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Distribution of radionuclides and assessment of risk exposure to the miners on a kaolin field

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Abstract. Mining of kaolin deposits are common in Nigeria without considering the background radiation in such environment and the health risks it might pose on the miners. In this study, in-situ measurements of the naturally occurring radionuclides were carried out with the aim of determining the distribution of these radionuclides on the mining field and estimation of the hazard indices exposure risks (γ- and α-radiation risks) to the miners. The study was achieved with the aid of gamma ray detector Super-Spec (RS-125) and global positioning system. The detector used has ability to measure activity concentrations of ^{238}U, ^{232}Th and ^{40}K and gamma doses. For the purpose of this study, only the concentrations of the three radionuclides were considered. For each location, measurements were taken four times, while its mean value was estimated for better accuracy. In all, nineteen locations were occupied in order to cover the study area. Basic kriging method was adopted for the production of spatial distribution of these radionuclides and their corresponding γ- and α-radiation hazard indices. The mean values of ^{238}U, ^{232}Th and ^{40}K are 46.7, 71.8 and 108.7 Bq kg^{-1}, respectively. When compared to the global standard, it was revealed that ^{238}U and ^{232}Th are greater than the global standard, while ^{40}K fall below the permissible limit. The γ- and α-radiation exposure risks estimated revealed that the mean values of I_γ and I_α are 0.6 and 0.2 respectively. Though the estimated γ- and α-radiation indices showed that the kaolin field is safe for the miners, periodic check is required in order to monitor the rate at which these natural primordial radionuclides (^{238}U and ^{232}Th and their progenies) are being enhanced.

Keywords: Miners, Radioactivity concentrations, Gamma index, Kaolin deposits, Risk exposure

1. Introduction

The occurrence and distribution of radionuclides in soils is a function of the radionuclides' compositions in their parent rocks [1]. In most topsoils, enhancement or depletion of natural radionuclides have been recorded [2-3]. This variation had been attributed to either multi-geochemical/geogenic process (such as erosion, sedimentation, deposition, weathering and so on) or anthropogenic activities (such as mining, quarrying, use of fertilizers for agricultural purposes, energy generation from geothermal sources, use of building materials with enhanced concentrations of radionuclides among others) [1]. Zones with anomalously high concentrations of natural radionuclides are known as High Background Radiation Areas (HBRA). The two forms of radiation are ionizing and non-ionizing radiation [4]. Ionizing radiation has sufficient energy to knock off electrons from atoms, while non-ionizing radiation does not own sufficient energy to ionize atoms. The natural radionuclides (^{232}Th and ^{238}U and their progenies as well as ^{40}K) contribute greatly to the received dose by 'man' [5], and have been the major source of radiation exposure to humans [6]. Effects of overexposure to these natural radionuclides have been documented by [7], [8], [9], [10] and [11]. Among these effects are cancers of various forms, hepatic, leukaemia, lung diseases, bone tumours and so on.

Kaolin is one of the mineral resources in Nigeria. It has been found useful in paint, construction, food, plastic, cosmetics, and agricultural industries. It has also been part of the constituents used in the production of ceramics, cement, toothpaste and some medical items [12-13]. Mining of kaolin deposits are common in Nigeria without considering the background radiation in such environment and the health risks it might pose on the miners. Quarrying, milling, mining and processing of radionuclide bearing minerals can enhance the levels of radiation exposure to the workers and inhabitants in such locations [14]. Elevated levels of radionuclides around mining sites, which are considered as Technological Enhanced Naturally Radioactive Materials (TENORM) have been reported by [6], [11], [15] and [16]. In this study, in-situ measurements of the naturally occurring radionuclides were carried out with the aim of determining the distribution of these radionuclides on the mining field and estimation of the gamma index risk exposure to the miners on the field. Some of the advantages of in-situ gamma ray spectrometry include: low-cost geophysical exercise, spatially representation of the investigated area and rapid measurement of environmental impact assessment of radioactivity concentrations in an area [1].

