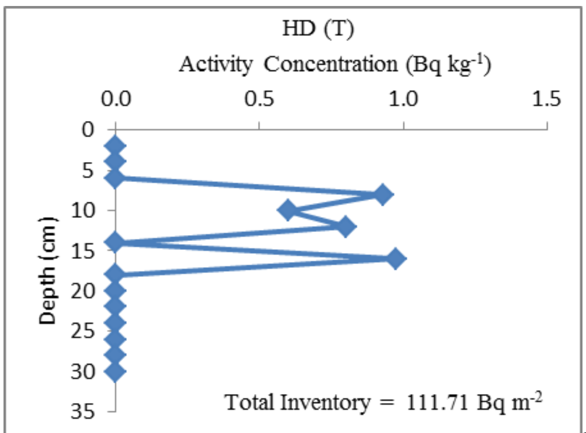
Table 2: Soil basic parameter results in study area

Location point	**Slope position**	**Bulk density (g/cm^3)**	**Organic Matter Content (%)**	**pH**	**Texture (%)**			**Textural Class Name**
					Clay	**Silt**	**Sand**	
HD	Top of hill	1.69	10.46	4.15	26.01	[illegible]	55.39	Sandy Clay Loam
	Center of hill	1.53	10.33	5.04	26.22	[illegible]	56.74	Sandy Clay Loam
	Bottom of hill	1.39	9.85	4.16	27.06	19.42	53.52	Sandy Clay Loam
HE	Top of hill	1.64	9.63	3.38	[illegible]	18.46	54.88	Sandy Clay Loam
	Center of hill	1.54	9.41	4.21	[illegible]	19.06	53.46	Sandy Clay Loam
	Bottom of hill	1.62	9.77	4.25	26.80	19.65	53.55	Sandy Clay Loam
HF	Top of hill	1.41	10.34	[illegible]	[illegible]	17.41	57.09	Sandy Clay Loam
	Center of hill	1.55	9.97	[illegible]	27.45	19.90	52.65	Sandy Clay Loam
	Bottom of hill	1.31	9.70	[illegible]	26.60	18.42	54.98	Sandy Clay Loam
FA	Undisturbed	1.23	9.49	4.63	24.80	16.20	59.00	Sandy Clay Loam
FB	Undisturbed	1.34	[illegible]	3.70	22.30	18.10	59.60	Sandy Clay Loam

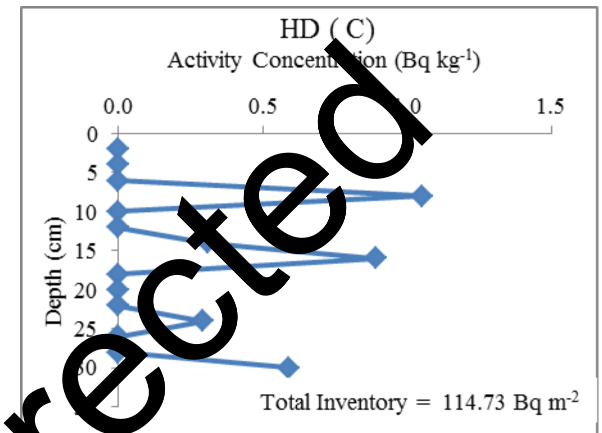
For the second pattern of ^{137}Cs activity concentration in soil profile, which is from the depth of 15 cm and 20 cm goes down to 30 cm, all the ^{137}Cs have initially high activity then change to low in activity. These means, the ^{137}Cs become loss in the increasing the soil depth. As stated in previous study, ^{137}Cs will decrease and finally lost in the depth [19]. It was a directly proportional of ^{137}Cs present highly in soil surface and decreases its value when the depth was increase. The first pattern could be due the ^{137}Cs that was come from the Chernobyl accidents that occurred in 1986 [20]. It was confirmed by the detection of Chernobyl fallout analysis of individual radionuclide in the air sample which first detected on the filter in 9 May 1986 and reaching a peak on 11 May 1986 [21]. The second pattern source of ^{137}Cs comes from the above ground nuclear weapon test during the 1950s to 1963s [20].

