THE SHORT-TERM EROSION RATES IN DIFFERENT LAND USE STUDY

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ABSTRACT

The main purpose of this study is to identify the short-term erosion rates in different land use. The study was conducted in Timah Tasoh, Perlis in the Peninsular of Malaysia from January 2016 until December 2016. The soil core samples were taken from each different land use using a metal corer during the wet and dry seasons. All these soil core samples were taken to the laboratory Radiochemistry and Environment Group Laboratory (RAS), Nuclear Malaysia in Bangi, Selangor for further treatment. In the laboratory, these samples were sectioned into 2 mm increments of 4 cm soil depth. Furthermore, all samples are dried using an oven at 45 - 60 ºC for a few days gently disaggregated and sieved using a sieve to obtain the desired particle size prior to inclusion in the Marinelli beaker for analysis. The analysed using Gamma spectrometry for 24 hours counting with 20% of the detector efficiency. On the other hand, the uncertainty of for each sample as calculated as a γ – detector-counting error at the 95% confidence level is in the order of ± 10%. Based on the results of the analysis on all the samples taken, indicates that the Jarum Sub-catchment site has given the lowest and highest values of the short term erosion rate during the one-year sampling period, 0.09 and 29.50 / (t /ha /y) from mixed crops in Alor Dalam 5 and sugar cane in Sungai Kwang Rua. Meanwhile, relatively high sedimentation rates have been recorded in the Sungai Telintong from the Chuchoh tSub-catchment when compared from the two other sites, 5.32/ (t / ha / y). Both the significant difference between the average soil erosion and sedimentation rates in all study sites was due to the rainy season more sedimentation process compared to soil erosion and so on during dry seasons. Hence, the rain and dry season factors have also played a crucial role in determining the average soil erosion rate and sedimentation at the study site. However, the results of these analyses also cannot be applied to long-term erosion rates because the amount of sediment is being transported out from the different land use considering that the estimation is based on the weekly or monthly basis.

