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Monstrous Hazards Produced by High Radioactivity Levels Around Assiut Thermal Power Plant

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ABSTRACT

The natural radioactivity level of heavy oil, ash and soil samples around Assiut Thermal Power Plant (ATPP) in Egypt was determined using gamma ray spectrometry. The average concentrations of ^{226}Ra, ^{232}Th and ^{40}K in fly ash were found to be 2307±143, 1281±80 and 1218±129 Bq kg^{-1}, respectively, while the corresponding values in soil samples were 2670±107, 1401±78 and 1495±100 Bq kg^{-1}, respectively. These are extremely high and higher by several orders of magnitude than the worldwide population-weighted average values in soil. The radium equivalent activity, the air absorbed dose rate, external hazard index and the annual effective dose rate were calculated and compared with the international recommended values. All averages of these parameters are much higher by several orders of magnitude than the international recommended values, indicating significant radiological health hazards around ATPP due to the radionuclides in the soil. Moreover, the water samples investigated have high activity concentrations indicating that the water is highly contaminated with radioactive materials. The results of the current study highlight the severity of this radioactive pollution on the population in the vicinity of ATPP.

Keywords: Fly Ash, Natural Radioactivity, Radiation Hazard, Water Contamination

1. INTRODUCTION

The concept of technologically enhanced natural radioactivity represents the exposure to natural sources of radiation which would not exist without the technological activity unintentionally undertaken to produce radiation (UNSCEAR, 1982). Earlier studies have shown that the main sources of technologically enhanced natural radioactivity are coal-fired power plants and artificial fertilizers applied in agriculture (Kljajic *et al*., 1996).

Coal-fired power plants became important for investigations as a result of the advancement of the scientific knowledge of biological effects of radiation action on humans and after dose limits reduction in international recommendations and standards. Coal combustion as well as oil combustion in power plants leads to redistribution of natural radionuclides originating from coal and oil and to their concentration in ash and slag. The basic problem of technologically enhanced natural radioactivity caused by thermal power plants is the increase of the

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background gamma radiation level. Therefore, the local population is exposed to higher gamma radiation doses than in their absence.

Egypt largely depends on heavy fuel oil for its energy requirements. More than 90% of the total power generated in Egypt is from that source (Mahmoud *et al*., 2011). Like most materials found in nature, the heavy fuel oil contains the natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K. As a result of heavy oil combustion in thermal power plants, natural radionuclides and their products are released and concentrated in solid combustion byproducts (bottom and fly ashes). Bottom ash is the coarse grained materials collected at the bottom of the boiler, whereas fly ash is composed of fine sized particles ranging from 0.5 to 200 μm (Baba, 2002; Mandal and Sengupta, 2006). The fly ash is carried through the furnaces with gas flow toward the stack. Depending on the emission control system of the stack, most of the fly ash is collected. But the collection efficiency is always less than 100% (Papaefthymiou, 2008) such that some fly ash is released into the atmosphere and deposited on the soil around the thermal power plant. The deposited ash and slag at depots may contain natural radionuclides with activities several times higher than respective average activities in the soil (UNSCEAR, 1982; 1988). Thus, oil combustion like coal combustion may increase environmental radioactivity levels in the vicinity of thermal power plants due to fly ash with high radionuclide concentrations released into the surrounding environment (Mondal *et al*., 2006). This can cause radiation exposure to the public living and working in the immediate vicinity of thermal power plants.

Assessment of the radiation doses in humans from natural sources is of special importance because natural radiation is the largest contributor to the collective dose received by the world population. So, knowledge of the doses from the natural background is necessary as a basis for comparison with man-made sources of exposure. Moreover, owing to the large variability of doses from natural sources of radiation, some individual doses may be high enough to obligate the introduction of remedial measures (UNSCEAR, 1988).

It was found that the ash produced by the combustion of heavy fuel oil in Assiut Thermal Power Plant (ATPP) contains nearly one thousand times of natural radionuclides more than raw oil (El-Gamal *et al*., 2013). The concentrations of natural radionuclides in the produced ash are extremely higher than the corresponding concentrations in the earth's crust and much higher than that in coal fly ashes in other countries (El-Gamal *et al*., 2013).

