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RESEARCH ARTICLE

Activity concentrations of ^{40}K, ^{232}Th, ^{226}Ra and radiation exposure levels in Nairobi Central business district and the industrial area.

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Abstract

Radiation levels were determined using a handheld meter device model Horiba PA- 1100. Soil samples were also collected and analyzed using gamma spectrometry. Radionuclides present were identified. The activity concentration for ^{232}Th and ^{226}Ra ranged between 21.1878±0.22 to 163.323±0.32 and 34.5543±0.03 to 198.467±0.14 $Bqkg^{-1}$ respectively. The mean air absorbed gamma radiation dose rate (D) was 156.1788366 $nGyh^{-1}$**,** 4 times higher than the world average value of 43 $nGyh^{-1}$. The average measured absorbed dose rate for the sampled sites was 1064.9229 $nGyh^{-1}$, 17 times higher than the world average value of 60 $nGyh^{-1}$. Mean values for External and Internal hazard indices were 0.880899 and 1.086053 respectively compared to the standard unity value (≤1). Average annual effective dose rate calculated from the soil sample was 0.957689 $mSvy^{-1}$**.** Nairobi and it's environ are highly polluted with radiative materials. The data partly explains the high incidences of cancer related diseases within the study area. The aim of this study is to enhance documented radiation data in Kenya which is important in creating awareness and assessing radiation related diseases, towards achieving global radiation reduction.

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Introduction

Radiation is energy given off by matter in the form of rays or high-speed particles. Human beings have always been exposed to ionizing radiations of natural origin, namely terrestrial and extra terrestrial radiation (Atambo, 2011) . Ionizing radiation falls into two broad groups; particulate radiations such as high energy electrons, neutrons, protons or alpha particles that ionize matter by direct atomic collisions and electromagnetic radiations or photons such as X-rays or gamma rays which ionize matter by other types of atomic interactions (Busby & Fucic, 2006). In the recent years the level of radiations in the environment has been found to be rapidly increasing due to increasing Technology. Knowledge of cancer risks in humans has advanced tremendously in the last half century. Much of this knowledge has come from studies of bomb survivors in Hiroshima and Nagasaki, who have now been followed for more than 50 years. Leukemia was the first type of cancer found to be in excess among the Japanese survivors of the atomic bombings of Hiroshima and Nagasaki in 1945 (Wakeford, et.al., 2009). In addition, there is now a wealth of data from studies of people who have been exposed for medical, occupational or environmental reasons (Gilbert, 2009). Cancer is the major stochastic effect of radiation exposure that has been demonstrated in human populations (UNSCEAR, 2011). According to (UNSCEAR, 2000) exposure from naturally occurring radioactive materials gives the major contribution to the total effective radiation dose of the population. The exposure pathways include internal exposure, mainly due to the inhalation of radon (^{222}Rn, half-life 3.8 d) and its progeny, and external exposure due to the gamma irradiation with radionuclides originated in primordial radionuclides of earth's crust (decay chains of

thorium (^{232}Th) and uranium (^{238}U, ^{235}U), as well as radionuclide potassium (^{40}K) .In the current study, the levels of exposure from terrestrial background radiation was determined from the soil samples as well as measurement of radiation from different locations within Nairobi metropolitan area which is the most densely populated area in East and Central Africa and with the highest concentration of Industries in the region.

1.2 MATERIALS AND METHODS

1.2.1 Study area

The levels of radiation were measured in Nairobi's CBD and the industrial area using a hand held meter (model Horiba PA-1100) held 1m above the ground. The study was carried out along the highways, near tall buildings (e.g. Afya centre, KICC etc), mining areas, and quarries as well as in and around industries within the study area.

1.2.1.1 Gamma Dose measurements

The levels of radiations were determined in 96 spots with a spacing of about two hundred meters from one point to the other. The sampling device comprised of a GPS enabled android pad and a radiation detector. The readings obtained using the pocket radiometer were sent to the android pad via Bluetooth. Mapping of the sampled area was also achieved by use of the GPS enabled ideo- pad.

