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The Use of Beryllium-7 as a Tracer In-Depth Penetration Study

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Abstract

This paper aims to study the depth penetration into the soil surface by Fallout Radionuclides (FRNs) as tracers. This approach is still not widely used in soil penetration studies until now and Beryllium-7 is used entirely as a short-term tracer in this study. Thus, in order to confirm the use of this tracer, a study was conducted in the catchment area of Timah Tasoh, Perlis which was selected as study site for both the rainy and dry seasons. This study involves taking soil samples by using a metal corer and taken to the Radiochemistry and Environment Laboratory (RAS), Nuclear Malaysia to carry out further procedures such as the preparation and finally the analysis data obtained from the analysis using Gamma Spectrometry counting system, consists of Hyper-Germanium detector (HPGe). Based on the analysis results shown in table 1, the depth penetration values in the study site area of Timah Tasoh has given different results as a whole for two seasons. The distribution of soil depth profile onto the soil surface or ho values are varying between 2.98 - 4.98 kgm-2 and 3.57 - 5.57 kgm-2 for dry and wet seasons, respectively. The value from this study is also not much different in the value of depth penetration distribution with some study that has been carried out by other. As a conclusion, Beryllium-7 which acts as a short-term tracer has been successfully used to determine the value of depth penetration into the soil surface in different seasons study.

Keywords: Aims, Depth Penetration, Beryllium-7, Gamma Spectrometry, Results

Introduction

Malaysia has an equatorial climate because of its location between the equatorial latitudes 0° - 10° U and 0° U – 10° S. Thus, there is a distinct pattern of rainy and hot seasons throughout the year with a high relative humidity between 10% and 90% depending on location and month. Meanwhile, the pattern of rainfall on the west coast of Peninsular Malaysia is characterized by the occurrence of 'Sumatra' in May to August and the range of maximum and minimum variety does not exist. October and November are the months with maximum rainfall, while February is the month with minimal rainfall. Furthermore, the dry season often occurs early in the year, during January until early March with an average rainfall of 34 mm per day. However, rainfall is not exhaustive throughout the dry season as some places receive relatively high rainfall in January.

Meanwhile, the term "environmental isotope" refers to the isotopes that are usually widely distributed in the environment or in the landscape. In most cases, these isotopes are naturally occurring but in some cases is a man-made. It is also known as Fallout Radionuclides (FRNs) such as 137Cs, 210Pbex and 7Be which have been widely used as tracer sediments in soil erosion studies and sedimentation by scientists all over the world. 137Cs is a man-made isotope that is widely used as a sediment tracer and its half-life is 30.2 years. It is formed into the atmosphere through thermonuclear weapons during the period extending from the mid-1950s to the 1960s. Naturally derived 210Pb (Pb-210, half-life 22.2 yr), another relatively long-lived fallout isotope, is adsorbed by soil particulate material and subsequently redistributed within the landscape in a manner similar to 137Cs, but its potential as a tracer for studying soil redistribution has to date received only limited attention [1, 2].

Radium-226 exists naturally in soils and rocks. The 210Pb in soils generated in situ by the decay of 226Ra is termed supported 210Pb and is in equilibrium with 226Ra. On the other hand, upward diffusion of a small portion of the 222Rn produced in the soil and rock introduces 210Pb into the atmosphere, and its subsequent fallout provides an input of this isotope to surface soils and sediments that will not be in equilibrium with its parent 226Ra [3]. Fallout 210Pb is commonly termed as unsupported or excess 210Pb when incorporated into soils or sediments in order to distinguish it from the 210Pb produced in situ by the decay of 226Ra. The amount of unsupported or atmospherically derived 210Pb in a soil or sediment sample can be calculated by measuring both the 210Pb and 226Ra activities and subtracting the 226Ra supported 210Pb component from the total 210Pb in the sample.

7Be is a naturally occurring radionuclide that is produced by the bombardment of the earth's atmosphere by cosmic radiation [4]. 7Be, a radioactive isotope, with a half-life 53.29 days is produced when nuclear spallation processes interact with oxygen and nitrogen in the upper troposphere and lower stratosphere [5]. Existing studies have shown that about 70 % of 7Be is produced in the stratosphere, whilst ca, 30% is still produced in the troposphere. 7Be is normally removed from the troposphere by wet and dry deposition. Scavenging (washout) normally occurs during the early stages of precipitation events and quickly cleanses the lower troposphere of 7Be as bearing aerosols [6]. In meantime, evidence indicates that about 90% of total 7Be deposition in temperate zones generally takes place through the wet deposition process [7-13]. The Be2+ ion as the main component in the 7Be reaches the soil surface primarily as the Be2+ ion, which is extremely competitive for cation exchange sites due to its high charge density [14]. Furthermore, 7Be is rapidly and strongly absorbed by soil particles in most environments [15].

