Jurnal Sains Nuklear Malaysia, 2025, 37(No. 2): 34 – 43
*ISSN: 2232-0946*

e-JSNM

# A SEDIMENT CONTRIBUTION FROM DIVERSITY OF LAND USE TO THE SEMBRONG CATCHMENT AREA, KLUANG, JOHOR, MALAYSIA

**Jalal Sharib@Sarip[1*], Dainee Nor Fardzila Ahmad Tugi[1], Mohd Tarmizi Ishak[1] and Mohd Izwan Abdul Adziz[1]**

[1*]Radiochemistry and the Environment Group
Waste and Environment Technology Division
Malaysian Nuclear Agency,
Bangi, 43000 Kajang, Selangor, Malaysia
*Corresponding author email: jalal@nm.gov.my

## ABSTRACT

Soil erosion and sedimentation are significant environmental concerns affecting freshwater reservoirs. This study investigates the sources of sediment contributing to the Sembrong catchment in Kluang, Johor, Malaysia, by analysing sediment samples from various land uses during both dry and wet seasons. The study area includes the Sembrong Reservoir (7.76 km², 24.84 million m³ capacity) and a catchment of approximately 130 km². The Compound-Specific Stable Isotope (CSSI) technique, using $\delta^{13}C$ as non-radioactive tracer was applied to identify sediment sources. Results indicate that banana plantations are the dominant sediment contributors, accounting for 41% of the total sediment load, compared to 11% from recreational areas, with no significant seasonal variation. These findings highlight the effectiveness of CSSI in tracing sediment sources and emphasize the need for targeted erosion control in agricultural landscapes.

**Keywords:** Sediment sources, Stable Isotopes, Compound-Specific Stable Isotopes (CSSI), Sembrong catchment

## *ABSTRAK*

*Hakisan tanah dan pemendapan adalah merupakan satu kebimbangan ketara alam sekitar yang menjejaskan takungan air tawar. Kajian ini adalah merupakan siasatan terhadap sumber sedimen yang menyumbang kepada tadahan Sembrong di Kluang, Johor, Malaysia, dengan menganalisis sampel sedimen daripada pelbagai guna tanah semasa musim kering dan basah. Kawasan kajian adalah termasuk Takungan Sembrong (7.76 km², kapasiti 24.84 juta m³) dan kawasan tadahan kira-kira 130 km². Teknik Isotop Stabil Khusus Kompaun (CSSI), menggunakan $\delta^{13}C$ sebagai penyurih bukan radioaktif telah digunakan untuk mengenal pasti sumber sedimen. Keputusan menunjukkan bahawa ladang penanaman pisang adalah penyumbang sedimen yang dominan, menyumbang 41 % daripada jumlah bebanan sedimen, berbanding 11 % dari kawasan rekreasi tanpa perubahan musim yang ketara. Penemuan ini memperkukuhkan keberkesanan CSSI dalam mengesan sumber sedimen dan menekankan bahawasanya keperluan kawalan hakisan yang disasarkan dalam landskap pertanian.*

***Kata kunci:*** *Sumber sedimen, Isotop Stabil, Isotop Stabil Khusus Kompaun (CSSI), Tadahan Sembrong*

## INTRODUCTION

Soil erosion and sedimentation are significant environmental issues that frequently disrupt tropical ecosystems. These processes lead to nutrient loss from the soil surface, reduced soil water retention, decreased fertility, and inhibited plant growth (Vásquez-Méndez et al., 2010). Soil erosion occurs when natural forces such as water, wind, waves, and glaciers remove soil from the Earth's surface. Major contributing factors include heavy rainfall, continuous water flow after storms, tornadoes, sandstorms, and coastal wave action. These forces accelerate soil erosion, leading to widespread environmental and economic consequences. One of the most pressing concerns is the economic impact of soil erosion on a global scale. Beyond the recurring erosion process itself, human activities have significantly intensified the problem—land degradation due to deforestation and unsystematic land clearing for agriculture and development has increased erosion rates by 10 to 40 times worldwide.