The main objective of the present study was to evaluate the effect of radionuclide emission on the environment from ATPP which is located in Assiut city, on the Nile in central Egypt. The concentrations of natural radionuclides such as ^{226}Ra, ^{232}Th and ^{40}K in raw oil and fly ash samples were measured, as well as the concentration of the same radionuclides in surface soils. The radiological effect of these radionuclides involves gamma ray exposure of the body and irradiation of lung tissue from inhalation of radon and its daughters. Therefore, the assessment of gamma radiation from soil samples is of particular importance in terms of the natural radiation to which the population is exposed around ATPP. This study was motivated by the desire to determine the concentration of radioisotopes in smoke stack and water discharge and to evaluate any environmental impact in the area surrounding ATPP. There had been no previous experimental or monitoring data for the gamma radiation from soil and water samples around ATPP. The outcomes of this study provide essential knowledge about the natural radioactivity concentrations and the dose estimations from surface soil and water samples around the plant. Analysis of the radiological influence of the plant, of the wind direction and contamination at a long distance were the main subjects of this study.

2. MATERIALS AND METHODS

2.1. The Study Area

Assiut is the largest town in Upper Egypt and lies about 234 miles south of Cairo. The city of Assiut is located at 27°11′00″N 31°10′00″E and spread across 26000 km_2. It is located between two mountains ranges of about 600 m height. There is also a lowering in altitude in mid Egypt, from the Mediterranean and the Red Sea. This gives the city and nearby towns and villages the typical properties of a continental climate meaning that the city has harsh and chilly cold winter weather and very hot but non-humid summers. The ATPP (27o 12' 46" N and 31o 9' 56" E) is located 3.5 km from Assiut city. It is located on the western bank of the River Nile and covers a total area of 4×10^5 m^2. There are two units with maximum power of 2×312

MW. The two units consume about 8.76×10^5 ton yr^{-1} of heavy oil; the combustion of this amount produces about 0.6×10^5 ton yr^{-1} of ash.

The widely used Gaussian Plume Model (GPM) for a point source which is mainly used to estimate the pollutants considered can be used to identify the study area of this work. For a point source, the pollutant concentration is governed by the Equation (1) (Heinsohn and Kabel, 1999):

$$c = \frac{Q}{2\pi U\sigma_y\sigma_z} * \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left\{\exp\left(-\frac{(z-H^2)}{2\sigma_z^2}\right) + \exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right)\right\} \quad (1)$$

The effective stack height H is the sum of the physical stack height h and the plume rise Δh Equation (2):

$$H = h + \Delta h \quad (2)$$

The plume rise can be calculated from Holland's formula Peavy *et al*. (1987) Equation (3):

$$\Delta h = \frac{V_s D}{U}\left[1.5 + 2.68 * 10^{-3} \times p \times D \times \frac{(T_s - T_a)}{T_s}\right] \quad (3)$$

The characteristics of plume dispersion depend on the stability classification assigned to the scenario being studied. For dispersion estimation and modeling purposes, the levels of atmospheric stability are classified into six stability classes based on five surface wind speed categories, three types of daytime insolation and two types of night time cloudiness.

These stability classes are referred to as Pasquill-Gifford stability classes and are introduced by Peavy *et al*. (1987) Horizontal and vertical dispersion parameters σ_y and σ_z are estimated using the Briggs formulae for urban sites (Griffiths, 1994). The study area as identified by GPM is shown in **Fig. 1**.

2.2. Natural Radioactivity Measurements of ash and Surface Soil Samples

All collected ash and surface soil samples (0-5 cm) were stored in polyethylene bags. They were dried for 2 h at 150°C and sieved through an 18 mesh. The samples were packed in plastic containers 75 mm in diameter and 90 mm in height. The samples were weighted and stored for a minimum period of one month to allow daughter products to come into radioactive equilibrium with their parents ^{226}Ra and ^{232}Th and were then counted, the counting time depending on the concentration of the radionuclides. Laboratory measurements of ^{226}Ra, ^{232}Th and ^{40}K in soil and ash samples were undertaken using a gamma-ray spectrometric set-up at the Physics Department, Assiut University. The detector was a 3×3 inch NaI(Tl) gamma-ray spectrometric system with 7.5% energy resolution (^{60}Co 1.33MeV). The detector was housed in a chamber of two layers starting with stainless steel (10 mm thick) and lead (30 mm thick) to reduce the gamma-ray background. It was coupled to a 1024 micro-computer multi-channel pulse height analyzer.