2. Geological Settings and the Study area

The study area is located in Ifonyintedo, Ogun State, Nigeria. The study area is bounded by longitude 2.7922 to 2.7929° E and latitude 6.7676 to 6.7682° N, with the mean elevation of 88 m above the sea level. The study area is one of the newly discovered locations for miners in Ogun State. The major occupation of the dwellers is farming, with few cottage industries within the town. Rainy season, which varies from March to November annually and dry season, which spreads over 5 months (from November to March) are the basic two seasons in the study area.

The Nigerian geology is part of the remobilized basement rocks of West Africa, which resides on the Pan-African mobile belt that separates Congo Cratons from West Africa [12-14]. The two major geological settings in Nigeria are Sedimentary Basins and Basement rocks. Some of the documented works from either of the two settings could be found in Refs. [15-31]. Ifonyintedo is concealed within the sedimentary terrain of southwestern Nigeria [32-33], which is popularly known as Dahomey Basin (Figure 1a). Dahomey Basin is part of the extension from the eastern part of Togo, Republic of Benin and Ghana. It shares boundary with Okitipupa Ridge, which separate Niger Delta from Dahomey Basin. Dahomey six depositional groups are: Abeokuta, Benin, Akinbo, Oshosun, Ewekoro and Ilaro Formations (Figure 1b). The study area is classified into Benin Formation, which is also known as

Coastal Plain Sands. Further explanation on Dahomey Basin and its depositional groups has been documented by [10], [32], [33], [37] and [38].

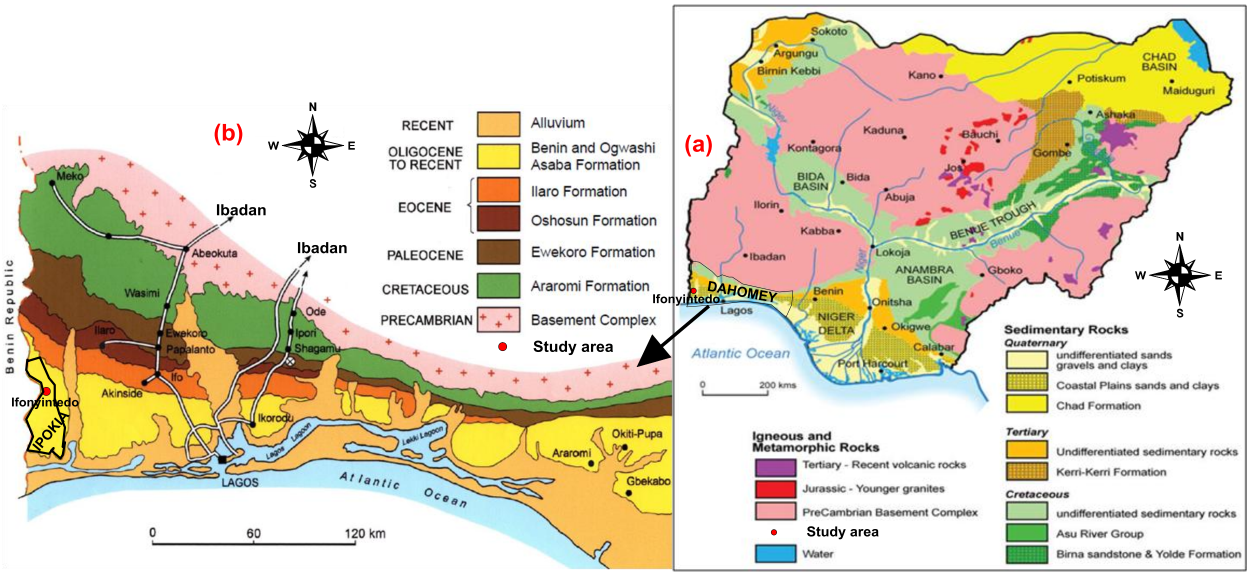

Figure 1: Geological maps of (a) Nigeria (b) Dahomey (Benin) Basin revealing the study area (adapted from [32]).