In the reference site, the vertical distribution of ^{137}Cs at location FA (Figure 5a) was increased in ^{137}Cs activity concentration which is from the depth of 6 cm to 16 cm. After that, ^{137}Cs activity concentration began to decrease at the depth of 18 cm until 30 cm. This represents the pattern of ^{137}Cs decreased exponentially with depth. At the second reference site, location FB (Figure 5b), the ^{137}Cs activity concentration getting increases its value. The first pattern showed decreased of ^{137}Cs from the depth of 0 cm until the layer of 14 cm. Then, the second pattern was from the depth of 16 cm that was decreased also its value until the depth of 30 cm. This second pattern which is below 16 cm depth, the ^{137}Cs activity in the soil decreased rapidly. This shape with subsurface peak reflects both the fallout source of the radionuclide and thus its delivery to the soil surface, slow post-fallout downward migration, thus surface replacement of fallout inputs, in the early 1970s [22].

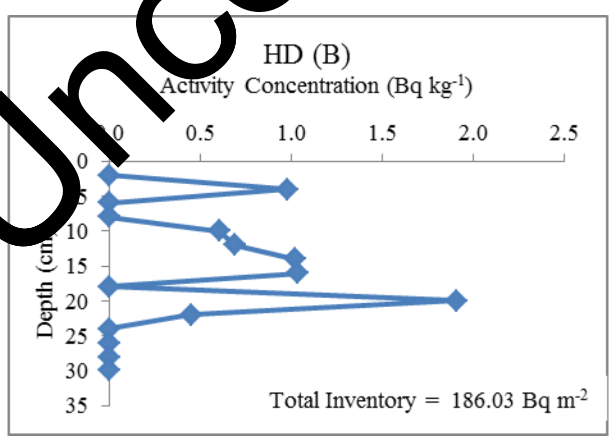
In the entire core profile soil samples collected in each hills, the ^{137}Cs activity concentration showed from top to the center and lastly goes to the bottom, the rising value obtained. The accumulation of this radionuclide clearly showed in this sloping area, where there is a movement of ^{137}Cs from the upper site down to lower placed. This reflects the progressive accumulation of soils contains ^{137}Cs at the bottom of the slope [22]. In location HD and HE (Figure 2 and 3), the soil containing ^{137}Cs can be seen clearly increased down to the lower land of the slopes. That is about 1 Bq kg^{-1} (HD top) to 1.9 Bq kg^{-1} (HD bottom) and 0.5 Bq kg^{-1} (HE top) to 2.5 Bq kg^{-1} (HE bottom). For location HF, there is high value of ^{137}Cs in the center location, then decrease again at the bottom low land area. This is due to the location of the sampling point, soil was collected at slightly high of the area with no plantation and erode. Thus, the high accumulation of soil (soil gain) in that location makes the activity of ^{137}Cs high.