^{226}Ra activity of the samples was determined via its daughters (^{214}Pb and ^{214}Bi) through the intensity of the 295.22, 351.93 keV for ^{214}Pb Gamma-lines and 609.31, 1120, 1764.49 keV for ^{214}Bi Gamma-lines. ^{232}Th activity of the sample was determined from the daughters (^{228}Ac, ^{212}Pb and ^{208}Ti) through the intensity of 209.25, 338.32, 911.2 keV Gamma-lines for (^{228}Ac), (^{212}Pb) emissions at 238.63 keV and (^{208}Ti) emissions at 583.19, 2614 keV Gamma-lines, whereas ^{40}K activity was measured directly through its gamma ray energy peak of 1460.8 keV (El-Taher and Althoyaib, 2012). The spectra were either evaluated with the Maestro (EG&G ORTEC) computer software program, or manually with the use of a spread sheet (Microsoft Excel) to calculate the natural radioactivity.

2.3. Natural Radioactivity Measurements of Heavy Oil and Water Samples

The oil and water samples were collected in standard (1 liter) polyethylene Marinelli beakers. Before use, the containers were washed with dilute hydrochloric acid and rinsed with distilled water. Each beaker was filled up to its brim and a tight cap was pressed onto it so that air was completely removed. Samples were acidified by adding 0.5 mL of conc. HNO_3 per liter to prevent any loss of radium isotopes around the container walls and to avoid growth of micro-organisms (Navratil *et al*., 1997). These samples were also stored in the laboratory for a minimum of 1 month to allow daughter products to come into radioactive equilibrium with their parents ^{226}Ra and ^{232}Th before radiometric analysis. Measurements of the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq L^{-1} of the collected samples were carried out using a gamma ray spectrometric system as described before.