The studies of 7Be deposited at the soil surface and have demonstrated that it is predominantly retained in the uppermost of the soil layers have been reported by other scientists [16-21]. The objective of this study was to examine the 7Be penetration onto the soil surface within two seasons of different agricultural activity areas. Moreover, the 7Be has been shown to offer considerable potential to provide information over shorter timescales in depth distribution study.

Material and Methodology

Soil Sampling and Preparation of Samples

Sampling activities for this study have been carried out in the Timah Tasoh catchment area involving the rainy and dry seasons from October 2015 to March 2016. This study has identified Timah Tasoh as a suitable study site because it is a small catchment area located in State of Perlis, Northern Peninsular Malaysia on diversity that has been considered. It is located approximately 13 km north of the city of Kangar close to the Thai border (6° 36'N and 100° 14'E) with an average surface area of 13.33 km2 and a water storage capacity of approximately 40 million m3 surrounded by diverse land uses such as planting sugarcane, rubber trees, paddy, forest reserves and mixed crops (Figure 1).

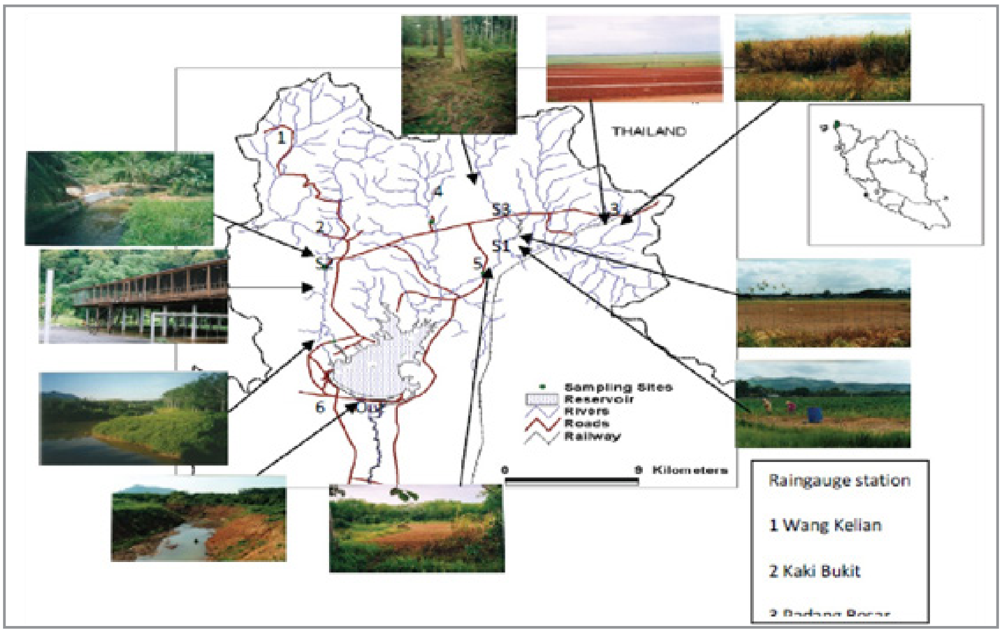

Figure 1: The study sites and land use activities around the Catchment Area

This sampling activity has taken a total of sixteen (16) core soil samples from four different land uses using a metal corer. All core soil samples that have been sliced to increments of 2 mm to the inner 4 cm and taken to the Laboratory of the Radiochemical and Environmental Group (RAS), Nuclear Malaysia in Bangi, Selangor for further treatment (figure 2). All processed samples were put into a 250 ml Marinelli beaker for counting using Gamma Spectrometry.

Figure 2: Soil core sample in the plastic core is ready to slice

Counting of ^{7}Be in Soil Samples
Sample counting using Gamma Spectrometry for 24 hours with a detection efficiency of 20% considering the uncertainty value of each sample. The uncertainty of each sample as calculated as a detector error γ at 95% confidence level is in the order of ± 10%. 7Be activity in the soil sample was done using a Gamma Spectrometry counter consisting of a Hyper-Germanium (HPGe) detector, taking 86400 seconds or 24 hours of counting time. Considering the energy of 7Be, is 477.6 KeV as well as 20% detector efficiency with uncertainty for each sample as calculated as γ – detector counting error at 95% confidence level is in the order of ± 10%. The 7Be 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 477.6 keV gamma line energy that characterized 7Be (in counts), ε was the efficiency of the detection system for the 477.6 keV gamma line energy (in counts. Bq-1. s-1) obtained from equation 1, pγ was the absolute probability transition for 477.6 keV gamma line for 7Be.

