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Topographic View of the Distribution of Radionuclide Particles over an Abandoned Quarry Site

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ABSTRACT

Soils and rocks of granite composition are known to contain significant amounts of terrestrial radionuclides of Uranium, Thorium and Potassium. These radionuclides emit radon, thoron and argon gas into the quarry pit and by their decay, gamma ray is obtained in the area. The aim of this study is to obtain the topographic distribution of radionuclide particles in an abandoned quarry pit as this will help to explain the distribution of the gamma ray levels at the various points within it. Measurement of the distribution of radionuclides in counts per second was carried out in the quarry pit at Supare, Ondo State, Nigeria, using a portable microprocessor based digital scaler/rate meter, model DSM-500. The result shows that the topography of the physical features of the pit base and of the radio-nuclide counts per second in the pit are similar when there is a negative temperature gradient above the pit base. In both cases, the radionuclide counts per second in the quarry depends on the height of the measuring spot above the sea level.

Key words: Quarry site, count rate, contour, quarry pit, radionuclide

INTRODUCTION

Background radiation in an environment is due to the presence of cosmic radiation from the outer space and the terrestrial radiation from the radioactive materials in the soil and rocks in the environment (Ballinger, 1991).

Cosmic rays are streams of charged and uncharged nuclear particles consisting of protons and heavy nuclei from the outer space. The dose rate from cosmic radiation at the sea level is about 30 nGyh^{-1} while that from the terrestrial radiation is very much larger (UNSCEAR 2000). The major contributors to the terrestrial radiation are the radionuclides belonging to uranium, thorium and potassium which are relatively abundant in the environment (Erees et al., 2006). These radionuclides are present in various degrees in all environmental media and their concentration in soils vary, depending on the type of rocks from which the soils were formed (UNSCEAR 2000, 2008; IAEA 2003, Tzortzis et. al., 2003, Abba et al., 2018). Higher radiations levels are associated with the igneous rocks while lower levels are associated with the sedimentary rocks (UNSCEAR 2000). These radionuclides produce gamma radiation of sufficient energy and intensity that are measurable by gamma ray spectrometer (IAEA, 2003).

The naturally occurring radionuclides include, ^{40}K and the three radioactive decay chains originating with ^{238}U, ^{232}Th and uranium ^{235}U. Uranium is present in virtually all soils, rock and water as trace elements. Radon gas isotopes ^{219}Rn (actinon), ^{220}Rn (thoron) and ^{222}Rn (radon) occur in the environment, being respectively produced in the natural decay chains of ^{235}U, ^{232}Th and ^{238}U, all decaying by alpha emission. Because of its relative high half-life time of 3.82 days, the ^{222}Rn isotope is considered the most important among them in the applied nuclear and environmental studies. Radon isotope is the daughter product of radium which is a solid and which decays under ordinary conditions of temperature and pressure, emitting alpha particles and followed by gamma radiation emission (Singh et al., 2009). Radon being an inert gas, and having sufficient half-life, can diffuse through the soil and enter the atmosphere. The radon produced in the soil migrates through the mechanism of emanation,

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diffusion and convection through the pores in the soil, fractures in rocks and through weak zones such as shear, faults and thrusts. The amount of radon that escapes from the earth therefore depends on the amount of ^{226}Ra and ^{232}Th in the ground and the porosity of the soil in which they exist (Shashikumar et al., 2009). The half-life of potassium 40 is 1.25 billion years and it decays to Calcium 40 by emitting a beta particle with no attendant gamma radiation and also to a gas argon 40 (^{40}Ar) by electron capture with emission of energetic gamma rays.

At least 80% of the radon emitted into the atmosphere comes from the top few meters of the ground (NCRP, 1984), the radon emanation rate varying from place to place due to the differences in radium concentration and soil parameters such as moisture content, porosity, permeability, grain size and also the diurnal variations of the radon concentration in the uppermost soil layer and at the soil/air interface. (Kayrat et al., 2001; Shweikani et al., 1995; Ershaidat et al., 2013). Farai and Vincent (2006) had earlier stated that radiation emitted by these radionuclides within 15-30cm of the topsoil can reach the earth surface, supporting the emission of gas nuclides from the soil. Previous studies (Adewale et al., 2015, Banzi et al., 2000, Ode et al., 2017) have shown that soils and rocks of granite composition contain significant amounts of terrestrial radionuclides.

