Assessment of Radiological Risk of Sediment Samples from 7mile Mini Beach, Doathtawati River Mandalay Region

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Abstract

The main purpose of this research work is to investigate the natural radiological hazard of sediment samples from Doathtiwati River, near Mandalay city. The sediment samples were collected from five different places in 7 mile mini beach, Mandalay, have been investigated by Gamma Spectroscopy. The collected sediment samples were measured by NaI (Tl) detector and analyzed by gamma vision 32 software. The some natural radionuclides are present in all sediment samples. The natural radionuclides such as ^{208}Tl (75.77keV), ^{212}Pb (238.63keV), ^{214}Pb (351.93keV) and ^{208}Tl (583.19keV) were identified. According to the analyzed data, the radionuclide ^{208}Tl (75.77keV) concentration is the highest value in all the radionuclides of sediment samples. According to the value of external hazard index and absorbed dose rate, it is in the good agreement for the recommended value of UNSCEAR 2000, Hex <1. So, it can be assumed that it is not hazard to the surrounding.

Introduction

Sediment in a stream is natural, but if sediment levels get too high, it can disrupt ecosystems. Excess sediments can cause the damage by blocking light that allows algae (an important food source) to grow, harming fish gills, filling up important habitats, and stopping fish from seeing well enough to move around or feed. Sediments are a natural part of a stream, lake, or river, and the type and amount found in streams are influenced by the geology of the surrounding area. Natural processes that add to sediments in waterways include in stream scouring of the river bed and banks and erosion of sediments from the surrounding catchments from natural slips and any exposed soils. Sediments can enter streams from alongside a reach or from upstream via the myriad smaller interconnecting streams that form a river network within a catchments area.

Sediments in waterways travel downstream in suspension when water velocity is high or turbulent. When there is a decrease in velocity, especially in pools and deep areas of a stream/river, sediments will eventually settle and can be seen as deposits of fine material or by the formation of sand bars on the river or stream bed.

Sediments in suspension can have a significant impact on the water quality of a waterway because sediments decrease water clarity, which reduces visibility. Water clarity is usually measured as turbidity. Turbid waters prevent the growth of aquatic plants and algae (because plants need light for photosynthesis) and decrease the ability of fish to find food or to detect predators and prey, thereby increasing stress. Sediments may smother stream invertebrates which are an important food source for fish.

Excessive sediment deposits on the river/stream bed can significantly alter and degrade habitat. Some animals are dependent on the rocky bottoms of stream, while others live in deep sandy pools or around woody debris. Sediments fill the spaces between stones that invertebrates live in, and in extreme cases can bury woody debris, stony substrates (gravels and cobbles), and root mats, and fill pools and channels. This reduces the amount of invertebrate habitat and cover and spawning grounds (a place to lay eggs) for fish. An increase in the amount of sediment deposited on the river/stream bed can also significantly change the flow and depth of rivers or streams over time and infill lakes and estuaries. Natural cleaning processes- where the water flows through the gravel bed of a stream and interacts with the

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microbes living on stone surfaces, removing nutrients and some pollutants – can also be short-circuited by excessive sediment deposits.

Naturally Occurring Radiation

Naturally occurring radiation or so-called "background radiation" on average accounts for approximately 50% of our exposure. Naturally occurring radiation can be found all around us. Natural radioactivity widely exists in the air, water, plants and the soil of earth's environment. Radiation come from rock have a significant portion of background radiation exposure of the population. Because it occurs in our natural environment, we encounter it every day through the food we eat, the water we drink, and the air we breathe. It is also in building materials and items we commonly use.

Natural environmental radioactivity and the associated external exposure due to gamma radiation depend primarily on the geological and geographical conditions and appear at different levels in the rocks of each region in the world. Gamma radiation emitted from terrestrial materials is known as the major external source that affects the human body. The interaction of radiation with human body leads to various biological effects which may later show up many diseases. Information of radioactive level of an environment leads to control and preventing of diseases. Therefore monitoring natural radioactivity in the environment is an important parameter for public health studies and assessing possible changes in the environment radioactivity.

Absorption of Gamma Rays

The interaction of gamma rays with matter is markedly different from that of charged particles such as alpha and beta particles. The most important mode of interaction between gamma radiation and matter which leads to a reduction of the gamma rays energy is that between gamma radiation and the electron of the absorbing materials. The electrons (or positrons) produced by these interactions deposit their energy in the counter and generate a voltage pulse that signifies the passage of the photon. The height of the voltage pulse is proportional to the energy deposited in the detector. There are several ways in which gamma rays interact with an absorbing material; three namely, the photoelectric absorption, the Compton effect and pair production.

Photoelectric Absorption

The photoelectric absorption is the complete absorption of a photon by an atom. The most likely interaction is one between the photon and the most tightly bound electron. In the photoelectric effect, a gamma-ray photon, with energy greater than the binding energy of an orbital electron in an atom, interacts with the matter in such a way that the whole of the gamma-ray energy is transferred to an electron which is consequently ejected from the atom. If E is the energy of this gamma-ray photon and B is the binding energy of the electron in an atom, the kinetic energy of the ejected electron is obtained by the difference, i.e, E-B. The photoelectron behaves like a beta particle of the same energy in its passage through matter.

