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Assessment of Radiological Hazards in Soil, Water and Plants Around Coal Power Plant

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ABSTRACT

The existence of a Coal-Fired Power Plant (CFPP) is suspected to affect the environment quality, especially the increment of natural radionuclides content which is found in coal as raw material. Therefore, systematic analysis of natural radionuclides (^{210}Pb, ^{234}Th, ^{238}U, ^{228}RA, ^{40}K, ^{226}RA and ^{232}Th) in water, soil, and plant were conducted to establish a database of environmental contamination in the area around a CFPP. This research was conducted in the area around Adipala Cilacap CFPP which operates with two towers. Samples were taken from three locations around the Adipala CFPP based on the secondary wind direction data from Indonesian Agency for Meteorological, Climatological, and Geophysics in the 2018 dry season. Samples were prepared in the Radiochemistry Laboratory, Center for Accelerator Science and Technology, BATAN. The concentration of radioactivity in environmental samples were analyzed using gamma spectrometry with a high purity germanium detector for 24hours after reaching its secular equilibrium. The result of samples analyses shown that the mean value of the radionuclides specific activities (^{210}Pb, ^{234}Th, ^{238}U, ^{228}RA, ^{40}K, ^{226}RA and ^{232}Th) for water, cassava leaves, grass, and soil were 0.789 Bq/L, 14.685 Bg/kg, 15.036 Bq/Kg, and 75.083 Bq/kg, respectively. The mean of radium equivalent activity (Ra_{eq}) for water, cassava leaves, grass, and soil were 1.692, 30.792, 18.699 and 137.513 Bq/kg, respectively. The absorbed dose rate (ADR) for water, cassava leaves, grass, and soil were 0.775, 14.332, 8.627, and 64.135 nGy/h, respectively, whilst the annual effective dose rate (AEDR) were 0.004, 0.070, 0.042, and 0.315 mSv/y. The mean of external and internal hazard indices (H_{ex} and H_{in}) for water, cassava leaves, grass, and soil were 0.005 and 0.006, 0.083 and 0.129, 0.050 and 0.078, and 0.371 and 0.554, respectively, while the mean of excess lifetime cancer risk (ELCR) wre 0.014×10^{-6}, 0.246×10^{-6}, 0.148×10^{-6}, and 1.101×10^{-6}. According to the calculation of radiation hazard index in this research, it was understood that all parameters of all samples were within acceptable limits by the world average value reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

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INTRODUCTION

Since early September 2016, coal-fired power plants (CFPP) of Adipala in Buton Village, Adipala District, Cilacap, Central Java, has begun operating with the ability to generate 660 MW of electrical power. Coal combustion will result in byproducts such as fly ash and bottom ash, both containing a number of radionuclides such as ^{232}Th and its decay daughters, ^{238}U and its decay daughters, and also ^{40}K into the surrounding ecosystem [1-3].

Coal combustion in a CFPP in the Brazilian city of Figueira from 1963 until 2016 caused an increase in radionuclide concentrations in atmospheric particles, with enrichment factors up to 5 to 10 times and high activity of ^{238}U, ^{226}Ra and ^{210}Pb radionuclides was found in coal, ash, and soil layers [2,4].

Environmental samples such as water, soil, cassava leaves, and grass contain primordial natural radionuclides. Therefore, it is necessary to identify radionuclides around Adipala CFPP, Cilacap. This power plant uses coal as a heat source for electricity generation and as a side result emits natural radionuclide emissions to the surrounding environment. The trace elements in coal, which are

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categorized as naturally occuring radioactive nuclides, are uranium (U), thorium (Th) along with its decay daughters, and ^{40}K [1,3].

Soil is the primary component that will affect the ecological chain of soil-plants-animals-humans, so it has an important role in the distribution and transfer of radionuclides in animal feed. For this reason, information about radioactive contamination in soils and plants is an important foundation that can be used to assess all radiation safety criteria and norms. Radioactive contamination in plants occurs due to various environmental factors (atmosphere, pedosphere, and hydrosphere) that dynamically affect the radioactive content in these plants. In general, the influence of the pedosphere is more dominant, because the main part of the minerals that make up the plant parts, comes from the soil. Therefore, the physical-chemical characteristics of the soil are the main parameters that determine the amount of accumulation of radioactive substances in plant organs [5-8].