3. Materials and Methods

The major materials used for this study are potable gamma ray spectrometer and Global Positioning System (GPS). The GPS was used for recording of coordinates and elevation of each data point while the gamma ray spectrometer (Super-Spec RS 125) was used for background in-situ measurement of radionuclides in the study area. The measurements were taken randomly in order to cover the study area. This gamma ray detector uses sodium iodide (NaI) crystal doped with thallium (Tl) as activator. The performance of this detector is rated higher than the detector that uses ordinary sodium iodide (NaI). This device is auto-stabilizing on the three naturally occurring radionuclides (^{40}K, ^{232}Th and ^{238}U), it does not require any external source or test sample before the activity concentrations of the radionuclides are measured. The device mode is being set to assay in order to measure the activity concentrations of ^{40}K, ^{232}Th and ^{238}U. At the beginning of the survey, the device was allowed to stabilize for 120 seconds before the measurements started. At each sampling point, four different readings were taken at each location, where the mean value of the four readings was used as the final value for such location. This was done to ensure accuracy in the data collected at each sampling point. The activity concentration of each radionuclide was displayed on the digital readout (screen) section of the device, where the potassium is displayed in percentage (%), while thorium and uranium were displayed in part per million (ppm). These readings were converted to Becquerel per kilogram (Bg kg^{-1}) using the conversion factor as reported by [39]. In all, nineteen sampling locations were randomly occupied in order to cover the study area.

4. Results and Discussion

The spatial distribution of each radionuclide is plotted and compared with the global standard based on kriging method. As documented by [19] and used in other literature [6, 8, 32, 40], threshold limit of 32.0, 45.0 and 420.0 Bq kg^{-1} were used for ^{238}U, ^{232}Th and ^{40}K respectively. The activity concentrations of ^{238}U in the study area varied from 11.1 to 116.1 Bq kg^{-1}, with the mean concentration of 46.7 Bq kg^{-1}; ^{232}Th varied from 58.1 to 98.1 Bq kg^{-1}, with the mean concentration of 71.8 Bq kg^{-1}; ^{40}K varied from 31.3 to 187.8 Bq kg^{-1}, with the mean concentration of 108.7 Bq kg^{-1}. As shown on Figure 2, apart from the southeastern and northeastern tips of the study area, other zones are above the threshold limit. The enhanced concentrations of uranium in the study area might be due to mining activities. Overexposure to uranium by the miners could cause chronic lung diseases, nasal and cranial nerves, bone tumours, leucopoenia, anaemia and NPD (Necrotizing Periodontal Disease) [8]. Figure 3 reveals the spatial distribution of thorium in the study area. It was revealed that the activity concentrations of thorium in the study area exceed the threshold limit. This field might be dangerous to the miners, because excessive inhalation of thorium had been attributed to diseases such as cancers, hepatic and leukaemia [8, 41]. Spatial distribution of potassium in the study area is within the threshold limit (Figure 4). Moderately low concentrations of potassium in the study area could have been as a result of low feldspar minerals on the kaolin field, since the key geogenic sources of potassium in soil are micas and feldspars during weathering [42]. Unlike nitrogen and/or phosphorous, soil with enhanced potassium concentration may become depleted after several successive activities on such field. Also, low concentrations of potassium on the kaolin field could have been due to leaching of potassium ions (K^+) from soil, because K^+ are highly soluble and could leach without colloids. The mean values of the three radionuclides showed that ^{238}U and ^{232}Th are greater, while ^{40}K is less than the global mean value.

In order to estimate the risk of miners' exposure to radiation, gamma and alpha radiation hazard indices were used for the measure. Gamma radiation hazard index (I_γ) is one of the indices used in estimation of human safety when exposed to γ-radiation, which emanates from topmost layer of the Crust [34, 43]. The I_γ presented in this study is estimated using Eq. (1) as given by [32, 43].

$$I_\gamma = 0.0003C_K + 0.0050C_{Th} + 0.3333C_U \quad (1)$$

where C_K, C_{Th} and C_U are the concentrations of the three naturally occurring radionuclides (^{40}K, ^{232}Th and ^{238}U). As reported by [32], an estimated I_γ that is less than or equals 0.5 corresponds to an outdoor annual effective dose of 0.3 mSv y^{-1}, while the one that is less than or equal 1.0 corresponds to the outdoor annual effective dose of 1 mSv y^{-1}. The estimated I_γ varied from 0.38 to 0.81, with the mean value of 0.6. This result corresponds to the outdoor annual effective dose of 0.3 mSv y^{-1}. Variation of the I_γ on this kaolin field needs periodic check, because of the miners' safety (since its mean value is above ½).

