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Soil Erosion and Sedimentation Rate using Cesium-137 in the Sembrong Catchment

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Abstract

The use of Fallout Radionuclides (FRNs) as tracers for the study of soil erosion and sedimentation in catchment areas is still not very popular when compared to conventional methods in Peninsular Malaysia. However, this approach is gaining ground among researchers because various factors have been identified especially in small study areas in parallel with the time period of the study. In this study, Cesium-137 is used as a medium-term tracer to measure the rate of soil erosion in the Sembrong catchment area, Kluang as a study site for two different study seasons. The Sembrong catchment area is the main choice for this study and the area is not very large and is among the catchment areas that have the most important ecosystems in Peninsular Malaysia. It has a fresh water reservoir of 7.76 km2, with an estimated storage capacity of 24.84 million m3 and covers an entire catchment area of approximately 130 km2. Sediment core sampling is carried out in two different seasons, namely the rainy and dry seasons, using standard metal corers, involving sampling at several sampling stations that involve a variety of land uses. All the sediment samples taken were pre-sliced by 2cm and brought to the Radiochemistry and Environment Group (RAS), Nuclear Malaysia to undergo the sample preparation process such as drying, sieving and finally for analysis using a Gamma Spectrometry. The results of the analysis show that the rate of soil erosion and sedimentation for both seasons is variable where the dry season only gives the value of the soil erosion rate. Meanwhile, the rainy season has provided both soil erosion values and sedimentation rates for the overall results. This situation is shown in the dry season which has given the value of the soil erosion rate between 5.09 t/ha/y to 65.2 t/ha/y. Meanwhile, the value of soil erosion and sedimentation during the rainy season ranges 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. Rubber and oil palm plantations refer to Station 17 and station 4/6 which are located near Lake Semberong and Sungai Sembrong have the highest soil erosion and sedimentation rates at 51.03 t/ha/y and -50.81 t/ha/y respectively. In conclusion, 137Cs 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.

Keywords: Soil Erosion, Sedimentation, Cesium-137, Gamma Spectrometry, Catchment

Introduction

Land degradation as a result of frequent soil erosion events and it has provided a global threat that can negatively affect ecosystem function and its ability to provide ecosystem services [1]. It involves various aspects such as nutrient cycling, water retention and habitat provision [2]. Moreover, it is a natural phenomenon in the whole world and Malaysia including most of the land movement such as falling rocks, failure of banks in the slope, river flows that are increasingly collapsing the surrounding banks and the internal level becomes shallow as a result of the occurrence of excessive sediment deposition, especially after the occurrence of floods. In addition, soil erosion is one of the main processes that lead to the occurrence of land degradation [3]. The effects of erosion around the world as much as 75 billion tons of soil is eroded from the ground every year involving a faster erosion rate because it is a natural erosion process which is 13-40 times [4]. On the other hand, some available global modeling studies project an increase in soil erosion between 9 and 56% but have some conceptual limitations [5-8]. The incidence of soil erosion is expected to increase in the coming decades worldwide due to the projected increase in extreme precipitation and the possible negative effects of land use change due to increased human activities. Soil erosion is a process that involves the breaking of large pieces of soil on the surface of the soil or earth and then several erosion agents act to move them to nearby catchment areas such as flood water that brings with it mud, ice in areas with a moderate climate or strong winds especially in vast desert areas.