1.2.1.2 Sample collection

Soil samples were collected from Mavoko and Embakasi constituencies. At Mavoko the soil samples were collected near the Athi River mining Industries, Mlolongo and also at Kenya Meat Commission staff quarters. At Embakasi, soil samples were collected at the Mwiki dumpsite, Njiru quarry and also at Tetra Pak industry which is in the industrial area. The sample collection was done on the basis of the levels of effective dose rates obtained using the handheld meter and also the economic activity of the area. The soil samples were packed in polythene bags for transportation to the laboratory where the analysis were carried out.

1.2.1.3 Sample preparation

After collection, the soil samples were separately crushed into powder form and sieved through a 0.6 mm mesh sieve. This was then dried in an oven at 80°C for 24 h, completely removing water from the samples. A mass of 200 g of each sample was packed in special gas tight polyethylene plastic containers, then closed and tightly sealed using a tape. The containers were labeled appropriately and then stored for 30 days so as to attain secular equilibrium i.e. the decay products of ^{232}Th series and ^{226}Ra subseries were in radioactive equilibrium with their daughters. The samples were analyzed using gamma spectrometric method for the identification and quantification of the NORMS at the Institute of Nuclear Science and Energy (University Of Nairobi).

1.2.1.4 Activity concentration measurements.

The concentrations of radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in each sample were determined using a high purity germanium (HPGe) gamma ray spectrometer consisting of a p-type intrinsic germanium coaxial detector (ORTEC model 7450) mounted vertically. The detector had a relative efficiency of 31.6 % and full width at half maximum (FWHM) of 2.0 keV energy resolution for the 1332 keV gamma ray line of ^{60}Co. The detector was connected to a Canberra multichannel analyzer (MCA) with apex software, that allowed data acquisition, display of gamma-spectra, analysis of the gamma-spectra and storage of the results in memory counters called channels. The MCA was interfaced with a computer and a printer. The detector was housed inside a 10 cm thick lead shield internally lined with 2 mm Cu foils. This provided an efficient suppression of background gamma radiation present within the laboratory. To ensure that all nuclides due to ^{238}U and ^{232}Th were visible in the gamma spectrum, spectral data acquisition time for each sample was 12 hours. The activity concentration for each radionuclide in the measured samples was determined by the net intensity of respective peaks which were compared to the standard. Equation below was used to calculate activity concentration of the radionuclides.

$$\frac{M_s A_s}{I_s} = \frac{M_r A_r}{I_r}$$

M_s = Mass of the sample — M_r = Mass of the standard

A_s = Activity of the sample — A_s = Activity of the standard

I_s = Intensity of the sample — I_s = Intensity of the standard

The system was calibrated using a standard reference material (**SRM-1**). The radionuclides in the SRM were identified as ^{137}Cs and ^{60}Co.

The ^{226}Ra activities for samples assumed to be in radioactive equilibrium were estimated from ^{214}Pb (351.92 keV) and ^{214}Bi (609.31 keV). The gamma-ray energies of ^{212}Pb (238.63 keV) and ^{228}Ac (911.60 keV) were used to estimate activity of ^{232}Th. The activity concentrations of ^{40}K were measured directly by its own gamma rays (1460.81 keV).

Table 1: Spectroscopic parameters employed for the quantification of activity levels (Tsai, Lin, Wang, & Chu, 2008)

Element	Emitter nuclide	Half-life of nuclide	Gamma-ray energy (keV)	Absolute emission probability of gamma decay (%)
^{226}Ra	^{214}Bi	19.90 min	609.31	46.30
	^{214}Pb	26.80 min	351.92	37.20
^{232}Th	^{212}Bi	60.55 min	727.17	11.80
	^{212}Pb	10.64 h	238.63	44.60
	^{228}Ac	6.25 h	911.60	27.70
^{40}K		1.3×10^9 y	1460.81	10.67

1.2.2. ABSORBED DOSE

The external absorbed doses that results from deposition of radionuclides in soil surfaces were estimated through direct measurements and calculations based on radionuclide deposition densities.