Water is a critical component for life on earth, because it is one of the most valuable resources. The quality and quantity of water is indispensable for drinking, sanitation, agriculture, industry, urban development, hydroelectric power, inland fisheries, transportation, recreation, and many other human activities. This is related to the economic, mental, and physical health of a population. Radionuclides are present around us; in the Earth's crust, air, water, plants and so on. They may occur naturally or are produced artificially which emits radiation or particles [9-11]. Therefore, measurements of naturally occurring radioactivity in the environment are needed.

The natural radionuclides such as ^{40}K, ^{232}Th, and ^{238}U along with their decay daughters give the largest contribution to natural radioactivity in the environment, both in soil and plants [12,13]. It is postulated that similarities will be found in plants (grass through animals and cassava leaves) which are the main pathways of natural radionuclides that enter the human body through the food chain. In various concentrations, radionuclides are always present in every part of the Earth and in the living tissues.

The purpose of this study is both determination of natural radioactivity in a number of environmental samples (water, soil, and plants) around the Adipala Cilacap power plant and the evaluation of the radiological hazard parameters of thosenaturally occurring radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) such as radium equivalent activity (Ra_{eq}), absorbed dose rate (ADR), annual effective dose rate (AEDR), hazard index (H_{ex} and H_{in}), and excess lifetime cancer risk (ELCR).

METHODOLOGY

Equipment

A set of Gamma Spectrometers (γ), HPGe detectors, ball mill, sample drying, 100 mesh sieve and homogenizer, glassware, analytical scales, electric heaters, IR lamps and polyethylene bottles (diameter 6.5 cm × height 7.5 cm).

Materials

Environmental, water, soil and cassava leaf samples were taken at three locations around Adipala CFPP, radioactive source ^{152}Eu and ^{60}Co were used to determine the eficiency curve. Standard Reference Materials IAEA-135 radionuclides marine sediment and IAEA-4359 Seaweed Radionuclide Standard were used respectively to quantitatively analyze the soil samples and the plants samples.

Sampling location

The samples used were water, soil, grass, and cassava leaf samples. The samples were taken from the area around Adipala CFPP, which consists of 3 different locations as follows: Location 1 is ± 2.8 km from the exhaust flue, Cibolang Hamlet, Gombong Harjo, (S 07041'07.3" and E 109008'15.2"), Location 2 is ± 2.0 km, Silang Sur Hamlet, Wlahar Village. (S: 07°40'11" and E 109°08'05.5"), and Location 3 ± 2.1 km, Bauton Hamlet, Sawangan Village (S: 07°41'06.0" and E 109°09'22.9"). All locations are in Adipala District. The three sampling locations can be seen in Fig. 1.

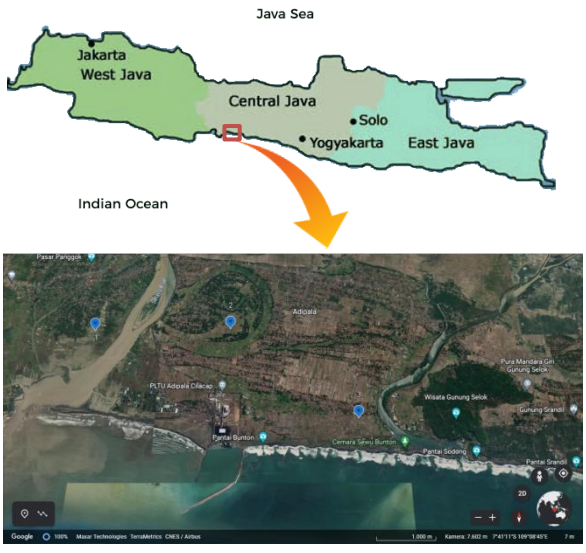

Fig. 1. Sampling locations around the Adipala CFPP – Cilacap.

