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Quantifying the Relative Amounts of Soil Erosion and Sedimentation in Different Land Use

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This paper was prepared to estimate soil erosion and sedimentation rate from different land use in the catchment areas using Fallout Radionuclides (FRNs). The FRNs widely used for soil erosion and sediment source tracing are ^{137}Cs, ^{210}Pb and ^{7}Be. Therefore, these FRNs had been recognied as particularly indicates can be used to estimate from short-term to long-term the amount of soil erosion and sedimentation rates in the catchment during the period of the study. The study also found that both medium-term and long-term soil erosion rate is comparable to each other even though at different temporal scale. During the wet season, most sediment was stored in each catchment land use bore being transported out to the stream during the dry season. Whereas for short-term scale, large quantities of sediment are transported out of different land uses into the flow system. However, the results of this study will be discussed in more detail in this full paper.

Keywords: soil erosion; catchment, FRNs; temporal; transported

I. INTRODUCTION

Soil erosion is a process of displacement between two dense and different particles of the surface by several agents such as wind, water and ice. This shift occurs continuously in descending motion of the slope, which is one of the actions of gravity. Among the human activities that can cause erosion are the clearing and hijacking of hill serum that causes no plant that can withstand the soil from being streamed together with water when heavy rains, deforestation, overgrazing and extensive cultivation are only one plant type . Erosion incidents have given some adverse effects related to soil productivity as well as some off -site problems such as silt, drainage disruption, road damage, eutrophication, loss of wildlife habitat, damage to public health and also increased cost of water treatment. In Malaysia alone, the clearing of land particularly through opening of jungle land under climate-vegetation ecosystems leads to marked changes in the hydrological balance. The erosion event causes river water to be tainted with silt and insoluble elements. This event has caused the river to become shallow and thus disrupt the aquatic ecology and in turn will cause flood conditions due to river overflow. As such, researchers pay more attention to the ever-changing slop or water flow scale, such as slope scales or small catchment areas. This is crucial in order to create a very effective model of soil erosion caused by water at a regional scale although it is not perfect. Therefore, data on annual sedimentation rates have been calculated from previous measurements due to loss of soil resources through quantification of river sediment transport. Also, some distribution maps and landslides, slump and debris flow over multiple years (Gardner & Gerrard, 2001; Gardner & Gerrard, 2002; Gardner & Gerrard, 2003).

Fallout radionuclides are potentially used to obtain the necessary data on sediment catchment budgets as has been emphasised by Wailing *et al.* (2001). Furthermore, common environmental isotopes refer to their widespread distribution in the landscape environment and are at relatively low levels and are easy to measure. In most cases, they are of natural origin and also man -made. This is because the useage of the

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amount of isotope used is so rapid and widely applied by the soil, which they mostly accumulate on or near the surface, by tracing the sedimentation and deposition of sediment by documenting the subsequent distribution of isotopes moving in parallel with the soil particles or sediments. Based on several observations, subsequent isotope redistribution has provided the basis for determining the rate and pattern of sediment removal in the landscape. Isotopes that have been widely used as sediment tracers in studies especially budget sediments are such as Cesium-137, 137Cs (Ritchie & McHenry, 1990; Zapata, 2002). 137C is a man-made isotope, a half-life of 30.2 years that resulted after the occurrence of atmospheric testing of nuclear weapons over a period of time from the mid-1950s to the 1960s. This radioactive cesium is released into the stratosphere and in turn has spread globally. The global collapse of 137C began in 1954, peaked in the early 1960s and then declined slowly until it reached zero in the mid-1980s. Its fall rate shows fluctuations globally and this is to reflect both annual rainfall and location when compared to major weapons tests (Wailing, 1999).

Whereas, 210Pb is a naturally produced product through the 238U decomposition series obtained from the decomposition of 222Rn gas (half-life 3.8 d), daughter 226Ra (half-life 1622 years) as shown as Figure 1. Meanwhile, Radium-226 which being in soil and rocks occurs naturally. 210Pb also found in the soil is produced by decomposition of 226Ra and is later named supported 210Pb after being in equilibrium equivalent to 226Ra.

