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STUDY OF RADIONUCLIDES LINKAGES BETWEEN FISH, WATER AND SEDIMENT IN FORMER TIN MINING LAKE IN KAMPUNG GAJAH, PERAK, MALAYSIA

(Kajian Mengenai Hubungan Radionuklid di antara Ikan, Air, dan Sedimen dalam Tasik Bekas Lombong di Kampung Gajah, Perak, Malaysia)

Ahmad Saat [1,2], Norannisak Muhd Isak[1]*, Zaini Hamzah[1], Ab Khalik Wood[1]

[1]*Faculty of Applied Sciences,*
[2]*International Education Centre (INTEC),*
Universiti Teknologi MARA, 40200 Shah Alam, Selangor, Malaysia

**Corresponding author: nysa_chy@yahoo.com*

Abstract

Tin mining activities not only released metal contaminants into environment, but also radionuclides into the native soil and sediment. There is a possibility that radionuclides be transferred between sediment, water and biota as a result of exchanges between them through biological, physical and chemical processes. Fishes from former tin mining lakes in Kampung Gajah, have become main sources of protein supplies and economic profit to the local resident. The present study is to determine linkages between activity concentrations of natural radionuclides in biota (fish), water and sediment in one of the former tin mining lake. The study involved analysis of radionuclides in water, edible part of fish and sediment. Filtered and unfiltered water samples collected from the study area were filled into marinelli beakers, sealed and count using gamma spectrometry. Fish and sediment samples prior to measurement were dried, grind and sieved through 250 µm and kept in special container for measurement of radionuclides activity concentration using gamma spectrometry. The range of transfer ratio of ^{226}Ra, ^{228}Ra and ^{40}K from unfiltered water samples to fish are 1.95 to 3.42, 0.86 to 2.70 and 12.63 to 18.69, while, for sediment to fish are from 1.30 to 2.27 x 10^{-2}, 0.43 to 1.13 x 10^{-2} and 9.08 to 13.45 x 10^{-2} , respectively. Transfer ratio of ^{226}Ra, ^{228}Ra and ^{40}K from sediment to unfiltered water is 7.00 x 10^{-3}, 4.26 x 10^{-3} and 7.30 x 10^{-3}, respectively. This present study shows that there is transfer for radionuclides from water to fish, sediment to fish and lastly sediment to water column.

Keywords: radionuclides, sediment, water, fish, tin mining lake, gamma spectrometry

Abstrak

Aktiviti perlombongan bijih timah bukan sahaja mengeluarkan pencemaran logam kepada alam sekitar, tetapi juga radionuklid ke dalam tanah dan sedimen. Radionuklid mungkin dipindahkan antara sedimen, air, dan biota akibat pertukaran antara mereka melalui proses biologi, fizikal dan kimia. Ikan dalam tasik bekas lombong bijih timah di Kampung Gajah menjadi bekalan sumber utama protein dan sumber kewangan kepada penduduk tempatan. Kajian ini menentukan hubungan antara kepekatan aktiviti radionuklid tabii dalam sedimen, air dan biota (ikan) dalam satu tasik bekas lombong bijih timah. Kajian ini melibatkan radionuklid analisis dalam air, ikan dan sedimen .Sampel air yang dituras dan tidak dituras yang diambil dari tempat kajian diisi di dalam bekas marinelli yang ditutup rapi dan diukur menggunakan spektrometri gama. Sampel ikan dan sedimen dikeringkan, dikisar dan diayak dengan 250 µm dan disimpan di dalam bekas khas untuk mengkaji kepekatan aktiviti menggunakan spektrometri gama. Julat nisbah pindahan masing-masing daripada sampel air yang tidak dituras kepada ikan ialah 1.95 hingga 3.42, 0.86 hingga 2.70 dan 12.63 hingga 18.69 dan bagi sedimen kepada ikan ialah 1.30 hingga 2.27 x 10^{-2}, 0.43 hingga 1.13 x 10^{-2} dan 9.08 hingga 13.45 x 10^{-2}. Nisbah pindahan masing-masing bagi ^{226}Ra, ^{228}Ra and ^{40}K daripada sampel sedimen kepada air yang tidak dituras ialah 7.00 x 10^{-3}, 4.26 x 10^{-3} dan 7.30 x 10^{-3}. Kajian ini menunjukan bahawa terdapat pemindahan bagi radionuklid daripada air ke ikan, sedimen kepada ikan dan akhirnya sedimen ke air.