In Malaysia, land clearing, particularly through deforestation within climatic vegetation ecosystems, continues to significantly alter the hydrological balance. This, in turn, leads to soil erosion, causing rivers to become polluted with silt and insoluble elements. As sediment accumulates, the riverbed becomes shallower, disrupting aquatic ecosystems and increasing the risk of flooding due to excessive water overflow. Local studies on soil erosion have primarily focused on slope-scale or small river basin areas, often employing soil erosion models. Globally, extensive research has explored the interaction of geomorphological factors in catchment areas concerning soil erosion and land degradation (Nyssen et al., 2005). Excessive soil erosion, especially following heavy rainfall, has caused numerous environmental issues, including reduced agricultural productivity due to soil degradation, sedimentation of waterways, and ecological collapse from nutrient depletion. Farmers often compensate for nutrient loss by increasing fertilizer use, which further impacts the environment. Research has identified rainwater as the primary contributor to soil degradation, accounting for approximately 84% of cases. Soil erosion remains a critical global environmental challenge due to the energy exerted by raindrops, which dislodge and fragment soil particles upon impact. This process intensifies when rain persists over extended periods, continuously eroding the soil surface and accelerating land degradation.

Over the last few decades, numerous publications have explored the various applications of Fallout Radionuclides (FRNs), particularly $^{137}Cs$, in soil erosion studies (e.g., Ritchie & McHenry, 1990; Walling & Quine, 1990, 1993; Zapata, 2002; Ritchie et al., 1974). $^{137}Cs$ has proven to be an effective diagnostic tool for fingerprinting sediment sources (e.g., Wallbrink et al., 1998; Motha et al., 2003) and is widely used as a sediment tracer (Ritchie & McHenry, 1990; Zapata, 2002). Several local studies have also utilized the FRNs approach to determine erosion and deposition rates, particularly in the short and medium term. For instance, Jalal et al. (2019, 2020, 2021) applied $^{7}Be$ and $^{137}Cs$ tracers to assess seasonal variations in erosion and deposition at the Timah Tasoh study site, Perlis. Additionally, Jalal et al. (2020, 2021) used $^{7}Be$ to analyse soil penetration rates across rainy and dry seasons at a study site in Bangi, Selangor. These studies demonstrate the effectiveness of FRNs as tracers in successfully identifying erosion and sedimentation rates over short and medium timescales.

However, the use of Fallout Radionuclides (FRNs) alone cannot fully identify the source of sediment transported into the catchment area. To address this limitation, a study using the Compound Specific Stable Isotope (CSSI) approach was conducted in the Timah Tasoh catchment area, Perlis, to trace sediment sources (Jalal et al., 2020) in relation to soil erosion and sedimentation. The relationship between sediment sources, mobilization, transport, deposition, storage, and yield at the basin outlet can be highly complex, especially when sediment storage equals or exceeds sediment export (cf. Trimble, 1983; Phillips, 1992; Walling et al., 2000). Sediment budgets provide valuable insights into sediment sources, sinks, and yields (Golosov et al., 1992; Reid & Dunne, 1996; Walling, 2000; Walling et al., 2001) and are increasingly recognized as essential tools for sediment management (Walling & Collins, 2008). To support this study, sediment samples collected after heavy rainfall were processed at the Radiochemical and Environmental Group Laboratory (RAS), Nuclear Malaysia, for pre-treatment before analysis. The organic composition of CSSI markers was analysed using Gas Chromatography Mass Spectrometry (GC-MS) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS), both of which are suitable for detecting fatty acid content in environmental samples. These fatty acids, derived from decomposed plant material in sediment deposits after flood events, serve as environmental forensic indicators to quantify sediment contributions and trace their sources.

This study aims to determine the sources of soil erosion and assess sediment contributions from various agricultural activities and land uses within the catchment area using the CSSI approach.

## MATERIAL AND METHODOLOGY

### 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. 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 $km^2$. Over the years, land use has changed dramatically, with agricultural activity increasing from 8% in 1984 to 82% in 2014 around the study site (Figure 1).

A total of 30 soil surface samples were taken from 6 sampling stations. All samples were collected and mixed in a bucket using a metal scraper hand tool (Figure 2). It is important that the sample is well mixed to ensure it accurately represents the site. The combined sediment samples were t transported to the Radiochemistry and Environment Group Laboratory (RAS), Block 23, Nuclear Malaysia for further processing. Each core sample was dried in an oven at a temperature of 45- 60 until a constant dry weight was achieved. The dried samples were then finely ground and sieved at 2 mm before undergoing $^{13}C$ analysis. The preparation procedure involved converting fatty acids and fatty acid derivatives into Fatty Acid Methyl Ester (FAMEs) to ensure that the $^{13}C$ analysis analysis provided reliable results for the study.