The photoelectric effect is the dominant energy transfer mechanism for X-ray and gamma ray photons with energies below 50 keV (thousand electron volts), but it is much less important at higher energies.The photoelectric effect increases with increasing atomic number of the absorber and decreasing energy of the gamma rays.

Compton Effect

In a Compton interaction, a gamma-ray photon makes an elastic collision with an electron of the absorbing material. Such as electron behaves as if it were free, because its binding energy is much less than the photon energy. In the collision both momentum and energy are

conserved, and part of the energy of the incident photon is transferred to the electron. Then, the relation between the energy E of the incident photon, E' of the scattered photon, both on MeV, and the scattered angle θ is given by

$$E = \frac{0.51}{1-\cos\theta + \frac{0.51}{E'}} \qquad (1)$$

where 0.51MeV is the equivalent energy of the electron rest mass according to the Einstein equation.

Since the Compton effect involves interaction between a photon and an electron, its magnitude is dependent on the number of orbital electrons in the atom of the absorber i.e. the atomic number. The Compton interaction decreases steadily with increasing energy of the gamma radiation.

Pair Production

When a gamma-ray photon with energy in excess of 1.02MeV passes near the nucleus of an atom, the photon can be annihilated in the strong electrical field with the formation of an electron-positron pair. Since the equivalent energy of the total mass of an electron and positron is 1.02MeV, this is the minimum energy necessary for the production of the pair of particles. Any energy of the gamma-ray photon in excess of 1.02MeV appears mainly as kinetic energy of the electron and positron, with a small fraction transferred to the atomic nucleus. The particles tend to travel in the forward direction, the effect becoming more evident with increasing gamma-ray energy. The total kinetic energy of the electron positron pair is

$$E_{kin}^{-} + E_{kin}^{+} = (E - 1.022)\text{MeV} . \qquad (2)$$

It increases with the atomic number of the absorbing material and with increasing photon energy in excess of 1.02MeV. By interaction with the electric field of a nucleus, the energy of the incident photon is converted into the mass of an electron-positron pair. Any gamma energy in excess of the equivalent rest mass of the two particles (totaling at least 1.02 MeV) appears as the kinetic energy of the pair and in the recoil of the emitting nucleus. The important factor is that the pair production process cannot occur in free space. Since the photoelectric and Compton effects decrease with increasing gamma-ray energy, whereas pair production increases, it is evident that the latter process will become of major important at higher energies. The three gamma interactions are illustrated in Fig.1, 2 and 3.

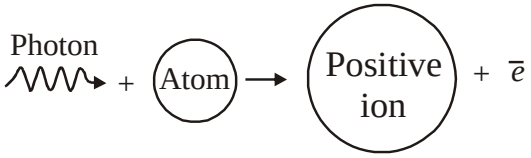


Figure1. Photoelectric Effect

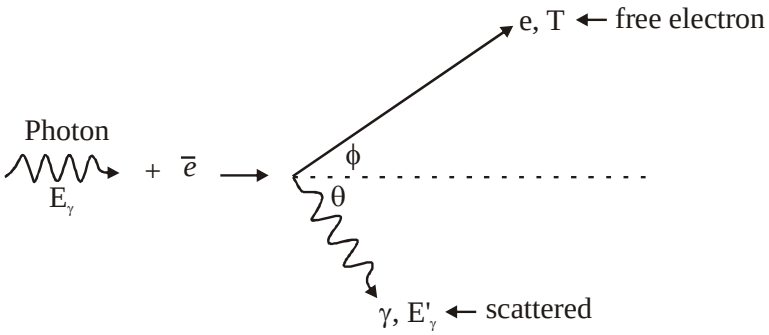


Figure 2. Compton Effect

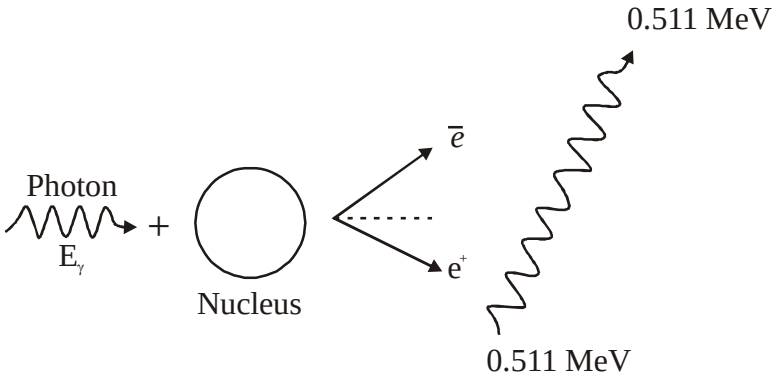


Figure3. Pair Production

Gamma Spectroscopy System

A gamma spectroscopy system consists of a detector to collect and process the signals produced by the detector, and a computer with processing software to generate the spectrum and display and store it for analysis. Gamma spectroscopy detectors are passive materials that wait for a gamma interaction to occur in the detector volume. The most important interaction mechanisms are the Photoelectric effect, the Compton effect, and Pair Production. The Photoelectric effect is preferred, as it absorbs all of the energy of the incident gamma rays. Full energy absorption is also possible when a series of these interaction mechanisms take place within the detector volume. When a gamma ray undergoes a Compton interaction or Pair Production, and a portion of the background rate in the spectrum is increased by one count. This count will appear in a channel below the channel that corresponds to the full energy of the gamma rays. Larger detector volumes reduce this effect. The voltage pulse produced by the detector (or by the photomultiplier in a scintillation detector) is shaped by a multichannel analyzer (MCA).The multichannel analyzer takes the very small voltage signal produced by the detector, reshapes it into a Gaussian or trapezoidal shape, and converts it into a digital signal.

