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# A STUDY OF SOIL EROSION AND SEDIMENTATION BETWEEN TWO DIFFERENT SEASONS IN SEMBRONG CATCHMENT USING CESIUM-137

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## ABSTRACT

*Incidents of soil erosion and sedimentation occur frequently in catchments area around the world as a result of human activities and the impacts of global climate change. This research paper aims to determine the rate of soil erosion and sedimentation by using Cesium-137 ($^{137}Cs$) as a medium-term tracer in the Sembrong catchment over two different study seasons. The Sembrong catchment area is located in Kluang, Johor and is one of the most important ecosystems in Peninsular of Malaysia. Soil and sediment samples were collected using a standard metal corer and integrated suspended sediment trap samplers. A total of 50 samples were collected at 20 sampling stations consisting of various land uses in the vicinity of the site for both the dry and wet seasons. The dry season of soil erosion rate ranged between 5.09 t/ha/y to 65.2 t/ha/y. Meanwhile, soil erosion and sedimentation rates during wet season ranged between 8.02 t/ha/y to 39.78 t/ha/y and -4.81 t/ha/y to -50.81 t/ha/y, respectively. Rubber and oil palm plantations referring to station 17, stations 4 and 6 located near Sembrong Lake and Sembrong River had the highest rates of soil erosion and sedimentation at 51.03 t/ha/y and -50.81 t/ha/y, respectively. This situation may be due to the fact that rubber and oil palm plantations in these two areas are still new planting areas and allows the rainfall received in both seasons to continue to penetrate into the soil. In conclusion, $^{137}Cs$ as a medium-term tracer was successfully used to determine rates of soil erosion and sedimentation in two different seasons for the Sembrong catchment area. The data on soil erosion and sedimentation rates will be very useful for present and future land and water management in the Sembrong catchment area, and may be compared with other similar catchments in Malaysia.*

**Keywords:** Soil erosion; sedimentation; Cesium-137; gamma spectrometry; catchment management

## INTRODUCTION

Soil erosion is a process that involves the removal of the soil surface as a result of the effects of receiving large amounts of rain and the resulting flooding. It follows the transport of particles or grains of soil and rock from the surface of the earth through the action of natural processes such as wind or water flow and then transported with the flow of rainwater to lower areas. Excessive soil erosion will cause huge problems such as desertification, reduction of agricultural productivity due to land degradation, sedimentation of waterways, destruction and collapse of ecosystems due to the loss of nutrients in the upper layer of the soil surface. Soil erosion is one of the latest conditions that are so significant to the global environmental problems faced now as the diversity of human activities has increased the rate again from 10-40 times (Blanco et al., 2010; Toy et al., 2002). Among them is one of the activities that are so widespread at the moment such as deforestation and land clearing aimed at clearing land for agricultural activities and settlement development with the opening of new residential. However, this activity has caused the strength of the soil to decrease and when there is heavy rain filled with such a large amount of volume, there will be a process or state of landslides due to the rapid activity of surface runoff.

Erosion events become even worse when the land surface lacks any vegetation that can prevent landslides continues. A high rate of rainfall is one of the main contributing factors to soil erosion and this kind of situation occurs as a result of the water content in the soil becoming saturated. The soil cannot receive or accommodate an excessive amount of water, especially during the rainy or monsoon season. The situation becomes even worse if the amount of rain received exceeds the level received before. Incidents like this are further reinforced by the existence of various development activities carried out in the highlands and slopes for economic, tourism and settlement purposes. This is further reinforced by the slope terraces that are not carried out in an orderly and neat manner in addition to a very weak slope management system such as cutting the slope vertically. There is no drainage system that is not very good for the purpose of water flow and is not accompanied by earth cover plants to prevent surface erosion also increases the occurrence of soil erosion especially in hilly and mountainous areas.