Beryllium-7, 7Be is produced naturally in the upper atmosphere by the cosmic space of nitrogen and oxygen. This nuclear reaction known as spallation process produces BeO or Be (OH) 2 which is then absorbed into the atmosphere until it attaches completely to the atmospheric aerosol. Furthermore, subsequent sedimentation processes occur to the soil surface due to wet and dry sedimentation although it has been shown that 7Be depletion is primarily associated with precipitation (Olsen et. Al., 1985; Wallbrink & Murray, 1994). In most environments, the fall of 7Be reaching the ground surface is much faster as well as strongly bonded completely above the ground surface (Wallbrink & Murray, 1996). Evidence has also shown that approximately 90% of the total 7Be deposition in the temperate zone as a whole is associated with wet deposition (Benitez-Nelson *et. al.,* 1999; Brown *et. al.,* 1989; Fogh *et al.,* 1999). The main component of the charged 7Be Ion Be2+ reaches a surface that is so competitive for cation exchange sites due to its high -density charge (Kaste *et al.,* 2002). Furthermore, 7Be is rapidly and vigorously absorbed by soil particles into most environments (Hawley *et al.,* 1986). This research paper implemented is to estimate the rate of soil erosion and sedimentation from a variety of land uses by using the Fallout Radionuclides (FRNs) approach as tracers at the study site.

II. MATERIALS AND METHOD

A. Soil Sampling and Preparation of Samples

50 samples were taken in the form of soil and sediment cores from the Timah Tasoh reservoir area (6 ° 36'N and 100 ° 14'E) located about 13 km north of Kangar city and also near the Thailand border during the study period. All these samples were taken using a metal corer and a sediment trap. The catchment area has an average surface area of 13.33 km2 and a storage capacity of about 40 million m3. It receives input from two major river sources, Tasoh and Pelarit, which have a combined area of 191 km2 and can supply about 97 million m3 of water into the reservoir annually. Meanwhile, Sungai Tasoh is formed from two main tributaries, namely Sungai Jarum and Sungai Chuchuh. The area around the reservoir and upstream catchment is an inclusion of agricultural areas consisting of various crops such as rubber, paddy, sugarcane and timber plantations (Figure 1). In addition, the Sungai Pelarit catchment area consists of agriculture, quarrying and urban areas. Meanwhile, before the samples are ready to be counted using gamma spectrometry, all samples must first be dried to a constant dry weight using an oven at a temperature range between 45 - 60 °C for several days. The constant dry sample was then ground to a fine and had to be sieved to a size of 2 mm using a sieve before the sample was placed in a 250 ml plastic pot for the purpose of calculation and analysis of 7Be, 210Pb and 137C (Figure 2).