The natural background radiation level at the quarry site is therefore enhanced when quarrying activities bring out large amount of these materials containing naturally occurring radionuclides onto the surface of the environment (Saleh et al., 2007, Karangelos et al., 2004). However, abandoned quarries are free from the cloud of radionuclides spewed into the air by the quarrying activities as the radionuclides created during the activities are blown away by wind or are already settled on the pit and the surrounding. The pit is a three dimensional space hewn out of the hill site. The block of rock cut out are moved out and away for commercial purposes. The temperature at the top of the pit is controlled by the temperature and the direction of the wind blowing over the pit. The radionuclides emanating from the quarry surface walls and the quarry base will be suspended in the air above the base of the pit, with a concentration gradient guided by the gas law.

The aim of this work therefore, is to find how radionuclide particles are distributed over an abandoned quarry site as this will help to explain the distribution of gamma radiation levels above the abandoned quarry site.

MATERIALS AND METHOD

Study Area

The study area was located in Supare Akoko, Ondo Stae, South western Nigeria, and was assessable through a road from Akungba Akoko in the northern part of Ondo State. The area was one of the Sutol quarries that lie between Latitudes 7.4430 and 7.4447 N, and longitudes 5.6550 and 5.6558 E. This area was very close to Supare town in Ondo State and was situated on the range of hills, called Kukuruku hills that ran from Osun State, through Ondo State to Edo state. The area was underlain by magmatite-gneiss quartzite complex rocks with the granite gneiss and grey-gneiss being the major unit (Rahaman, 1976, 1988). Two quarry pits were studied in this area and their mean heights above the sea level were 368.0 ± 0.6 m for pit 1 and 411.4 ± 0.4 m for pit 2.

Figure 1a. Quarry pit 1

Figure 1b. Quarry pit 2

Instrument

The Geiger-Mueller counter of Model DSM-500 used in this work, is a portable microprocessor based digital scaler/ratemeter with one external probe connector designed for use with scintillation, and proportional type detectors for measuring ionizing radiation. The instrument was used in the mode of counts per second to estimate the radioactive particles in the area. A digital basal clinical thermometer (Model DT-12A) that measures to two decimal places was also used to measure the air temperature at the bottom and at the top of the tallest wall of each pit.

Method of measurement

Measurement of radionuclide particle counts per second was carried out between 11 am. And 4 pm. by adopting the standard practice of positioning the GM counter at a height of one meter above the ground level (Rafique et al, 2014; Agbalagba et al, 2016). A special stool 1.0 m high was built to ascertain this for each measurement. Measurement at each point was repeated three times and their mean value was recorded as the measurement at the point.

The geographical location in terms of latitude and longitude, and the height above the sea level at each point of measurement were determined, using the GPS application of the android phone. The android phone used for the GPS measurements was later calibrated by using it to measure the height of bottom and the top of a quarry pit wall.

The temperature at the bottom and also at the top of one of the walls of the pit were measured to determine the nature of the temperature gradient above the pit during the time of measurement.

RESULTS

Table 1.0 Height and air temperature of the the bottom and top of one side wall of quarry pit

Quarry Pit	Mean Height of a pit wall (m) a,s,l		Mean radionuclide particle counts per second at one pit wall		Mean Air Temperature (^{O}C) at one pit wall	
	bottom	top	bottom	top	bottom	top
Pit 1	368.0 ± 0.6	373.3± 0.2	480±10	591 ± 16	38.48 ±0.05	38.14 ±0.05
Pit 2	411.4 ± 0.4	416.0±0.5	685±53	771 ± 12	42.99 ±0.05	41.50 ±0.05

a.s.l = above the sea level

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Table 1.0 shows the mean height of the bottom and the top of the tallest walls of pit 1 and 2 above the sea level (a.s.l.), the mean radionuclide particle counts per second at the bottom and at the top of the walls. It also shows the mean temperature of the air at the bottom and at the top of the pit walls. The table shows that the temperature at the bottom of the pits were generally higher than their values at the top during the time of measurement (11 am. – 4 pm.).

