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ASSESSMENT OF RADIOACTIVITY LEVELS IN COAL AND COAL ASH IN KIWIRA COAL MINE USING GAMMA-RAY SPECTROMETRY

Ismael N Makundi[1], Mungubariki M Nyaki[1,2] and Najat K Mohammed[1]
[1]Department of Physics, University of Dar es Salaam, P.O. Box 35063, Dar es Salaam, Tanzania.
[2]Tanzania Atomic Energy Commision, P. O. Box 743, Arusha.
Corresponding author: ismakundi@udsm.ac.tz

ABSTRACT

This study aimed to assess the radioactivity levels and associated dose rates from the naturally occurring radionuclides ^{226}Ra, ^{232}Th and ^{40}K in coal and coal ashes at Kiwira coal mine. The radioactivity of 40 representative coal, fly ash samples were measured using gamma spectroscopy of the Tanzania Atomic Energy Commission (TAEC) in Arusha, Tanzania. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in coal and coal ashes from Kiwira were higher by several orders of magnitude than their worldwide average values. The calculated radium equivalent activity, the air absorbed dose rate, external hazard index and the average annual effective dose rate in fly ashes were 1335 ± 60 Bq kg^{-1}, 610 ± 29 nGy h^{-1}, 4 ± 0.4, 738 ± 52 µSv y^{-1} which were higher than the international recommended values of 370 Bq kg^{-1}, 57 nGy h^{-1}, and 70 µSv y^{-1} for fly-ashes respectively. The results provide information for the radiation protection when the coal and its by-products in the vicinity of Kiwira coal field is used. The data can be used by the authorities to design an appropriate method for handling wastes and implement intervention measures to protect the miners, the public as well as the environment.

Keywords: Coal, fly ash, soil, radioactivity, gamma-ray spectrometry.

INTRODUCTION

Coal based thermal power plants all over the world are cited to be among the major source of natural radioactivy pollution in the environment and radiation dose exposure to population (Ashoka et al. 2005, Pandit et al. 2011, Hany et al. 2013). It has been indicated that coal is associated with elevated concentrations of radioactivity mainly from potassium (^{40}K), uranium (^{238}U), radium (^{226}Ra), thorium (^{232}Th) and their daughters (Aycik and Ercan 1997, UNSCEAR 2000, Balogun et al. 2003, Jankovic et al. 2011, Omale et al. 2017). Filiz and Yaprak (2010) reported elevated concentrations of ^{238}U, ^{232}Th, ^{226}Ra and ^{40}K above the world average in coal samples from Turkey, the mean activity concentration of ^{226}Ra was found to be in the order of 2 to 5 times higher than the recommended world mean value. In the coal based thermal plant huge amount of coal is being burnt to produce tons of fly ash and bottom ash containing natural radionuclides (Pandit et al. 2011). Research has shown that coal ash, contains higher concentrations of ^{226}Ra, ^{232}Th and ^{40}K than the feed coal itself (Xinwei et al. 2006, Jankovic et al. 2011). Therefore, if the fly ash and bottom ash not properly controlled it could be the significant sources of exposure to the naturally occurring radionuclides that affect the population in the vicinity of the power plants and coal industries.

Tanzania has about 700 million tons of coal deposit viable for mining (Kreuser 1994). The Songwe Kiwira coal deposit is the one which has been commercially exploited and have a power plant within the mining site. Sawe (2010) and Shao (2012) reported uncontrolled release of byproducts from coal

burning at Kiwira which has increased the concentration of toxic metals in the proximity of the power plant. However, both studies did not include the analysis of natural radionuclides in coal and how it contributes to radiation dose to population in the surrounding area.

Shao (2012) reported that coal ashes around the Kiwira coal mine are also used by local people to make kitchen stoves and road pavements. These building materials could also be a source of radon daughter exposure which can result into lung cancer (Rajeev et al. 2011). Therefore, it is necessary to assess the natural radioactivity content in coal ashes for subsequent evaluation of dose received by the workers and population surrounding Kiwira coal mine for the purpose of continuous monitoring and protection.

MATERIALS AND METHODS

Study Area

Songwe-Kiwira coal-field is defined by longitude 33°35´-33°45´E and latitude 9°20´-9°35´S. The field is about 45 km from Lake Nyasa and is along the western rift valley. The area of study is accessible to carbonatites rocks with highest phosphorus concentrations (Chesworth et al. 1989).