1.2.2.1 Measurement of Absorbed Dose Rates in Air

Absorbed dose rates in air were measured 1m above the surface at different spots of the study area using a hand held environmental radiation monitor Horiba PA-1100 model with a reading of up to 35 μSvh^{-1}. Absorbed dose rates in air in $nGyh^{-1}$ were computed from the dose rates in μSvh^{-1} as measured in the field using the conversion coefficient factor of 0.7 $SvGy^{-1}$ as recommended by UNSCEAR, 2000.

1.2.2.2 Calculation of Radium equivalent activity

The radiation hazards associated with the radionuclides were estimated by calculating the radium equivalent activity (Ra_{eq}). It is a weighted sum of activities of ^{226}Ra, ^{232}Th, and ^{40}K; and it is based on the assumption 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 radiation dose rate (Alaamer, 2008). To avoid radiation hazards, materials whose Ra_{eq} is greater than 370 Bq kg^{-1} should not be used. Ra_{eq} is defined by the following formula:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_k \quad (1)$$

where A_{Ra}, A_{Th}, and A_K are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K, respectively.

1.2.2.3 Calculation of Absorbed Dose Rates

Radiation emitted by a radioactive substance is absorbed by any material it encounters.
activity. Concentrations of ^{226}Ra, ^{232}Th and ^{40}K into dose ($nGyh^{-1}$ per $Bqkg^{-1}$) as 0.427, 0.662 and 0.043 respectively. Using these factors, the total absorbed dose rate in air was calculated as given in the equation (UNSCEAR 2000).

$$D = (0.427C_{Ra} + 0.662C_{Th} + 0.043C_K)\ nGyh^{-1} \quad (2)$$

where C_{Ra}, C_{Th} and C_K are the activity concentrations ($Bqkg^{-1}$) of radium, thorium and potassium in soil respectively.

1.2.2.3 Calculation of Annual Effective Dose

Effective dose is a dosimetric quantity used for comparing health effects of radiation to the human body. To estimate the annual effective dose (AED), take into account the Conversion coefficient, (0.7 SvGy-1) from the absorbed dose in air to effective dose and the outdoor occupancy factor. The average fraction of time spent indoor and outdoor (Occupancy factors) in Kenya are 0.6 and 0.4 respectively. The world average indoor and outdoor occupancy factors are 0.8 and 0.2 respectively (Kebwaro, Rathore, Hashim, & Mustapha, 2011). The effective dose rate in units of $mSvy^{-1}$ was estimated using the formula

Effective dose rate = $\eta\Phi s\ (\ 8.76\times 10^{-6})$ (3)

where s = 0.7 $SvGy^{-1}$ is the conversion coefficient, Ƞ is absorbed dose rate in $nGyh^{-1}$ and Φ= 0.4 is the outdoor occupancy factor in Kenya as in UNSCEAR 1998.

1.2.2.4 External Hazard Index (H_{ex})

Radiation exposure due to ^{226}Ra, ^{232}Th and ^{40}K may be external. This hazard, defined in terms of external hazard index or outdoor radiation hazard index and denoted by H_{ex}, can be calculated using the equation (Beretka and Mathew 1985):

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_k}{4810} \quad (4)$$

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_k}{4810} \quad (5)$$

where C_{Ra}, C_{Th} and C_K are activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively in $Bqkg^{-1}$. The value of this indices should be less than 1 in order for the radiation hazard to be considered acceptable to the public (Beretkab and Mathew, 1985).

1.3 RESULTS AND DISCUSSION

Radionuclides present were identified as ^{226}Ra, ^{232}Th and ^{40}K. The activity concentrations were calculated from the spectrum of the identified radionuclides. Data on activity concentration of radionuclides ^{226}Ra, ^{232}Th and ^{40}K in rock and soil (all values reported as $Bqkg^{-1}$) collected from different locations in the study area is as in **Table 2**.