Sample preparation

The water sample was filtered using 0.22 µm millipore filter paper to remove impurities such as moss. 1000 ml of filtered water was taken, concentrated into 20 ml using an electric heater and then put in a polyethylene bottle which was labeled and tightly closed. Cassava leaves were weighed wet, then washed using aquadest. The clean cassava leaves and grass were dried using an IR lamp and then mashed with a ball mill until they passed 100 mesh. Samples that have been refined weighing 70 grams were put in a polyethylene bottle, labeled, and tightly closed. The soil was cleaned of dirt and dried in the sun., To follow, it was mashed using a ball mill to pass the size of 100 mesh then weighed 70.0 grams, put in a polyethylene bottle, labeled, and tightly closed. Each sample was ensured to be tightly closed by applying plastic glue so that the radon gas that occurs does not leak out. Samples were stored for approximately 30 days before measurement to achieve secular equilibrium [6,14].

Gamma spectroscopic measurement

To qualitatively identify the radionuclide content in the environmental sample material around the Adipala CFPP,, all prepared samples were analyzed using a gamma spectrometer with a measurement time of 86,400 seconds [15]. Gamma spectroscopy was equipped with a coaxial HPGe ORTEC detector with a relative efficiency of 35 % and an energy resolution of 1.97 keV FWHM at a peak of 1332.5 keV from ^{60}Co. Energy calibration and relative efficiency calibration of the gamma spectrometer were done using several radioactive sources such as ^{137}Cs, ^{60}Co, and ^{152}Eu.

The radionuclides measured by the gamma ray spectrum emitted from the sample are ^{212}Pb (with the main gamma energy at ~239 keV and probability ~43.1 %), ^{214}Pb (~352 keV, ~37.1 %), ^{214}Bi (~609, 1120 and 1765 keV, ~46.1, 15 and 15.9 %, respectively), ^{228}Ac (~911 keV, ~29 %), ^{208}Tl (~2615 keV, ~35.9 %) and ^{40}K (~1461 keV, ~10.7 %). Assuming that secular equilibrium was reached between ^{232}Th and ^{238}U and their decay daughters, the concentration of ^{232}Th was determined from the average concentrations of ^{212}Pb, ^{208}Tl, and ^{228}Ac in the sample, the concentration of ^{226}Ra was determined from the average concentration of ^{214}Pb and its decay daughter ^{214}Bi, while ^{228}Ra concentration can be determined through the decay of the radionuclide ^{228}Ac (~911.07 keV, ~29 %) [16,17].

Radiological hazard estimates

To assess the radiological hazards associated with the health status of the irradiated environment, radium equivalent activity (Ra_{eq}) was used. It is a general index used to compare the specific activity of materials containing ^{226}Ra, ^{232}Th, and ^{40}K, taking into account the radiation hazards associated with them. Ra_{eq} activity is defined mathematically by Eq. 1 [18,19].

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (1)$$

where C_{Ra}, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg.

Absorbed gamma dose rate

The absorbed dose rate in air one meter above ground level represents the dose received in the open air from the radionuclides ^{226}Ra, ^{232}Th and ^{40}K. The absorbed dose rate can be determined using Eq. 2 [18,20].

$$\mathrm{ADR} = 0.461\mathrm{C_{Ra}} + 0.623\mathrm{C_{Th}} + 0.0414\mathrm{C_K} \quad (2)$$

Annual effective dose

The estimated annual effective dose rate received by human body was calculated using a dose conversion factor of 0.7 Sv Gy^{-1} [21,22], which is used to convert the absorbed dose rate to the human effective dose with a value of 20 % for outdoors [23]. The annual effective dose (mSv/y) uses Eq. 3.

$$\mathrm{AEDR(mSv.y^{-1})} = \mathrm{AD(nGy.h^{-1})} \times 8760\ \mathrm{(h)} \times 0.2 \times 0.7\ \mathrm{(Sv.Gy^{-1})} \times 10^{-6} \quad (3)$$

Hazard Index

Many radioactive materials decay naturally. When these materials decay, they produce an external radiation. The presence of humans around it can cause exposure to these external radiations. In terms of dose, the primary primordial radionuclides are ^{232}Th, ^{226}Ra, and ^{40}K. The Th and U series radionuclides produce significant external exposure. The external hazard index (H_{ex}) and internal hazard index (H_{in}) are calculated by Eqs. 4 and 5 [20,24-26].