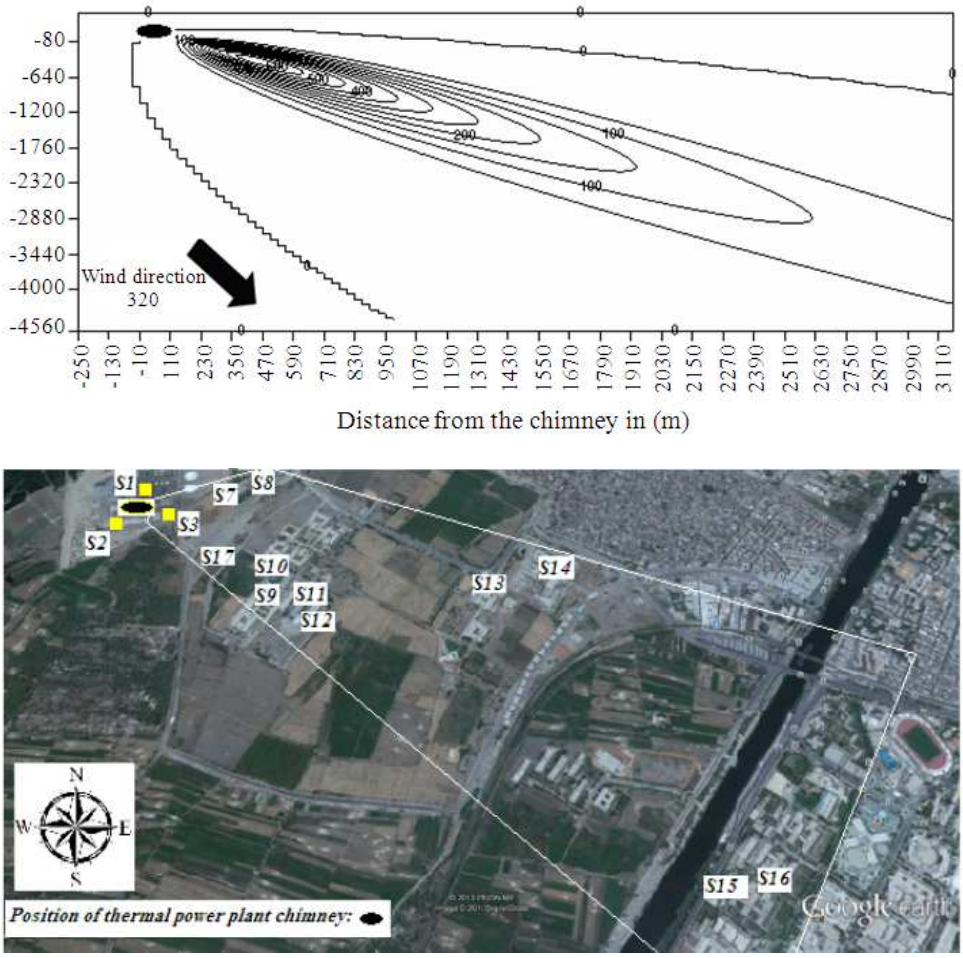

Fig. 1. The study area around ATPP as identified by GPM model and the locations of each sampling point (The dimensions of the two parts are not the same)

3. RESULTS AND DISCUSSION

3.1. Natural Radionuclides in Heavy Oil and ash Samples

The average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in heavy oil and ash samples collected from ATPP are shown in **Table 1**. The average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in oil are 17.2±6.9, 7.9±1.2 and 53.1±3.0 Bq L^{-1} respectively, while the corresponding values in fly ash samples are 2307±143, 1281±80 and 1218±129 Bq kg^{-1} respectively. As expected, all measured radionuclides are found to be enriched in fly ash samples by about 135 times for ^{226}Ra, 160 times for ^{232}Th and 23 times for ^{40}K compared with those in oil samples.

Table 1. Average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in raw oil in Bq L^{-1} and the corresponding values in fly ash (FA) samples in Bq Kg^{-1} from ATPP

Sample code	^{226}Ra	^{232}Th	^{40}K
Oil (Average)	17.2±6.9	7.9±1.2	53.1±3.0
FA (Average)	2307±143	1281±80	1218±129

The enhancement of natural radioactivity in ash samples mainly depends on the physicochemical properties of the elements and their chemical compounds in heavy oil (Cevik *et al*., 2007; Pandit *et al*., 2011). The different physicochemical properties of ^{226}Ra, ^{232}Th and ^{40}K lead to different behaviors inside the power plant. The behavior of radionuclides during the combustion process depends upon the conditions of the furnace as well as the chemical and physical characteristics of the

input fuel. For example, the radioisotopes (^{238}U, ^{226}Ra, ^{232}Th and ^{40}K) may exist in the fuel in different chemical compositions, so that volatile and nonvolatile species may be formed during combustion. For example, during the combustion of heavy oil which contains ^{238}U in the form of uraninite, a portion of ^{226}Ra will reside with the uraninite fraction of its ^{238}U parent, while the more mobile species will be allowed more than the others, e.g., the silica associated with ^{226}Ra (Pandit *et al*., 2011; El-Gamal *et al*., 2013).

The observed activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in ash samples are much higher by several orders of magnitude than the values reported by several researchers for coal fired thermal power plants situated in different countries, e.g., activity concentration of ^{226}Ra is about 15 times the value in Turkey (Cevik *et al*., 2007) and 24 times the value in India and Poland (Mahur *et al*., 2008; Bem *et al*., 2002). Also, ^{232}Th activity concentration is about 22 times the value in Turkey (Cevik *et al*., 2007), 12 times the value in India (Mahur *et al*., 2008) and 10 times the value observed in Poland (Bem *et al*., 2002). The activity concentration of ^{40}K is about 13 and 2 times the values in Turkey (Cevik *et al*., 2007) and India (Mahur *et al*., 2008), respectively. Furthermore, the obtained activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in ash samples are much higher than the average world value for coal (UNSCEAR, 1982).

3.2. Natural Radionuclides in Soil Samples

The distribution of activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K around ATPP is shown in **Table 2**. The results show that the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K range from 13±8 to 15446±540 Bq kg^{-1}, 18±6 to 8594±296 Bq kg^{-1} and from 188±14 to 8610±425 Bq kg^{-1} with an average of 2670±107, 1401±78 and 1495±100 Bq kg^{-1}, respectively. These results make it clear that the average activity concentrations of ^{232}Th are lower than those of ^{226}Ra and ^{40}K. The total activity concentration of the three radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in the studied soil samples ranged from 357 to 32650 Bq kg^{-1} with an average of 5566±1372 Bq kg^{-1}.