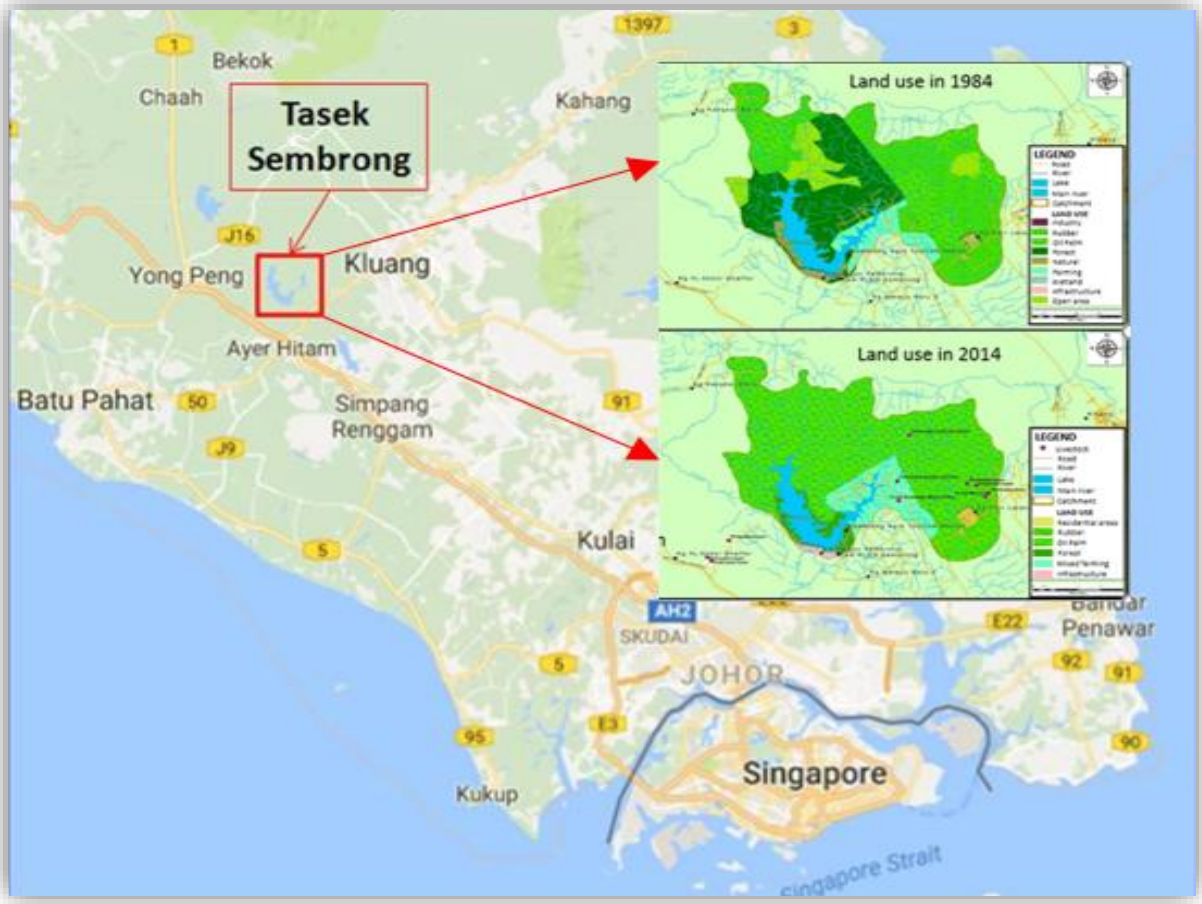


Figure 1: Study site in different land use in Sembrong catchment, Kluang, Johor

Table 1: The physical characteristics of Sembrong catchment

| No. | Parameter | Value |
|---|---|---|
| 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 |

Figure 2: A metal scraper hand tool for CSSI sampling

**Preparation for $\delta^{13}C$ analysis of fatty acids**

The solvent used in this procedure is a high purity Dichloromethane (DCM) , specifically High-Performance Liquid Chromatography (HPLC) grade or double-distilled DCM Grade High Performance Liquid Chromatography (HPLC) or double distillation and Accelerated Solvent Extractor (ASE) cells must Accelerated Solvent Extractor (ASE) cells must be thoroughly cleaned beforehand to prevent contamination and ensure accurate analysis results.Shaker extraction typically takes 24 hours, while ultrasonic extraction requires 6–8 hours. Before extraction, the sample must be soaked in 100 mL of DCM inside a 250 mL Erlenmeyer flask with a ground-glass stopper. The sample must then be filtered to remove soil particles. The solvent is reduced to dryness in a 100 mL round-bottom flask using a Büchi evaporator and should be stored for recycling through the distillation system.