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \quad (4)$$

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \quad (5)$$

H_{ex} = 1 is a quantity corresponding to the upper limit of Ra_{eq} (370 Bq/kg) [27]. This index value must be equal to or less than one in order for radiation hazards to be neglected.

Excess lifetime cancer risk (ELCR)

ELCR can be used to assess the possibility of someone getting cancer when exposed to a certain dose of radiation during their lifetime. Lifetime cancer risk is calculated by Eq. 6 [28,29].

$$ELCR = AEDR \times DL \times RF \quad (6)$$

where AEDR is the annual effective dose rate, DL is average lifespan (estimated to be 70 years), dan RF (Sv^{-1}) is fatal risk factor (5.10^{-2} Sv^{-1}) [30].

RESULTS AND DISCUSSION

The specific radioactivity of ^{226}Ra, ^{232}Th, and ^{40}K in the environment are widely distributed in minerals located almost everywhere on the Earth. All foods contain low-level natural radionuclides, which are distributed from soil to plants and from water to fish in the diverse aquatic environtment. However, the amount of natural radionuclides can increase depending on the character and geology of soil, climate and activites of the surrounding community that can increase radionuclide activity to the environment, such as CFPP [1,3,4]. From the identification of radionuclides in the environment around Adipala CFPP, natural radionuclide isotopes were detected (^{210}Pb, ^{232Th}, ^{238}U, ^{228}Ra, ^{40}K, ^{226}Ra and ^{232}Th) andcan be seen in Figs. 2-5.

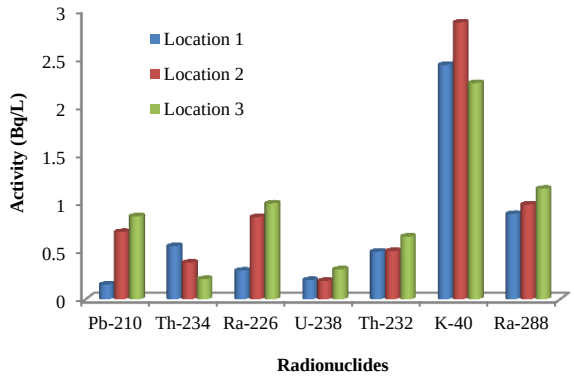

Fig. 2. Histogram of natural radionuclide activity in water.

Figure 2 shows the radioactivity histograms in the water at 3 sampling locations. The values of specific activity ranged from (0.152 ± 0.07) Bq/L in ^{210}Pb to (2.870 ± 0.49) Bq/L in ^{40}K. The mean specific activity of ^{40}K, ^{226}Ra, and ^{232}Th were 2.073 Bq/L, 0.714 Bq/L and 0.548 Bq/L, respectively. These values are below the world average value as mentioned by the United Nation Scientific Committee on Atomic Radiation (UNSCEAR-2000) [23]. According to Perka BAPETEN No 7 Year 2013, which was updated in Perka BAPETEN No. 7 Year 2017, regarding the maximum radioactivity limit value for water, there are three standard radionuclides for radioactivity levels, namely ^{232}Th (700 Bq/m^3 or 0.70 Bq/L), ^{226}Ra (1.0 Bq/L), and ^{238}U (21 Bq/L) [31,32]. The results of the analysis of water measurements around Adipala CFPPare still below the limit value permitted by BAPETEN.

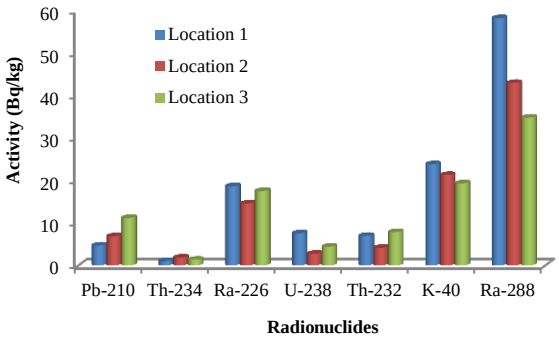

Fig. 3. Histogram of natural radionuclide activity in cassava leaves.