Kata kunci: radionuklid, sedimen, air, ikan, tasik lombong bijih timah, spektrometri gama

Introduction

Malaysia was once been the world's largest tin producer by the end of the 19th century [1]. The factors that contributed to the success were discovery of rich tin fields in Perak and Selangor as well as high demand in market at that time [1]. However, depletion in tin deposits and decreasing in demand of tin in the world market, the tin mining activities has ceased operation about 30 to 40 years ago [2] which lead Malaysia nowadays to produce less than 1.5% of total world production [1]. As a result, the mining areas now are left with many abandoned lakes, which later have found secondary land uses in the form of aquaculture and vegetable cultivation plots [2, 3, 4]. The abandoned areas are also naturally rich with varies fresh water fish species that become the main sources of protein to local residents. However, some of them have still left abandoned.

The tin mining activities had left tin ores residue, quartz sand and certain minerals such as monazite, ilmenite, zircon and xenotime in the industry byproduct in the form of 'amang' (tin tailings) [5]. Monazite and xenotime are two minerals rich in natural radionuclides, particularly uranium, thorium and potassium [3, 5]. The natural radionuclide can be accumulating into the environment. The hyper-accumulation may become toxic and will affect the surrounding living organisms [6].

According to Suresh *et al*., [7], sediment is a basic indicator of radiological contamination as it plays a dominant role and also can plays role in accumulating and transporting contaminants within the geographic area. Hence it is useful in aquatic radioecology study. The water and biota in the former tin mining lake also can contain natural radionuclides due to interaction of chemical, physical and biological processes with sediments, in which the amount of the natural radionuclides in materials determined by their respective exchanges processes.

Fishes from this mining lake can pose health risk to human due to the natural radionuclides that have been accumulated in fish' body via food chain [4, 8]. The present study was carried out to determine the activity concentration of ^{226}Ra, ^{228}Ra and ^{40}K in some of fish species (biota). The activity concentration in water and sediment samples from the area were also determined in the representative sites of the lake with the final aim to determine the radionuclide linkage in water, sediment and fish.

Materials and Methods

Sampling site

The study area is located at Kapal 7 Lake. It is one of the former tin mining lakes in Kinta Valley in the State of Perak, Malaysia. The size of lake is about 0.5 km x 1.5 km. The deepest part is about 40 m near the center of the lake. There are four small islands located near the centre of the lake. The uniqueness of this lake is the water in Kapal 7 Lake is connected to Sungai Kampar on the west side and Air Hitam Lake on the east side via water channel which allowed the water to flow in and out in two ways under certain condition. Besides, there are palm oils that have planted along east side of the lake. Table 1 shows the latitude, longitude (measured by using global positioning system (GPS)) and water depth of sampling locations for water and sediment. The water depth at most locations ranged between nearest 9 to 10 m.

Table 1: The coordinate for sampling locations

Location	Latitude	Longitude	Water depth (m)
KT1	N 04º 12.537'	E 101º 02.631'	9
KT2	N 04º 12.527'	E 101º 02.517'	10
KT3	N 04º 12.568'	E 101º 02.339'	10
KT4	N 04º 12.556'	E 101º 02.215'	10
KT5	N 04º 12.419'	E 101º 02.179'	10

Physical and chemical water quality was measured *in situ* for some parameters (temperature, specific conductivity, total dissolved solid, salinity, dissolved solid and pH) using calibrated YSI multi sensor probe, while, the turbidity (Table 2) was measured using calibrated turbidity meter.

Sampling collection and preparation

Eight species of fish were collected as representative of biota sample including Jelawat (*Leptobarbus hoevenii*), Lampam (*Puntius schwanenfeldii*), Patung (*Pristolepis fasciatus*), Raja (*Cichla monoculus*), Terbui (*Osteochilus hasselti*), Tilapia (*Oreochromis mossambicus*), Toman (*Channa micropeltes*) and Tongsan (*Aristichthys nobilis*). As far as possible, for each species samples of the same size were used. Before analysis, the edible flesh of fish samples were separate from the non-edible parts and oven dried at 60°C until constant weight was obtained. Then the samples were pulverized and sieved through 250 µm sieves. About 500 g were packed into special container (height (~90 mm) and diameter (~83 mm)) and sealed properly.