Furthermore, the detector efficiency calibration can be calculated or defined as:

$$f(M_0) = (C_0/T_0 - C_b/T_b) \text{ x } (1/M_0 \text{ x } A_0 e^{-\lambda(t+t)}) \quad {}_0$$

where f is the activity efficiency of the detector, which is defined as the efficiency τ (emission rate) multiplied by the r (emission probability of the gamma ray), Mo is the standard mass in kg, Co is total counts, Cb is the background of an unspiked sample, To is time count for the sampling was being counted, Tb is the corresponding background count time, and λ is the decay constant of the radionuclide, which can be defined as:

$\lambda = \ln_2/T0.5$

where T0.5 is the half-life for the radionuclide. Meanwhile, using the model by [22-24]. which can be assumed and characterized the depth distribution of 7Be in the soil by an exponential function. The depth distribution of 7Be is represented by an exponential decline with depth,

$C(x)=ce^{(-x/h0)}$

Where C(x) is the mass activity density of 7Be at mass depth x, Bqkg-1, h0 is the coefficient describing profile shape kgm-2 and also known as the relaxation mass depth. If the value of h0 increases, the penetration of the 7Be can be assumed to be greater into the soil profile depth.

Results and Discussion

The analysis results of the depth increment (cm) for 7Be two seasons for all sixteen (16) samples taken in this study are shown in Table 1 and Fig.3. Overall, it shows that the penetration of 7Be decreases exponentially the decay in the soil depth as presented in the literature [21, 25]. The depth penetration of 7Be to the soil surface was absorbed more than 2 centimeters (cm) for both seasons except for mixed crops and the value of the respective depth increase varied between 1.2 cm to 2.8 cm for both seasons. However, all the values of the results from this study are not significantly different from the analysis results that have been reported by others [16-19, 20, 21, 25, 26]. Moreover, the dry season have yielded the lowest and highest depth increment over a period of sampling is carried out in the rubber tree and mixed crop plantation area which that 1.2 cm and 2.8 cm, respectively. The value of the difference between these two results is due to various factors that need to be considered such as the type of soil, rocks, 7Be concentration, frequency of rain and the volume of rainwater received throughout the two seasons of the study.

Table 1: The ho (kgm-2) and depth increment (cm) values in different land use

Land Use	ho value (kgm-^{2})		depth increment (cm)	
	Dry season	Wet season	Dry season	Wet season
1. Sugar cane	4.98	5.57	2.2	2.6
2. Rubber tree	5.12	5.45	2.8	2.2
3. Forest	2.98	3.57	2.4	2.6
4. Mixed crop	4.65	4.21	1.2	1.6

The results of the distribution of soil depth profile onto the soil surface or ho value of the four land uses are shown in table 1 and Figure 4. Thus, the results that vary between the two study seasons are 2.98 - 4.98 kgm-2 and 3.57 - 5.57 kgm-2, each respectively. The results have shown that the value of ho in the dry season is lower when compared to the wet season for all land uses except in the mixed land use area. However, where the value is higher in the dry season when compared to the wet season, 4.65 kgm-2 and 4.21 kgm-2. It may be due to the relatively low concentration of 7Be in rainwater which has a high volume and can then seep into the soil surface during the rainy season when compared to the dry season. However, some other factors such as the type of soil where there is likely to be a stony soil content in the mixed crop area that can cause some obstacles for more rainwater percolation to occur on the soil surface. This is reinforced by the statement of previous studies saying that sand-sized particles can be characterized as having relatively high 7Be activity [27]. On the other hand, the ho value in the rubber tree area has given both values above 5.0 kgm-2 for both seasons which are 5.45 kgm-2 and 5.12 kgm-2.

Furthermore, the two values of ho are not significantly different even though the frequency of precipitation occurs in the wet rainy season compared to the dry season and certainly the difference in how value between the two is not that significant (p value > 0.05). This situation is possible due to the factor of newly planted rubber trees and causing the 7Be contained in the rainwater to fully absorb to the ground surface without any obstacles such as the size of the leaves acting as a canopy. However, it did not happen in the ho value forest area where the two seasons of ho yield did not show very different values and were even recorded as the lowest values for all land uses in the study site, recording kgm-2 and 3.57 kgm-2 each respectively.