Radioactivity histograms detected in cassava leaves at three sampling locations around Adipada CFPP are presented in Fig. 3. The highest measured radioactivity was ^{40}K with activities ranging (34.835 ± 2.89) to (58.264 ± 7.54) Bq/kg with an average activity of 45.036 Bq/kg. The activity of ^{40}K in cassava leaves was much lower than cassava leaves in Nigeria, which was around 160-172 Bg/kg [12] and the average activity of ^{40}K in several types of Malaysia vegetables, which was around 646.42 Bg/kg [13]. The radionuclide with the lowest activity is ^{232}Th with activity value ranging from (4.17±3.25) to (7.87±0.30) Bq/kg with an average activity of 6.34 Bq/kg. In this research, the activity of ^{232}Th in cassava leaves is significantly lower than cassava leaves grown in Nigeria mining area which ranged from 1018-2614 Bg/kg [12]. Moreover, the activity of ^{234}Th in cassava leaves is detected as the lowest among other radionuclides, ranged from 1.044-1.881 Bq/kg with an average of 1.427 Bq/kg. The radionuclide that has the lowest activity is ^{266}Ra with an activity value of (14.617 ± 1.71) Bq/kg to (18.680 ± 0.61) Bq/kg, with an average activity of 16.951 Bq/Kg. The absorption rate of these radionuclides is highly dependent on the concentration of activity in the

soil. Root absorption depends on soil properties such as pH, mineral composition, organic matter content, and nutritional status as well as metabolic and physiological characteristics of plant species [12,33]. The uptake of radionuclides into cassava leaves and grass is one of the many factors for the migration of natural radionuclides to human from the environment through the food chain [34,35].

The results of the concentration of natural radionuclide activity in grass can be seen in Fig. 4. The measured radioactivity with the smallest activity is ^{234}Th radionuclides whose activity ranging from (2.594±0.39) to (4.820±0.29) Bq/kg with an average activity of 3.665 Bq/kg. Meanwhile, the radionuclide with the largest activity is the ^{40}K , with activity of (40.948±3.39) Bq/kg and an average activity of 35.621 Bq/kg. Other radionuclides such as ^{226}Ra and ^{232}Th have an average activity of 13.752 Bq/kg and 4.355 Bq/kg, respectively. When compared to the natural radionuclides activity in grass in a phosphate mining in aregion of Togo, the activity concentration of the ^{226}Ra radionuclide was 54±10 Bq/kg, and ^{40}K was 547±36 Bq/kg [36]. The activities of ^{226}Ra, ^{232}Th and ^{40}K on grass in the northeastern of Turkey were in the range of 21.8 ± 6.3–49.6 ± 13.4, 51.9 ± 13.2–127.7 ± 23.8 and 309.5 ± 33.5–807.3 ± 64.4 Bq/kg, respectively [37]. Radionuclide activity in grass depends on the age of the grass and the soil in which it is grown. Grass is the direct pathway for radionuclides to enter the body of animals and then to human through meat and/or milk. The radionuclide content of grass can provide a basis for deciding whether cattle can be allowed to graze in a particular area [38,39].

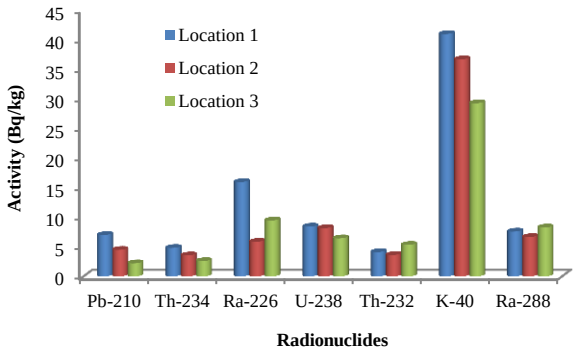

Fig. 4. Histogram of natural radionuclide activity in grass.