**Fatty acid derivatives to fatty acid methyl esters (FAMEs)**

The dry extract should be transferred from a 100 mL round-bottom flask to a 10 mL Kimax screw-cap reaction tube using 2 mL of DCM with a cleaned Pasteur pipette. Next, add 2 mL of 5% boron trifluoride ($BF_3$) in methanol to the Kimax tube, securely screw the cap, and place the tube in a test tube rack inside a fan oven at 70°C for 20 minutes. After heating, add 2 mL of a hexane/DCM mixture (4:1) to each Kimax tube, screw the cap tightly, and mix using a vortex mixer for 2 minutes. The hexane content is then reduced to dryness in an aluminum heating block at 40°C under a gentle flow of dry nitrogen, directed onto the solvent surface via a vertically positioned stainless-steel needle. Finally, the processed vials are sent to an analytical laboratory for the $\delta^{13}C$ FAMEs measurement.

**Compound Specific Stable Isotope (CSSI) analyses**

Methyl groups ($-CH_3$) added to fatty acids to produce fatty acid methyl esters (FAMEs) will have different isotopic values than fatty acids; therefore, the isotopic signature of FAMEs must be corrected to account for this addition. Although the correction for a single methyl group is relatively small, it must be applied to every fatty acid in every sample. This correction can be efficiently performed using a simple equation in a in a spreadsheet (Equation 1).

$$\delta^{13}C_{FA} = \frac{\delta^{13}C_{FAME} - (1 - X)\delta^{13}C_{Methanol}}{X} \qquad (1)$$

In this equation, FA represents a fatty acid, and X is the fractional contribution of the fatty acid (FA) to its corresponding FAME. X is calculated by dividing the number of carbons in the FA molecule by the total number of carbons in the resulting FAME.
For example, stearic acid (C18:0) produces methyl stearate, which contains one additional carbon (19 carbon atoms in total). Thus, the X value for stearic acid is 18/19 or 0.9474.

**The IsoSource Mixing Model software**

Data processing for Compound Specific Stable Isotope (CSSI) analysis using the IsoSource mixing model and was conducted to identify the sources of sediment in the catchment area. The IsoSource mixing model is a software tool designed to calculate the range of possible proportional contributions of various sources to a mixture based on stable isotope data. It is particularly useful when the number of sources exceeds the number of isotopes + 1, making a unique solution impossible (Phillips & Gregg., 2003). Therefore, the IsoSource mixing model was designed for situations where there are too many sources. Although originally intended to study food webs, it is well suited to identifying and partitioning sources in sediment mixtures. Although the model can handle too many sources, running the model requires at least 3 sources. The model also requires at least 2 isotopes, one of which must be $^{13}C$ for bulk soil carbon. To use the model, data from potential source soils and sediments from the depositional zone must be compiled into a table including bulk $^{\delta13}C$ values and CSSI-corrected $^{\delta13}C$ values for Fatty Acids (FAs). A limitation of using IsoSource is that there must be a $^{\delta13}C$ value for each FA from each source soil as well as the sediment mixture. Obviously, a useful starting point is to take the $^{\delta13}C$ isotope values for bulk soil carbon and two fatty acids, oleic and palmitic acids, to test the level of discrimination.

## RESULTS AND DISCUSSION

Data processing for Compound Specific Stable Isotope (CSSI) analysis using the Iso-Source Mixing model was conducted to identify the sources of sediment in the catchment area. The statistical approach produced multiple solutions, with mean histogram increments ranging from 0.0 to 1.0 for each source. The model compared CSSI data from sediment sources with mixed sediment samples to determine their origins. To achieve this, potential sediment sources within the catchment were characterized, enabling comparisons based on stable $^{13}C$ isotopic properties measured in both sources and sediments. The CSSI analysis results provided insights into sediment contributions from different land uses across two seasons (Table 2 and Table 3). The highest sediment contribution originated from banana plantations, accounting for 36% and 41% of the total sediment deposition in both seasons, particularly at Station 12. This high contribution is likely due to intense soil erosion following floods caused by heavy rainfall.

Table 2: Sediment contribution results from different land uses (dry season) estimated using the Iso-Source mixing model (Philips & Gregg ., 2003)

| Station | Land use | Contribution | Remarks (matrix of sample) |
|---|---|---|---|
| Station 16 | Palm oil plantation | 0.19 | Sediment |
| Station 19 + 20 | Forest | 0.21 | Sediment |
| Station 12 | Banana Plantation | 0.36 | Sediment |
| Station 14 | Modern agriculture | 0.13 | Sediment |
| Station 5 | Recreation area | 0.11 | Sediment |
| Total | | 1.0 | |