Fig 2.0a shows the topographic view of the elevation of the various points of measurement of pit 1, while Fig 2.0b shows the topographic view of the radionuclide particle counts per second at the various points of measurement in pit 1. On the average, it0is observed that the two figures look alike, supporting the suggestion that the radionuclide [article counts per second increases with the height of the point of measurement above the sea level.

Fig3.0a shows the contour of the elevation of the various points of measurement of pit 1, while Fig 3.0b shows the contour of the radionuclide particle counts per second at the various points of measurement in pit1. The two contours maps also look alike and suggest that the radionuclide counts per second increases with the height of the point of measurement above the sea level.

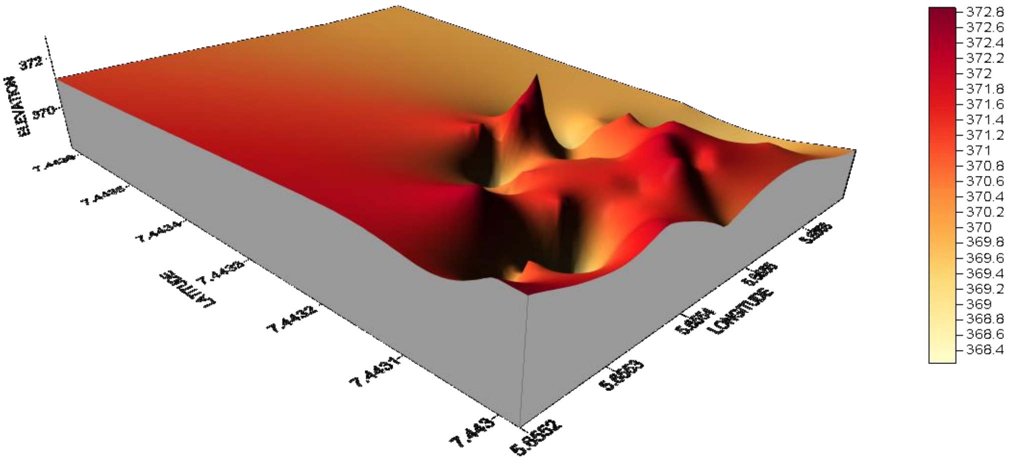

Figure 2a. Topographic view showing the elevation (m) of the various points of measurement in the abandoned quarry pit 1.