In some systems, the analog to digital conversion is performed before the peak is reshaped. The analog to digital converter (ADC) also sorts the pulses by their height. ADCs have specific numbers of bins to sort the pulses into; these are the channels in the spectrum. The number of channels can be changed in most modern gamma spectroscopy system by changing a software or hardware setting. The number of bins is a power of two. Common values include 512, 1024, 2048, 4096, 8192, or 16384 channels. The choice of number of channels depends on the resolution of the system and the energy range being studied. The MCA output is sent to a computer which stores, displays, and analyzes the data. A variety of software packages are available from several manufacturers, and generally include spectrum analysis tools such as energy calibration, peak area and net area calculation. Other components, such as rate meters and peak stabilizers, may also be included.

Energy Calibration

The energy of radioactive elements in sement sample is unknown. The standard radioactive sources of energies were used to calibrate the spectrometer. Therefore, energy calibration was first made for 300 seconds by using ^{60}Co (1173.23 keV), ^{137}Cs (661.66 keV) and ^{133}Ba (30.97 keV and 356.02keV) sources. In this work, conversion gain is set at 2048. And then sources were placed on the detector surface and a spectrum was accumulated for times period long enough to determine the peak position. The amplifier gain and shaping time were adjusted until peaks were obtained at the desired energy. The energy range is 0 keV to 3381.48keV and 0.83 keV per channel.

A ^{60}Co source is convenient because its two peaks at 1.173 MeV and 1.332 MeV are close energy for ^{40}K (1.460 MeV). Establishing a direct relationship between photo peak energy and multi channel analyzer channel number can do the energy calibration process. In doing so, energy calibration curve was obtained. Energy calibration data is listed in Table 1 and energy calibration curve is shown in Fig.4.

Table1. Energy Calibration Data

Source	Channel Number	Energy (keV)
^{133}Ba	20	30.97
^{133}Ba	322	356.02
^{137}Cs	608	661.66
^{60}Co	1061	1173.23
^{60}Co	1203	1332.27

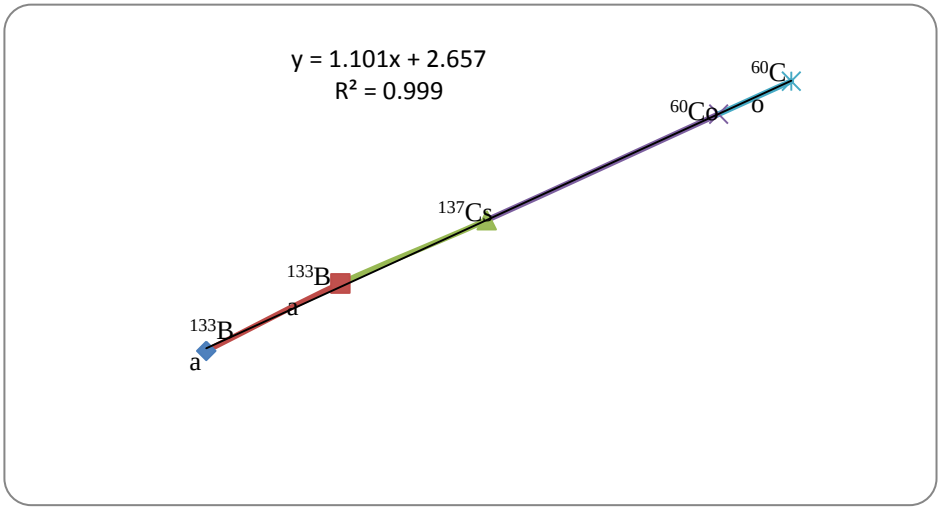


Figure 4. Energy Calibration Curve

Efficiency Calibration

It is not certain that a particle will be counted when it enters a detector. The detector efficiency depends upon the density and sizes of detector material, types and energy of radiation and electronics. The quantity that gives the fraction of particles being detected is called the detector efficiency, ε, given by

$$\varepsilon = \frac{\text{number of gamma photons regersisted by the detector}}{\text{numbers of gamma photons emitted by the source}}$$

$$\varepsilon = \frac{N}{A(t)P_r T} \qquad (4.1)$$

A (t) = Present activity of the standard sources

ε = Counting efficiency of the energy of interest (Cs^{-1}/Bq)