The alpha index (I_α) is the measure to estimate the risk of man's exposure to α-radiation as a result of inhalation from materials with radon concentrations [32]. This parameter is estimated from Eq. (2) as given by [32, 44].

$$I_\alpha = 0.005C_U \text{ (Bq kg}^{-1}\text{)} \quad (2)$$

Exhalation of radon from a material can be over 200 Bq m^{-3} when the uranium concentration is > 200 Bq kg^{-1}, and less than that when the uranium concentration is < 200 Bq kg^{-1} [32, 43]. The variation of I_α in the study area ranged from 0.06 to 0.58, with the mean value of 0.2. The estimated I_α on this kaolin field pose no threat to miners due to radon emanation from the subsurface. As reported by [45] that unusual enhancement of ^{40}K could constitute a form of geological 'noise' during mineral exploration campaign when adopting radiometric method, the pattern depicted in Figures 2, 3, 5 and 6 has confirmed that ^{238}U and ^{232}Th are the key players on this kaolin field.

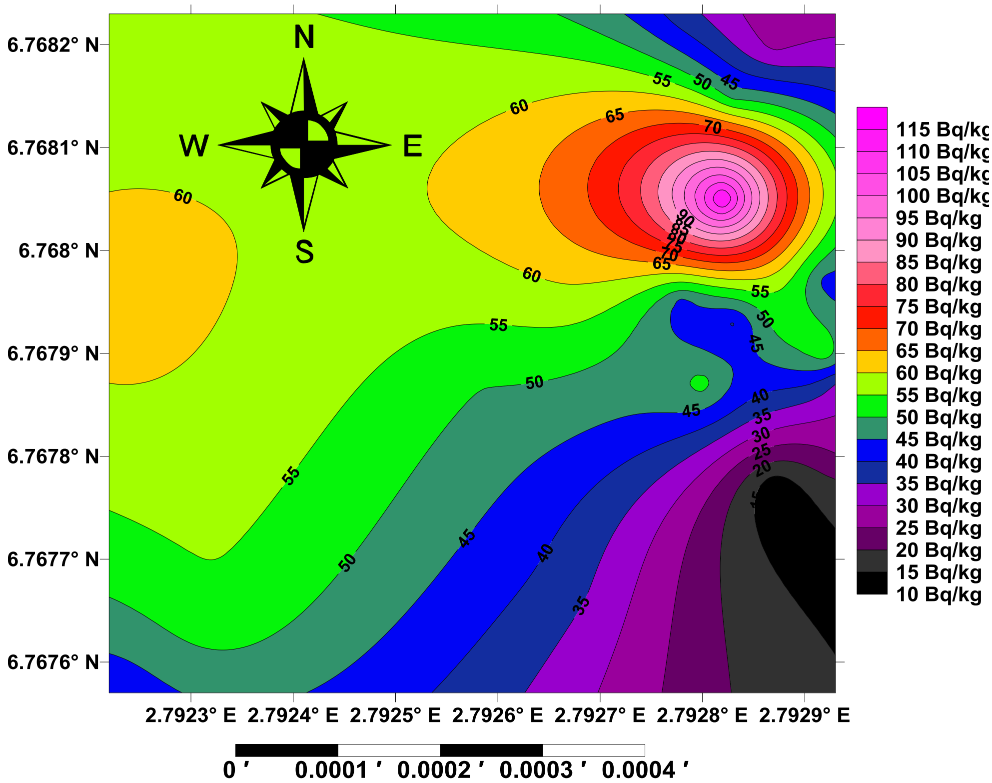

Figure 2: Spatial distribution of ^{238}U in the study area.