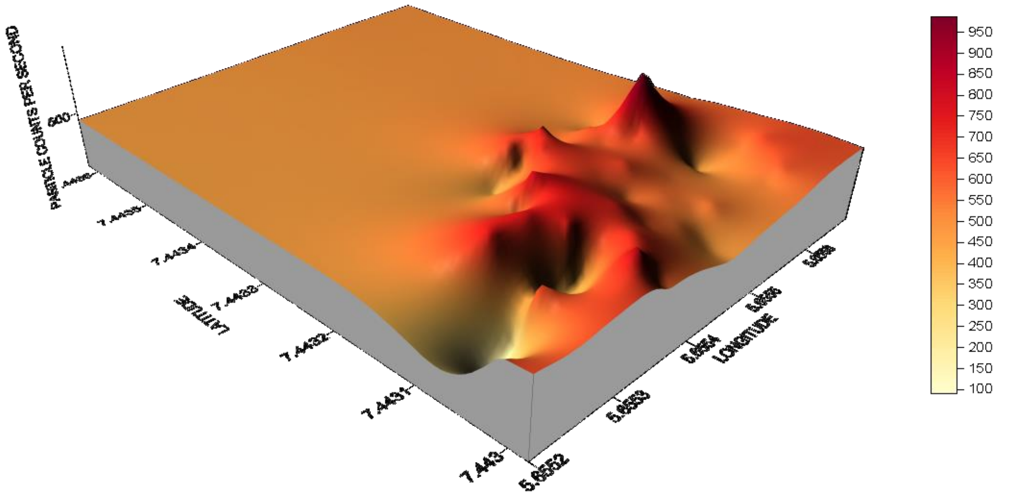

Figure 2b. Topographic view showing the radionuclide particle counts per second at the various points of measurement in the abandoned quarry pit 1

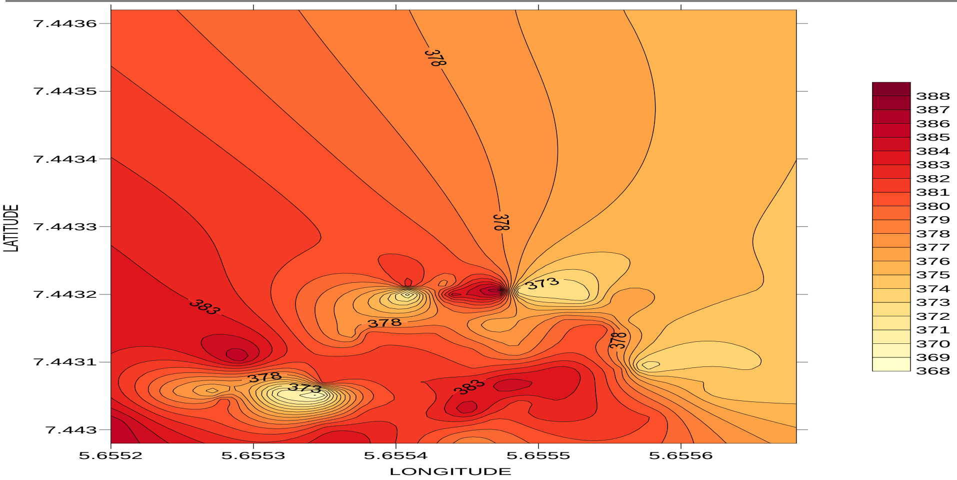

Figure3a. Topographic view showing the contour of the elevation (m) of the various points of measurement in the abandoned quarry pit 1

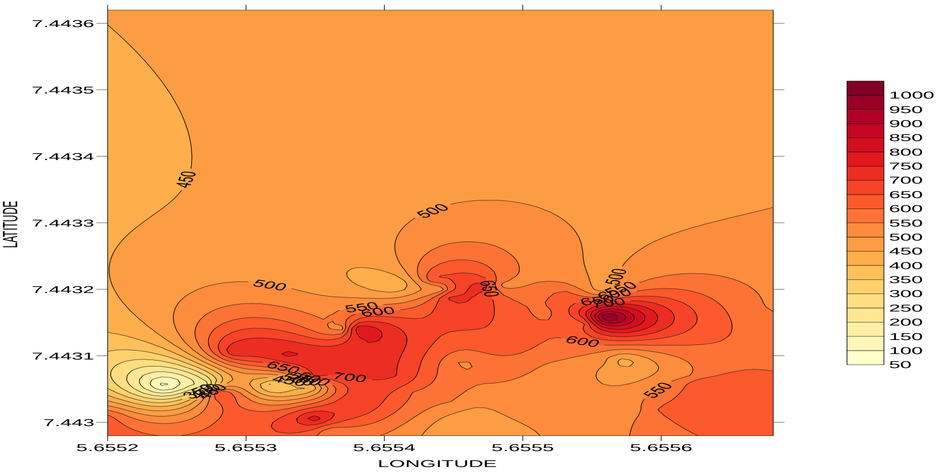

Figure 3b. Topographic view showing the contour of the radionuclide particle counts per second at the various points of measurement in the abandoned quarry pit 1