The intensity of rain is high and unpredictable in Malaysia since recently so strongly affecting the movement of surface runoff on the exposed land surface, and this situation has a high potential to cause the process of soil erosion and eroded soil mobility channeled into the nearby river drainage system especially in the nearby catchment area. Therefore, the effect or impact of events like this further increase the rate water turbidity that will cause disturbance to the ecosystem. In addition, the increase in sediment from the movement of mud that erodes from the soil surface has the potential to cause other environmental problems such as excessive sedimentation in the river flow leading to flash floods. In order to understand the process of soil erosion, various techniques have been developed to estimate the rate of soil erosion and sedimentation that occurred long ago. However, various techniques are used especially conventional techniques which are still many practiced in most agricultural areas and vulnerable areas such as using experimental plot techniques. Anyhow, this technique requires a relatively expensive or high cost while implementing systematic periodic monitoring of trap sediment especially after a flood. However, according to the modeling technique used cannot provide data used to understand the spatial pattern of the soil erosion process at the study site. In addition, the existing models are only able to produce data on the rate of soil erosion as a whole and they cannot fully help in identifying soil erosion that occurs [9].

As such, the use of Fallout Radionuclides (FRNs) is gaining ground among local researchers especially in supporting the study of soil erosion and sedimentation processes. Fallout Radionuclides (FRNs) or "Environmental Isotopes" are commonly used to refer to isotopes that exist naturally or artificially widely in the environment or landscape and, although occurring at relatively low levels, can be easily measured using counter equipment. Over the last few decades, there have been many publications related to the various uses of FRNs especially 137Cs in soil erosion studies [9-13]. Thus, this 137Cs tracer has also been found to be very effective as a diagnostic property in fingerprinting sediment sources and it has been widely used as a medium-term sediment tracer [9, 10]. 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, 7Be and 137Cs between two different seasons in Timah Tasoh study site, Perlis. In addition, the use of these FRNs can also be seen in the use of 7Be 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 [14-22]. 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 in Peninsular of Malaysia. This research paper aims to determine the rate of soil erosion and sedimentation by using Cesium-137,137Cs as a medium-term tracer in the Sembrong catchment, Kluang, Johor, Malaysia.

Materials and Methods

Study Area

Sembrong Reservoir is one of an important ecosystem in Peninsular Malaysia. Since 1960’s, this reservoir has evolved from natural ecosystem to human-dominated ecosystem. 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 (Figure 1). The morphology provides significant information about the physical characteristics of the reservoir (table 1). The reservoir area is 7.7547 km with an estimated storage capacity of 24.84 million m3, while the catchment area is about 130 km2.The land use has changed extensively with the increase of agricultural activities covering 8% (1984) to 82% in 2010 in the area around the study site until the study is conducted.

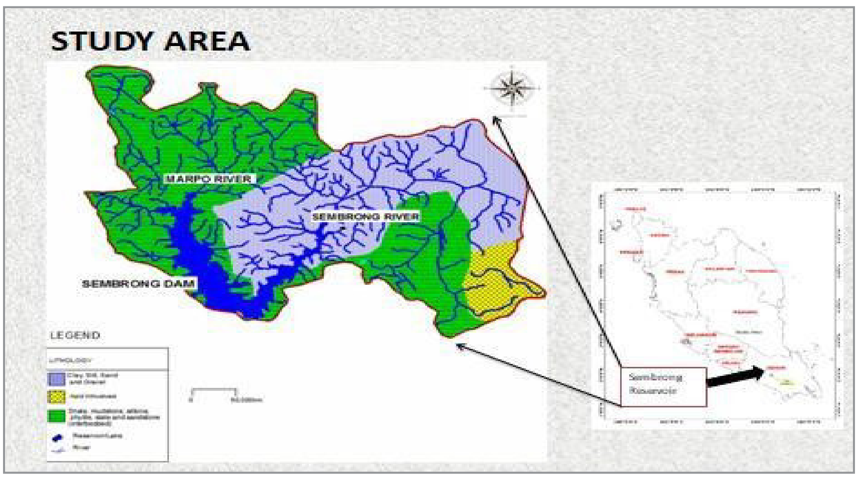

Figure 1: Hydrogeological map of Sembrong Reservoir. Modified from Department of Minerals and Geoscience Malaysia (2008)