N = Net area at energy E

P_γ = Gamma emission probability for energy E of standard source

T = Counting (Live) time in seconds

For measuring the counting efficiencies of NaI (Tℓ) scintillation detector for different energies, ^{133}Ba, ^{137}Cs and ^{60}Co sources were used. Then, gamma source was placed on the detector surface and its spectrum was accumulated for 300s.The same procedure was repeated

for all sources. The spectra stored in MCA were analyzed by Gamma Vision 32 software and determined the gross area and net area of full energy peak. Then full energy peak efficiencies of detector for different energies were calculated. Information about the standard gamma sources and full energy peak efficiency of NaI (Tℓ) scintillation detector for different energies are listed in Table 2. The efficiency values of standard gamma sources were then plotted against their corresponding energies to obtain the efficiency calibration curve in Fig.5

Table 2. Information about the standard gamma source and full energy peak efficiency of NaI (Tℓ) detector for energies

No	Gamma Source	Source Activity (A_0)μCi	Present Activity A (t)μCi	Half Life ($T_{1/2}$) Year	Gamma Energy (E_γ) keV	Emission Probability (P_γ)	Efficiency ε (E)
1	^{133}Ba	1	0.738	10.8	30.97	63.40 %	1.92%
					356.02	62.05 %	5.7%
2	^{137}Cs	1	0.895	30.1	661.66	85.00 %	3.7%
3	^{60}Co	1	0.540	5.27	1173.23	99.85 %	3.8%
					1332.27	99.98 %	3.7%

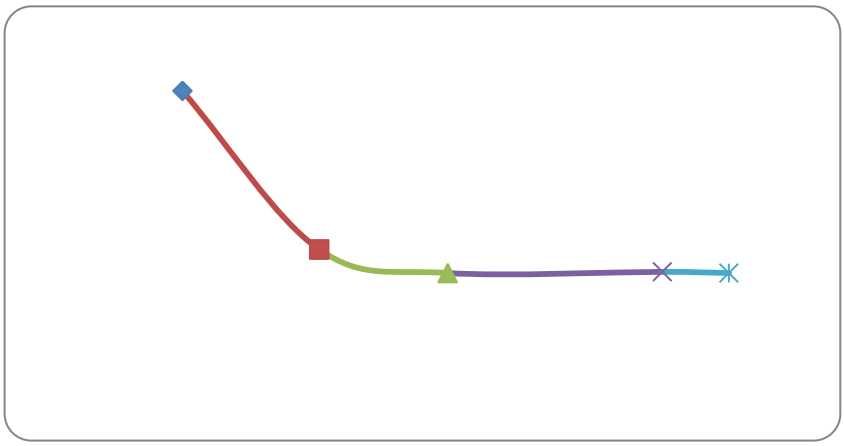


Figure 5. Efficiency Curve of Gamma Counting System

Calculation of Activity, Absorbed Dose Rate and External Hazard

The activity of the radionuclides are calculated by using

$$A = \frac{N}{m \times t \times P_r \times E_{ff}}$$

A = activity
m = mass
t = time
P_r = branching ratio (%)
E_{ff} = efficiency

The absorbed dose rate of the radionuclides are calculated by using

$$D = 0.621A_{Th} + 0.462A_{Ra} + 0.0417A_K$$

D = absorbed dose rate ($nGyhr^{-1}$)

A_{Th}, A_{Ra}, A_K = The activity concentration of ^{232}Th, ^{238}U and ^{40}K in Bq/kg respectively

The external hazard of the radionuclides are calculated by using

$$H_{ex} = A_{Ra}/370 + A_{Th}/259 + A_K/4810$$

H_{ex} = external hazard ($nGyhr^{-1}$)

A_{Th}, A_{Ra}, A_K = The activity concentration of ^{232}Th, ^{238}U and ^{40}K in Bq/kg respectively

Radium equivalent activity (Ra_{eq})

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_k$$

A_{Th}, A_{Ra}, A_K = The activity concentration of ^{232}Th, ^{238}U and ^{40}K in Bq/kg respectively

Sample collection and preparation

Sediment samples were collected from different locations in Doathtawati River near Mandalay city during the period in December, 2017. Deposited top layer of the bottom sediment samples at the depth of 5feet under surface of water were collected by using two inches diameter and five feet length pipe. The sample location and the sampling site are shown in Fig.6 and Fig.7.

The collected sediment samples were air-dried at room temperature over a period of two week. These samples were left to dry until their weight become constant. After drying, the samples were cleaned, dried and grounded. Samples were made to become the fine powder. The plastic container was used to all sediment powder samples measurements.

Measured samples were sieved through a mesh, sealed in beaker and weighed. Each sample was put into the shielded NaI (Tℓ) detector and measured for 3 hours. Prior to the samples measurement, the environmental gamma background at the laboratory site has been determined with an empty beaker under identical measurement conditions. It has been later subtracted from the measured γ-ray spectra of each sample. Each measured γ-ray spectrum has been analyzed by a dedicated software program (GammaVision-32). Menu-driven reports are available for summaries including centroid channel, energy, net area counts, background counts, intensity and width of identified and unidentified peaks in the spectrum, as well as peak and average activity in Bq kg^{-1} for each detected radionuclide. The results of reported activity concentrations obtained for each of the measured samples. The photographs of prepared samples are shown in Fig.8.