Key words: Short-term, Land use, samples, Marinelli beaker, Gamma spectrometry

INTRODUCTION

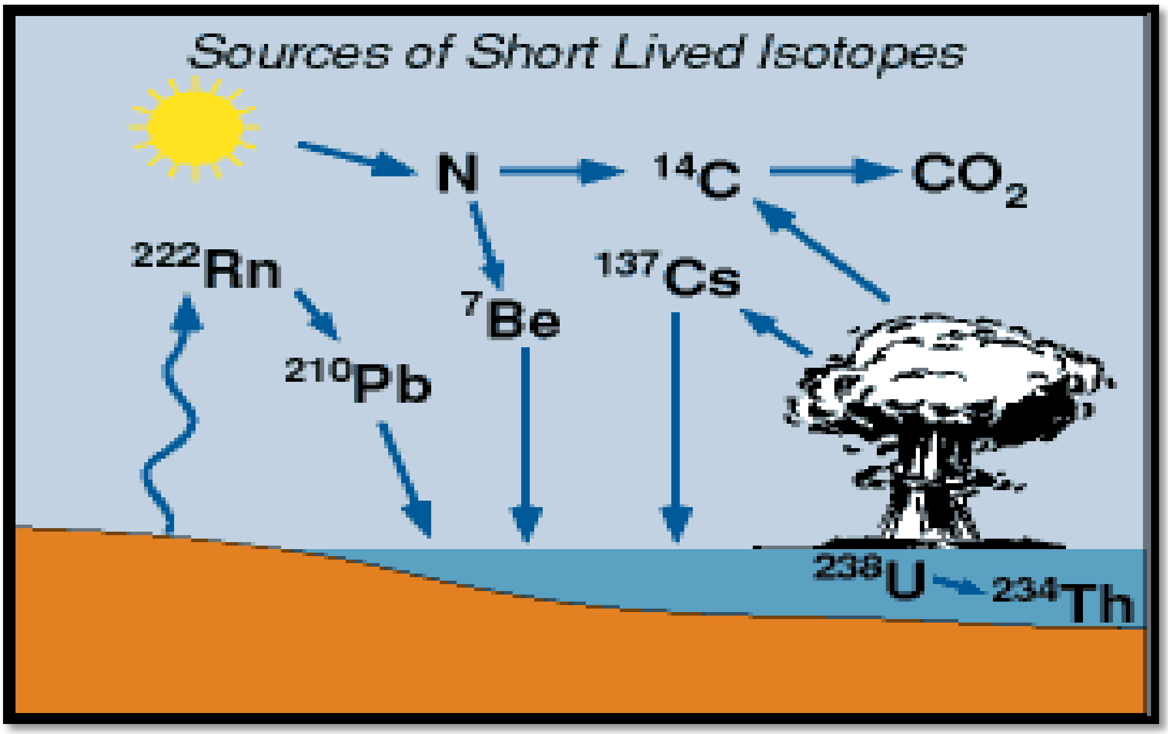
Soil erosion is a major problem in many countries in the world such as in the developing and developed countries. The occurrence of soil erosion or denudation process on the surface of the earth is a common occurrence. Erosion or denudation involves the processes that cause the wasting of surface by moving water, it will affect in reduction of elevation or volumes of soils or altering the relief of landforms and landscapes. On the other hand, soil erosion usually occurs from processes or actions of solid shifts such as soil, mud, rocks and other particles with causative agents such as wind, water and ice. These erosion events have caused environmental damage and destruction, especially in terms of economic and human security such as landslides in the hillsides and mud floods. Among the factors that cause widespread land erosion are weather changes, human activities such as widespread logging for agricultural and development purposes as well as geophysical types found in a land surface. Although the occurrence of soil erosion occurs quickly and slowly, it will still have adverse effects in short or long periods of time. The impact of this soil erosion has resulted in the pollution of the river or the estuary caused by soiled mud soils. With this occurrence, the river's water condition becomes sluggish as a result of unsustainable and suspended elements. Likewise, the conditions of the river level become shallower and thus disturb the ecological life of the river or the estuary itself. The mud flood situation has destroyed all agricultural produce and also affected the health of the locals as a result of polluted water. Therefore, the on-site and off-site are the most common in the soil erosion study. Most of the main on–site impact is the reduction in the soil quality, which is loss of structural stability, the redistribution of soil and losses of the organic matters and nutrient element during the soil erosion processing. In addition to its on-site effects, the soil is detached by accelerated water, wind erosion may be transported considerable distances, and this gives rise to off-site problems. Water erosion’s main off site – effect is the movement of sediment and agricultural pollutants in the watercourses. In addition to the direct effects of eroded material both on-site and off-site, fine sediment also plays an important role in the fate of non-agricultural contaminants that might enter watercourse from, for example, industrial sources.

Fallout radionuclides have been successfully used as tracers in numerous studies of soil erosion and sedimentation investigations process since the 1970s (Walling, 1998, 2002; Zapata, 2002). In essence, the approach is founded on the assumption that the fallout input of the radionuclide is uniform across the landscape and that; upon deposition, the fallout radionuclides are rapidly and strongly fixed by fine particles (Brown & Stensland, 1989; Hawley *et al*., 1986; Owens *et al*., 1996). The four major Falout Radionuclides (FRNs) commonly used for soil erosion and sedimentation studies include anthropogenic radionuclides such as medium-life cesium 137 (137Cs) and long-lived plutonium isotopes (239 + 240Pu), nuclear weapons tests in the atmosphere as well as from nuclear power plant accidents. Meanwhile, natural radionuclides and cosmogenic such as lead lead-210 (^{210}Pb) and Beryllium-7 (^{7}Be) to have a medium and short-term life (Alewell, Pitois, Meusburger, Ketterer, & Mabit, 2017, Alewell, Meusburger, Juretzko , Mabit, & Ketterer, 2014; Guzman, Quinton, Nearing, Mabit, & Gómez, 2013; International Atomic Energy Agency [IAEA], 2014; Mabit, Benmansour, & Walling, 2008; Mabit, Meusburger, Fulajtar, & Alewell, 2013 ; Mabit et al., 2014; Matisoff, 2014; Matisoff & Whiting, 2011; Taylor, Blake, Smith, Mabit, & Keith - Roach, 2013; Zapata, 2002).