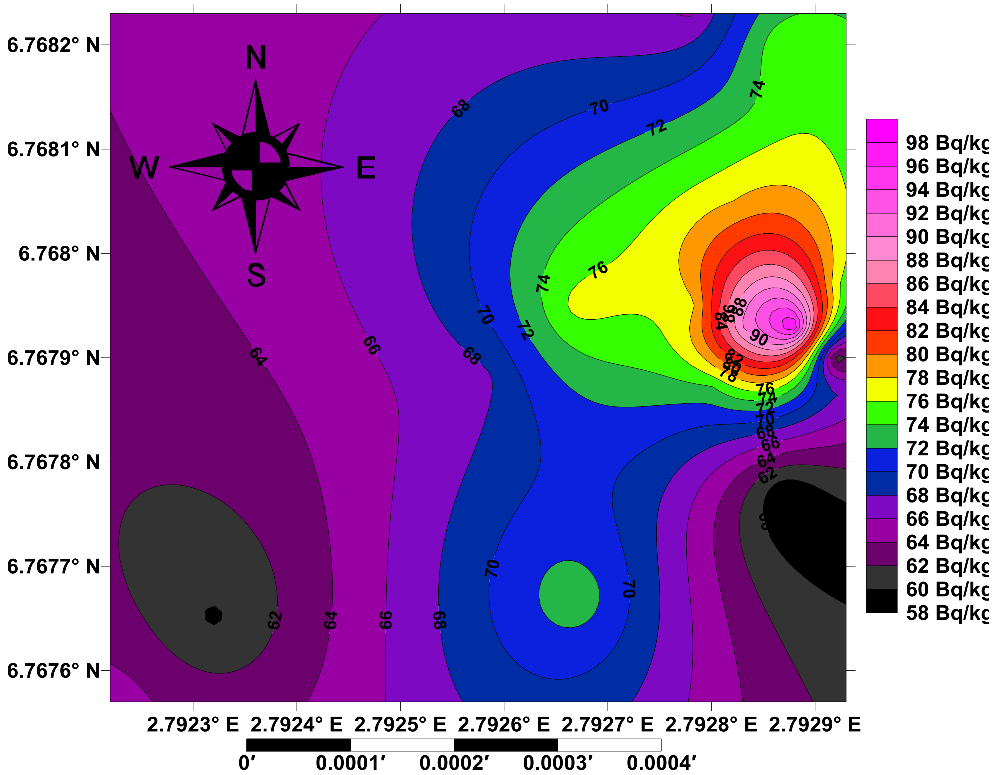

Figure 3: Spatial distribution of ^{232}Th in the study area.