Meanwhile, the term "Environmental Isotope" or Fallout Radionuclide (FRNs) is usually used to refer to isotopes that are common and widely distributed in the environment or landscape and, although occurring at relatively low levels, can be easily measured. In most cases, it is of natural origin but in some cases, it is man-made. One of the most frequently used FRNs in soil erosion and deposition studies in catchment systems is $^{137}$Cs. $^{137}$Cs is an artificial or anthropogenic environmental radionuclide that can also be classified as a fall radionuclide. Over the last few decades, there have been many publications related to the various uses of FRNs especially $^{137}$Cs in soil erosion studies (Ritchie & McHenry, 1990; Walling and Quine, 1990; Walling and Quine, 1993; Zapata, 2002: Ritchie et al., 1974). Thus, this $^{137}$Cs tracer has also been found to be very effective as a diagnostic property in fingerprinting sediment sources (Wallbrink et al., 1998; Motha et al., 2003) and it has been widely used as a medium-term sediment tracer (Ritchie & McHenry, 1990; Zapata, 2002). Apart from that, some local and international studies have also reported to determine the rate of erosion and deposition by using the FRNs approach as a tracer especially short and medium term, Beryllium-7 ($^{7}$Be) and $^{137}$Cs between two different seasons (Blake et al., 1999, 2000, 2002; Jalal et al., 2019, 2020, 2021) in Timah Tasoh study site, Perlis. In addition, the use of these FRNs can also be seen in the use of $^{7}$Be to determine the penetration rate into the interior of the soil based on the two different seasons, namely the wet season and the dry season at the study site in Bangi, Selangor (Jalal et al., 2020, 2021).

The findings from these three studies have proven that the use and importance of FRNs as a tracer has been successful and can identify erosion and sedimentation rates for the short and medium term. A study using the Compound Specific Stable Isotope (CSSI) approach was also carried out in the Timah Tasoh catchment area, Perlis to identify the source or cause of sediment contribution to the catchment area (Jalal et al., 2020). Moreover, this can be seen clearly, that there is a relationship between sediment sources, sediment mobilization, transport, deposition, storage and sediment yield at the basin outlet can be very complex, especially in situations where sediment storage equals or exceeds sediment export (Trimble, 1983; Phillips, 1992; Walling et al., 2000). Sediment budgets, which provide information on sediment sources, sediment sinks and sediment yields (Golosov et al., 1992; Reid and Dunne, 1996; Walling, 2000, Walling et al., 2001). Therefore, it is increasingly seen as a key sediment management tool (Walling and Collins, 2008). It is considered to be the single most important information about the fluvial system (Dietrich et al., 1982; Meade, 1982; Trimble, 1983; Reid and Dunne, 1996; Walling, 1998) and its importance in carrying sediments along with heavy metal concentrations and geochemical to the interior of the catchment area.

The study of soil erosion and sedimentation must be seen from various angles of interest, especially from the factors of ecological balance and natural ecosystems as well as their importance to humans. Therefore, humans need to take various initiatives in slope management that are more systematic and detailed so that the destruction of nature is more controlled and not destroyed for the benefit of future generations. This matter also determines that universal security can be preserved and that it will be able to avoid the loss of life, property and public facilities every time there is a major flood and then soil erosion, especially landslides. This research study aims to determine the soil erosion and sedimentation rate by using $^{137}$Cs as a medium-term tracer in the Sembrong catchment, Kluang, Johor, Malaysia.

## MATERIALS AND METHOD

### Study area

The Sembrong Reservoir is one of the important ecosystems in Peninsular Malaysia since the 1960s and it has evolved from a natural ecosystem to a human-dominated one. The Sembrong catchment is located in Kluang, Johor between latitudes 3°26′42″ to 3°26′42″ N and longitudes 102°54′18″ to 102°55′54″E (Fig. 1). The morphology provides significant information about the physical characteristics of the reservoir (Table 1). The freshwater reservoir area is 7.7547 km$^2$ with an estimated storage capacity of 24.84 million m$^3$, while the catchment area is about 130 km$^2$. Thus, prior to conduct of this study, land use had changed considerably, with an increase in agricultural activity covering 8% (1984) to 82% (2010) in the area around the study site.