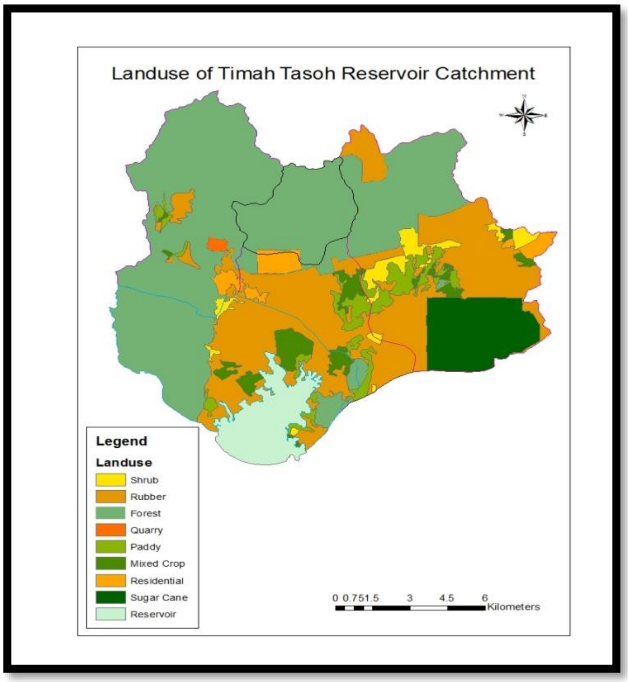

Figure 1. Landuse of Timah Tasoh Reservoir catchment

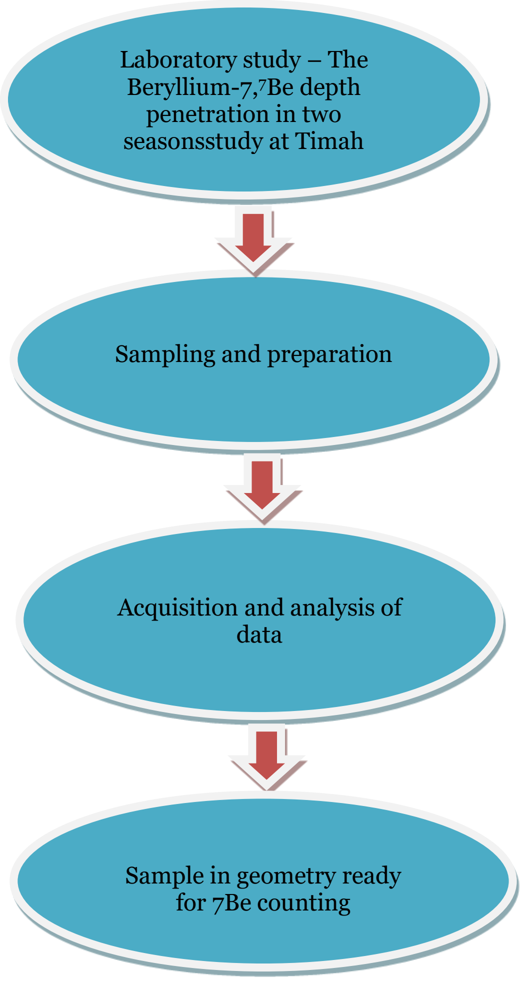

Figure 2. Flow chart Measurements of fallout radionuclides concentration

B. Measurement of ^{7}Be, ^{210}Pb and^{137}CsRadioactivity in Soil and Sediment Sample

Determinations of ^{7}Be, ^{210}Pb and^{137}Cs radioactivity in soil and sediment samples will be carried out using low-resolution N-type High Detection Germanium (HPGe) detectors coupled to an amplifier and multi-channel analysers. Measurements of ^{7}Be, ^{210}Pb and^{137}Csradioactivity in soil and sediment samples will be carried out using low-resolution N-type High Detection Germanium (HPGe) detectors coupled to an amplifier and multi-channel analysers.

1. Measurement of the radioactivity of^{137}Cs

HPGe with a relative efficiency of 28% fully utilised for the measurement of 137Cs will be performed using gamma spectrometry. These detectors are calibrated based on the geometric variability as well as the soil density selected as the standard calibration. And next, the gamma spectrum is analysed using specialised computer software provided by the supplier. The sample to be counted is expected to have a low concentration of 137Cs, then next the calculation time is set to a long calculation time (> 20h) for each sample, to achieve a better measurement accuracy of 10% at a 95% confidence level. Marinelli Geometry The detection limit of 137Cs for the measurement time of this counted sample is estimated to have approximately 0.3 Bq / kg. Meanwhile, the analysis or calculation of the activity of 137Cs in the study sample was calculated using Equation (1) as shown below:

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

where N is the net calculation below the 662 keV gamma power peak representing 137Cs (in numbers), ε is the reference to the total efficiency of the detection system for the 662 keV gamma line (in counts.Bq-1.s-1) which is the same as in equation 1, pγ is the absolute probability transition for the gamma line 662 keV keV for 137Cs, m and t are the total mass and computation time over the period the sample counting is carried out. 137Cs can be found in any area of the landscape especially in soils and sediments and in turn can be measured in terms of activity (Bq/kg) using a spectrometric gamma counter.