a) Location Hill D Top

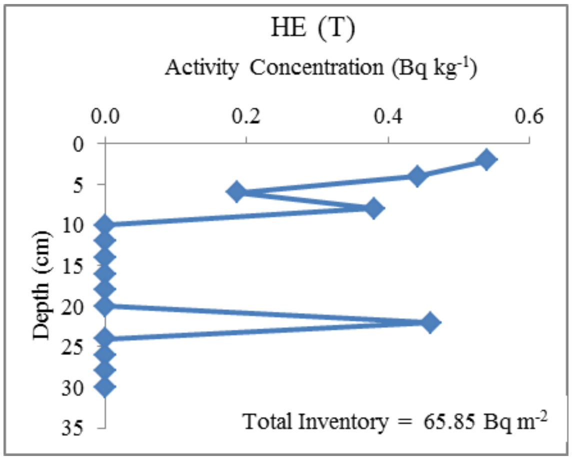


b) Location Hill D center

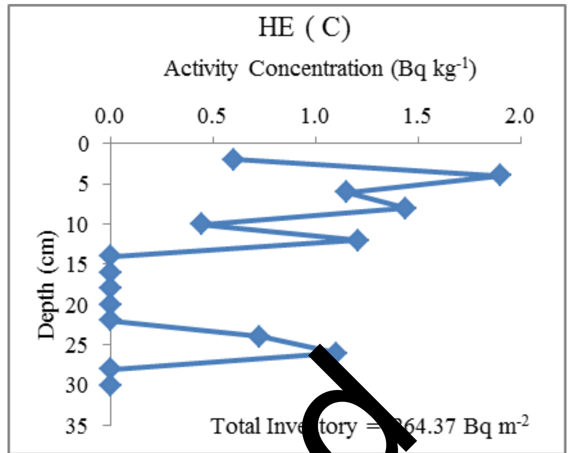


c) Location Hill D bottom

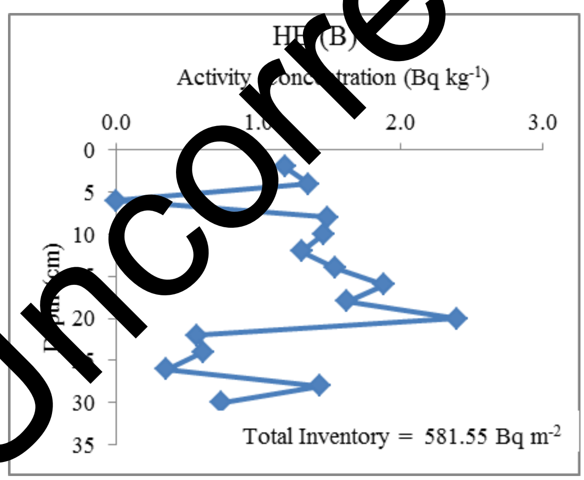
Figure 2: Vertical profile of ^{137}Cs in hill HD for top, center and bottom location



a) Location Hill E top

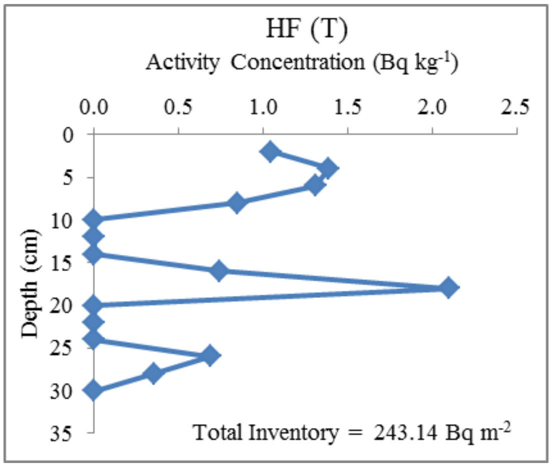


b) Location Hill E center

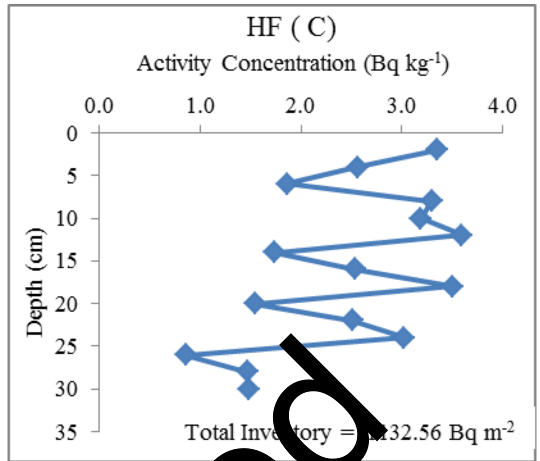


c) Location Hill E bottom

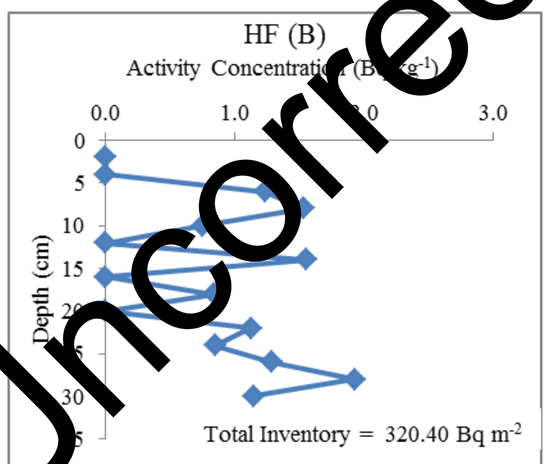
Figure 3: Vertical profile of ^{137}Cs in hill HE for top, center and bottom location