The depth penetration of 7Be or the h0 value from the overall results of this study is slightly higher when compared to the study reports in Valdivia, Chile and Brazil 1.28 to 2.15 kgm-2, respectively [26],. The forest covers almost part of the Timah Tasoh area and it is a canopy that is the top of the land of a plant or plant community. Shade trees usually have a solid canopy that blocks sunlight and rains reach to lower vegetation or ground level. This has caused most rainwater that brings together the content of 7Be inhibited penetrations into the soil surface during the wet and dry seasons.

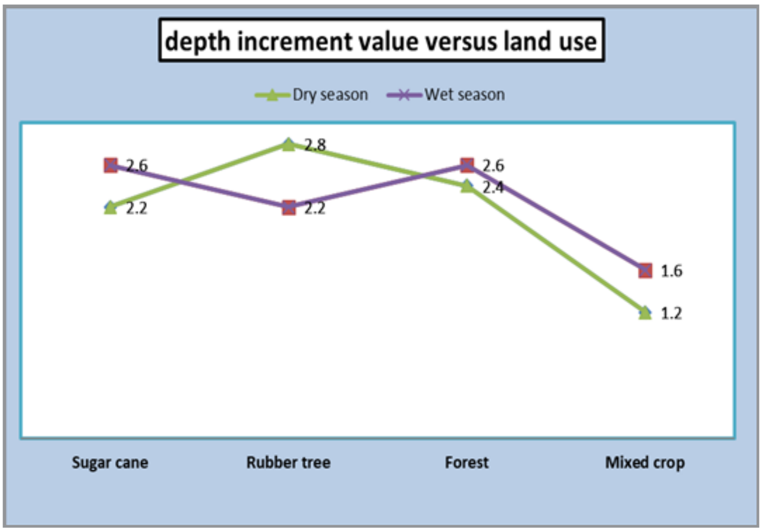

Figure 3: The depth increment (cm) versus land uses in two seasons

The depth increment also plays an important role in determining the ho values that are found to be different for this study as shown in Table 1 and Figure 3. The highest and second highest ho values are records recorded from sugar cane and rubber tree planting areas for the rainy season from depth increments of 2.6 and 2.2 cm. Nevertheless, the value of ho and depth increment decreased in the dry season for all land uses except mixed crop and it is possible that this change occurred due to the frequency of rain that contained a higher concentration of 7Be cations before. This has caused the soil surface to become more saturated with Be^{2+} cation concentration content and the strong gravity pull allows more penetration of 7Be concentration exponentially deeper with depth and vice versa does not occur during the dry season in addition to the relatively short life span of ^{7}Be.

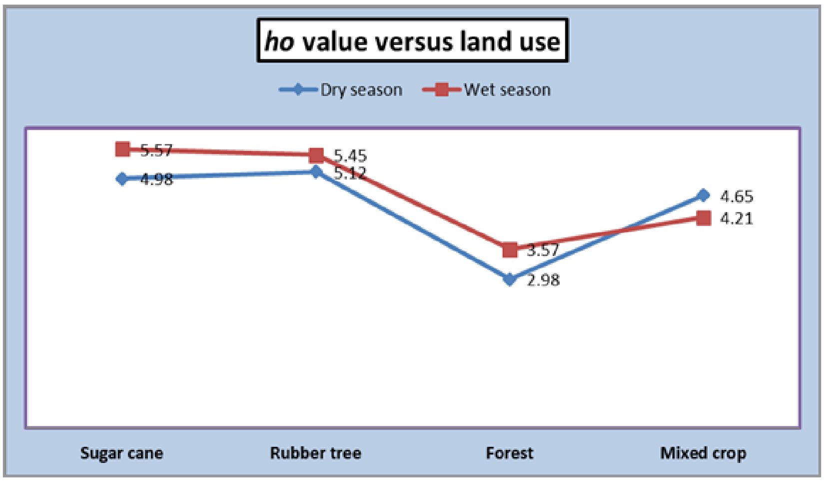

Figure 4: ho (kgm-2) value versus land uses in two seasons

Conclusion

As a conclusion, the depth distribution of 7Be from this study for all land uses for both seasons has decreased exponentially with depth and is limited in the top few centimetres and similar to other work has been reported. Meanwhile, this study also found that the value of h0 and the increase in depth were not completely affected by the two seasons during the study period although there was a slight difference that was not significant. This study was found to give a slightly higher ho value than in Valdivia, Chile and Brazil. However, a more extensive study in the future, especially in the addition of the study area, needs to be carried out to obtain more and complete analysis data to enable it to be used as future comparison data.

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