It has also been used as a tracer for studying atmospheric processes (Feely *et al*., 1989; Dibb, 1990; Todorovic *et al*., 1999) to determine the rate of erosion occurring in exposed areas by receiving large amounts of rainfall over a given period. Subsequent redistribution these radionuclides within the catchment will reflect the mobilization and transport of soil and sediment particles. By comparing radionuclide inventories (Bqm^{-2}) for different sampling point with that for an undisturbed reference site, which has experienced neither erosion nor deposition, rates of erosion and deposition can be estimated (Walling and He,1997). To date, most attention has focused on the use of the environmental radionuclides Cesium-137 (^{137}Cs) and excess lead-210 ($^{210}Pb_{ex}$) to provide information on the operation of catchment sediment budgets over medium-term (e.g 40-50 year) and longer-term (50-100 year) timescales (figure 1). There is, however, also a need for the information related to shorter timescales and Beryllium-7 (^{7}Be) shows considerable potential or providing information on soil and sediment redistribution over the short-term scale.

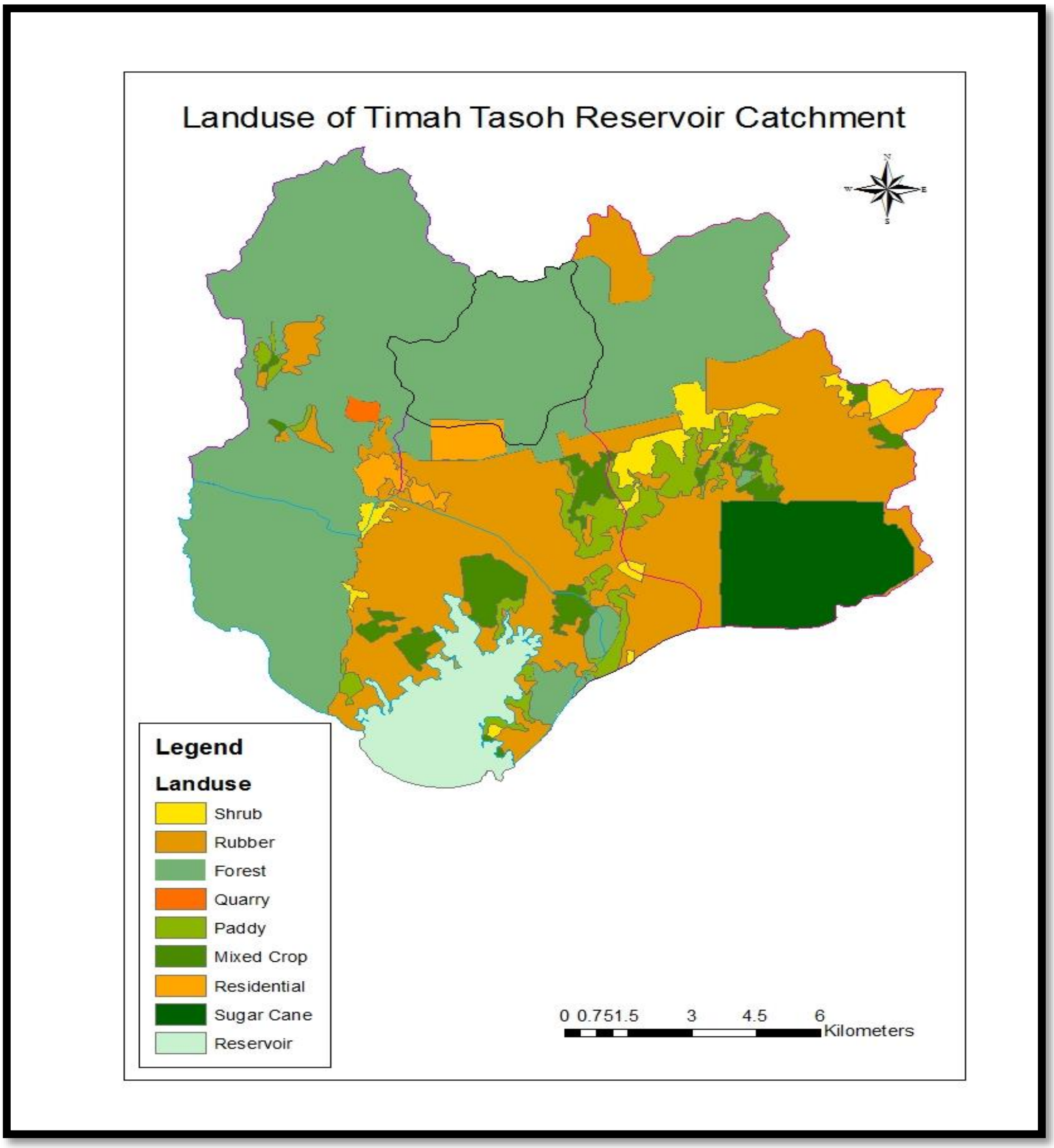
Thus, ^{7}Be is naturally cosmogenic occurring radionuclides is produced by nuclear spallation reactions between high energy cosmics-rays and atmospherics nuclei, ^{7}Be quickly attaches to sub-micron atmospheric aerosols that are distributed throughout the atmospherics and deposited to the earth surface from the scavenging process is known as rainfall (figure 1). The precipitation or washout from the rainfall washing of the^{7}Be into the surface earth goes to the soil and fluvial system. Arnold and Al-Salih (1995) was first discovered and identified the potential to use the short-live radionudlides, ^{7}Be as a tracer in the meteorological applications and others starts to improve the understanding of ^{7}Be production in the atmosphere. Since its first discovered, many researches such as Lal *et a.,* (1958) determined the production rates of ^{7}Be and predicting concentrations of radionuclides in the atmosphere based on production theories. Another reported from Rama and Honda (1961) and Friend *et al* (1961) who measured ^{7}Be concentrations at several localities compared the predictions with actual measured values. The results look