2. Measurements of the radioactivity of ^{7}Be

Whereas, the calculation of the uncertainty of each sample as a γ detector error was at the 95% confidence level in the order of ± 10%.. 7Be activity in the soil was determined using a Gamma Spectrometry computation system consisting of a Hyper-Germanium detector (HPGe) and counted for 86400 seconds or 24 hours for all samples. Meanwhile, the 7Be energy is in the range of 477.6 KeV with 20% along with the efficiency level of the detector with uncertainty for each sample as calculated as γ - detector calculation error at 95% confidence level in the order of ± 10%. Therefore, the concentration or activity of 7Be from the sample is calculated using the Equation as below:

$$A = \frac{N}{\varepsilon . p_{\gamma} . m . t} \tag{1}$$

where N is the net count below the gamma line energy peak of 477.6 keV, ε is the efficiency of the detection system (in counts. Bq-1.s-1) obtained from Equation (1), pγ is the absolute probability transition, m and t is as the mass and the computational time is the total gamma line energy of 477.6 keV for the 7Be characterisation (as in the computation).

3. Measurements of the radioactivity of unsupported ^{210}Pb

The soil and sediment samples were packed into a marinelli beaker for the measurements of excess ^{210}Pb with the < 2 mm fraction each, respectively. The plastic pot was sealed with tape and left for a minimum at least 3 weeks for the equilibrium of ^{226}Ra with ^{214}Pb before the measurement.However, before the measurement of the excess ^{210}Pb, the detector efficiency calibration is calculated (2) as below:

$$\eta\ (h) = [n(h)/\ A_0(h)\tau\ ] \tag{2}$$

where η (h) is a detector recording - γ rays, A0 (h) and τ are the two known activities of plastic pots based on the values of total mass and height and abundance of - γ rays. Thus, the samples were soil and sediment in plastic pots and placed on a detector for 24 hours counting with an accuracy of ca. ± 10% at 90% confidence level for γ -ray spectrometry measurements. For the calculation of the total activity of 210Pb, the samples were measured at 46.5 keV for 210Pb and 350 keV for 226Ra. Therefore, the excess or unsupported 210Pb concentration was calculated by subtracting the supported 210Pb concentration of 226Ra from the total 210Pb concentration. Otherwise, 226Ra was measured from a short -lived daughter of 214Pb. The activity of 210Pb can be calculated based on below formula:

$$A_{\text{Pb-210ex}} = A_{\text{Pb-210}} - A_{\text{Pb-214}}$$

where A Pb-210 is the unsupported concentration of 210Pb (Bq kg-1), A Pb-210 is the supported concentration of 210Pb (Bq kg-1) and while A Pb-214 is the unsupported 214Pb concentration supported (Bq kg-1). Whereas, 222Rn is the parent to the 214Pb inert gas, the use of 214Pb activity to estimate the yield of 210Pb activity supported by 226Ra - can be overestimated due to the partial release of 222Rn from soil samples and fine sediments. It often happens and can be corrected by using the proportion factor ά:

$$A_{\text{Pb-210ex}} = A_{\text{Pb-210}} - \acute{\alpha} A_{\text{Pb-214}}$$

And ά can be calculated as:

$$\acute{\alpha} = (\ A_{\text{Pb-210.deep}})/(\ A_{\text{Pb-214}}.\text{deep})$$

where (A Pb-210 deep) is the total concentration of 210Pb for soil and sediment samples below the depth of penetration of 210Pb (Bq kg-1). Meanwhile, (A Pb-214 deep) is a 214Pb concentration for samples from a depth penetration below 210Pb of the atmosphere (Bq kg-1). Therefore, the value of ά is usually in the range of 0.80– 1.0. All FRNs will then be converted to concentration/surface area (Bq/m2) or FRN inventory.