The concentration of ^{226}Ra accounts for approximately 48% of the total gamma activity of the soil samples (**Fig. 2**), which indicates that the specific activity due to ^{226}Ra is the largest contributor to the total activity for most of soil samples. The average values of ^{226}Ra, ^{232}Th and ^{40}K concentrations in soil samples collected from the surrounding environment of ATPP are much higher than the worldwide population-weighted average values in soil (by multiples of 32, 45 and 420 Bq kg^{-1}, respectively) (UNSCEAR, 2000).

Table 2 shows that there is large variation in activity concentrations of soil samples. This variation in the results depends on two parameters; the distance from chimney and the wind direction which is mainly from NW to SE (**Fig. 1**). Although samples S_1 and S_2 are the nearest samples to the chimney they have moderate concentrations because they are located to the north and to the west of the chimney respectively, i.e., opposite to the wind direction (**Fig. 1**). Samples S_4, S_5, S_6 were collected from the area around the pond, which is located to the north of the chimney (**Fig. 3**). The area of this pond is about 1250 m^2 and it is used for collecting washing water (discharge water) where ash from the boiler and ash removed by the precipitations are flushed with water to the pond. The sample S_5 had the highest concentrations in all samples; it is located in the eastern side of the pond, the bottom of the pond descends to the east such that the dissolved radionuclides are more highly precipitated in the eastern part of the pond. Samples S_4 and S_6 were located in the northern and western sides of the pond, respectively and they had lower activity concentrations than those of S_5.

Except for samples S_8, S_{13} and S_{14}, the activity concentrations of the samples have an exponentially decreasing behavior with increasing distance from the chimney, as demonstrated by solid lines in **Fig. 4**. The lower concentrations of these samples might be interpreted as due to their locations which are in the boundary of the studied area but not exactly in line with the wind direction (**Fig. 1**).

Table 2 shows that the activity concentrations of ^{226}Ra and ^{232}Th of sample S_7 are lower than the activity concentrations of the samples located at a distance farther away from chimney (S_9-S_{12}) while the activity concentration of ^{40}K is higher. This situation may be related with the wind direction and the location which is to the northeast of the chimney (**Fig. 1**) and the deposition of fly ash.

3.3. Radiological Effects

For evaluating the external exposure from naturally occurring radionuclides, the total air absorbed dose rate (D) due to the mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K (Bq kg^{-1}) in the surface soil samples was calculated using the formula of Beck *et al*. (1972):

$$D = (0.462A_{Ra} + 0.604A_{Th} + 0.0417A_{K})\ \text{nGy h}^{-1} \quad (4)$$

Table 2. Activity concentrations (Bq Kg^{-1}) of ^{226}Ra, ^{232}Th and ^{40}K of surface soil samples around from ATPP

Sample code	Distance (m)	^{226}Ra	^{232}Th	^{40}K
S_1	40	1471 ± 61	594 ± 30	790 ± 61
S_2	70	526 ± 35	281 ± 22	519 ± 65
S_3	90	13436 ± 470	6031 ± 214	6641 ± 352
S_4	130	39 ± 7	130 ± 71	188 ±14
S_5	135	15446 ± 540	8594 ± 296	8610 ± 425
S_6	140	185 ± 13	98 ± 6	406 ± 28
S_7	450	971 ± 51	536 ± 34	487 ± 58
S_8	540	15 ± 4	19 ± 3	505 ± 27
S_9	800	1391 ± 59	714 ± 31	312 ± 35
S_{10}	700	2000 ± 145	1164 ± 83	897 ± 184
S_{11}	850	1323 ± 64	918 ± 46	442 ± 64
S_{12}	950	1163 ± 84	614 ± 43	294 ± 90
S_{13}	1200	19 ± 5	18 ± 6	552 ± 35
S_{14}	1400	13 ± 8	27 ± 2	459 ± 24
S_{15}	2600	311 ± 23	138 ± 14	412 ± 50
S_{16}	2650	94 ± 14	49 ± 7	319 ± 30
S_{17}	350	7000 ± 244	3896 ± 136	3582 ± 179
Average	-	2670 ± 107	1401 ± 78	1495 ± 100

