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Assessment of radiological hazards in the industrial effluent disposed soil with statistical analyses

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ABSTRACT

Soil is the most important source of natural radiation which can pass on to the food chain and the air, contributing to the internal dose received by the population. Human activities can modify the natural concentrations of radionuclides by the release of residues or effluents to the environment, which cause the accumulation of radioactive elements. In this study, the radiological hazard parameters due to the natural radioactivity, such as, Radium equivalent activity (Ra_eq), Representative level index (RLI), Activity utilization index (AUI), Absorbed dose (D), Annual Effective Dose equivalent (AEDE), Annual gonadal dose equivalent (AGDE), External hazard index (H_{ex}), Internal hazard index (H_{in}) and Excess lifetime cancer risk (ELCR) are assessed from the sugar industrial effluent disposed soil. The calculated radiological parameters are compared with that of soils around different industries across the world. The recorded average value of AUI and ADGE is 0.713 and 316.72 μSv/y, respectively, are higher than the globally approved values (0.07 and 300 μSv/y, respectively). Further, the average values of RLI and ELCR are closer to the world average values. The Pearson correlation analysis and cluster analysis are employed to analyse the data and identify the existing relationships between the radiological hazard parameters with the natural radionuclides.

1. Introduction

People are exposed to natural radiation on a daily basis as our planet earth is radioactive. More than 60 naturally occurring radioactive materials are found in soil, water and air. These radioactive elements are classified into the following categories:

1. Primordial – from the creation of earth.
2. Cosmogenic – formed as a result of cosmic ray (from sun and outer space) interactions with earth's atmosphere.
3. Human produced – enhanced or formed due to human activities.

In recent years, the source of radioactive elements in soil, water and air is considerably increased by various human

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activities such as: disposing the hospital wastes, nuclear wastes and industrial effluents to the environment, etc. Wastes associated with various industrial activities were enhanced levels of natural radioactivity (Hilal, Attallah, Gehan, & Fayez-Hassan, 2014). Hence people can be exposed to radiation either externally by a close source of radiation or exposed internally by radioactive material that has entered the body. Soil not only acts as a source of continuous radiation exposure to humans but also as a medium of migration for transfer of radionuclides to biological systems (Mehra, Badhan, Sonkawade, Kansal, & Singh, 2010). Hence, the basic indicator of radiological contamination in the environment is the soil.

The particular area in Sethiyathope (11.2600° N, 79.3200° E), Tamilnadu, India, has been identified as contaminated by heavy metals and toxic chemicals (Senthilkumar & Narayanaswamy, 2002; Senthilkumar, Narayanaswamy, & Sriramachandrasekaran, 2002) due to the continuous disposal of industrial effluent. In this study, an attempt has been made to assess the various radiological hazard indices and discuss them with statistical analyses. This is an extension of previous study which is briefed in Section 2 of this article. The results of this study will offer necessary information in the monitoring of environmental contamination and provide appropriate protection guidelines to the public living around the area studied.

2. Previous study

In my earlier study (Senthilkumar, Narayanaswamy, & Meenakshisundaram, 2012), heavy metal concentration and activity concentration of natural radioactive elements in the effluent disposed soil at Sethiyathope are reported. This study revealed that mean concentration of ^{232}Th activity is higher by 1.33 times compared to that of world average value, while the concentration of ^{232}U and ^{40}K are found lower than the world average values. Furthermore, the mean activity of ^{232}Th and ^{238}U were found higher compared to the Indian average value by 1.55 times and 2 times, respectively. A moderately good correlation between the heavy metals presented in the soil samples and the ^{232}Th activity was observed. As a continuation to the previous study, the various radiological hazard indices including excess lifetime cancer risk are presented in this article. In addition to that, an attempt has made to identify the relations among various radiological parameters using multivariate statistical method.

3. Materials and methods

3.1. *Sample collection and preparation*

Twenty-two sampling sites have been selected across the polluted area. Soil samples were collected according to the standard procedures (Baeza, Del Rio, Miro, & Paniagua, 1992) and they were labelled as S_1–S_{22}. To find the radioactivity levels, the samples were dried in an oven at 110 °C till a constant dry weight was obtained. Then these samples were powdered and sieved through a 150-μm mesh. The processed soil samples were packed in a 250 ml plastic container to its full volume with uniform mass. These containers were sealed hermetically and also sealed externally to ensure that all the daughter products of uranium and thorium and in particular, radon isotopes formed do not escape. A time of 30 days was allowed after packing to attain secular equilibrium between ^{226}Ra and its short-lived daughter products. The net-weight of each sample was determined before counting. To reduce the contribution from background radiation while recording the spectrum in the laboratory, the samples were kept in a lead shield, which has a shielding efficiency of 95% (Beck, 1972).

3.2. *Radioactive measurements*

The gamma-ray spectrometer was used to determine the activity of the radionuclides, ^{238}U, ^{232}Th and ^{40}K. A sodium iodide [NaI(Tl)] crystal detector of 3″ × 3″size combined with an 8 k multi-channel analyser (model PCA-II) was used to record the gamma-ray spectra. The detector was shielded by 15 cm thick lead on all four sides and 10 cm thick on top to reduce background due to cosmic ray component by almost 98%. The inner sides of lead shielding are lined by 2 mm thick cadmium and 1 mm thick copper to cut off lead X-rays and cadmium X-rays respectively. This graded lining shield further reduces the background especially in the low energy region. The energy resolution of Standard International Atomic Energy (IAEA) sources were used for calibrating the gamma-ray spectrometer. The soil samples were placed on the top of 3″ × 3″ NAI (T1) crystal. Count spectra were obtained for each sample using gamma ray spectrometer and multichannel analyser. The counting time for each sample was 20,000 s. From the counting spectra, the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K were determined using computer program. The peak corresponds to 1.461 Mev (K-40) for ^{40}K, 1.765 Mev (Bi-214) for ^{238}U and 2.615 Mev (Ti-208) for ^{232}Th were considered for the activity concentration (Bq/kg) measurement.

3.3. *Mutivariate statistical analysis*

To identify the privity of various parameters obtained from natural radionuclides, multivariate statistical analyses (Pearson's correlation analysis, and cluster analysis) have been carried out using the statistical software package “Statistical Program for Social Science (SPSS)”.

4. Results and discussion

4.1. *Activity concentrations of ^{238}U, ^{232}Th and ^{40}K*

Table 1 lists the concentration of natural radioactive elements determined in the soil samples. The activity concentration of ^{238}U, ^{232}Th, and ^{40}K range from 20.28 to 24.72 Bq kg^{-1}, 37.3–43.2 Bq kg^{-1}, and 220.9–270.3 Bq kg^{-1}, respectively. The world average concentration of ^{238}U, ^{232}Th and ^{40}K is 35, 30 and 400 Bq kg^{-1}, respectively (UNSCEAR, 1988). When comparing the activity concentration of radionuclides with the world average value, ^{232}Th is higher by a factor of 1.33 whereas both, ^{238}U and ^{40}K, are lower by a factor of 0.62. It is noticed from the results that activity concentration values are