The measured radioactivity in the surface soil can be seen in Fig. 5, with the smallest activity found in ^{234}Th radionuclide (4.288 ± 0.66) Bq/kg with an average concentration of 27.843 Bq/kg. The radionuclide with the highest activity is ^{40}K with activity (430.729 ± 47.21) Bq/kg and average activity of 360.245 Bq/kg. The value is still below the maximum allowed according to UNSCEAR,which is around 400 Bq/kg [23]. The activities of ^{226}Ra and ^{232}Th for the soil around the Adipala CFPP are found to be in the range of 28.288±2.63 to 33.068±5.387 Bq/kg, with an average activity of 30.830 Bq/kg, and 12.78±0.19 to 41.56±4.84 Bq/kg with an average activity of 35.052 Bq/kg, respectively. According to UNSCEAR, the activity of ^{226}Ra is below the worldwide average (35 Bq/kg), while the activity of ^{232}Th exceeds the value of the worldwide average (30 Bq/kg) [23].

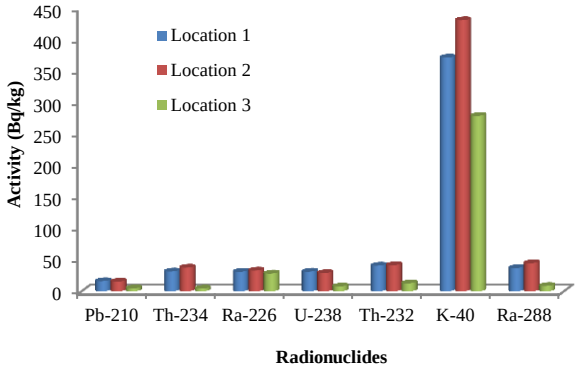

Fig. 5. Histogram of natural radionuclide activity in the soil.

Table 1. Comparison of radionuclides concentrations in soil samples with other countries.

District/region	Radioactivity concentration (Bq/kg)		
	^{226}Ra	^{232}Th	^{40}K
Adipala, Cilacap (This study)	30.830	35.052	360.245
Guliakhali Sea Beach, Sitakunda, Chittagong, Bangladesh [22]	56	31	412
Digor district, The northeastern of Turkey [37]	80.157	65.7	617.028
The Hoai Duc District, Vietnam [40]	23.2	26.4	312
Penang and Kedah district, Malaysia [41]	80 ± 41	56 ± 12	516 ± 119
Iraqi Kurdistan Region, Northern Iraq [42]	16.04 ± 0.71	10.32 ± 0.64	293.08 ± 15.99
The Udalia Tea Estate, Bangladesh [43]	38.8	55.8	383.8
Niš, Serbia [15]	19	30	409
Qatar [44]	17	10	201
South Africa [45]	8.47- 38.03	8.65- 41.18	94.22 - 381.89
USA and Lithuania [45]	13.7- 22.9	3.1-6.6	124.6- 470.1
India [46]	32.5	79	640

The comparison of the activities of ^{226}Ra, ^{232}Th and ^{40}K in various countries soils is provided in Table 1. In this study, the activity of ^{226}Ra in soil is higher than the activity of ^{226}Ra in soils from Vietnam, Northern Iraq, Serbia, Qatar, South Africa, USA, and Lithuania, but lower than Bangladesh, Turkey, Malaysia, and India. Furthermore, the activity of ^{232}Th in soil is higher than the activity of

^{232}Th in soil from Bangladesh, Vietnam, Northern Iraq, Serbia, Qatar, South Africa, USA and Lithuania, but lower than Turkey, Malaysia, and India. Meanwhile, the activity of ^{40}K in soil is higher than the activity of ^{40}K in soil from Vietnam, Northern Iraq, Qatar, South Africa, USA and Lithuania, but lower than Bangladesh, Turkey, Malaysia, Serbia, and India.

In general, the distribution of ^{226}Ra, ^{232}Th, and ^{40}K in environmental samples including environmental water materials is not uniform. To address radionuclide non-uniformity, a general index Ra_{eq} is used to obtain a radiological hazard assessment by ambient water. As shown in Fig. 6, the three natural radionuclides will determine the indication of radiation hazard in a water sample. The mean specific activity values of ^{226}Ra, ^{232}Th, and ^{40}K were 0.714 Bq/L, 0.380 Bq/L, and 2.073 Bq/L, respectively. The results obtained for Ra_{eq} using Eq. 1 show that the Ra_{eq} values at Locations 1, 2, and 3 are 1.191, 1.788 and 2.096, with mean ranges of 1.692 Bq/kg. The Ra_{eq} value obtained is still within the allowable limit of the recommended radiological safety standards designated by UNSCEAR-2000, which is 370 Bq/kg [23].