Sample Collection

The coal, coal ash and soil samples were collected from various sites inside and in the vicinity of the Kiwira coal mine plant. The sampling sites were chosen in such a manner that the representative collection of samples could be obtained (IAEA 2004). A total of 41 samples were collected; 10 samples from coal storage area of the power plant, 20 samples of fly ash (10 from the beg filter and 10 from water membrane) and 11 soil samples collected randomly in the directions west, east, north, and south around the washing plant and power generation plant and in farms about 1 km from the power generation plant. The top layers of the soil which contain wastes that are yet to decompose were removed. At each sampling location, soil samples were collected at a depth of (0–15 cm). About 1000 g of each sample (coal, fly ash and soil) was packed in a plastic bag at the sampling points. All samples were transported to the laboratory for further preparations.

Sample Preparation

All coal samples were crushed and milled to fine powder with particle sizes less than 0.2 mm. The samples were homogenized in order to attain uniformity and dried in a temperature-controlled furnace at about 60 °C for 24 hours to remove moisture. Similarly, soil samples were ground to 0.2 mm, homogenized to attain uniformity, dried and hermetically sealed in a standard 500 ml marinelli beaker. All samples were left for about 30 days to attain radioactive equilibrium before counting for radium and thorium daughters (IAEA 2004). The concentrations of ^{226}Ra, ^{232}Th, ^{234}Th and ^{40}K in the samples of coal, fly ash and soil were measured by gamma-ray spectrometry equipped with a Hyper-Pure Germanium (HPGe) detector.

Gamma- ray Spectrometer

The study used a P-type coaxial high purity germanium detector (HPGe) with relative efficiency of 51.0% and resolution of 1.80 keV at 1332 keV energy of ^{60}Co. Detector chamber is shielded with three layers of copper, cadmium and lead of 30 mm, 3 mm and 100 mm thick, respectively. Energy and efficiency calibration were performed using the multi-nuclide standard packed in a 500 ml marinelli beaker. The standard (MBSS 2) contained 10 radionuclides (^{241}Am, ^{109}Cd, ^{139}Ce, ^{57}Co, ^{60}Co, ^{137}Cs, ^{113}Sn, ^{85}Sr, ^{88}Y and ^{203}Hg) with production No. 130113-1395013 and reference date of 8th February 2013. The activity of ^{226}Ra was determined using the gamma-lines of ^{214}Pb (295.2 and 351.9 keV) and ^{214}Bi (609.3 keV). The activity for ^{232}Th was measured from ^{212}Pb (238.6 keV), ^{228}Ac

(338.3 and 911.1 keV) and ^{208}Tl (583.2 keV). The ^{40}K was measured from its gamma line energy of 1460.8 keV. Activity concentration (Bqkg^{-1}) of ^{226}Ra, ^{232}Th and ^{40}K in the samples were calculated using the analytical equation (1), (Tzortzis et al. 2004).

$$A_{sp} = \frac{N_{sam}}{P_E \varepsilon(E) T_c M} \qquad (1)$$

where, A_{sp} is the specific activity concentration of radionuclide in the sample,
N_{sam} is the net counts of the radionuclide in the sample,
P_E is the gamma-ray emission probability,
$\varepsilon(E)$ is the absolute counting efficiency of the detector system,
T_c is the sample counting time,
M is the mass of the sample in kg or volume in litres.

Determination of Radium Equivalent (Ra_{eq}) and External Hazard Index (H_{ex})

The assessments of the radiological hazard of natural radionuclides are determined by using radium equivalent concentration (Ra_{eq}) and external hazard index (H_{ex}). This is based on the estimation that 370 Bq kg^{-1} of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th and 4810 Bq kg^{-1} of ^{40}K produce the same gamma ray dose rate (Xinwei et al. 2006). The value of the external hazard index must be less than one for the radiation hazards to be considered negligible. In this works the radium equivalent (Ra_{eq}) and external hazard index (H_{ex}) were calculated according to equations (2) and (3) (Beretka and Mathew 1985).

$Ra_{eq} = A_{Ra} + 1.43\ A_{Th} + 0.077\ A_K$ (2)

$H_{ex} = A_{Ra} / 370 + A_{Th} / 259 + A_K / 4810$ (3)

where; $A_{Ra,}$ A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1}, respectively.