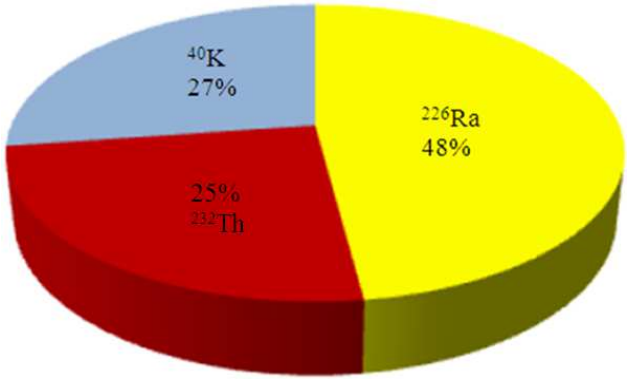

Fig. 2. The percentage of ^{226}Ra, ^{232}Th and ^{40}K of the total gamma activity of the soil samples

Fig. 3. The location of the pond in the north of ATPP and the location of soil samples around the pond

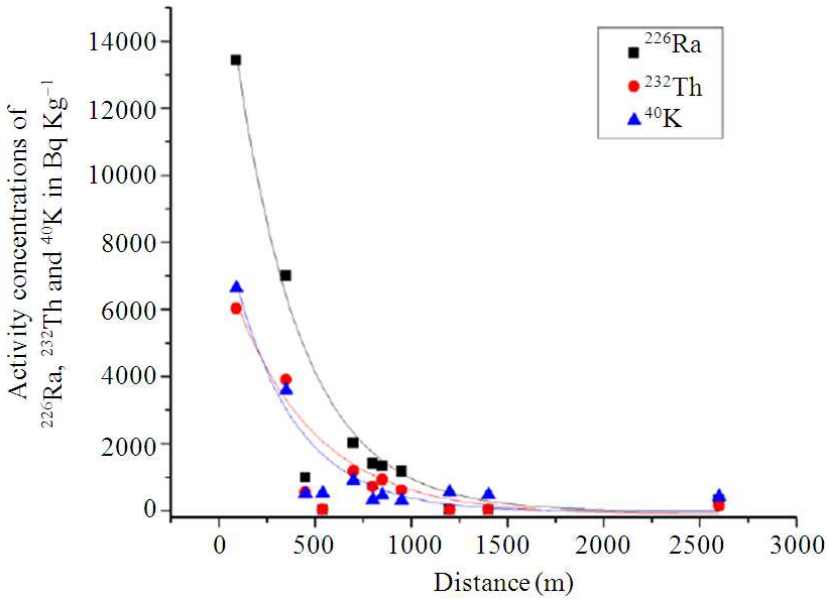

Fig. 4. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K from soil samples versus the distance from the chimney. (The solid lines represent the exponential decrease of activity concentrations with the distance from the chimney)

where, D is in nGy h^{-1} and A_{Ra}, A_{Th} and A_K are the activity concentrations in Bq kg^{-1} of ^{226}Ra, ^{232}Th and ^{40}K respectively. The absorbed dose rates due to soil were calculated according to Equation (4) and were included in **Table 3**. The average absorbed dose rate was found to be 1814 nGy h^{-1}. This value is higher by about 30 times than the estimated world average external exposure rate from terrestrial gamma radiation of 57 nGy h^{-1} (UNSCEAR, 2000). The absorbed dose rates were used to calculate an annual effective dose from gamma terrestrial radiation at each site and an average annual effective dose for the population in the vicinity of ATPP. For the conversion from absorbed dose rate in air to annual effective dose, the coefficients proposed by (UNSCEAR, 2000) have been used, i.e., an outdoor occupancy factor of 0.2 and absorbed dose rate in air to effective dose conversion factors for gamma rays of 0.7, 0.8 and 0.9 Sv Gy^{-1} for adults, children and infants respectively. The effective dose rate in units of mSv yr^{-1} was calculated according to the following relations Equation (5):

$$E(mSv\,y^{-1}) = D(nGy\,h^{-1}) \times 8760\,h \times 0.2 \times 0.7Sv\,Gy^{-1} \times 10^{-6} \quad (5)$$

The estimated annual effective doses for adults range from 0.05 to 15.6 mSv yr^{-1} with an average of 2.2 mSv yr^{-1}. The external worldwide average annual effective dose for adults is 0.07 mSv yr^{-1} (UNSCEAR, 2000). According to these results, it seems that the concentrations of the radionuclides in the examined soil samples are of great radiological importance. As this study was based on a rather small number of soil samples, the values of external exposure assessment should be considered as indicative of the population of the examined city.