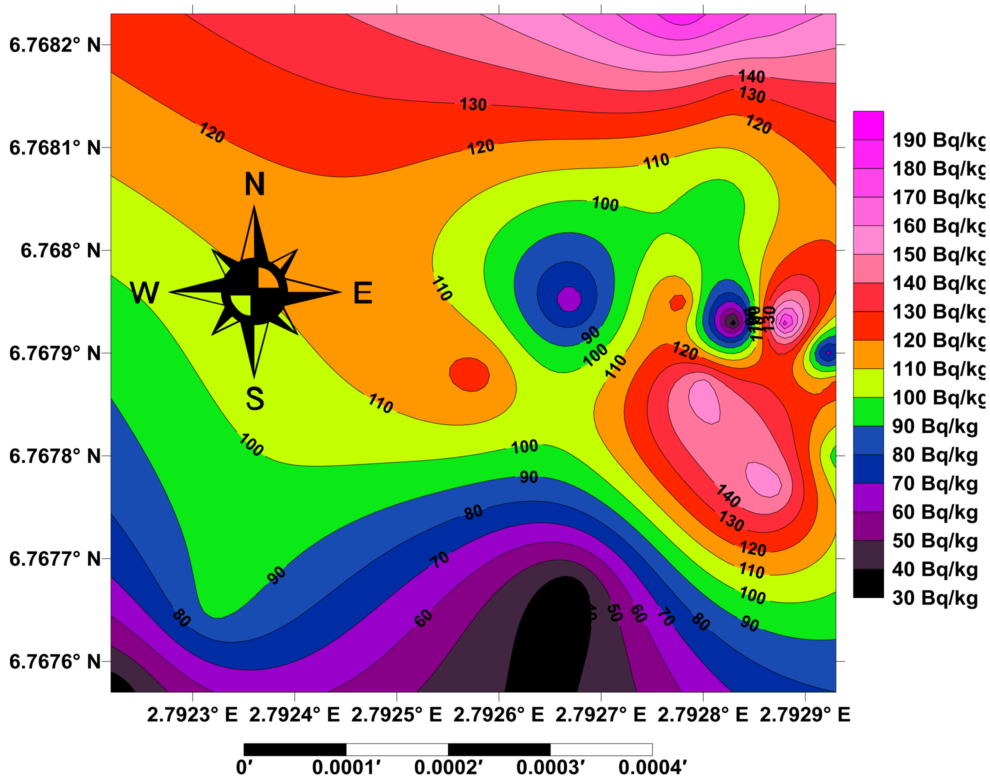

Figure 4: Spatial distribution of ^{40}K in the study area.

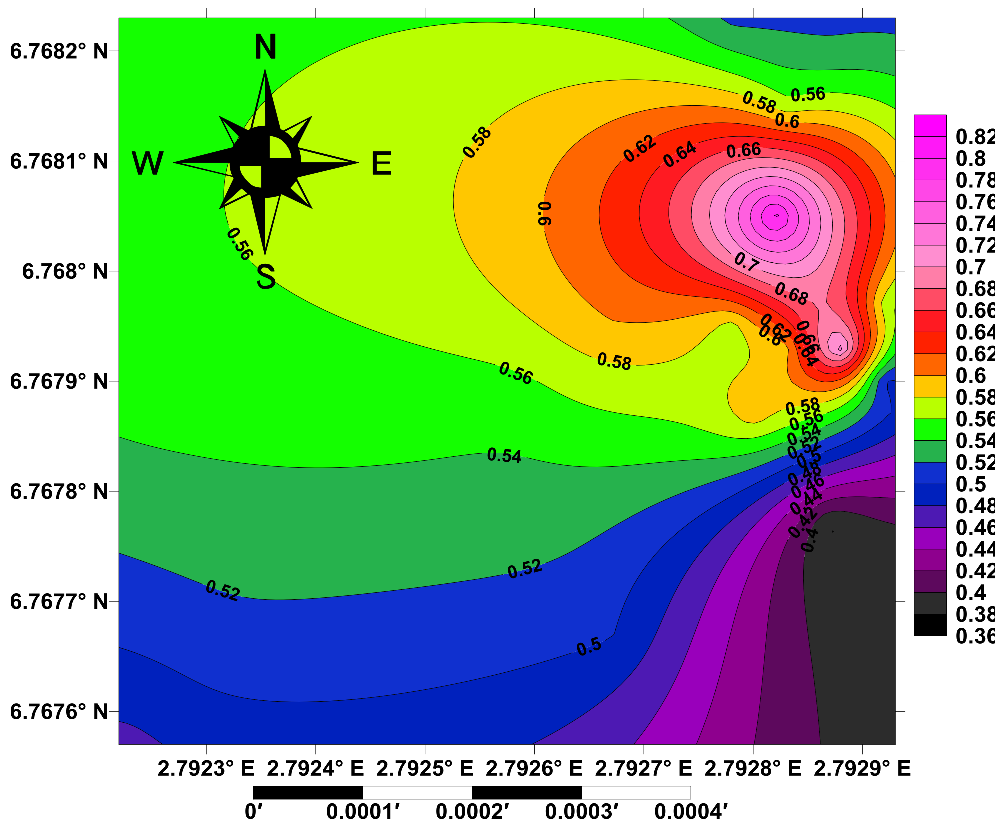

Figure 5: Spatial distribution of I_γ in the study area.