Meanwhile, such requirements to be implemented for the conversion of concentrations to FRN inventory, A are as follows:

A = CMS (Bq/m2)
Where;
C = sample FRN activity concentration (Bq/kg),
M = total dry mass of soil core collected (kg),
S = cross section of the sampling counter (in m2), for which two types of inventory will be used to compare;

- Reference inventory
- Sample inventory

Comparison of sample and reference inventories using a conversion model, the rate of soil erosion can be estimated and can usually be expressed in tons/hectare/year (t/ha/y). The conversion model used in this study is a Proportional Model that is frequently used for budget sediment studies. This model is based on the premise that the 137Cs /210Pb /7Be inputs need to be fully mixed in the plow or planting layer and the soil loss is directly proportional to the reduction in 7Be, 210Pb and 137C inventories due to soil loss from the soil profile. Since the beginning of 7Be, 210Pb and 137Cs accumulation or the beginning of cultivation is carried out in agricultural areas.

The use of the model as above is representative of the following::

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

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 ^{1137}Cs/^{210}Pb /^{7}Be inventory (defined as (Aref-A)/Aref×100);
T = time elapsed since the initiation of ^{137}Cs/^{210}Pb /^{7}Be accumulation or the commencement of cultivation, whichever is later (w/yr);
A ref = local ^{137}Cs/^{210}Pb /^{7}Be reference inventory (Bq/m^2);
A = measured total^{137}Cs/^{210}Pb /^{7}Be inventory at the sampling point (Bq/m^2);
P = particle size correction factor for erosion (P=1).

III. RESULT AND DISCUSSION

An average rate of erosion or sedimentation by land use from Pelarit, Jarum Sub-catchment and Chuchoh tSub-catchment calculated by Proportional Model (PM) are presented in Table 1 to 3. When the PM was used used throughout the period the study was conducted, average erosion and sedimentation rates varied from - 0.53 to - 47.91 t/ha^{-1}/y^{-1} and + 0.09 to + 47.53 t/ha^{-1}/y^{-1}, respectively. Therefore, Pelarit Sub-catchment has provided the second highest sedimentation rate for all three land use after Jarum Sub-catchment for medium-term for wet season period, -16.47 t/ha^{-1}/y^{-1} and - 47.91 t/ha^{-1}/y^{-1}. Whereas, long-term have given another higher erosion rates in the rubber area compared to forest land use, 41.25 t/ha^{-1}/y^{-1} and 4.66 t/ha^{-1}/y^{-1} . The sedimentation rate for medium-term in rainy seasons has given the lowest sedimentation rate from all study data, -1.57 t/ha^{-1}/y^{-1}. Kg Pak Omar for medium-term from the dry season has given higher erosion rate in rubber area compared to forest land use, 29.01 t/ha^{-1}/y^{-1} and 4.28 t/ha^{-1}/y^{-1}, respectively. It also can be seen where both land use record values for relatively low short-term for both erosion and sedimentation levels, -0. 86 t/ha^{-1}/y^{-1} and 0.13 t/ha^{-1}/y^{-1}. Two results of this analysis have shown that factors such as rainfall frequency and low ^{7}Be content in rainwater need to be considered as shown in Table 1.

Table 1. Summary of erosion and sedimentation rate according to land use from Pelarit Sub-catchment

Location	**Land use**	**Short-term**	**Medium-term**		**Long-term**
			Dry season	**Wet season**	
		Average erosion/sedimentation rate (t/ha/y)	Average erosion/sedimentation rate (t/ha/y)	Average erosion/sedimentation rate (t/ha/y)	Average erosion/sedimentatio n rate (t/ha/y)
KG PAK OMAR	Rubbe r	-0.86	29.01	-16.47	41.25
PELARIT -1 (SEDIMENT)					
PELARIT -2 (SEDIMENT)	Forest	0.13	4.28	-1.57	4.66
PELARIT-BTN (SEDIMENT)					

Note: (-) values indicate sedimentation

The different erosion rates occur in Chuchoh tSub-catchment compared with Pelarit Sub-catchment as shown in Table 2. The highest and second highest erosion rates were recorded for the medium-term for dry and wet seasons for the three catchments during the study period implemented 47.53 t/ha^{-1}/y^{-1} and 46.26 t/ha^{-1}/y^{-1}. These two erosion rates are not much different from each other due to the ^{137}Cs inventory reference factor which has not changed much throughout the time period this study was implemented. The erosion rate for the long and medium term is fully applied to all land use compared to short-term. This condition is seen only two of the four land uses experiencing low erosion rates of 1.22 t/ha^{-1}/y^{-1} and 1.83 t/ha^{-1}/y^{-1}. Whereas, relatively high sedimentation rates have also been recorded as a result of significant yields in grazing areas by livestock.