agreed with those predicted by Lal *et al* (1958) in terms of spatial distribution patterns, but the concentrations were not similar. Meanwhile, TimahTasoh, Perlis area has been selected as to be study located area which is consists of a reservoir or small catchment area. TimahTasoh is located approximately 13 km north of Kangar town near the Thailand border (6˚ 36’N and 100˚ 14’E). This reservoir area has a mean surface area of 13.33 km^{2} and a storage capacity of about 40 million m^{3}. This study area has been surroundings by different agricultural land use such as sugar, rubber, paddy and timber plantations. The land use diversity at TimahTasoh catchment can be used as initial overview about the sediment production around the catchment. At present, the main purpose of the reservoir is to supply water for domestic and industrial use as well as for irrigation and flood control. Three rivers flowing into the reservoir have been selected as the study area, namely the Sg. Jarum, Sg. Pelarit Hulu and the Sg. Chuchuh (figure 2).

Figure 1: Sources of Short lived Fallout Radionuclides (FRNs) isotopes



The main objective of this study was to identify short term soil erosion rates by using the nuclear analytical technique to different study site areas. The search for new techniques for assessing soil erosion short to long-term rates and sedimentation to complement conventional modeling and measurement methods, such methods still require a large number of parameters and measurements over many years. Therefore, alternative approaches such as the application of Fallout radionuclides (FRNs) have made it more efficient in terms of analysis and sampling results.Therefore, the study was to identify short-term erosion and sedimentation rates of less than 3–6 months during the rainy and dry season. With this study, it is possible to determine the amount of erosion and soil sedimentation rates after heavy rainfall at certain times and conditions for replacing the conventional method used in previous studies. The application of this study has not only saved time and costs, but has been able to provide more relevant analysis results compared to conventional methods. Moreover, the data obtained from this study can be used for comparative data between short and medium-term soil erosion and sedimentation rates in the near future study.