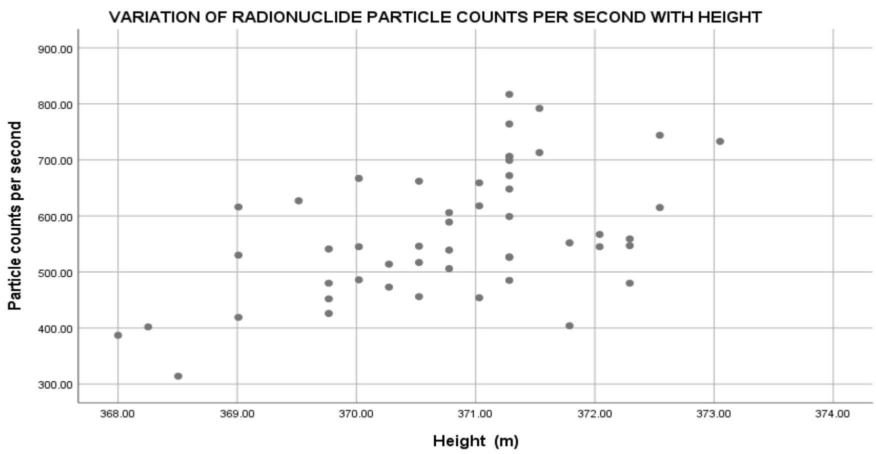

Fig 4.0 Variation of radionuclide particle counts per second with height above the sea level (m) for Pit 1

Fig. 4.0 shows that the radionuclide particle counts per second in pit 1 increases with the height of measurement above the sea level.

By comparing figs. 2.0a and 2.0b with figs 5.0a and 5.0b, figs 3.0a and 3.0b with figs 6.0a and 6.0b, and fig 4.0 with fig 7.0, it is seen that the trend of the measurements made in pit 2 which was just above pit 1 agrees with those made in pit 1; suggesting that the physical behaviour of the two pits are the same.

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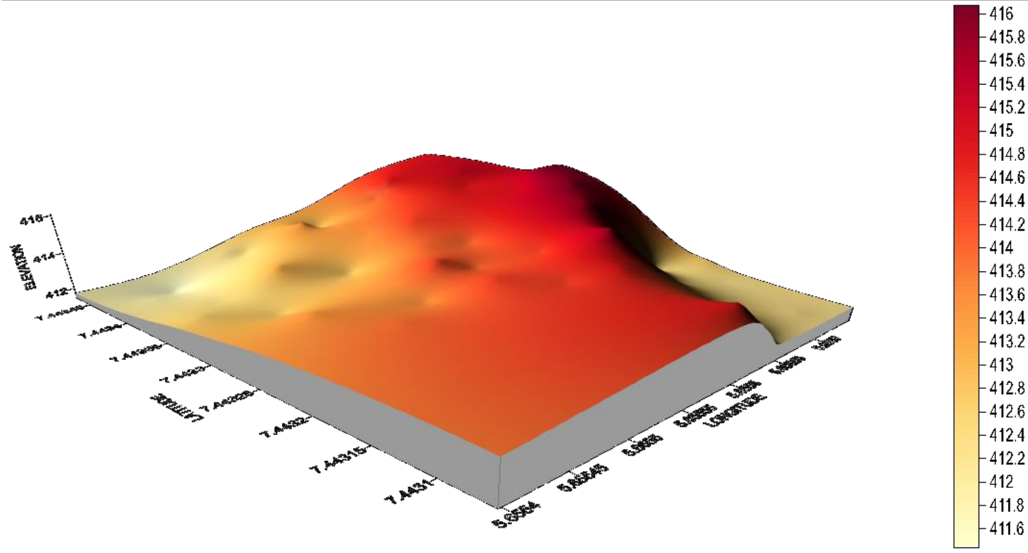

Figure 5a. Topographic view showing the elevation (m) of the various points of measurement in the abandoned quarry pit 2.