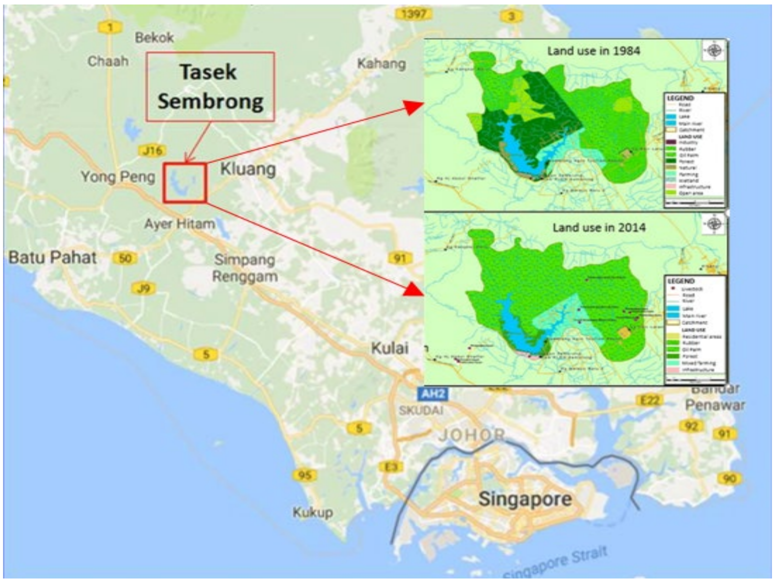


Figure 1. Study site in Sembrong catchment and land use

Table 1. The physical characteristics of Sembrong catchment

| No. | Parameter | Result |
|---|---|---|
| 1. | Lake area (km$^2$) | 7.7547 |
| 2. | Volume (km$^3$) | 36 |
| 3. | Maximum depth (m) | 7 |
| 4. | Mean depth (m) | 3.2 |
| 5. | Mean slope (%) | 4 |
| 6. | Height (m) | 9 |
| 7. | Catchment's area (km$^2$) | 130 |
| 8. | Storage capacity (million m$^3$) | 24.84 |
| 9. | Spillway | Concrete Fixed Ungated Ogee Crest |

**Soil sampling and preparation of samples**

All soil and sediment samples were collected using metal corers and integrated suspended trap samplers of the type described by Philips et al. (1993) and Russell et al. (2001) at 20 sampling stations (Figure 2). The samples were then taken to the Radiochemical and Environmental Laboratory (RAS), Nuclear Malaysia for further treatment. Hence, all samples were dried in an oven at 45 - 60 ºC for several days until they reached a consistent or stable weight. The completely dried sample was pounded using a mortar and pestle until fine and sieved with a 2 mm siever before being transferred into a 250 ml Marinelli beaker for the $^{137}$Cs counting and analysis.