Figure 2: The study sites and land use activities around the catchment area

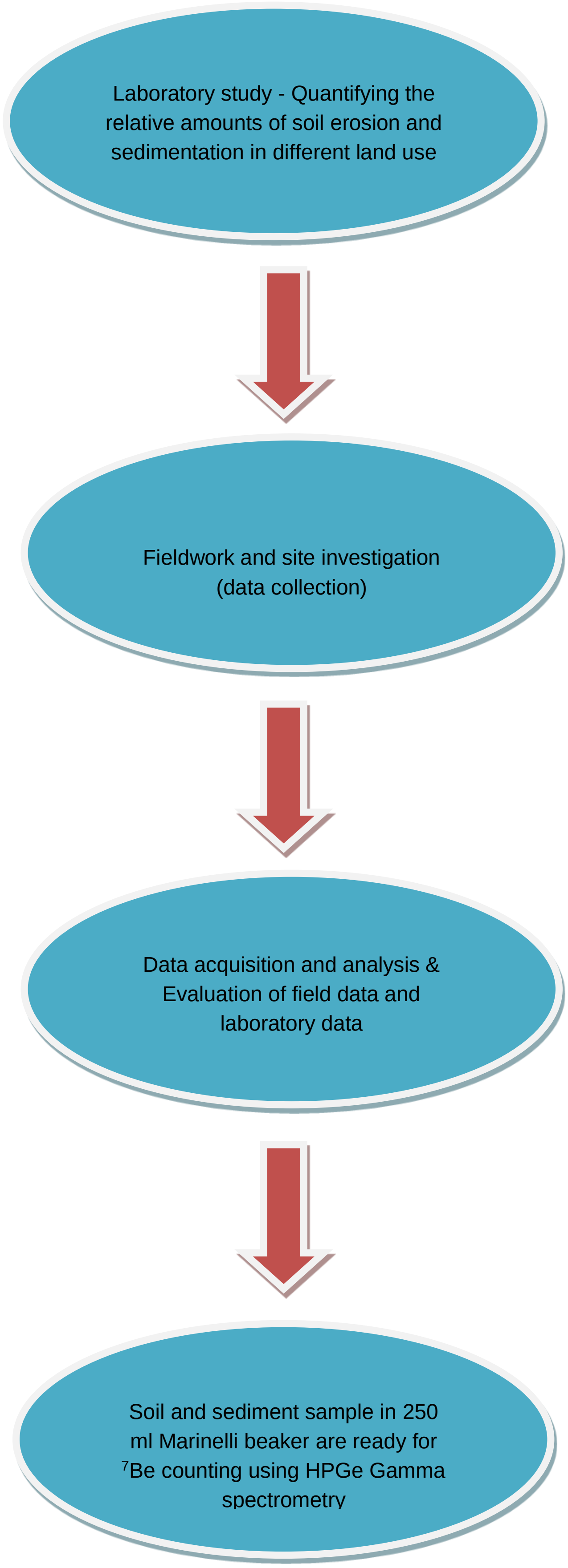


MATERIAL AND METHODOLOGY

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. 2). 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. The study was conducted from January 2016 until December 2016. The soil core samples were taken from each different land use using a metal corer during the wet season (figure 2). All core soil samples that have been sectioned into 2 mm increments to a depth of 4 cm done in Radiochemistry and Environment Group Laboratory (RAS), Nuclear Malaysia in Bangi, Selangor for further treatment. Then, all samples are 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 ^{7}Be analysis (fig.3).

Fig. 3 Flow chart Measurements of ^{7}Be radioactivity



Counting of ^{7}Be in soil samples

The determination of ^{7}Be activities in the soil were done using Gamma Spectrometry counting system, consists of Hyper-Germanium detector (HPGe) for 86400 seconds or 24 hours (figure 3.0). The energy of ^{7}Be is 477.6 KeV with 20% of the detector efficiency with the uncertainty of for each sample as calculated as a γ – detector-counting error at the 95% confidence level is in the order of ± 10%. 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 ^{7}Be concentrations or activity from the samples was calculated using equation as below:

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

Where;

N = the net count under the peak of 477.6 keV gamma line energy that characterized ^{7}Be (in counts),
ε = the efficiency of the detection system for the 477.6 keV gamma line energy (in counts.$Bq^{-1}.s^{-1}$) obtained from equation 1,
p_{γ} = the absolute probability transition for 477.6 keV gamma line for ^{7}Be .