The radium equivalent activity (Ra_{eq}) was calculated so as (Beretka and Mathew, 1985; Rahman *et al*., 2008) to assess the radiation hazard associated with the activities due to ^{226}Ra, ^{232}Th and ^{40}K:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (6)$$

In defining Ra_{eq} activity according to Equation (6), it has been assumed that the same gamma dose rate is produced by 370 Bq kg^{-1} of ^{226}Ra or 259 Bq kg^{-1} of ^{232}Th or 4810 Bq kg^{-1} of ^{40}K. **Table 3** indicates that the calculated Ra_{eq} in soil around ATPP ranges from 82 to 28399 Bq kg^{-1} with an average of 4079 Bq kg^{-1}, which is higher by about 11 times than 11 the recommended limit of 370 Bq kg^{-1}. However, it is noteworthy that the Ra_{eq} value in 35% of soil samples was lower than the limit recommended by (UNSCEAR, 2000).

Table 3. Absorbed gamma dose rate, radium equivalent activity, external hazard index and annual effective dose in ash samples

Sample code	Absorbed dose rate (nGy h^{-1})	Radium Equivalent activity (Ra_{eq}) (Bq kg^{-1})	External hazard index (H_{ex})	Annual effective dose (mSv yr^{-1})
S_1	1072	2382	6.43	1.30
S_2	434	968	2.61	0.50
S_3	4543	1048	28.00	5.60
S_4	105	241	0.65	0.10
S_5	12689	28399	76.00	15.60
S_6	162	357	0.96	0.20
S_7	792	1775	4.79	1.00
S_8	40	82	0.22	0.05
S_9	1087	2437	6.60	1.30
S_{10}	1665	3734	10.08	2.00
S_{11}	1184	2670	7.21	1.50
S_{12}	920	2064	5.57	1.10
S_{13}	43	89	0.24	0.05
S_{14}	42	89	0.24	0.05
S_{15}	244	451	1.46	0.30
S_{16}	85	189	0.51	0.10
S_{17}	5737	12847	34.00	7.00
Average	1814	4079	11.00	2.20

The external hazard index (H_{ex}) was also used to assess the radiological hazards of soil samples and can be calculated according to the Equation (7) (Beretka and Mathew, 1985):

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (7)$$

The calculated values of H_{ex} for soil samples studied in this work range from 0.24 to 76 with an average of 11 (**Table 3**). Most of these samples are much higher than unity indicating that these samples have a significant radiological risk.

3.4. Natural Radionuclides in Water Samples

The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in water samples could not be measured by using the gamma ray spectrometric system described before as its concentrations in water was lower than the detection limits of the system. However, we measured large concentrations of these radionuclides, indicating that the water samples are highly polluted by large quantities of radioactive materials.

The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in water samples are presented in **Table 4**. These samples were collected from the pond (W_1 and W_2) and from groundwater wells (W_3-W_5) which are quite close to the plant and are used for agricultural purposes. As seen, the concentrations of ^{226}Ra, ^{232}Th and ^{40}K vary from 1.83 to 18.53 Bq L^{-1}, from 1.47 to 12.78 Bq L^{-1} and from 8.09 to 64.48 respectively. The values of ^{226}Ra in groundwater samples are much higher than the maximum contaminant levels of 1.85 mBq L^{-1} proposed in the USA (EPA, 1991). The measured concentrations of ^{226}Ra and ^{232}Th evidently exceed the values of the River Nile water and groundwater in Upper Egypt which are 0.05, 0.03 Bq L^{-1} for the River Nile water and 0.12, 0.05 Bq L^{-1} for groundwater (Ahmed, 2004), respectively. These results apparently confirm the presence of actual harmful impacts of the plant on the surrounding aquatic environment.