Table 3: Sediment contribution results from different land uses (wet season) estimated using the Iso-Source mixing model (Philips & Gregg ., 2003)

| Station | Land use | Contribution | Remarks (matrix of sample) |
|---|---|---|---|
| Station 16 | Palm oil plantation | 0.16 | Sediment |
| Station 19 + 20 | Forest | 0.18 | Sediment |
| Station 12 | Banana Plantation | 0.41 | Sediment |
| Station 14 | Modern agriculture | 0.15 | Sediment |
| Station 5 | Recreation area | 0.10 | Sediment |
| Total | | 1.0 | |

Furthermore, the absence of adequate ground cover between banana plants exacerbated surface erosion, especially after heavy rains. Despite this, statistical analysis indicated no significant difference in sediment contribution between the two seasons at this station ($p > 0.05$). In contrast, Station 14, a modern agricultural area, exhibited the second-lowest sediment contribution (13%), significantly lower than that of Station 12. This can be attributed to well-managed land use practices, including closed-crop systems with plastic coverings, which reduce rainwater infiltration and minimize soil erosion. The second and third largest sediment contributions came from Stations 19+20 (Forest) and Station 16 (Palm Oil Plantation), with values showing minimal seasonal variation. The dry season led to a slight increase in sediment deposition due to heavy rainfall in November 2019, particularly at Stations 19+20 (Forest). This rainfall event likely triggered soil erosion and subsequent sediment transport.

However, the presence of extensive vegetation cover in forests and palm oil plantations played a crucial role in mitigating erosion compared to the banana plantation. Large leaf surface areas and forest floor coverage reduced rainfall impact and runoff, resulting in lower sediment transport. Station 5, a recreational area, had the lowest sediment contribution throughout the study period for both seasons, with values of 10% and 11%, respectively. The minimal erosion at this site can be attributed to the presence of well-maintained ground cover, including managed grazing systems and controlled replanting of high grasses.

Overall, sediment contribution patterns observed in this study align with findings by Zullyadini et al. (2013) in Timah Tasoh, Perlis. However, the erosion and sedimentation rates remain lower than those reported for large-scale agricultural areas in the United States (6 Mg $ha^{-1}$ $yr^{-1}$) and Northeast China (15 Mg $ha^{-1}$ $yr^{-1}$) (Mark A.N. et al., 2017).

## CONCLUSION

This study identified Station 12 (banana plantation) as the highest contributor to sediment entering the Sembrong catchment, while Station 5 (recreational area) had the lowest contribution. However, the difference between these values was not statistically significant ($p > 0.05$). Station 14 (modern agriculture) recorded the second-lowest sediment contribution, attributed to well-organized land use practices, including closed-crop systems (plastic coverings) and widespread cover crops. These measures effectively reduced soil erosion, highlighting the importance of structured agricultural practices in minimizing sediment deposition. Overall, this study successfully identified the primary sediment contributors from various land uses within the catchment area across both study seasons. However, no significant seasonal differences were observed.

In conclusion, the Compound Specific Stable Isotope (CSSI) approach using the IsoSource Mixing Model proved to be a valuable tool for identifying sediment sources in erosion-prone areas, particularly in highly agricultural regions. Future research should expand its application to other catchments across Peninsular Malaysia and the rest of the country to further enhance sediment source tracking and erosion management strategies.

## ACKNOWLEDGEMENTS

The author expresses sincere gratitude to the members of the IAEA/RCA RAS 5084: Assessing and Improving Soil and Water Quality to Minimize Land Degradation and Enhance Crop Productivity Using Nuclear Techniques project for their invaluable cooperation and assistance. Special thanks are extended to those directly and indirectly involved in sampling, preparation, and analysis throughout the study. Their contributions ensured the smooth execution and successful completion of this research. The author also appreciates the continued support in sharing research findings for future publications.

**CONFLICTS OF INTEREST**

The authors declare no conflict of interest.

**REFERENCES**

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., 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., 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., 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., 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., (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., 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

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 Tamura, T. 1964. Selective sorption reactions of $^{137}$Cs with soil mineral. Nucl. Saf. 5: 262-268

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

Nyssen, J., Vandenreyken, H., Poesen, J., Moeyersons, J., Deckers, J., Mitiku, H., Salles, C., Govers, G., (2005). Rainfall erosivity and variability in the Northern Ethiopian Highlands. Journal of Hydrology 311, 172-178.

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

Phillips, D. L. and Gregg, J. W. (2003). Source partitioning using stable isotopes: coping with too many sources. Oecologia, 136: 261 – 269.

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

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

Vásquez-Méndez R, Ventura-Ramos E, Oleschko K, et al. (2010). Soil erosion and runoff in different vegetation patches from semiarid Central Mexico. Catena, 80: 162–169.CrossRef Google Scholar

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, 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