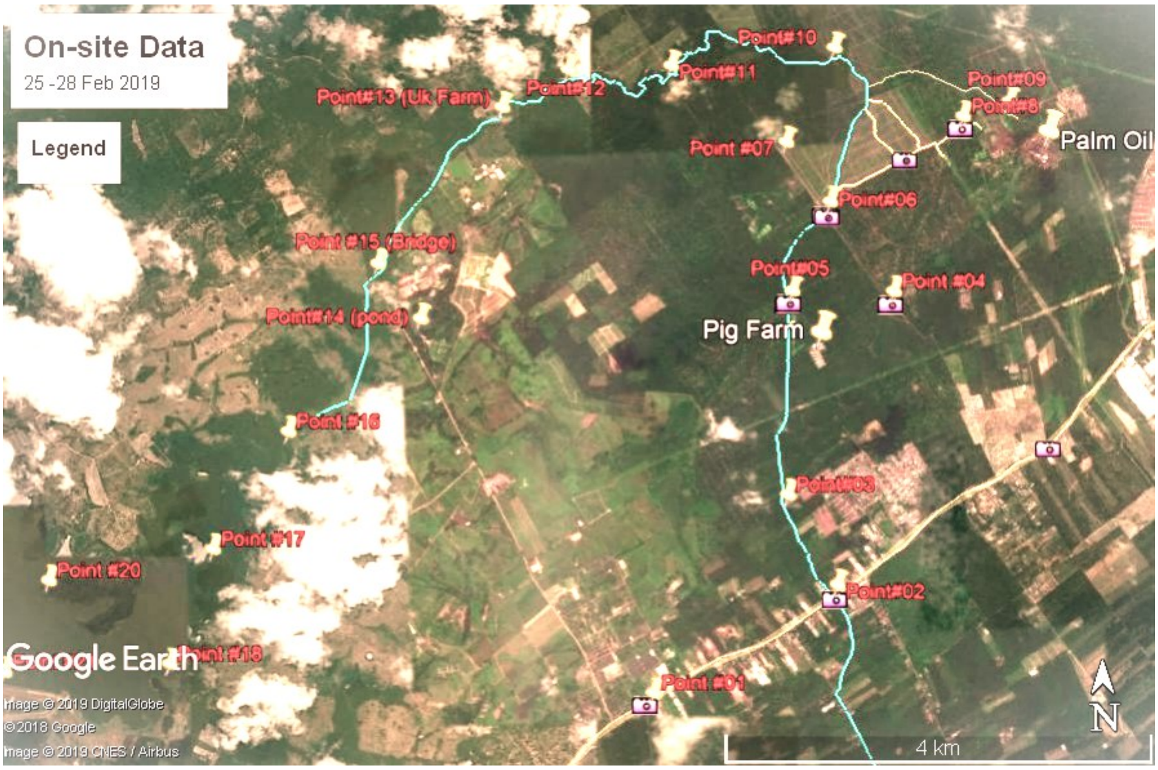


Figure 2. Sampling activities at 20 sampling stations

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

Measurement of $^{137}$Cs by gamma spectrometry using a high purity Germanium (HPGe) detector with a relative efficiency of 28%. The detector was calibrated for selected measurement geometries and different soil densities by standard calibration samples and specialized computer software was used for gamma spectrum analysis. Walling and Quine (1993) have suggested that the sample counting time be extended to identify relatively low fallout activity such as $^{137}$Cs, usually taking in a very efficient time period ranging from 29000 to 55000s to achieve better measurement accuracy (>10%) at the 95% confidence level. Meanwhile, the detection limit of $^{137}$Cs for this measurement was estimated to be about 0.3 Bq/kg for the Marinelli geometry.

Thus, the charge magnitude in the crystal detector of gamma spectrometry was directly related to the energy emitted from the gamma rays from the sample. The γ-rays emitted from the detector sample are absorbed and subsequently lost during processing between the detector and the sample, where the γ-ray emission loses all energy by producing an electron pulse (Blake et al., 2000). Electron pulses generated from radioactivity emitted from the sample were amplified by a pre-amplifier as voltage pulses into a multi-channel analyser. The multi-channel analyser works by compiling the output pulses from multiple channels into a counting system, while transferring the emitted γ-ray pulses into a total count that were processed and displayed in the gamma spectrometry screen (Blake et al., 2000). Furthermore, the $^{137}$Cs activity from the samples was calculated using Equation (1) 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), $p_{\gamma}$ was the absolute probability transition for 662 keV keV gamma line for $^{137}$Cs . Meanwhile, m and t are mass and time based on the number of minutes or seconds for $^{137}$C measurement from soil and sediment samples and it is measured based on concentration (Bq/kg). Moreover, 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

The soil erosion rate was estimated by comparing the sample and reference inventory using a conversion model, that expressed in ton/hectare/year (t/ha/y). The conversion model used in this study was the Proportional Model ( Walling *et al.,* 2002). This model is based on the total fallout input of $^{137}$Cs being completely mixed in the plowed or cultivated layer. Thus, soil loss is directly proportional to the reduction in $^{137}$Cs inventory due to soil loss from the soil profile, since the beginning of $^{137}$Cs accumulation or the beginning of cultivation . Therefore, if half of the $^{137}$Cs  input was removed, the total soil loss over the period assumed to be 50% of the plough depth. The model 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

Table 2 shows the overall results of the analysis of soil erosion and sedimentation rates from 20 stations throughout the study period. Indications of the results of this comprehensive analysis show various rates of soil erosion and sedimentation from the diversity of land use. The dry season indicated the result of soil erosion rate only at each station when compared to the wet season which is more mixed with the rate of sedimentation and soil erosion itself. The soil erosion rates showed values between 5.09 t/ha/y to 65.2 t/ha/y throughout both seasons. Stations 10 and 11 from mixed crop recorded the highest erosion rate values compared to station 14 from modern agriculture which were only able to record the lowest rate. However, the soil erosion rate values for all study seasons did not show any significant differences (p value is > 0.05). The difference in values between the highest and lowest values is clearly visible, and this is most likely due to the diversity of the soil which plays an important role especially in the process of soil erosion. However, these two values are also not significantly different compared to the highest value recorded (p value is > 0.05).