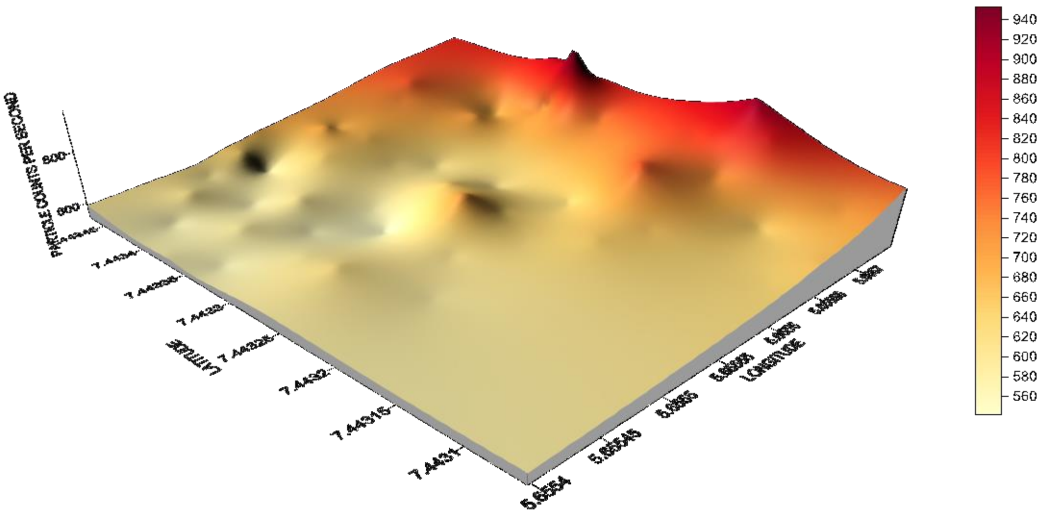

Figure 5b. Topographic view showing the radionuclide particle counts per second at the various points of measurement in the abandoned quarry pit 2.

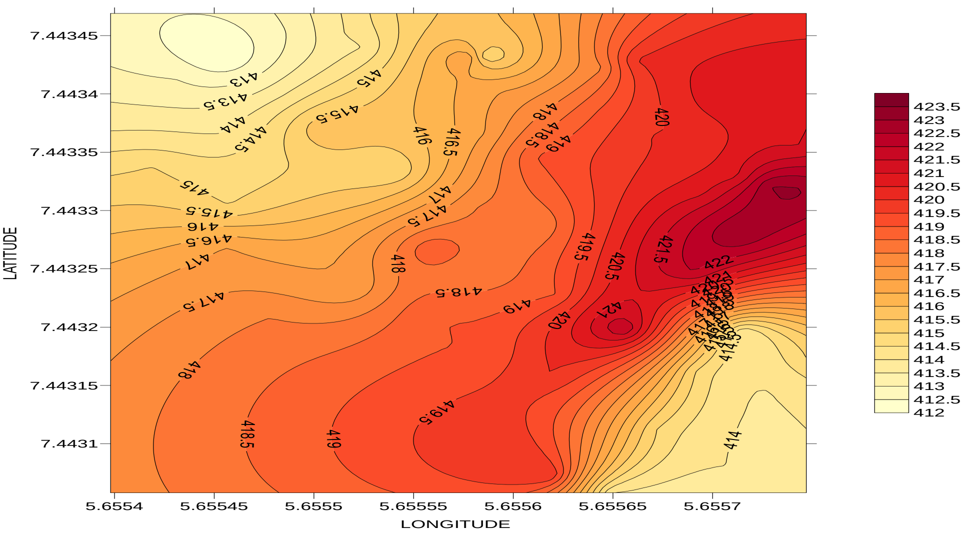

Figure 6a: Topographic view showing the contour of the elevation (m) of the various points of measurement in the abandoned quarry pit 3