Estimation of Annual Effective Dose Equivalent

Absorbed dose rate in air at 1 m above the ground surface, is what directly connects the radioactivity concentrations of natural radionuclides and their exposure. The absorbed dose rate was calculated using equation (4) (UNSCEAR 2000),

$$D(nGyh^{-1}) = 0.462\,A_{Ra} + 0.604\,A_{Th} + 0.0417\,A_K \qquad (4)$$

where: A_{Ra}, A_{Th}, and A_K are activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively in Bq kg^{-1} and 0.462, 0.604 and 0.0417 are the respective dose converting factors.

The absorbed dose rates obtained using equation (4) was used to calculate an annual effective dose from gamma terrestrial radiation at each sample. For the conversion from absorbed dose rate in air to annual effective dose, the coefficients proposed by (UNSCEAR 2000) was used, i.e., an outdoor occupancy factor of 0.2 and absorbed dose rate in air to effective dose conversion factor for gamma ray of 0.7 Sv Gy^{-1} for adults. This value is assumed to apply equally to both adult males and females and to indoor and outdoor environments. The annual effective dose equivalent from outdoor terrestrial gamma radiations was determined by equation (5).

$$E_{out}(\mu Sv/y) = D(nGy/h) \times 24h \times 365.25d \times 0.2 \times 0.7(Sv/Gy) \times 10^{-3} \qquad (5)$$

The values obtained from equations (2), (3), (4) and (5) were used to assess the radiation exposure to workers and the population surrounding the Kiwira coal mine.

REULTS AND DISCUSSIONS

Radioactivity Concentration in Coal sample

The obtained activity concentration of ^{226}Ra,^{232}Th and ^{40}K in Kiwira coal are listed in Table 1. The standard deviations for the data from all three radionuclides are very small indicating that their concetration levels in all 10 samples were somewhat similar.

Table 1: The activity concentration of radionuclide **(Bq/kg ± SEM)** in coal samples collected from Kiwira coal mine

Sample name	**Sample**	**Activity concentration (Bq/kg ± SEM)**		
Coal	**code**	**Ra-226**	**Th-232**	**K-40**
	C1	37.5 ± 5.2	37.5 ± 5.4	276.4± 30.0
	C2	41.7 ± 6.0	44.6 ± 7.0	332.5± 42.3
	C3	44.4 ± 6.8	40.8 ± 5.6	366.3± 45.0
	C4	41.9 ± 6.8	32.7 ± 3.4	216.1± 20.5
	C5	40.0 ± 5.6	33.4 ± 3.6	283.9± 20.5
	C6	43.0 ± 2.1	38.1 ± 5.8	283.0± 20.5
	C7	37.7 ± 3.5	35.6 ± 5.9	266.1± 29.5
	C8	43.2 ± 8.6	38.8 ± 5.5	281.4± 20.0
	C9	44.3 ± 7.6	35.4 ± 5.2	280.4±39.8
	C10	39.1 ± 4.7	35.5 ± 5.7	343.8± 44.0
Standard deviation		**2.6**	**3.6**	**43.3**
Mean ± SEM		**41.3 ± 1.0**	**37.2 ± 1.1**	**293 ± 14**

Coal from different places in the world exhibit different levels of radioactivity depending on the geological structure of the region. UNSCEAR 2000, reported a world range of the three radionuclides as ^{226}Ra (17 – 60 Bq kg^{-1}), ^{232}Th (10 – 64 Bq kg^{-1}) and ^{40}K (140 – 850 Bq kg^{-1}) and the world average data as 35 Bq kg^{-1}, 30 Bq kg^{-1} and 400 Bq kg^{-1}, respectively for ^{226}Ra, ^{232}Th and ^{40}K. Most ^{232}Th in coal is contained in common phosphate minerals such as monazite or apatite. In contrast, uranium and ^{226}Ra are found in both mineral and organic fractions of coal. The mean activity concentration for ^{226}Ra and ^{232}Th in coal samples analysed in this work were found to be slightly higher while the mean concentration for ^{40}K was about 1.4 times lower than the world average coal data presented by UNSCEAR 2000. However, the mean activities of all three radionuclides obtained in this work lies within the world range reported by UNSCEAR 2000.