Table 1: The physical characteristics of Sembrong catchment

No.	Parameter	Result
1.	Lake area (km2)	7.7547
2.	Volume (km3)	36
3.	Maximum depth (m)	7
4.	Mean depth (m)	3.2
5.	Mean slope (%)	4
6.	Height (m)	9
7.	Catchment's area (km2)	130
8.	Storage capacity (million m3)	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 [23,24]. This sample was then taken to the Radiochemical and Environmental Laboratory (RAS), Nuclear Malaysia for the process of drying, sieving and counting. Before the samples are counted using gamma spectrometry, first all samples need to be dried first by using an oven at a temperature of 45 - 60 ºC for several days until the weight becomes constant or stable. And next, the sample that has become completely dry is then ground until fine and sieved at 2 mm using a sieve before the sample is transferred and packed into a 250 ml Marinelli beaker to undergo the 137Cs analysis.

Measurements of 137Cs Radioactivity in Soil and Sediment Sample

Measurements of 137Cs will be carried-out by using gamma spectrometry utilizing high-purity Germanium (HPGe) detector with relative efficiency of 28%. The detector will be calibrated for the selected measuring geometries and different soil densities by standard calibration samples. The gamma spectra are analysed using dedicated computer software provided by the manufacturer. Due to expected low 137Cs concentrations in the samples, the count time will be set to long counting hours (>20 h) per sample, in order to achieve a measurement precision of better than 10% at the 95% level of confidence. [11] noted and suggested that more counting time were needed to detect the fallout activity from all samples such as 137Cs and commonly in the range of 29000 to 55000s because of the low activity in the fallout samples. The 137Cs detection limit for this measuring time is estimated to be approximately 0.3 Bq/kg for the Marinelli geometry.

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 [20]. 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 [20]. Meanwhile, the 137Cs concentrations or activity from the samples was calculated using equation as below:

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

where N was the net count under the peak of 662 keV gamma line energy that characterized 137Cs (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), pγ was the absolute probability transition for 662 keV keV gamma line for 137Cs .Meanwhile, m and t were the mass and time of counting in minutes or second for 137Cs 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 spectrometry.

Meanwhile, 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 m2), which two types of inventories will be used for comparing;

- 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 the Proportional Model [25] and is based on the premise that 137Cs fallout inputs are completely mixed within the plough or cultivation layer and that the soil loss is directly proportional to the reduction in the 137Cs inventory due to loss of soil from the soil profile, since the beginning of 137Cs accumulation or the onset of cultivation. The proportional model used to estimate soil erosion rate in tonnes/hectare/year is based on the premise that 137Cs fallout inputs are completely mixed within the plough or cultivation layer and that the soil loss is directly proportional to the reduction in the 137Cs inventory due to loss of soil from the soil profile, since the beginning of 137Cs accumulation or the onset of cultivation, whichever is later. Thus, if half of the 137Cs input has been removed, the total soil loss over the period is assumed to be 50% of the plough depth. The model can be represented as follows:

BdX

Y = 10

Where: 100*TP*

Y = mean annual soil loss (t/ha/yr);
d = depth of the plough or cultivation layer (m);
B = bulk density of soil (kg/m3);
X = percentage reduction in total 137Cs inventory (defined as (Aref-A)/Aref×100);
T = time elapsed since the initiation of 137Cs accumulation or the commencement of cultivation, whichever is later (w/yr);
A ref = local 137Cs reference inventory (Bq/m2);
A = measured total 137Cs inventory at the sampling point (Bq/m2);
P = particle size correction factor for erosion (P=1).

Results and Discussion

Table 2 shows the overall results of the analysis of soil erosion and sedimentation rates from twenty (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 has given 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. Soil erosion rates have given values between 5.09 t/ha/y to 65.2 t/ha/y throughout for both seasons. Meanwhile, the value of soil erosion and sedimentation in the rainy season is 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. Station 10 and station 11 have recorded the highest erosion rate values when compared to station 14 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. This can be clearly seen that the difference in value between the highest and lowest values is not as great as any and it is likely due to the variety of soil that plays such an important role especially in the process of soil erosion. Meanwhile, station 17 and station 1-3 also gave the second and third highest soil erosion values from this study. However, these two values are not significantly different when compared to the highest value recorded.