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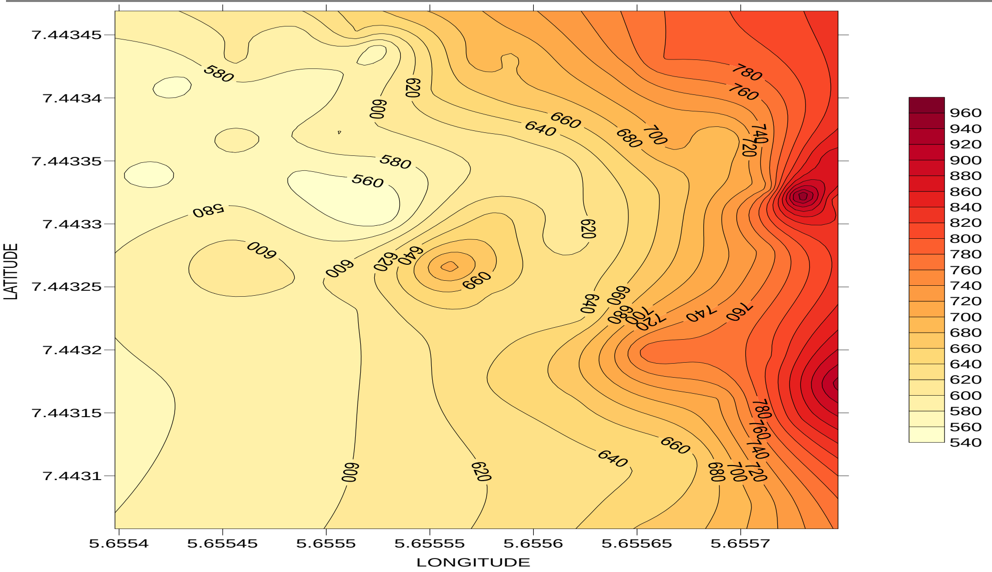

Figure 6b: Topographic view showing the contour of the radionuclide particle counts per second at the various points of measurement in the abandoned quarry pit 3.

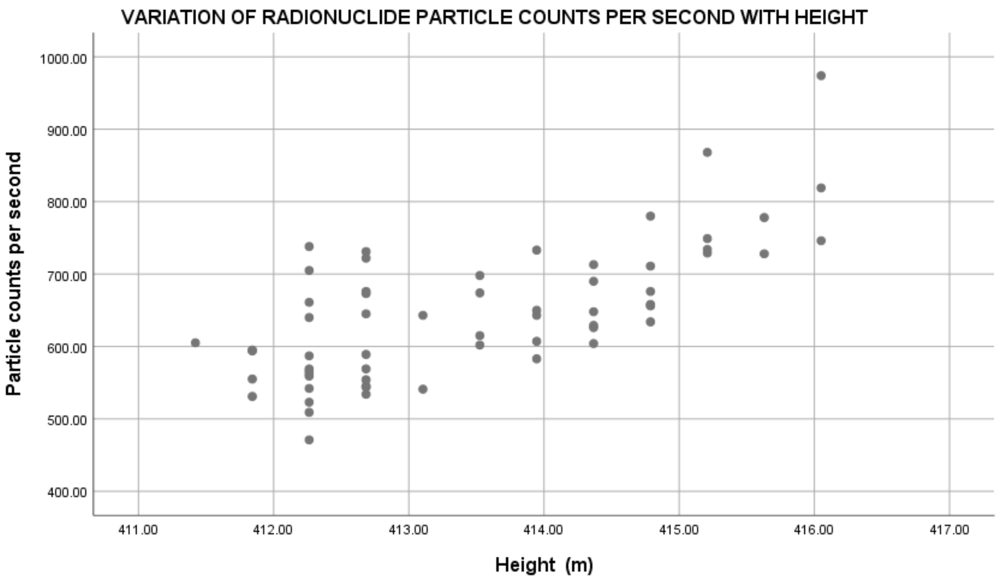

Fig. 7.0 Variation of radionuclide particle counts per second with height above the sea level (m) for Pit 2

DISCUSSION

Rahaman (1976, 1988) reported that the area under study is underlain by magmatite-gneiss quartzite complex rocks, granite gneiss and grey-gneiss. These types of rocks are known to contain radionuclide elements of ^{238}U, ^{232}Th and ^{40}K, and the gas disintegrations from these elements when not more than 30 cm from the earth's surface can escape into the atmosphere (Ershaidat et al., 2013; Farai and Vincent, 2006).