The water samples were collected 1 meter below the water surface using grab sampler and transferred into plastic container that have been rinsed with acid nitric and distilled water, respectively. Water samples were acidified using 6 M nitric acid to pH 2 to stabilize the water [9]. Then samples were divided into two portions which are filtered and unfiltered water samples in order to determine the dissolved and suspended solid. Cellulose membrane nitrate filter 0.45 µm was used for filtering the samples [9]. The water samples (filtered and unfiltered) were transferred into the marinelli beaker and sealed properly prior to gamma counting using gamma spectrometer system.

Sediment cores were collected by using manual gravity corer with PVC core tube of 45 mm inner diameter. Sediment samples in PVC core tube were left air-dried in vertical position for about 3 to 4 weeks to obtain the shape of PVC column [10]. To form homogenous sample for each locations, the cores were sub-sampled by slicing it into 2 cm and mixed with other cores of the same depth. The first two top layers were used for analysis of radionuclides in surface sediments. The aggregates were oven dried at 60˚C until constant mass, pulverized and sieved through 250 µm sieves and seal properly into a special plastic container (height ~20mm and diameter ~50 mm) [10]. All samples were kept for 21 days, to establish secular equilibrium between ^{226}Ra and ^{228}Ra and their respective radioactive progenies prior to gamma counting.

Measurement of ^{226}Ra, ^{228}Ra and ^{40}K

The measurement of activity concentrations of radionuclides for all samples were done by using ORTEC® gamma rays spectrometer with HPGe detector with resolution 1.84 keV, 25% relative efficiency at 1332 KeV ^{60}Co gamma ray and couple to Multi Channel Analyser (MCA) [11]. The measurement is possible by assuming secular equilibrium between parents and various daughters were achieved after about 21 days [11]. Since ^{226}Ra is an alpha emitter with weak gamma line, the measurements of ^{226}Ra are based on radon daughters of either ^{214}Bi or ^{214}Pb [11]. In this study, ^{214}Bi were selected for measurement of ^{226}Ra activity concentration due to higher intensity compared with ^{214}Pb. Meanwhile the ^{228}Ra was measured by determining the activity of ^{228}Ac [11]. The ^{226}Ra, ^{228}Ra and ^{40}K activity concentration were determined based on 609, 911 and 1460 KeV gamma ray, respectively. The fish and sediment samples were counted for 4 hours (14400s) while, 8 hours (28800s) for filtered and unfiltered water samples. The efficiency calibration was made by using secondary standard prepared by mixing known amount UO_3 and KCl in the same container of the same geometry as samples [11].

Results and Discussion

The data generated in this research include water quality parameters, activity concentrations of ^{226}Ra, ^{228}Ra and ^{40}K in edible part of the selected biota (fish), water and sediment. From these results, the radionuclides linkages in fish-water-sediment system were determined. The physical and chemical water quality parameters that have been measured on-site during the sampling are shown in Table 2. Generally in all sampling locations, the temperature is in the ranged of 29.89°C to 31.67°C [12]. It is important to note that the water temperature is varies depending on the weather at a particular time. The pH values are in general close to neutral and its comparable with others study as Samudi *et al.,* [4] which stated that the pH ranged is 7.21-7.92 in former tin mining water at Puchong, Malaysia. Specific conductivity value is ranged from 155 to 225µS/cm. The total dissolved solid and turbidity are in the range from 0.090 to 0.134 mg/L and 2.50 to 6.89 NTU respectively, which indicated that the amount of suspended solid in water is low. Total suspended solid is in the range of 1.92 to 8.40 mg/L which is 0.45 µm. Meanwhile, dissolved oxygen is ranged from 6.96 to 11.15 mg/L which allowed the aquatic organisms and plants to live. The reading of salinity is low which is on average of 0.08 mg/L. According to Zaini *et al*., [9], in low salinity environments radium is strongly adsorbed on water molecules of surfaces water. Generally, the physical water quality parameters in this study are comparable with other studies by Samudi *et al*., [4] and Zaini *et al*., [12]. The *in-situ* parameter in Table 2 shows that most of the parameter falls into Class I (practically no treatment necessary) while certain parameter falls into Class IIA (conventional treatment required) based on National Water Quality Standard, NWQS (DOE, 2008) [13].