FRN 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 spectrometer. It will then convert into concentration/surface area (Bq/m2) or FRN inventory.

Conversion of concentration into FRN inventory, A are as follows:
A = CMS (Bq/m^2)
Where;
C = FRN 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).

2 Types in inventories

- 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 Proportional Model. The model is based on the premise that ^{7}Be fallout inputs are completely mixed within the plough or cultivation layer and that the soil loss is directly proportional to the reduction in the ^{7}Be inventory due to loss of soil from the soil profile, since the beginning of ^{7}Be accumulation or the onset of cultivation.

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

RESULTS AND DISCUSSION

The short-term soil erosion is normally referred to soil mobilization of surface-mixed layer of sediment at maximum of 4 cm soil depth. The use ^{7}Be is for very short-term investigations (single events) or between cropping seasons. The short-term soil erosion by using ^{7}Be radionuclide as tabulated in table 1 - table 3 are estimated as average erosion or sedimentation rate according to each land use in the catchment and the rates are normally expressed in tonne/hectare/year.

Table 1: Summary of soil and sedimentation rate according to land use from Pelarit Sub-catchment (short – term)

Sampling Location	Land use	Inventory (Bq/m-2)	Average Erosion/sedimentation (t/ha/yr)
Kg Pak Omar	Rubber	6.37	-0.86
Pelarit-1 (Sediment)	Forest	4.87	0.13
Pelarit-2 (sediment)	Forest	4.87	0.13
Pelarit- BTN (Sediment)	Forest	4.87	0.13

Note: (-) values indicate sedimentation

Based on the results of the analysis from table1 - table 3, soil erosion rates and sedimentation at all study sites have shown varying results. These results have given the average soil erosion rate across all study sites to have value between, 0.09 - 29.50 / (t /ha /y). The sub-catchment study site has given the average soil erosion rate results from ten different stations compared to two other study sites, each providing four and five stations. Therefore, the Jarum Sub-catchment site has given the lowest and highest values of soil erosion rate during the one-year sampling period, 0.09 and 29.50 / (t /ha /y) from mixed crops in Alor Dalam 5 and sugar cane areas in Sungai Kwang Rua area. Both of these conditions are due to some factors to consider such as the amount of rain that has been received at the site during the rainy season.

The amount of rain volume that has fallen in the mixed crop Alor Dalam 5 area is higher and often occurs when compared to the sugar cane land use area. This condition causes more mud flooding occurring in mixed crop area and causing sediment movement into the nearby river stream. However, the low soil erosion rate at Sungai Kwang Rua is due to the harvest time is not as frequent as in the mixed crop area. Other factors need to be taken into account; the relatively large and wide sugarcane leaf condition can cover raindrops on the soil surface compared with mixed crop land use.

Table 2: Summary of soil and sedimentation rate according to land use from Jarum Sub-catchment (short – term)

Sampling Location	Land use	Inventory (Bq/m-2)	Average Erosion/sedimentation (t/ha/yr)
Tasoh	Paddy	7.89	1.76
Rima Mas (Dekat Kg Felda- Jambatan)	Settlement	8.97	1.37
Bukit Manik	Forest	10.27	1.41
Anak Sungai Jarum (L)	Rubber	6.62	0.84
Anak Sungai Jarum (U)	Sugarcane	16.38	0.09
Sungai Kwang Rua (U)	Sugarcane	16.38	0.09
Sungai Kwang Rua (L)	Sugarcane	16.38	0.09
Alor Dalam 5	Mixed crop	65.47	29.50

Note: (-) values indicate sedimentation

Table 3: Summary of soil and sedimentation rate according to land use from Chuchoh t- Sub-catchment (short – term)