Figure 6. Photo of location map of sample collecting

Figure 7. Photo of sample collecting

Experimental procedure

Figure 7. Photo of sample collecting

Experimental procedure

In this experiment, NaI(T*l*) detector was used to detect the gamma radiation after passing through the absorbing material and these passed informations (electron pulses) were amplified by preamplifier and the fast spectroscopy amplifier and collected by using MCA based on personal computer. The NaI(T*l*) detector used in operating voltage 1000V. This value is fixed for all measurements and measuring time in 10800 seconds. The experimental setup used in this investigation is shown in Fig.9.

Figure 8. The prepared sediment samples

Figure 9. The detection system of NaI(T*l*) detector

Results and Discussion

The experimental work was performed at the Department of Physics, Mandalay University. The gamma rays spectra of sediment samples are detected by using NaI (T*l*) detector and analyzed by Gamma Vision 32 software. Counting time for each sample is 10800s. The comparison of the energy spectra for various sediment samples (S1, S2, S3, S4 and S5) and background are shown in Fig.10, 11, 12, 13, 14 and 15. The comparison of radium equivalent activities and dose ratesfor all samples are shown in Fig.16 and 17. The comparison of net counts of different radionuclides oc curred in sediment samples are shown in Table 3. The activity concentration of all natural radionuclides from sediment samples are shown in Table 4.The value of the absorbed dose rate and external radiation hazard for all sediment samples are shown in Table 5.

According to the Table 3, he measured the values of the radionuclide concentration in sediment sample S1 is the most. According to the result from Table 4, the activity concentration of ^{208}T*l* (Energy-75.77keV) is the highest and ^{208}T*l* (Energy-583.19keV) the activity concentration is the lowest in all sediment samples.

Table 3. Comparison of Net Area or Counts for various radionuclides in sediment samples

Sample Name	Radionuclides			
	^{208}TI	^{212}Pb	^{214}Pb	^{208}TI
Sample 1	42557	6768	226	273
Sample 2	13391	1582	94	278
Sample 3	10371	1051	116	244
Sample 4	10881	766	385	116
Sample 5	11824	1087	283	103

Table 4. The activity for all sediment samples

Name	A_{Th}	A_{Ra}	Ra_{eq} Bq/kg	Dose (nGy/h)	Hex (nGy/h)
S1	29.9113	0.453	43.226	18.2757	0.1167
S2	9.3782	0.188	13.599	5.7514	0.0367
S3	7.2475	0.233	10.596	4.4849	0.0286
S4	7.5439	0.772	11.559	4.9129	0.0312
S5	8.2234	0.567	12.327	5.2290	0.0333

Table 5. The values of the absorbed dose rate and external radiationhazard for all samples

Nuclides	Energy (keV)	Activity Bq/kg (S1)	Activity Bq/kg (S2)	Activity Bq/kg (S3)	Activity Bq/kg (S4)	Activity Bq/kg (S5)
^{208}TI	75.77	87.275	27.462	21.269	22.315	24.248
^{212}Pb	238.63	2.334	0.546	0.363	0.264	0.375
^{214}Pb	351.93	0.453	0.188	0.233	0.772	0.567
^{208}TI	583.19	0.125	0.127	0.111	0.053	0.047