Table 2: Water Quality Parameters measured in Kapal 7 Lake

Location	**Temp (°C)**	**Sp C (µS/cm)**	**TDS (mg/L)**	**Salinity (mg/L)**	**DO (mg/L)**	**pH**	**Turbidity (NTU)**	**TSS (mg/L)**
KT1	29.9	225	0.13	0.10	6.96	7.10	4.24	1.92
KT2	30.0	187	0.11	0.08	8.61	7.21	4.55	2.83
KT3	30.0	193	0.11	0.08	11.15	6.98	6.89	7.00
KT4	31.6	190	0.11	0.08	10.94	7.81	3.16	2.85
KT5	31.7	155	0.09	0.06	10.36	7.16	2.50	8.40
*NWQS	-	I	I	IIA	IIA	I	IIA	I

*National Water Quality Standard (NWQS)

The activity concentrations of radionuclides in edible part of fish flesh samples in Jelawat (*Leptobarbus hoevenii*), Lampam (*Puntius schwanenfeldii*), Patung (*Pristolepis fasciatus*), Raja (*Cichla monoculus*), Terbui (*Osteochilus hasselti*), Tilapia (*Oreochromis miloticus*), Toman (*Channa micropeltes*) and Tongsan (*Aristichthys nobilis*) are shown in Table 3. The results, the ^{226}Ra, ^{228}Ra and ^{40}K activity concentration are higher in Tongsan, Patung and Toman species which is 5.67 ± 0.47, 4.48 ± 0.63 and 239.7 ± 8.6 Bg/kg, respectively. Meanwhile, the lowest activity concentrations of ^{226}Ra, ^{228}Ra and ^{40}K are in Jelawat, Toman and Tongsan species which is 3.24 ± 0.36, 1.42 ± 0.37 and 161.9 ± 6.9 Bg/kg, respectively. The differences between activity concentrations of radionuclides in various edible fish flesh samples from the same lake indicate that there are different amount of radionuclides uptake depending on fish species. In addition, the water chemistry, the physiology of fish which included the feeding behavior and their digestion of food may also affect the amount of radionuclides accumulated in their body [13]. In all fish species, activity concentrations of radionuclides is of the order ^{228}Ra < ^{226}Ra < ^{40}K. This may due to the amount of ^{238}U parent of ^{226}Ra is higher than ^{232}Th parent of ^{228}Ra in edible parts of fish.

Table 3: Activity concentrations of radionuclides in fish samples

Fish (local name)	**Activity concentrations of radionuclides (Bg/kg)**		
	^{226}Ra	^{228}Ra	^{40}K
Jelawat	3.24 ± 0.36	1.71 ± 0.39	172.9 ± 7.1
Lampam	4.66 ± 0.42	2.08 ± 0.42	169.4 ± 6.9
Patung	3.48 ± 0.37	4.48 ± 0.63	178.1 ± 7.1
Raja	4.13 ± 0.40	3.93 ± 0.59	184.3 ± 7.3
Terbui	4.70 ± 0.43	3.26 ± 0.54	209.1 ± 7.9
Tilapia	3.84 ± 0.40	3.70 ± 0.59	216.8 ± 8.2
Toman	3.80 ± 0.40	1.42 ± 0.37	239.7 ± 8.6
Tongsan	5.67 ± 0.47	3.51 ± 0.56	161.9 ± 6.9

Table 4 shows the activity concentrations of radionuclides in water samples for filtered and unfiltered water. The average of activity concentration of ^{226}Ra, ^{228}Ra and ^{40}K in all locations is 1.66 ± 0.30, 1.66 ± 0.46 and 12.82 ± 2.26

Bg/kg for unfiltered water samples, while, for filtered water samples is 1.25 ± 0.26, 0.73 ± 0.32 and 10.63 ± 2.04 Bg/kg, respectively. The activity concentration of radionuclides in filtered water samples is less than in unfiltered water samples. This may explain that some of the radionuclides had been adsorbed to the surface of suspended solid in water. The amount of ^{228}Ra attached to suspended solid is higher than ^{226}Ra may due to the residence time. Results obtain in Table 3 and Table 4 of filtered water samples shows the same trend of radionuclides. This may explain that uptake of radionuclides by fish depends on the concentration and on the speciation of the radionuclides in dissolved water [14]. In addition, the concentration of radionuclides in water may possibly used to predict accumulation in fish [14].