The dry season has provided the results of overall erosion values, while no sedimentation values were recorded for all study stations. However, the wet season recorded both erosion and sedimentation values. The sedimentation rate ranged from -4.81 t/ha/y to -50.81 t/ha/y. Meanwhile, the soil erosion rate in the wet season signified a slightly lower value compared to the dry season. This situation is likely due to the factor of receiving a volume of rain that is much more than the normal level at a certain time. This situation has also allowed such rainwater to penetrate the soil surface and further cause it to become softer resulting in a higher incidence of soil erosion than usual. Stations 4 and 6 recorded the highest values and while stations 1-3 were the lowest and likely due to different land use factors in addition to other factors. Stations 4 and 6 were areas that overgrown with new oil palm plantations. This may affect more sedimentation events in this area due to the lack of palm oil leaves to cover or prevent the amount of rain from falling directly to the ground surface. Furthermore, the boundaries between these palm trees that are not covered by grass accelerate the rate of erosion further bringing mud to the surrounding area as sediment piles.

Table 2. Soil erosion and sedimentation rate during two seasons at different land use estimated using $^{137}$Cs

| **Sampling location** | **Land use** | **Erosion/sedimentation rate (t/ha/yr)** | |
|---|---|---|---|
| | | **Dry season** | **Wet season** |
| Station 1-3 | Settlement | 41.4 | -4.81 |
| Station 4 and 6 | Oil Palm Plantation | 28.39 | -50.81 |
| Station 5 | Animal farm | 6.33 | -8.16 |
| Station 7 | Modern agriculture | 35.6 | 23.8 |
| Station 8<br>Station 9 | Oil palm plantation | 11.06 | -7.88 |
| Station 10<br>Station 11 | Mixed crop | 65.2 | 29.78 |
| Station 12 | Banana plantation | 15.39 | 28.11 |
| Station 13 | UK's Farm | 28.66 | 8.0 |
| Station 14 | Modern agriculture | 5.09 | 8.02 |
| Station 15 | Mixed crop | 21.63 | 28.42 |
| Station 16 | Oil palm plantation | 11.08 | 19.44 |
| Station 17 | Rubber tree plantation | 51.03 | 39.78 |
| Station 18 | Fruit orchard | 36.26 | 9.38 |
| Station 19<br>Station 20 | Forest | 18.11 | 23.92 |

Note: (-) values indicate sedimentation

Station 14 is an area that carries out modern agricultural activities and this gives a soil erosion rate value that is not significantly different from the other study stations (p value is $> 0.05$). The use of a systematic farming system has been able to reduce the occurrence of soil erosion despite receiving a large volume of rain. A very similar situation can also be seen at Stations 19 and 20, where the soil erosion rate values for both are not very different. This situation is likely due to the position of the trees found in the forest quite close to each other along with the concept of "canopy" by the plants in the forest of this station. However, Stations 13 and 18 showed a difference in the rate of soil erosion for each other. The dry season recorded a high soil erosion rate compared to the wet season. This kind of situation occurs due to the rain factor received together with the number of livestock were released in both seasons to graze grass in the UK's Farm area. Various factors also be considered such as soil types, the total volume of rainfall received for both seasons, as well as differences in land use at the study stations.