The gas radionuclides emitted into the atmosphere are thoron (^{220}Rn) of half life 55.6s from the disintegration of Thorium, radon (222Rn) of half life 3.8 days from the disintegration of Uranium and argon from potassium.

Radioactive disintegration from the rocks in the walls of the abandoned quarry pit spew radionuclides in into the air of the pit. These particles then produce gamma rays experienced in the pit.

Among the daughters of radon, ^{214}Pb and ^{214}Bi are significant emitters of gamma radiation, with 214Pb emitting radiation of energies 242 keV (8%), 295.2 keV (18%), 352 keV (35%) and 214Bi emitting radiation of energies

609 keV (43%), 168 keV (5%), 934 keV (3%), 1120 keV (14%), 1238 keV (6 %), 1377 keV (7%), 1764 keV (16%), 2204 keV (5%) (Seftelis et al, 2007).

The temperature of the pit base controls the temperature gradient of the air above it and the number of gas particles per unit volume suspended in the air immediately above it.

The top of the pit is exposed to the outside cool wind blowing over it, while the air at the bottom of the pit is trapped and is not moving freely as the one at the top. The air at the bottom of the pit will absorb heat from the pit base, thus raising its temperature higher than the temperature of the air at the top of the pit. During the day, the sun heats the base of the pit, and raises its temperature higher than the temperature of the air at the top of the pit. The diurnal variation of the temperature of the pit base will therefore dictate the nature of the temperature gradient above the base.

The gas law can be expressed as PV = nRT, where P = pressure, V= volume, n = number of particles per unit volume, R = Gas constant, T = temperature in degrees Kelvin (Noakes, 1970). This equation shows that n is inversely proportional to temperature. The radionuclide counts per second can be said to be proportional to n. During the time of measurement in the present study, it was found that the temperature of the base of the pit was higher than the temperature of the air at its top as shown in Table 1, showing the existence of a negative temperature gradient above the pits. Therefore n, vis a vis the radionuclide count per second will be inversely proportional to temperature, so that when temperature decreased with height as shown in Table 1 for pit1 and 2, the radionuclide counts per second will increase with height as shown by our result in figs 4 and 7 for pit 1 and 2 respectively.

Since the radon particles were mixed with the air above the pits, the medium above the pits could be considered as a radon gas of a certain concentration, vis a vis the radionuclide counts per second. Therefore as the temperature decreased with height in the pits, the concentration of the radon nuclides i.e. its counts per second would increase with height, agreeing with the works of Garcia-Talavera et al. (2001) and Latha (2003) who found a correlation between the concentration of radon particles and temperature.

CONCLUSION

It is shown in this study that the radionuclide counts per second, vis a vis the radionuclide concentration, varies with the height of the point of measurement in the abandoned quarry site. Since it is the daughters of radon nuclides that produce the gamma radiation, the level of gamma radiation at the various points of measurement in the quarry pit will therefore depend on the height of the measuring point. From the gas law, it is shown that the concentration of radionuclide particles, vis a vis the radionuclide particle counts per second is inversely proportional to temperature. Since the temperature gradients in both pits 1 and 2 were negative during the time of measurement, leading to the increase of radionuclide counts per second with height in both pits, the level of gamma radiation in both pits will therefore increase with the height of measurement in the pits.

Conclusion 2

It is shown in this study that the radionuclide counts per second, vis a vis the radionuclide concentration, varies with the height of the point of measurement in the abandoned quarry site. From the gas law, it is shown that the concentration of radionuclide particles, vis a vis the radionuclide particle counts per second is inversely proportional to temperature. Since the temperature gradients in both pits 1 and 2 were negative during the time of measurement, the radionuclide counts per second will therefore increase with height in both pits during that time.

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