Table 4: Activity concentrations of radionuclides in water samples

Water sample	**Activity concentrations of radionuclides (Bg/kg)**					
	^{226}Ra		**^{228}Ra**		**^{40}K**	
	Filtered	**Unfiltered**	**Filtered**	**Unfiltered**	**Filtered**	**Unfiltered**
KT1	1.07 ± 0.11	2.19 ±0.15	0.46 ± 0.11	1.33 ± 0.18	7.89 ± 0.79	13.29 ± 1.03
KT2	1.18 ± 0.11	1.55 ± 0.13	0.48 ± 0.11	2.48 ± 0.24	10.44 ± 0.82	11.73 ± 0.96
KT3	1.31 ± 0.12	1.34 ± 0.12	0.98 ± 0.15	1.21 ± 0.17	12.94 ± 1.01	14.04 ± 1.06
KT4	1.46 ± 0.12	1.56 ± 0.13	0.99 ± 0.15	1.47 ± 0.19	12.32 ± 0.99	12.47 ± 1.00
KT5	1.24 ± 0.11	1.67 ± 0.13	0.73 ± 0.13	1.79 ± 0.21	9.58 ± 0.87	12.57 ± 1.00
Average	1.25 ± 0.26	1.66 ± 0.30	0.73 ± 0.32	1.66 ± 0.46	10.63 ± 2.04	12.82 ± 2.26

Table 5 shows the activity concentration of radionuclides in surface sediment samples. The surface sediment were sampled and analyzed because the major water-sediments interaction by the chemical and biological processes occurred on the surface of benthic sediments layer. From Table 5, the average of sediment samples for ^{226}Ra, ^{228}Ra and ^{40}K activity concentration are 249.8 ± 19.5, 397.9 ± 42.1 and 1782.2 ± 201 Bg/kg, respectively. In sediment sample, activity concentration of radionuclides is of the order ^{226}Ra < ^{228}Ra < ^{40}K. This may due to the present of monazite which contained ^{232}Th and ^{40}K [14]. In the surrounding of study area (Kapal 7 Lake) there have planted palm oil which may results in high amount of ^{40}K in fish-water-sediment due to runoff of the fertilizers into the lake. Generally, the activity concentrations of radionuclides are higher in sediment than in fish and in water due to the characteristics of sediment that better in accumulating of radionuclides [7] than fish and water.

Table 5: Activity concentrations of radionuclides in sediment samples

Sediment sample	**Activity concentrations of radionuclides (Bg/kg)**		
	^{226}Ra	**^{228}Ra**	**^{40}K**
KT1	258.0 ± 8.5	434.7 ± 20.2	1647 ± 88
KT2	152.6 ± 7.1	344.2 ± 17.0	1905 ± 90
KT3	266.0 ± 8.3	373.5 ± 17.9	1731 ± 87
KT4	289.8 ± 9.1	422.7 ± 20.0	2095 ± 101
KT5	282.4 ± 8.5	414.9 ± 18.9	1533 ± 80
Average	249.8 ± 19.5	397.9 ± 42.1	1782 ± 201

Radionuclides maybe transferred between biota and reference media (water and sediment) in freshwater ecosystem. Referring to bioaccumulation models, the aquatic organisms are assuming in equilibrium with water and sediment in their surroundings [14]. The accumulation of radionuclides in biota can be represented in simplified ratio by relating radionuclides concentration in biota to radionuclides concentration in water and sediment [14]. The transfer radionuclides in fish-water-sediment can be calculated using Concentration Factor (CF) and Distribution

Coefficient, K_d as in Equation 1 and 2 [14]. In addition, the dissolved and particulate phase also been assumed to be equilibrium with exchanges of nuclides between particles and water being wholly reversible [16].

$$CF = \frac{\text{Activity concentration in biota (Bg/kg) (dry weight)}}{\text{Activity concentration of reference medium (Bg/kg)}} \quad \text{(Equation 1)}$$

$$K_d = \frac{\text{Activity concentration in sediment (Bg/kg)(dry weight)}}{\text{Activity concentration in unfiltered water (Bg/kg)}} \quad \text{(Equation 2)}$$

The Concentration Factor, CF from unfiltered water to fish samples as fish represent receiving medium, while, water as transfer medium which are shown in Table 6. The higher CF of ^{226}Ra, ^{228}Ra and ^{40}K activity concentration are Tongsan (*Aristichthys nobilis*), Patung (*Pristolepis fasciatus*) and Toman (*Channa micropeltes*) which is 3.42, 2.70 and 18.69, respectively. From this results, the transfer ratio, CF of ^{226}Ra are generally higher than ^{228}Ra while ^{40}K showed nearly 11 times the value of ^{226}Ra and ^{228}Ra. This may show that physicochemical factors of the water from which fish were caught also determining factors that vary from one location to others as shown in Table 2.