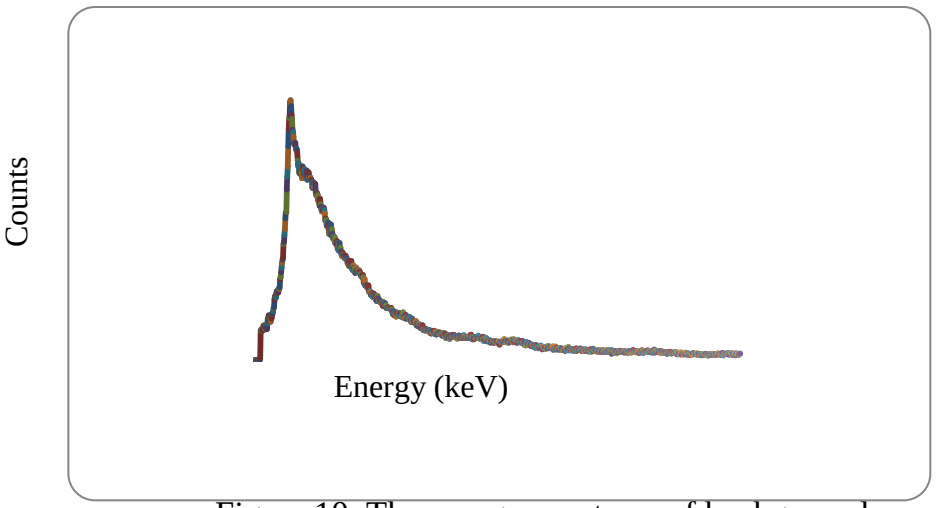


Figure 10. The energy spectrum of background

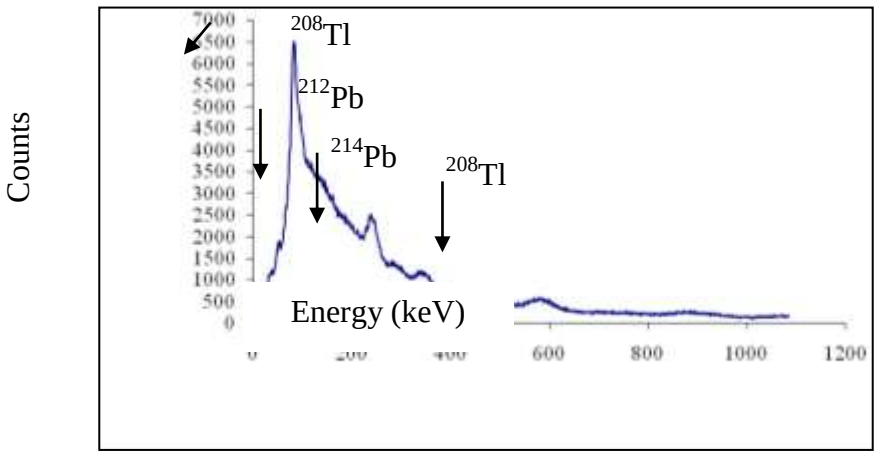


Figure 11. The analyzed spectrum of sediment sample S1