Several studies have been reported by Zullyadini et al., (2013) and (Jalal et al., 2019, 2020, 2021) in the Timah Tasoh study area in determining the rate of soil erosion and sedimentation. Zullyadini et al., (2013) reported that the total amount of annual erosion of the cliffs at Sungai Tasoh was the highest at 348.76 tonnes (1.38%) followed by Sungai Pelarit Hilir at 25.64 tonnes (0.68%), Sungai Jarum at 55.45 tonnes (0.55%), Sungai Chuchuh at 12.58 tonnes (1.18%) and Sungai Pelarit Hulu at 17.41 tonnes (0.27%), each respectively. Jalal et al. (2019, 2020, 2021) observed in the same area erosion and sedimentation rate estimates that are not significantly different when utilising the medium term FRNs approach as $^{137}Cs$ for this study area are similar to those in the Timah Tasoh, Perlis study site. The rates are still considered very low when compared under cultivation in large agricultural areas in the United States and from silt or soil brought into production in the last century in 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 and sedimentation analysis gave different values in all 20 study stations. Overall, the dry season has yielded soil erosion rate results only at each station when compared to the rainy season which is more mixed with both soil erosion and sedimentation rates. It has given the rate and soil erosion of values ranging from 5.09 t/ha/y to 65.2 t/ha/y throughout for both seasons, at two stations 10 and 11 from mixed crop and station 14 from modern agriculture, which are contributed the highest and lowest soil erosion rate values for both seasons. This can be clearly seen that the difference in the soil erosion rates between the highest and lowest values is not notable and is likely due to the diversity of land use and the amount of rainfall received together with other factors that play a very important role, especially the occurrence of soil erosion in the study site. Nevertheless, the rainy/wet season has provided soil erosion values and sedimentation rates only in some land use areas with reported values ranging from 8.02 t/ha/y to 39.78 t/ha/y and - 4.81 t/ha/y to - 50.81 t/ha/y, respectively. However, the value of the soil erosion rate in the rainy season gives a lower value when compared to the dry season in some study stations. The values of soil erosion and sedimentation rates from this study are not much different from studies that have been reported by previous studies for both seasons, the Timah Tasoh catchment area. Precisely, the values from this study for both soil erosion and sedimentation are still classified as small amounts when compared to the values of both in cultivated areas in large agricultural areas of the United States and from silt or soil brought into production on century ago in Northeast China due to several factors that need to be considered. In conclusion, $^{137}Cs$ as a medium-term tracer has been successfully used to determine the rate of soil erosion and sedimentation in two different seasons for the Sembrong catchment area throughout the study period based on several factors that have been considered.

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## CONFLICTS OF INTEREST

The authors declare no conflict of interest.

## REFERENCES

Blake, W.H. 2000. The use of $^{7}$Be as a tracer in sediment budget investigations. Geography Department, University of Exeter

Blake, W.H., Walling, D.E. and He, Q. (2002) Using cosmogenic beryllium-7 as a tracer in sediment budget investigations. Geografiska Annaler, 84A, 89-102.

Blake, W.H., D.E. Walling, and Q. He. 1999. Fallout beryllium-7 as a tracer in soil erosion investigations. Appl. Radiat. Isot. 51:599–605.

Blanco, Humberto & Lal, Rattan. 2010. "Soil and water conservation". Principles of Soil Conservation and Management. Springer. m/s. 2. ISBN 978-90-481-8529-0.

Dietrich, W.E., Dunne, T., Humphrey, N.F. & Reid, L.M. (1982) Construction of sediment budgets for drainage basins. In: Workshop on Sediment Budgets and Routing. Eds. Swanson, F., Janda, R.J., Dunne, T., Swanston, D. Pp

Golosov, V.N., Ivanova, N.N., Litvin, L.F. and Sidorchuk, A.Yu. 1992, Sediment budget in river basins and small river aggradation. *Geomorphologiya,* Vol.4, pp. 62-71 (in Russian)

Jalal , S., Dainee , N.F.A.T., Noor Fadzilah,Y., Mohd,T.I .,Mohd ,I.A.A., (2020). The Depth Distribution of Beryllium 7 In The Soil Study, International Journal of Agriculture, Forestry and Plantation, Vol. 9 (Feb) ISSN 2462-1757:11-18

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 2462-1757:120-127

Jalal , S., Zainudin, O., Dainee , N.F.A.T., (2021). Quantifying the Relative Amounts of Soil Erosion and Sedimentation in Different Land Use, ASM Sc.J.,16, Special Issue 1, 2021 for SCIEMATHIC 2019, 172- 179

Jalal , S., Zainudin, O., Dainee , N.F.A.T., Noor Fadzilah,Y., Mohd,T.I .,Mohd ,I.A.A., (2020). The Compound Specific Stable Isotope (CSSI) values in Timah Tasoh Soil Erosion Study , International Journal of Agriculture, Forestry and Plantation, Vol. 9 (Feb) ISSN 2462-1757:1-10