The annual effective doses were calculated according to the equation introduced by the EPA (1991) and recently by Degerlier and Karahan (2010). The calculated effective doses for different age groups: infants, children and adults are shown in **Fig. 5**. It should be noted that the doses ranged from 0.54 to 3.57 mSv yr^{-1} for infants, 1.03 to 6.59 mSv yr^{-1} for children and 0.88 to 4.22 mSv yr^{-1} for adults. According to the recommended reference level of 0.26, 0.2 and 0.1 mSv yr^{-1} for effective dose for infants, children and adults respectively, published by IAEA (1996) and UNSCEAR (2000) doses obtained from one year of consumption of drinking water are much higher than the recommended reference level. Consequently, it can be recommended that the investigated water is not acceptable for healthy life-long human consumption and a reduction in consumption or radionuclide concentration is essential.

Table 4. Activity concentrations (Bq L^{-1}) of ^{226}Ra, ^{232}Th and ^{40}K of water samples around ATPP

Sample code	^{226}Ra	^{232}Th	^{40}K
W1	18.53±9.01	12.78±1.26	64.48±3.43
W2	7.37±5.70	1.47±0.26	29.83±1.72
W3	6.24±2.90	9.91±0.78	19.82±1.91
W4	4.43±1.59	6.37±0.79	8.09±0.77
W5	1.83±0.37	9.83±0.61	13.8±116

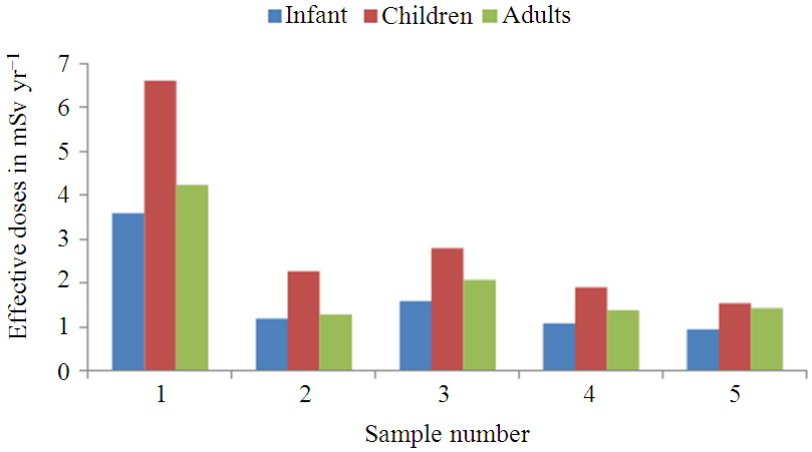

Fig. 5. The effective doses for infants, children and adults in mSv yr^{-1} due to the total ingestions of water samples which were collected from wells quite close to ATPP

4. CONCLUSION

The activity concentrations of natural radionuclides in ash and soil samples around ATPP in Egypt and their environmental radioactivity impact have been studied in the present work. The ashes produced in ATPP contain high levels of natural radioactivity and constitute a potential health hazard to the power plant personnel and to the population living in the vicinity of the plant, due to fly ash releases released to the surrounding environment. The mean concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the studied soil samples are much higher than the average values recommended by UNSCEAR (2000).

The average Ra_{eq} value of the investigated soil samples are evidently exceed the internationally accepted value. The observed average absorbed dose rate due to ^{226}Ra, ^{232}Th and ^{40}K in soil samples has a value of 1814 nGyh-1, which is much higher than the worldwide average value of natural gamma radiation dose rate. The annual effective dose rate received by the local residents outdoor due to natural radioactivity in soil ranges from 0.05 to 15.6 mSv yr^{-1} with an average of 2.2 mSv yr^{-1}, which is much higher than the worldwide average for outdoors annual effective dose rate. The obtained results shows that the ashes produced by ATPP increased the natural radioactivity level and enhanced the natural radiation in surrounding soil environment. So, the discharging management of ash should be enhanced and the natural radioactivity of soil around ATPP must be monitored periodically.

The high activity concentrations for ^{226}Ra, ^{232}Th and ^{40}K observed in water samples explain the high impact of water infiltration from the pond to the underground water in the surrounding areas and cautionary measures must be considered when using this water in agricultural irrigation.

The results of the current study highlight the severity of this radioactive pollution on the population in the vicinity of ATPP.

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