a) Location Hill F Top

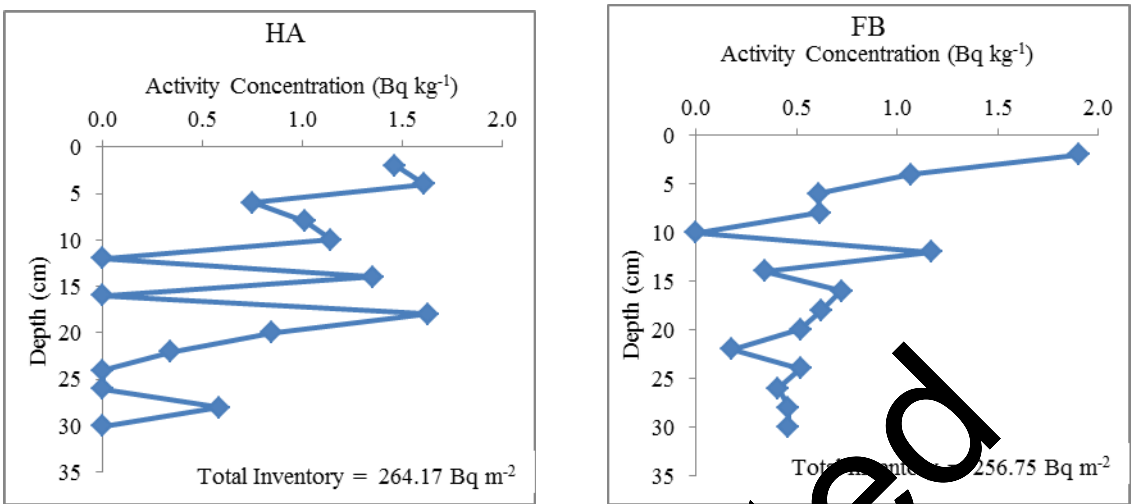


b) Location Hill F center



c) Location Hill F Bottom

Figure 4: Vertical profile of ^{137}Cs in hill HF for top, center and bottom location



a) Location Forest A (FA) b) Location Forest B (FB)

Figure 5: Vertical profile of ^{137}Cs in the two forests undisturbed area

Hill slope ^{137}Cs inventory

^{137}Cs inventories in the unit of Bq m^{-2} was derived from measured ^{137}Cs obtained by multiplying it with the depth incremental of soil sliced (0.02 m), density (g cm^{-3}) and sum up with the total core length, 30 cm. Results tabulated in Table 3 shows comparable trends observed in locations HD (Figure 2) and HE (Figure 3) in which the ^{137}Cs inventories is larger from top to bottom of the hill slope. In location HF, the ^{137}Cs inventory shows highest in the center location. This may happen due to the location itself at the lower area with most exposed soils, the area without tea trees cover the soil thus, high deposition occurred on that placed. The ^{137}Cs inventories are one of the main points when determining the soil erosion and deposition rate. The indicator is that, if the ^{137}Cs inventory measured in reference site, which refers to forest undisturbed flat top area have larger inventory than the sampling site, this mean the soil erosion occurred, and vice versa the soil deposition was occurred. It was assumed that, the reference site which is undisturbed have the ^{137}Cs from the soil that are not being disturbed since the year of 1964, as known as most fallout occurred of ^{137}Cs radionuclide [23]. Above ground nuclear weapon testing during the 1950s and 1960s resulted in the release of radioactive ^{137}Cs to the atmosphere. The passage of the nuclear test ban treaty in 1963 well halted further ^{137}Cs inputs of the atmosphere level of ^{137}Cs fell gradually and by the late 1970s, ^{137}Cs had essentially ceased [23].

In these three sloping hill areas, not all ^{137}Cs inventory was lower than that of its control field. This signified that in some places, the deposition was occurred and mostly at center and bottom of the hill. These inventory results are consistent with the soil erosion and deposition rate calculated. As shown in Table 3, the average calculated of inventory in the first reference site, was 17.61 Bq m^{-2} and the second reference site was 17.12 Bq m^{-2}. The first reference site was chosen as the indicator due to its have more value. The location that greater than this value will form of erosion site, whereas the location that have less than this value will have deposition site.