Jalal , S., Zainudin, O., Dainee , N.F.A.T., Noor Fadzilah,Y., Mohd,T.I .,Mohd ,I.A.A., (2020). The Short-Term Erosion Rates In Different Land Use Study, International Journal of Agriculture, Forestry and Plantation, Vol. 9 (Feb) ISSN 2462-1757:19-27

Jalal , S., Zainudin, O., Dainee , N.F.A.T., Nurrul , A.M.J., Nooradilah, A., Mohd, T.I., (2021). The Beryllium-7, $^{7}$Be Depth Penetration in Two Seasons Study at Timah Tasoh , Perlis, ASM Sc.J.,16, Special Issue 1, 2021 for SCIEMATHIC 2019, 180- 186

JC Ritchie, JR McHenry . 1990. Application of Radioactive Fallout Cesium-137 for Measuring Soil Erosion and Sediment Accumulation Rates and Patterns: A Review. Journal of environmental quality. Wiley Online Library

Mark A.Net al., (2017) Natural and anthropogenic rates of soil erosion , International Soil and Water Conservation Research Volume 5, Issue 2, Pages 77-84

Meade, 1982. Sources, Sinks, and Storage of River Sediment in the Atlantic Drainage of the United States. The Journal of Geology volume 90 number 3 (1982). The University og Chicago press Journals

Motha, J.A., P.J. Wallbrink, P.B. Hairsine, and R.B. Grayson. 2002. Tracer properties of eroded sediment and source material. Hydrological Processes 16:1983-2000

Phillips JD. 1992. The source of alluvium in large rivers of the lower Coastal Plain of North Carolina. Catena 19: 59–75.

Reid, L. R., Dunne, T, 1996. *Rapid Evaluation of Sediment Budgets*. Catena special publication (Geo-ecology Report). Catena Verl. GMBH Germany

Ritchie J.C. and McHenry J.R., 1974. Fallout $^{137}$Cs: A tool in conservation research. *Journal of water and Soil Cultivation*. 30, 283-286

Toy, T.J., Foster, G.R., Renard, K.G. 2002. Soil erosion: processes, prediction, measurement, and control. NewYork, New York. Wiley. ISBN 978-0-471-38369-7.

Trimble, S. W., 1983. A sediment budget for Coon Creek basin in the Driftless area, Wisconsin, 1883–1977. Am. J. Sci. 283: 454– 474.

Wallbrink, P.J., Murray, A.S. and Olley, J.M., 1998. Determining sources and transient times of suspended sediment in the Murrumbidgee River, New South Wales, Australia, using fallout $^{137}$Cs and $^{210}$Pb. Water Resour. Res., 34(4):879-887.

Walling D.E. and Quine T.A., 1990: Calibration of caesium-137 measurements to provide quantitative erosion rate data. *Land Degradation and Rehabilitation* 2: 161-175.

Walling DE, Collins AL (2008) The catchment sediment budget as a management tool. Environ Sci Policy 11: 136–143

Walling et al., 1998 D.E. Walling, P.N. Owens, G.J.L. Leeks The role of channel and floodplain storage in the suspended sediment budget of the River Ouse, Yorkshire, UK Geomorphology, 22 (1998), pp. 225-242

Walling, D.E. and Quine, T.A., (1993). Use of Caesium-137 as a Tracer of Erosion and Sedimentation: Hand Book for the Application of the Cesium Technique. Overseas Development Administration Research Scheme R4579. Department of Geography, University of Exeter, UK.

Walling, D.E., A.L. Collins, H.M. Sichingabula and G.J.L. Leeks. 2001. Integrated assessment of catchment suspended sediment budgets: a Zambian example. Land degradation & development, 12, pp.387-415

Walling, D.E., A.L. Collins. 2000. Integrated assessment of catchment sediment budgets: a technical manual. University of Exeter, UK, 168 p.

Zapata, F. (ed.) (2002) Handbook for the Assessment of Soil Erosion and Sedimentation Using Environmental Radionuclides. Kluwer, Dordrecht.

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