Table 6: The Concentration Factor (CF) of radionuclides from unfiltered water samples to fish samples

Fish (local name)	**Distribution coefficient, K_d**		
	^{226}Ra	**^{228}Ra**	**^{40}K**
Jelawat	1.95	1.03	13.49
Lampam	2.81	1.25	13.21
Patung	2.10	2.70	13.89
Raja	2.49	2.37	14.38
Terbui	2.83	1.96	16.31
Tilapia	2.31	2.23	16.91
Toman	2.29	0.86	18.69
Tongsan	3.42	2.11	12.63

Table 7 shows Concentration Factor, CF from sediment to fish samples. The higher ratio of ^{226}Ra, ^{228}Ra and ^{40}K activity concentration are Tongsan (*Aristichthys nobilis*), Patung (*Pristolepis fasciatus*) and Toman (*Channa micropeltes*) which is 2.27 x 10^{-2}, 1.13 x 10^{-2} and 13.45 x 10^{-2}, respectively. The observable results in Table 6 and Table 7 had shown the same species of fish have higher transfer ratio, CF for ^{226}Ra, ^{228}Ra and ^{40}K, respectively. However, the CF in unfiltered water to fish is higher than in sediments to fish. The observable difference may explain that fish received high amount of radionuclides in water than sediment.

The distribution coefficient, K_d from sediments to unfiltered water is shown in Table 8. The average ratio for all locations for ^{226}Ra, ^{228}Ra and ^{40}K are 7.00 x 10^{-3}, 4.26 x 10^{-3} and 7.30 x 10^{-3}, respectively. Location KT2 showed highest transfer ratio of ^{226}Ra and ^{228}Ra, while, ^{40}K shows highest at KT5. The highest transfer ratio of ^{226}Ra and ^{228}Ra at KT2 indicated that there is abundance of U and Th which is parents of ^{226}Ra and ^{228}Ra, respectively, at KT2 compared to other locations. Meanwhile, there is slightly difference in transfer ratio of ^{40}K at all location even though transfer factor of ^{40}K is highest at KT5.

Table 7: The Concentration Factor (CF) of radionuclides from sediment samples to fish samples

Fish (local name)	Distribution coefficient, K_d (x10^{-2})		
	^{226}Ra	^{228}Ra	^{40}K
Jelawat	1.30	0.43	9.70
Lampam	1.87	0.52	9.51
Patung	1.39	1.13	9.99
Raja	1.65	0.99	10.34
Terbui	1.88	0.82	11.73
Tilapia	1.54	0.93	12.17
Toman	1.52	0.36	13.45
Tongsan	2.27	0.88	9.08

Table 8: The Distribution Coefficient (K_d) of radionuclides from sediment samples to unfiltered water samples according to locations

Location	Distribution coefficient, K_d (x10^{-3})		
	^{226}Ra	^{228}Ra	^{40}K
KT1	8.49	3.06	8.07
KT2	10.16	7.21	6.16
KT3	5.04	3.24	8.11
KT4	5.38	3.48	5.96
KT5	5.91	4.31	8.20
Average	7.00 ± 2.23	4.26 ± 1.72	7.30 ± 1.14

Generally, the results (Tables 4, 5 and 6) shown that there are linkages between biota-water-sediment in the ecosystem. However, transfer ratio shows very low from sediment to unfiltered water and fish samples compared to transfer ratio from water to fish. This may indicated that the major transfer of radionuclide happen between unfiltered water with fish. The distribution of these radionuclides in fish can occur through solid suspensions as well involved of their food chain which may included the aquatic plants, plankton and etc. The transfer ratio is less in sediment to unfiltered water may due to the solubility and mobility of these radionuclides in water. In addition, solid particles from water can settle to the bottom of the lake thus be removed from the water column [14]. Besides, radionuclides dissolved in water can also be absorbed by the bottom sediment [14]. However, the absorbed of radionuclides by bottom sediment can be remobilized and available for uptake by biota [14]. This may indicate that there may possibly high transfer ratio from water to sediment compared transfer ratio from sediment to water.

Conclusion

There is linkage of radionuclides between fish-water-sediments samples in former tin mining lake in Kampung Gajah, Perak, Malaysia. The sequence of radionuclides activity concentration is; sediment > fish > water. While, transfer ratio is in the sequence of; water to fish > sediments to fish > sediments to water. The higher transfer ratio was found in Tongsan, Patung and Toman that could be attributed to their habitat, dietary and species.

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