Location point	Slope position	Slope gradient (°)	^{137}Cs activity concentration (Bq/kg)	^{137}Cs inventory (Bq m^{-2})	Net erosion rate (tha^{-1}yr^{-1})	
					PM	MBM1
HD	Top of hill	26	0.22	7.45	-41.50	-61.33
	Center of hill		0.21	7.65	-44.05	-64.37
	Bottom of hill		0.45	12.40	-17.49	-20.66
HE	Top of hill	61	0.13	4.39	-52.39	-95.53
	Center of hill		0.57	17.62	0.05	0.05
	Bottom of hill		1.28	38.77	82.82	54.86
HF	Top of hill	34	0.57	16.21	-4.78	-4.97
	Center of hill		2.44	75.50	216.82	97.51
	Bottom of hill		0.82	21.36	11.87	10.78
FA	Undisturbed Area	-	0.77	17.61	-	-
FB	Undisturbed Area	-	0.68	17.12	-	-

Table 3: Soil erosion and soil deposition in the study area

^{137}Cs derived soil redistribution rates

The proportional mathematical model and the mass balance 1 mathematical model were used for further data interpretation. Both mathematical models provide difference but comparable soil erosion and deposition rate. The results calculated using the proportional model signified low soil erosion and deposition rate as compared to the results obtained using mathematical mass balance model 1. For the calculation using the proportional model, the same formula was used to determine the soil erosion and deposition rates, except, the value of percentage in reduction of ^{137}Cs inventory or X (Eq.4). In the calculation of soil deposition, the X' used t was the measured total ^{137}Cs inventory at sampling point minus ^{137}Cs soil reference inventory.

The results are shown in Table 3, the soil deposition signified the soil loss is shown with negative sign and soil gain with positive sign. The overall observations showed, in the top of the hill, soil erosion occurred in almost all top of the hill, confirmed for both models used. The highest erosion rate occurred in hill-top HE, which were -52.39 t ha^{-1} yr^{-1} (Proportional Model) and -95.53 t ha^{-1} yr^{-1} (Mass Balance Model 1). It can be explained that, based on the slope gradient in this hill, which is 61^{o} was the steepest area. Thus, high erosion rate is attributed on that soil resulted in high soil loss. In location HD, the hill-top, hill-center and hill-bottom location showed the soil erosion occurred without the deposition of soil. This could be due to the slope gradient which is only 26^{o} thus avoids the deposition of eroded soil to the low lying area. Since the values obtain for the measured basic soil parameter quiet similar for every location, the only influence of soil erosion and deposition on the study area is the slope gradient factor. The calculated soil erosion was lowest at the top location of hill HF which was -4.78 t ha^{-1} yr^{-1} (Proportional Model) and -4.97 t ha^{-1} yr^{-1} (Mass Balance Model 1). In location HF hill- top area, same reason can be explained due to it slope gradient which was 34^{o}. This location was one of the steepest sloping areas, from top to the center location. The slope gradient was 34^{o}, thus the retention time for ^{137}Cs radionuclide retained in soil is very short.

The result of soil deposition shows that the highest deposition was at location HF hill center. As explained above, the soil sample taken at this location consists of the wash out the upper soil immediately above the location which is not covered with any plantation. The calculated results of soil deposition using proportional model was 216.82 t ha^{-1} yr^{-1} and 97.51 t ha^{-1} yr^{-1} using Mass Balance Model 1. The soil deposition also occurs in location HE and HF center and bottom of the hills. The observed small deposition at HE center is consistent with the fact that the hills is at higher sloping angle, hence shorter retention time for loose soil.

Conclusion

The anthropogenic ^{137}Cs radionuclide was present at measurable concentration in tea plantation soil in Cameron Highlands, Pahang. The ^{137}Cs tracer technique is applicable for the estimation of the soil erosion and soil deposition rates. The Proportional Model and Mass Balance Model 1 were applicable for data interpretation, the highest erosion rate was in location HE top which are -52.39 t ha^{-1} yr^{-1} and -95.53 t ha^{-1} yr^{-1} respectively and the lowest are at location HF top which is -4.78 t ha^{-1} yr^{-1} and -4.97 t ha^{-1} yr^{-1}. For deposition rate, HF top location has the highest value which is 216.82 t ha^{-1} yr^{-1} using the proportional model whereas 97.57 t ha^{-1} yr^{-1} using the mass balance model 1. The lowest deposition was at location HE center which is 0.05 t ha^{-1} yr^{-1} for both models used. The patterns in all three locations were different depending on the hill sampling site conditions and sloping gradient. The high sloping area has more potential to have the greater deposition and low slope tend to have less deposition rate.

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