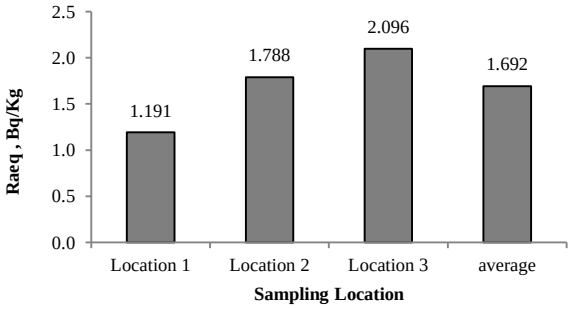

Fig. 6. Radium equivalent activity (Ra_{eq}) at 3 sampling locations.

The calculation of the absorbed dose rate at 1 meter of water surface is determined using Eq. 2. The absorbed doses in the samples for Locations 1, 2, and 3 were 0.545 nGy/hour, 0.823 nGy/hour, and 0.956 nGy/hour, respectively, with a mean value of 0.775 nGy/hour. The value of the absorbed dose rate is lower than the recommended average value (55 nGy/hour) [47].

The value of the annual effective dose rate in for water samples were calculated using Eq. 3. At Locations 1, 2 and 3, it was obtained that the total annual effective dose adjuvants were 0.003 mSv/y, 0.004 mSv/y, and 0.005 mSv/y with an average value of 0.004 mSv/y (Fig. 7). The value of the annual effective dose is lower than the recommended limit value (0.46 mSv/y) [23].

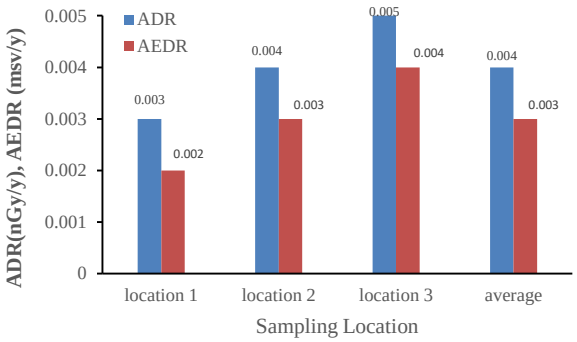

Fig. 7. Radiation hazard index for environmental water.

The external and internal hazard index (H_{ex} and H_{in}) are calculated using Eqs. 4 and 5, respectively. The external hazard indices for Locations 1, 2, and 3 are 0.003, 0.005, and 0.006, respectively, while the internal hazard indices for Locations 1, 2, and 3 are 0.004, 0.007, and 0.008, respectively. The external and internal hazard index mean are 0.005 and 0.006. The values of H_{ex} and H_{in} are smaller than 1, less than the critical value. These values are lower than the allowable limit, so that the radiation hazard was negligible [48].

Equation 6 is used to calculate the ELCR for water sample. The ELCR values for Locations 1, 2, and 3 are 0.01×10^{-6}, 0.014×10^{-6}, and 0.017×10^{-6}, respectively, with an average of 0.014×10^{-6}. This value is lower than the acceptable world value ELCR value, which is 1.45×10^{-3} for the total ELCR [23].

Table 2. Calculation results of radium equivalent activity (Ra_{eq}), absorbed dose rate (ADR), annual effective dose rate (AEDR), radiation hazard index (H_{ex} and H_{in}), and Excess Lifetime Cancer Risk (ELCR).

Sample	Location	Ra_{eq} (Bq/kg)	ADR (nGy/h)	AEDR (mSv/y)	Radiation Hazard Index		ELCR (10^{-6})
					(H_{ex})	(H_{in})	
cassava leaves	L1	34.682	16.198	0.079	0.094	0.144	0.278
	L2	23.892	11.117	0.054	0.064	0.104	0.191
	L3	33.802	15.681	0.077	0.091	0.139	0.269
	mean	30.792	14.332	0.070	0.083	0.129	0.246
Grass	L1	24.75	11.485	0.056	0.067	0.11	0.197
	L2	12.787	5.921	0.029	0.034	0.050	0.101
	L3	18.56	8.476	0.042	0.050	0.076	0.146
	mean	18.699	8.627	0.042	0.050	0.078	0.148
Soil	L1	168.092	78.204	0.384	0.454	0.673	1.343
	L2	184.125	85.8	0.421	0.497	0.749	1.473
	L3	60.323	28.401	0.139	0.163	0.239	0.487
	mean	137.513	64.135	0.315	0.371	0.554	1.101