On the other hand, Table 2 shows that the mean activity concentraions of ^{226}Ra in coal samples obtained in this study are higher than the values reported in 4 literatures cited in this work (Mishra 2004, Xinwei et al. 2006, Jankovic et al. 2011, Elena and Victor 2013). Moreover, the mean activity of ^{226}Ra is similar to the value reported in coal from Shangai, China and lower than the value reported in coal from Turkey and Brazil (Yu 1996, Flues et al. 2007, Akkurt et al. 2009). The Acitivity concentration of ^{232}Th in coal samples analysed in this study are similar to their activities reported in China, Serbia and India (Yu 1996, Mishra 2004, Xinwei et al. 2006, Jankovic et al. 2011), but higher than the values reported in Turkey, Spain and Brazil (Flues et al. 2007, Akkurt et al. 2009, Elena and Victor 2013).

Table 2: Comparison of activity concentration of ^{226}Ra and ^{232}Th and ^{40}K in coal from the study area with data from elsewhere

Location	Activity concentration (Bq/kg)			
	Ra-226 Mean	Th-232 Mean	K-40 Mean	Reference
Kiwira-Tanzania	**41**	**37**	**293**	**Present study**
Serbia	29	31	120	Jankovic et al. 2011
Baoji – China	26	37	100	Xinwei et al. 2006
Turkey	73	20	229	Akkurt et al. 2009
Spain	30	23	242	Elena and Victor 2013
India	24	39	83	Mishra 2004
Parana State – Brazil	321	22	191	Flues et al. 2007
Shanghai – China	40	37	59	Yu 1996
Worldwide	35	30	400	UNSCEAR 2000

Activity Concentration of ^{226}Ra,^{232}Th and ^{40}K in Fly ash sample

The activity concentration of ^{226}Ra,^{232}Th and ^{40}K in fly ash samples are shown in Table 3. In comparison, the mean concetrations of the three radioanucldes in the fly ash are about 10 times higher than their mean conentrations in the parent coal. Higher concentrations of radionuclides in the fly ash than in the parent coal was expected as the radioactivity becomes concentrated in the residues when the coal is burned. The observed activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in fly ash samples in this study are much higher by several orders of magnitude than the values reported for coal fired thermal plant in 3 literatures cited in this study.

Table 3: Mean activity concentrations of radionuclide **(Bq/kg ± SEM)** in the fly ash samples collected from Kiwira coal mine

Sample name	Sample code*	Activity concentration		
Fly ash		**Ra-226**	**Th-232**	**K-40**
	F1	470 ± 78	432 ± 75	3113±59
	F2	482 ± 43	472 ± 88	3072±60
	F3	492 ± 51	479 ± 74	2963±45
	F4	472 ± 43	466 ± 97	4541±75
	F5	505 ± 39	466 ± 90	3112±65
	F6	471 ± 55	469 ± 56	2963±47
	F7	460 ± 45	435 ± 99	2976±50
	F8	485 ± 44	459 ± 76	3035±63
	F9	474 ± 56	342 ± 59	3073±63
	F10	480 ± 43	470 ± 63	3087±65
	F11	433 ± 41	453 ± 62	2904±46
	F12	416 ± 25	458 ± 67	2924±45
	F13	413 ± 87	447 ± 76	2879±48
	F14	415 ± 88	449 ± 76	2893±48

	F15	409 ± 97	456 ± 78	3178±65
	F16	425 ± 75	441 ± 99	3036±69
	F17	426 ± 36	438 ± 97	2941±62
	F18	408 ± 15	451 ± 73	2878±57
	F19	408 ± 77	448 ± 78	2865±58
	F20	421 ± 86	468 ± 86	2957±65
Standard deviation		**33**	**14**	**358**
Mean ± SEM		**448 ± 97**	**455 ± 3**	**3069±80**

Table 4 shows that the mean activity concentration of ^{226}Ra in samples from Kiwira is about 5 times the value reported in India (Pandit et al. 2011) and about 4 times the value reported in Serbia and Spain (Jankovic et al. 2011, Elena and Victor 2013). However, the mean activity of ^{226}Ra, ^{232}Th reported in this study were lower than the mean values reported in Egypt (Hany et al. 2013). The mean activity concentration of ^{232}Th in samples from Kiwira was found to be about 5 times the value reported in fly ash from India (Pandit et al. 2011), 6 times the value obtained in Serbia (Jankovic et al. 2011) and 5 times the value observed in Spain (Elena and Victor 2013). The activity concentration of ^{40}K is about 30 times and 9 times the values in India (Pandit et al. 2011) and Serbia (Jankovic et al. 2011), respectively. Furthermore, the mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K obtained in fly ash samples from Kiwira are much higher than the average world values of the fly ash (UNSCEAR 1988).