And further, the Jarum Sub-catchment Needs to provide varying erosion rates and sedimentation from six land use as as illustrated in Table 3. The rainy season has once again provided the highest sedimentation rates of medium-term from the entire data of this study, of which -47.91 t/ha^{-1}/y^{-1} has been recorded insettlement land use. Moreover, paddy cultivation activities that require muddy soil and exposed to rain have resulted in the second highest long-term sedimentation rate, -22.13 t/ha^{-1}/y^{-1} . On the other hand, no short-term sedimentation rates occur in all six land use areas. Mixed cropland use has recorded the highest erosion rates for short-term for the entire study conducted, 29.50 t/ha^{-1}/y^{-1} as shown in Table 3. This is due to inconsistent planting of vegetables, causing the soil in Alor Dalam 5 to be loose and easy to carry by rainwater during wet season to the catchment area. However, this situation is unlikely to occur in the sugar cane area and another land use due to sugar cane cultivation activities is more consistent.

Table 2. Summary of erosion and sedimentation rate according to land use from Chuchoh tSub-catchment

Location	**Land use**	**Short-term**	**Medium-term**		**Long-term**
			Dry season	**Wet season**	
		Average erosion/sedimentation rate (t/ha/y)	Average erosion/sedimentation rate (t/ha/y)	Average erosion/sedimentation rate (t/ha/y)	Average erosion/sedimentation rate (t/ha/y)
SUNGAI TELINTONG (SEDIMENT)	Settlement	-5.32	47.53	46.26	37.95
SG MATA AIR (U)	Mixed-crop	1.22	43.18	6.83	34.98
FELDA MATA AIR	Rubber	1.82	29.72	26.12	22.39
SG MATA AIR (L)					
SG CHUCHOH POST- FLOOD	Forest	-0.53	14.9	16.64	14.17

Note: (-) values indicate sedimentation

Table 3. Summary of erosion and sedimentation rate according to land use from Jarum Sub-catchment

Location	Land use	Short-term	Medium-term		Long-term
			Dry season	Wet season	
		Average erosion/sedimentation rate (t/ha/y)	Average erosion/sedimentation rate (t/ha/y)	Average erosion/sedimentation rate (t/ha/y)	Average erosion/sedimentation rate (t/ha/y)
TASOH	Paddy	1.76	45.2	-4.69	-22.13
RIMBA MAS(DEKAT KG FELDA - JAMBATAN)	Settlement	1.37	39.43	-47.91	-6.77
BUKIT MANIK	Forest	1.41	9.59	-6.19	1.51
PERTEMUAN SG JARUM+ MANIK	Rubber	0.84	45.4	22.6	17.14
ANAK SUNGAI JARUM					
JARUM L					
JARUM U	Sugarcane	0.09	42.2	24.25	15.56
SUNGAI KWANG RUA (U)					
SUNGAI KWANG RUA (L)					
ALOR DALAM 5 (MIX CROP)	Mixed-crop	29.50	35.89	27.44	35.89

Note: (-) values indicate sedimentation

IV. CONCLUSION

In conclusion, this study indicates spatial variations in natural ^{210} Pb, ^{7}Be and fallout ^{137}Cs can be used to estimate short-term and, medium-term and long-term soil erosion and sedimentation rates activities in differnt land use types in the. Thus, this research paper also found that both medium-term and long-term soil erosion rate is comparable to each other even though at different temporal scale. During the wet season, most sediments was stored in each catchment land use before being transported out to the stream during the dry season. Whereas for short-term scale, large quantities of sediment are transported out of different land uses into the flow system.

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