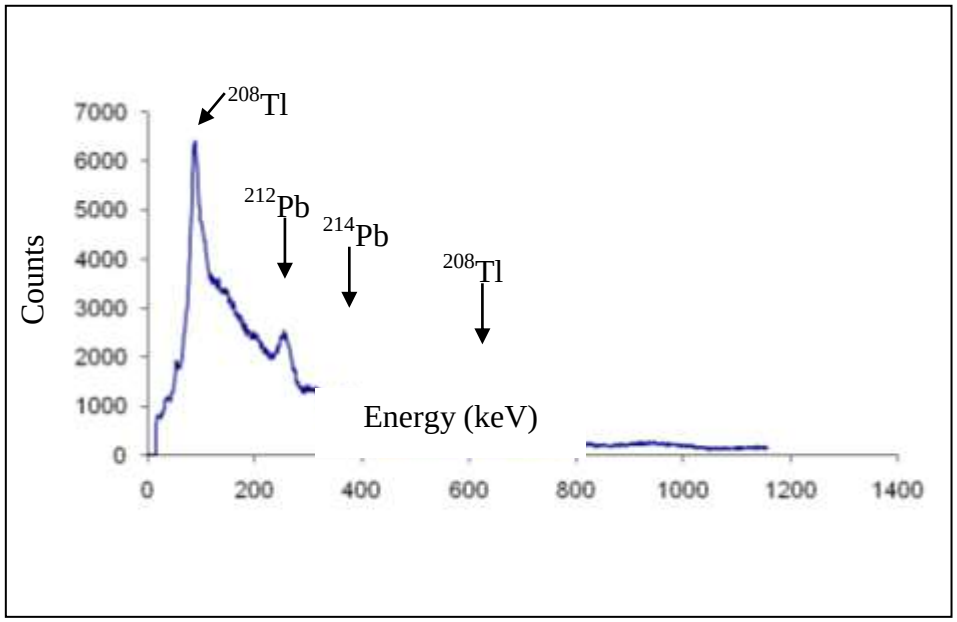


Figure12. The analyzed spectrum of sediment sample S2

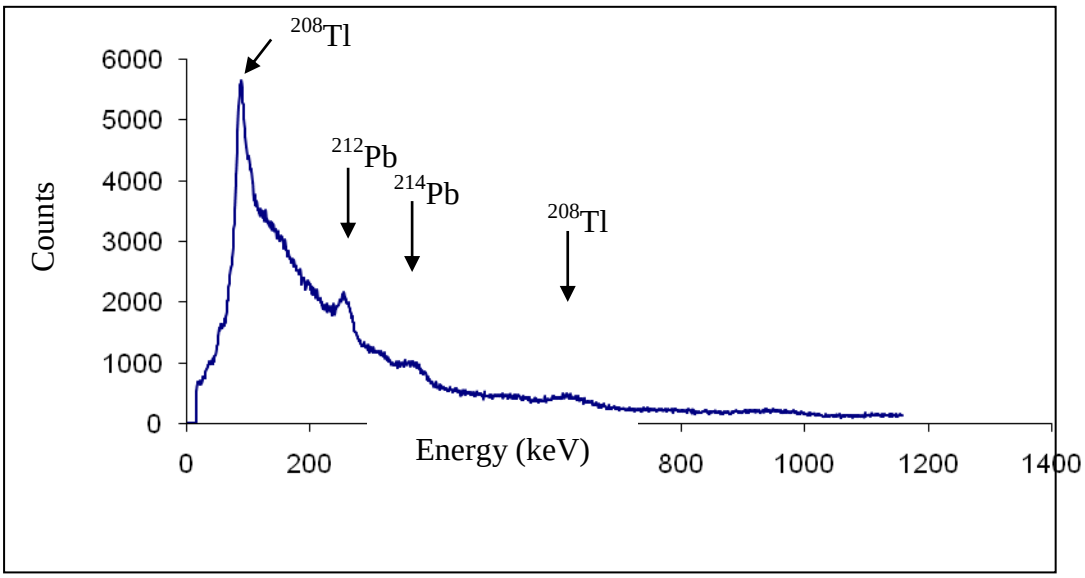
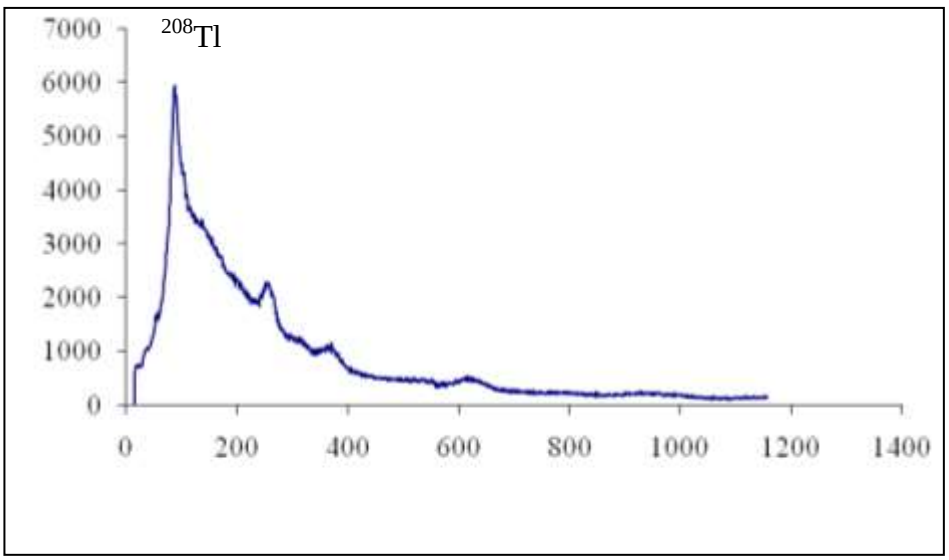