Sampling Location	Land use	Inventory (Bq/m-2)	Average Erosion/sedimentation (t/ha/yr)
Sungai Telintong (Sediment)	Settlement	20.37	-5.32
Sg Mata Air (U)	Mixed -crop	4.87	1.22
Felda Mata Air	Rubber	4.87	1.82
Sg Mata Air (L)	Rubber	4.87	1.82
Sungai Chuchoh Post-Flood	Forest	19.14	-0.53

Note: (-) values indicate sedimentation

In the rainy season, sediment samples were taken for analysis purposes and this caused a relatively high average sedimentation rate compared to the average soil erosion rate at all sampling sites. While during the dry season, the average sedimentation rate is the opposite. This can be seen from the results of the sedimentation rate at all study sites, where the lowest and highest sedimentation rates have been indicated in dry and wet seasons, - 0.53 and - 5.32 / (t /ha /y) each respectively. This result have been recorded from the Chuchoh tSub-catchment, in the Sungai Telintong area, - 5.32/ (t / ha / y) due to the mud flow or sediment movement during the heavy rainy season. On the contrary, Sungai Chuchoh Post-Flood area, forest land use can provide a low average sedimentation rate during the rainy season, - 0.53 / (t /ha /y). Therefore, it is the lowest sedimentation rate compared to other sedimentation results during the study period. This is due to the large-scale leaves of the forest land use closing down rainwater containing ^{7}Be radionuclide to the soil surface and consequently sedimentation rates are low. This situation is very different in the land use settlement area which has given the highest sedimentation rate as the amount of rainfall containing ^{7}Be radionuclide has reached the surface completely and consequently significant erosion and sedimentation. In addition, this area is a breeding ground for cattle and this causes the soil to become grazed due to high grazing on cover crops such as grass.

Jalal *et al.,* (2019) also reported the results of a medium-term study of soil erosion rates conducted at the same study site. From the study, it was found that the adopted Fallout Radionuclides (FRNs) method provided efficient and reliable analysis results at all times and without causing any problems to arise at the study site during the period under review. However, the results of this study cannot be compared with the medium-term because the amount of erosion and sedimentation rates varies with the time taken forshort-term of 3-6 months compared to the average duration of 40-50 years for medium-term erosion and sedimentation rates. Meanwhile, the results of this study have also provided analytical data for different soil erosion rates and sedimentation for two different seasons; whereas soil sedimentation usually occurs during the rainy season. The overall, the wet season has given a higher sedimentation rate than the rate of soil erosion in the study area. Furthermore, the results of short-term from this study are not much different as the results of the analysis have been reported by Zullyadini *et al., (2013)* for medium-term of soil erosion and sedimentation rates.

CONCLUSION

The rate of soil erosion and sedimentation rates in all three study sites conducted over a year has resulted in varying results. Both the significant difference between the average soil erosion rates and sedimentation in all study sites was due to the rainy season more sedimentation process compared to soil erosion and so on during dry seasons. Hence, the rain and dry season factors have also played a crucial role in determining the average soil erosion rate and sedimentation at the study site. However, the results of these analyses also cannot be applied to medium and long-term erosion and sedimentation rates because the amount of sediment is being transported out from the different land use considering that the estimation is based on the weekly or monthly basis. This study has shown that Timah and Tasoh are still two major contributors of mud and sediment entering the catchment area for both seasons. Thus, proposals for reducing soil erosion and sedimentation rates 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. As conclusion, this study has proven that ^{7}Be can be used as a short-term tracer for soil erosion and sedimentation rates studies in catchment areas and its surroundings for both seasons. Furthermore, a new study using the same nuclear applications will be carried out at other identified sites for more comprehensive and efficient data to enable detailed location and seasonal comparative analysis data to control soil erosion and sedimentation since global climate change drastically.