The results obtained for Ra_{eq}, ADR, AEDR, and radiation hazard index for samples of cassava leaves, grass, and soil are presented in Table 2. The results of the Ra_{eq} indicates that Ra_{eq} grass<Ra_{eq} cassava leaf <Ra_{eq} soil. The Ra_{eq} for grass, cassava leaves, and soil were 18.699 Bq/kg,

30.792 Bq/kg, and 137.513 Bq/kg, respectively. All Ra_{eq} in the samples are lower than the recommended average value (370 Bq/kg) [23]. This shows that the samples for grass, cassava leaves, and soil in the area around Adipala CFPP at 2018 are yet to pose radiological hazards.

The rate of gamma dose absorbed in the air due to the emission of gamma rays from radionuclides in environmental materials such as cassava leaves, grass, and soil can be calculated using Eq. 2 with units (nGy/hour). In Table 2, the absorbed dose rate for grass is 8.627 nGy/hour, cassava leaves are 14.332 nGy/hour, and surface soil around Adipala CFPP is 64.135 nGy/hour. The values of the absorbed dose rate for the three samples are lower than the recommended average value (55 nGy/hour) [47]. It can be drawn from this study that the existence of Adipala CFPP does not pose any radiological hazards to the environment and the surrounding population.

The mean values of annual effective dose for grass is 0.042 mSv/y, for cassava leaves is 0.070 mSv/yr, and for soil is 0.315 mSv/y. The observed mean values for grass and cassava leaves are below the worldwide average annual effective dose (0.30 mSv/y) [23]. This shows that the cassava leaves consumed by humans and grass grown for fodder around the Adipala CFPP Cilacap do not cause radiological health risks. The annual effective dose values for soil is lower than the world mean values (0.46 mSv/y) [23].

The external (H_{ex}) and internal (H_{in}) radiation hazard indexes are presented in Table 2. It shows that H_{in} is higher the H_{ex}, where the average external and internal radiation hazard index values for grass are 0.050 and 0.078, for cassava leaves are 0.083 and 0.129, and for the soil are 0.371 and 0.554. The values of H_{ex} and H_{in} are smaller than 1, showing that there is no radiation risk around the Adipala CFPP from natural radionuclides in grass, cassava leaves, and soil [48].

According to Table 2, it is known that the mean value of ELCR at three sampling locations for grass sample (0.148×10^{-6}) < cassava leaves (0.246×10^{-6}) < soil (1.101×10^{-6}). These values are lower than the acceptable world ELCR value, which is 1.45×10^{-3} for the total ELCR [23].

CONCLUSION

This study determined the radionuclides content (^{210}Pb, ^{234}Th, ^{226}Ra, ^{228}Ra, ^{232}Th, ^{238}U and ^{40}K) in enviromental samples (water, soil, and plant) around Adipala CFPP, Cilacap. It is important to determine the radiological hazard of radiation exposure and to understand its health effect due to the presence of the CFPP. Since long term radiation exposure might cause cancer, it is important to measure the amount of natural radiation in environment to minimize the risk of cancer occurring. Based on the investigation result of the water, cassava leaves, grass, and soil samples from around Adipala CFPP, it is found that the natural radioactivity value, Ra_{eq}, ADR, AEDR, hazard index (H_{ex} and H_{in}) and ELCR for water, cassava leaves, grass, and soil samples around Adipala CFPP are within the range of the world average values reported by UNSCEAR. According to this finding, the current presence of CFPP does not pose a potential risk of radiation exposure increment in environment which might cause cancer.

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AUTHOR CONTRIBUTION

Sri Murniasih contributed as the main contributor to this paper, such as coordinating work, sampling, measuring and analyzing samples. Devi Swasti Prabasiwi and Sukirno support this research activity,such as sampling and measuring samples. All authors have read and approved the final version of this paper.

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