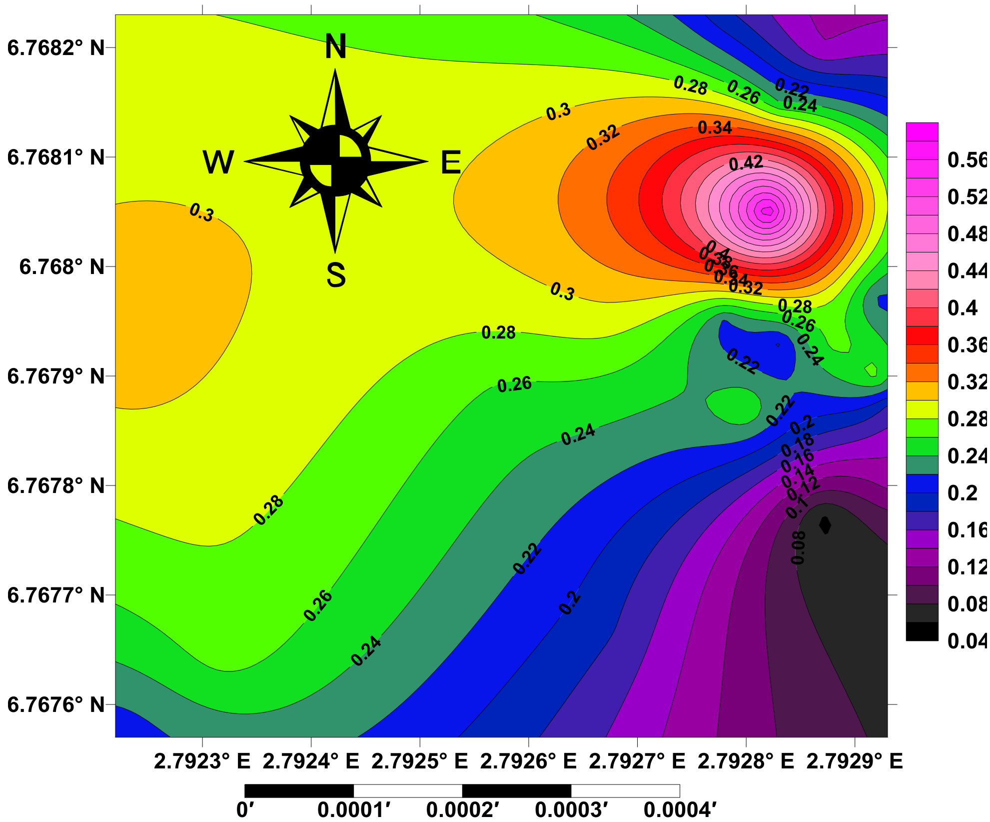

Figure 6: Spatial distribution of I_α in the study area.

5. Conclusion

Distribution of radionuclides and assessment of the γ- and α-radiation risks associated with overexposure of the miners to these primordial radionuclides have been presented using the basic kriging method. The mean values of ^{238}U, ^{232}Th and ^{40}K are 46.7, 71.8 and 108.7 Bq kg^{-1}, respectively. When compared to the global standard, it was revealed that ^{238}U and ^{232}Th are greater than the global standard, while ^{40}K fall below the permissible limit. The γ- and α-radiation exposure risks estimated revealed that I_γ varied from 0.38 to 0.81 with the geometric mean of 0.6, while the I_α varied from 0.06 to 0.58 with the geometric mean of 0.2. Variation of the I_γ on this kaolin field needs periodic check, because of the miners' safety, since its mean value is close to unity. The estimated I_α on this kaolin field pose no threat to miners due to radon emanation from the subsurface. The pattern depicted in Figures 2, 3, 5 and 6 has confirmed that ^{238}U and ^{232}Th are the key players on this kaolin field. However, regular check of the northeastern zone in the study area is paramount in order to monitor the rate at which these natural primordial radionuclides (^{238}U and ^{232}Th and their progenies) are being enhanced. This measure will ensure the safety of miners on this kaolin field.

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