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REFERENCES

1. Arnold JR, Al Salleh H (1995) Beryllium-7 produced by cosmic rays. Science 121:451- 453
2. Brown, L., Stensland, G. J., Klein, J. and Middleton, R. (1989). "Atmospheric deposition of ^{7}Be and ^{10}Be." *Geochim. Et Cosmo chim. Acta*, 53: 135.
3. DE Walling, Q He (1997). Investigating spatial patterns of overbank sedimentation on river floodplains. *Water, Air, and Soil Pollution* –Springer
4. Dibb , J.E., 1990. ^{7}Be and ^{210}Pb in the atmosphere and surface snow cover over the Greenland ice-sheet in the summer of 1989. J. Geophys. Res. (atmos.). 95(D13) 22407-22415.
5. Feely, H. W., R. J. Larsen, and C. G. Sanderson (1989), Factors that cause seasonal variations in beryllium-7 concentrations in surface air, J. Environ. Radioact., 9, 223– 249
6. FRIEND. J, P., FEELY,H . W., KREY,P . W., SPAR, J., and WALTON, A., 1961, High Altitude Sampling Program. DASA-639B, DASA-1300.
7. Hawley, N., J.A. Robbins, and B.J. Eadie. 1986. The partitioning of 7-beryllium in fresh water. Geochim. Cosmochim. Acta 50:1127–1131
8. Jalal , S., Zainudin, O., Dainee , N.F.A.T (2019). Determination of Medium-Term Soil Erosion and sedimentation Rates in Two Seasons, International Journal of Agriculture, forestry and Plantation, Vol. 8 (June) ISSN 2462-1757
9. Lal, D., P.K. Malhotra, and B. Peters. 1958. On the production of radioisotopes in the atmosphere by cosmic radiation and their application to meteorology. J. Atmos. Terr. Phys. 12:306–328.
10. Owens, P.N., D.E. Walling, and Q. He. 1996. The behaviour of bomb-derived caesium-137 fallout in catchment soils. J. Environ. Radioactivity 32:169–191.
11. RAMA and HONDA, ./M, (1961), Natural radioactivity in the atmosphere. *Jour. awphye. Re&, 66*, pp. 3227-3231.
12. Todorovic et al., 1999 D. Todorovic, D. Popovic and G. Djuric, Concentration measurements of ^{7}Be and ^{137}Cs in ground level air in the Belgrade City area, *Environment International* 25 (1999) (1), pp. 59–66
13. Walling D.E. and Quine T.A., 1990: Calibration of caesium-137 measureme*nts to provide quantita*tive erosion rate data. *Land Degradation and Rehabilitation* 2: 161-175.
14. Walling, D. E. (1998) Use of ^{137}Cs and other fallout radionu*clides in soil erosion investigation*s: Progress, problems and prospects. In: Use of ^{137}Cs in the Study of Soil Erosion and Sedimentation, International Atomic Energy Agency Publication IAEA-TECDOC-1028, IAEA, Vienna, pp. 39-64
15. Walling, D.E., He, Q., & Blake , W.H. (2000). Use of ^{7}Be and ^{137}Cs measurements to document short- and medium-term rates of water-induced soil erosion on agricultural land. *Water Resources Research*, *35*, 3865–3874.
16. Phillips JD. 1993. The source of alluvium in large rivers of the lower Coastal Plain of North Carolina. Catena 19: 59–75.
17. Blake, W.H. 2000. The use of ^{7}Be as a tracer in sediment budget investigations. Geography Department, University of Exeter
18. Russell, M.A., Walling, D.E., Hodgkinson, R.A., 2001. Suspended sediment sources in two small lowland agricultural catchments in the UK. Journal of Hydrology 252, 1 –24.
19. D.E. Walling, Q. He, P.G. Appleby (2002) **Conversion models for use in soil-erosion, soil-redistribution and sedimentation investigations**.
20. Zullyadini A. R, Mohd. F.M, Mohamad.A. O & Wan. R.I (2013) The Contribution of Riverbank Erosion to the Suspended Sediment Transport in Timah Tasoh Reservoir, Perlis, Geografi Vol 1, No 2, 17 – 29, Penerbit Universiti Pendidikan Sultan Idris