The dry season has provided overall erosion values and no sedimentation values were recorded for all study stations. However, the wet season has provided both erosion and sedimentation values. The sedimentation value given is in the range of -4.81 t/ha/y to -50.81 t/ha/y, respectively. Meanwhile, the soil erosion rate in the wet season gives a slightly lower value when compared to the dry season and 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. In addition, this situation has also allowed such rainwater to compete to penetrate the soil surface level and further cause it to become softer and subsequently the incidence of soil erosion becomes higher than usual.Station 4 and station 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. Station 4 and station 6 are areas that are overgrown with new oil palm plantations and is likely to enhance more sedimentation events in this area due to the lack of palm oil leaves to cover or prevent the amount of rain 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	Oil palm plantation	11.06	-7.88
Station 9			
Station 10	Mixed crop	65.2	29.78
Station 11			
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	Forest	18.11	23.92
Station 20			

Note: (-) values indicate sedimentation

Meanwhile, Station 14 is an agricultural area that carries out modern agricultural activities and further provides soil erosion rate values that are not significantly different from each other. 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 station 19 and station 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, station 13 and station 18 shows a difference in the rate of soil erosion in these two stations. The dry season has given a high soil erosion rate when compared to the wet season. This kind of situation occurs due to the rain factor received together with the number of livestock stars released both seasons to graze grass in the UK's Farm area. Oil palm plantation is a land use area that is so wide when compared to all the study stations. This situation may be due to the fact that oil palm plantations in these two areas are still new planting areas. This allows the rainfall received in both seasons to continue to penetrate into the soil and in turn cause greater erosion and sedimentation. Various factors must 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 also been reported by in the Timah Tasoh study area in determining the rate of soil erosion and sedimentation. [11] have reported that the total amount of annual erosion of the cliffs at Sungai Tasoh is the highest at 348.76 tonnes (1.38%), Sungai Pelarit Hilir is 25.64 tonnes (0.68%), Sungai Jarum is 55.45 tonnes (0.55%), Sungai Chuchuh is 12.58 tonnes (1.18%) and Sungai Pelarit Hulu is 17.41 tonnes (0.27%). It was also reported by in the same area giving erosion and sedimentation rate values that are not very different by using the short and medium term FRNs approach as 7Be and 137Cs. Meanwhile, the rate of soil erosion and sedimentation from this study is not much different when compared to the previous study in Timah Tasoh, Perlis [19-21]. The rate of soil erosion and deposition in this study is still considered very small 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/yr and 15 Mg/ha/yr, respectively [26].

Conclusions

The results presented in this paper are evaluated to confirm the potential to use 137Cs as a tracer in the investigation of soil erosion and sedimentation. By providing estimates of land redistribution rates related to erosion events in two different seasons for all samples for the medium-term period throughout the study period. 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 at station 10/11 and station 14, which are the highest and lowest soil erosion rate values for both two seasons. Meanwhile, the value of soil erosion and sedimentation in the rainy season is 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. Thus, the difference in the rate of soil erosion between the highest and lowest values is not that significantly great 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 study site. However, the rainy season has provided both soil erosion and sedimentation rate values of - 4.81 t/ha/y to - 50.81 t/ha/y, respectively. Meanwhile, the rate of soil erosion in the rainy season gives a slightly lower value when compared to the dry season in some study stations. Nevertheless, the value of the analysis results from this study is not much different from the study that has been reported by in the Timah Tasoh study area. However, it is relatively small in value when compared to 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/yr and 15 Mg/ha/yr, respectively [19-21, 26]. As a conclusion, 137Cs 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.

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