Figure 13. The analyzed spectrum of sediment sample S3



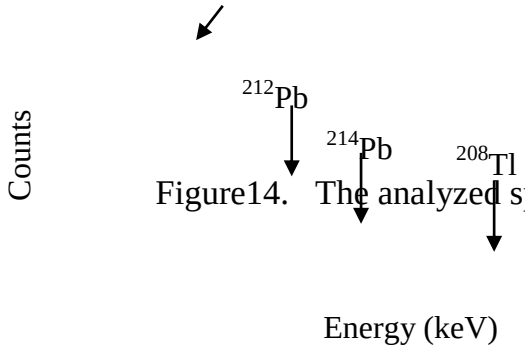


Figure14. The analyzed spectrum of sediment sample S4

Figure 14. The analyzed spectrum of sediment sample S4

Figure 14. The analyzed spectrum of sediment sample S4

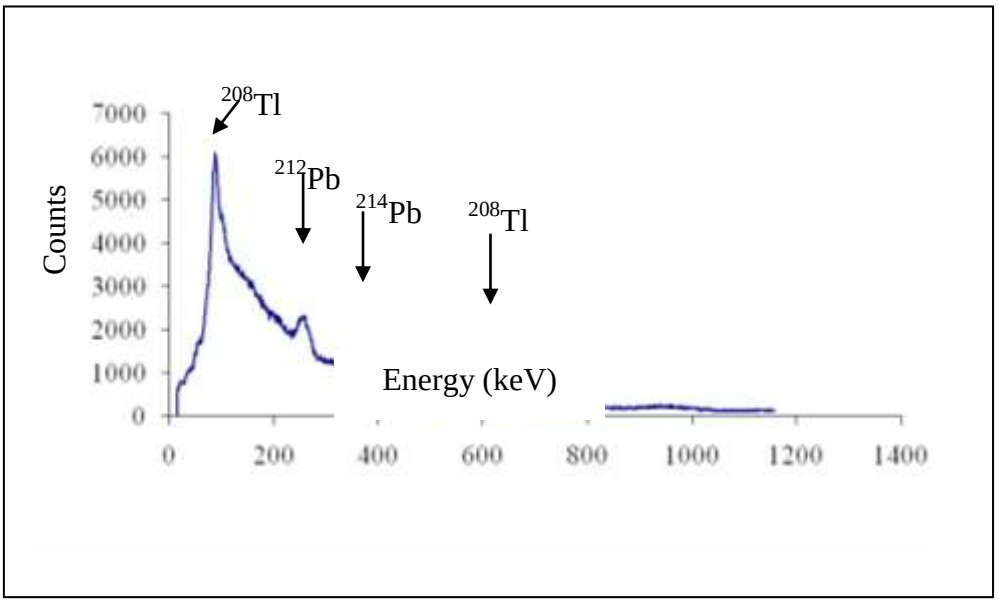


Figure 15. The analyzed spectrum of sediment sample S5

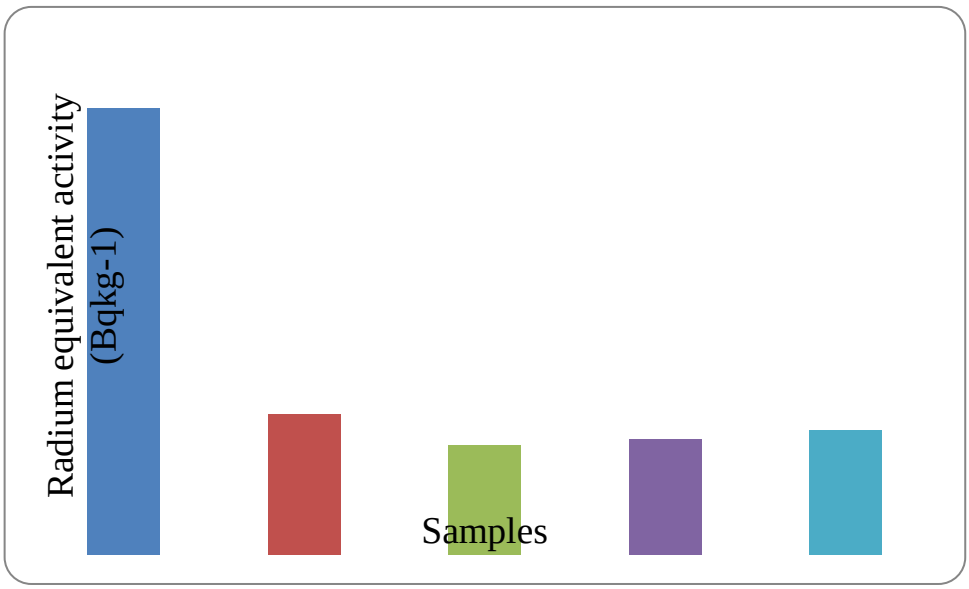


Figure 16. The comparison of Radium equivalent activities for all samples

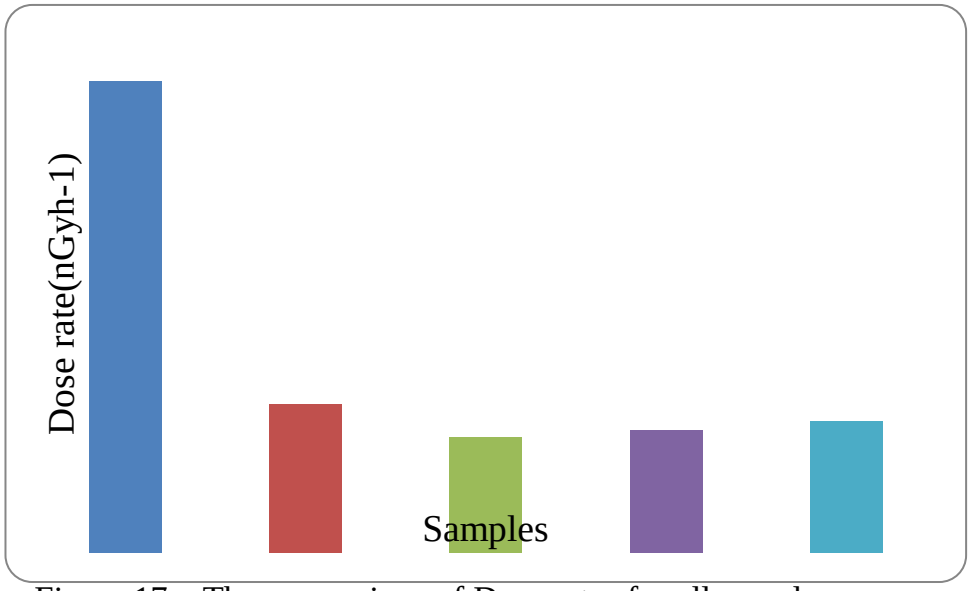


Figure 17. The comparison of Dose rates for all samples

Conclusion

The radionuclides ^{208}Tl (75.77keV) concentration is highest value in all the radionuclides of sediment samples. The radionuclides ^{214}Pb(351.93) concentration of sediment sample S2 is the lowest value. The radionuclides ^{208}Tl (75.77keV) concentration is highest value in all the sediment samples but the radionuclides ^{208}Tl (583.19keV) concentration of sediment sample is the lowest value for all activity. The highest values of activity ^{208}Tl (75.77keV) are S1(87.275Bg/kg), S2(27.462Bg/kg), S3(21.269Bg/kg), S4(22.315Bg/kg) and S5(24.248Bg/kg) but the lowest values of ^{208}Tl (583.19keV) are S1(0.125Bg/kg), S2(0.127Bg/kg), S3(0.111Bg/kg), S4(0.053Bg/kg) and S5(0.047Bg/kg).According to the value of external hazard index and absorbed dose rate, it is in the good agreement for the recommended value of UNSCEAR 2000, H_{ex} <1. So, it can be assumed that it is not hazard to the surrounding.

Acknowledgements

The authors are thankful to Dr Maung Maungg Naing, Rector, University Yadanabon, for his permission and encouragement to conduct this research work. We would like to express our gratitude to Dr Yi Yi Myint, Professor (Head of Department) University of Yadanabon, for her invaluable suggestions.

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