Table 4: Comparison of radioactivity concentration in fly ashes from the study area with values from other areas

Location	**Activity concentration (Bq/kg)**			
	Ra-226 Mean	**Th-232 Mean**	**K-40 Mean**	**Reference**
Kiwira - Tanzania	**448**	**455**	**3069**	**Present study**
Serbia	120	72	360	Jankovic et al. 2011
Baoji – China	112	148	386	Xinwei et al. 2006
Beijing – China	101	110	347	Gu et al. 1996
Spain	128	88	860	Elena and Victor 2013
India	80	140	100	Pandit et al. 2011
Assiut – Egypt	2207	1281	1218	Hany et al. 2013
Worldwide	240	70	265	UNSCEAR 1988

Radioactivity Concentration in Soil samples

Activity concentrations of the three radionuclide (^{226}Ra, ^{232}Th and ^{40}K) obtained in soil are presented in Table 5. The soil samples were collected in two different stations within the plant and from farms 1 km from the plant (SF). The two stations within the plants are area around the washing plant (SW) and area around the power generation (SP). With the exception of sample SP_1 and SP_2 the activities are the highest in samples from the washing plant than in samples from the other sampling stations. This is because the washing plant is where after being crushed the coal are washed before trasfering to the power generation plant. The other 2 samples from the power station (SP_3 and SP_4) has similar concentrations of both ^{226}Ra and ^{232}Th as the samples from the farms. Conversation with the farmers revealed that they use fly ashes and bottom ashes in their farms as a source

of additional nutrients. This might have increased the levels of radioactivities in the soil.

Table 5: Mean activity concentration of radionuclide (Bq/kg ± SEM) in the soil samples collected from Kiwira coal mine

Sample code*	Mean concentration (Bq/kg ± SEM)		
	Ra-226	**Th-232**	**K-40**
SW_1	435 ± 95	336 ± 53	2670±133
SW_2	404 ± 54	351 ±97	2618±136
SW_3	420 ± 90	367 ± 98	2967±200
SW_4	383 ± 73	340 ± 67	3102±144
SP_1	464± 87	326 ± 60	3244±145
SP_2	415 ± 61	415 ± 96	2912±132
SP_3	353 ± 92	307 ± 84	3105±147
SP_4	324 ± 97	321 ± 90	2991±124
SC_1	352 ± 91	364± 73	2166±126
SC_2	300 ± 86	350 ± 86	1926±157
SC_3	347 ± 72	258 ± 68	1894±144
Mean ± SD	**378 ± 22**	**331 ± 32**	**2632 ± 50**

*The sample code represent the sampling locations; SD means standard deviation.

Table 6 shows also that the activity concentration in soil samples obtained from this study are higher than the world-wide mean activity cencentrations for ^{226}Ra, ^{232}Th and ^{40}K (which are 33, 45, 420 Bq kg^{-1}, respectively (UNSCEAR 2000)). They are aslo higher than the levels reported in China, Brazil, Turkey and Saud Arabia (Flues et al. 2002, El-Aydarous 2007, Alaamer 2008, Huseyin and Ridvan 2008, Xinwei et al. 2013). However the activity concentrations of ^{226}Ra, ^{232}Th obtained in this study are much lower than their values reported in Egypt (Hany et al. 2013).

Table 6: Comparison of radioactivity concentration in soil from the study area with values from other areas

Location	Activity concentration (Bq/kg)			
	Ra-226 Mean	**Th-232 Mean**	**K-40 Mean**	**Reference**
Kiwira - Tanzania	378	331	2632	Present study
Baoji - China	40	60	751	Xinwei et al. 2013
Assiut – Egypt	2670	1401	1495	Hany et al. 2013
Figueira – Brazil	133	39	233	Flues et al. 2002
Gatalagzi – Turkey	31	40	379	Huseyin and Ridvan. 2008
El Taif – Saudi Arabia	24	19	163	El-Aydarous 2007
Riyadh – Saudi Arabia	14	11	225	Alaamer 2008
Worldwide	32	45	420	UNSCEAR 2000

Radiological effects

The present study have analysed the radiological effects to environment and human being surrounding the power plant and workers by using fly ash since it is distributed to the environment and is used in human activities. Coal is not considered since it is localized within the coal power plant.

The radium equivalent (Ra_{eq}), external hazards index (H_{ex}),absorbed dose rate and total annual effective dose were calculated on the basis of the equations (2), (3), (4), and (5), respectively, and the results are listed in Table 7.

Table 7: Mean values of radiation hazards parameters for fly ash sample

Sample - name	**Sample code**	**Radium equivalent (Bq/kg)**	**External hazard index**	**Dose rate (nGy/h)**	**Annual effective dose (µSv/y)**
Fly ash	F1	1327	4	608	746
	F2	1393	4	636	780
	F3	1404	4	640	785
	F4	1489	4	689	846
	F5	1411	4	645	791
	F6	1370	4	625	767
	F7	1311	4	599	635
	F8	1374	4	628.	770
	F9	1342	4	614	753
	F10	1390	4	635	779
	F11	1303	4	594	729
	F12	1295	4	590	725
	F13	1273	3	581	613
	F14	1280	4	584	716
	F15	1305	4	597	732
	F16	1290	4	589	723
	F17	1279	4	584	717
	F18	1274	3	581	713
	F19	1270	3	579	710
	F20	1318	4	600	737
Mean ± SD		**1335 ± 60**	**4.0 ± 0.4**	**610 ± 29**	**738 ± 52**

From Table 7, the calculated Ra_{eq} in fly ash ranges from 1270 to 1489 Bq kg^{-1} with an average of 1335 ± 60 Bq kg^{-1} which is about 4 times higher than the recommended limit of 370 Bq kg^{-1} (UNSCEAR 2000). This value indicates a significant radiological health hazards if the fly ashes are used for domestic activities. Similarly from Table 7 the calculated values of H_{ex} for fly ash samples range from 3 to 4 with an average of 4 ± 0.4. This shows that the fly ash has hazard index of about 4 times higher than the recommended limit of 1 (UNSCEAR 2000) indicating that the Kiwira coal mine fly ashes have a significant radiological risk to human health.

The absorbed dose rate ranged from 581 to 689 nGy h^{-1} with an average of 610 ± 29 nGy h^{-1}. This value is about 11 times higher than the estimated world average external exposure rate from terrestrial gamma

radiation of 57 nGy h^{-1} (UNSCEAR 2000). The asorbed dose rate were used to calculate an annual effective dose from gamma terrestrial radiation. From Table 7, the estimated annual effective doses for adult range from 710 to 846 µSv y^{-1} with an average of 738 ± 52 µSv y^{-1}. This value is about 11 times higher than estimated world average annual effective dose for adult which is 70 µSv y^{-1} (UNSCEAR 2000). According to these results, it seems that the concentration of the radionuclides in the examined fly ashes are of great radiological importance towards the population of the Kiwira coal mine plant especially because they are using the ash for domestic and agricultral activities.

CONCLUSIONS

The samples of coal from Kiwira analysed in this work have activity of ^{226}Ra, ^{232}Th and ^{40}K in values above the activity levels reported by UNSCEAR 2000 as the world activit average of the radionuclides in coal. However, the activity values obtained in this study were similar to the activites reported in 4 literatures reviewed in this work. As was expected, the activity of the three radionuclides were higher in fly ash samples than in the parent coal. This is because the activity concentrations accumulate when the coal is burned. The same obervations were reported in coal and fly ash samples reported elsewehere (Jankovic et al. 2011, Hany et al. 2013). Soil samples which were collected from farms 1 km from the coal power plant had lower activity than the samples collected from within the plant. However the soil samples had higher activity of ^{226}Ra and ^{232}Th than average world activiy values reported by UNSCEAR 2000. This is because the farmers use the fly ash as fertilizer. The radiation hazard indeces of the fly ash revealed that the fly ash are not safe for domestic and agricultural activites. We are hereby recommending that the authority should have strict controll over the use of fly ash by humans.

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