Table 2: Activity of the radionuclides that were identified in the soil samples

PLACE	ECONOMIC ACTIVITY	Activity concentrations (Bq/Kg)		
		^{232}Th	^{226}Ra	^{40}K
Kenya Meat Commission(KMC)	RESIDENTIAL	85.1241±0.36	65.5287 ±0.24	823.174± 0.10
MWIKI	RESIDENTIAL	96.4138± 0.18	198.467 ±0.14	1029.11± 0.09
MLOLONGO	RESIDENTIAL	21.1878± 0.22	75.7889 ±0.01	579.787± 0.10
NJIRU QUARRY	MINING	63.7714± 0.23	80.0973 ±0.22	860.87± 0.08
ATHI RIVER MINING	INDUSTRIAL	49.115±0.48	34.5543± 0.03	1113.86± 0.09
INDUSTRIAL AREA(T.P)	INDUSTRIAL	163.323± 0.32	95.5345± 0.14	1164.51± 0.1

The activity concentration for ^{232}Th and ^{226}Ra were in the range of 21.1878± 0.22- 163.323± 0.32 and 34.5543± 0.03- 198.467 ±0.14 $Bqkg^{-1}$ respectively with the highest activity values for ^{232}Th and ^{226}Ra being at Tetra Pak and Mwiki dumpsite respectively. In all the studied soil samples, ^{40}K had the highest activity concentration which ranged from 579.787± 0.10- 1164.51± 0.1 $Bqkg^{-1}$ with the highest activity value being at TetraPak and the lowest at Mlolongo. The variation of natural radioactivity levels at different sampling sites was due to the variation of concentrations of radionuclides in the geological formations and can partly be attributed to the economic activities of the different areas. The mean activity concentrations values of ^{232}Th, ^{226}Ra and ^{40}K were 117.137764, 75.90704 and 1074.915 $Bqkg^{-1}$ respectively. The activity values were higher than the world wide average activity concentrations which are 30, 35 and 400 $Bqkg^{-1}$ respectively as reported by UNSCEAR (2000). The activity concentrations of ^{232}Th, ^{226}Ra and ^{40}K for TetraPak were relatively higher than the rest of the sites. This can be attributed to the location of the industry which is at the core of the Nairobi Industrial area.

Table 3: Calculated Absorbed Dose Rates from soil

LOCATION	ABSORBED DOSE RATE ($nGyh^{-1}$)	ANNUAL EFFECTIVE DOSE RATE
KMC	198.7721294	0.734181
MWIKI	371.7851562	1.329192
MLOLONGO	149.4905626	0.516009
NJIRU QUARRY	194.4849126	0.719113
ATHI RIVER MINING	149.4645715	0.562567
INDUSTRIAL AREA (T.P)	514.2813511	1.885069

The absorbed dose rates due to terrestrial gamma rays 1m above the ground were calculated using equation 2 and were expressed in $nGyh^{-1}$. These values varied from 149 – 514 $nGyh^{-1}$.The average value of air absorbed gamma radiation dose rate (D) was 156.1788366 $nGyh^{-1}$, which is approximately 4 times higher than the world average value of 43 $nGyh^{-1}$ (UNSCEAR, 2000). The average annual effective dose (E) was 0.957689 $mSvy^{-1}$.

1.3.1 Measured absorbed dose rates

The absorbed dose rates in air measured 1 m above the surface at each sampled site are presented in Table 4. These values vary from 334-1604 $nGyh^{-1}$, the lowest dose being experienced at Athi River Mining and the Njiru quarry. The average measured absorbed dose rate for the sampled sites is 1064.9229 $nGyh^{-1}$, which is 17 times higher than the world average value of 60 $nGyh^{-1}$ (UNSCEAR, 2000).

Table 4: Comparison of the calculated and absorbed dose rates absorbed dose rates

The measured absorbed dose rates in air were much higher than the calculated absorbed dose rates for all the sampled areas. The difference was because measured absorbed dose rates included the dose due to cosmic rays.

LOCATION	CALCULATED ABSORBED DOSE RATE ($nGyh^{-1}$)	MEASURED ABSORBED DOSE RATE nGyh-1
KENYA MEAT COMMISSION	198.7721294	1036.141
Mwiki	371.7851562	1102.763
Mlolongo	149.4905626	928.3194
Njiru Quarry	194.4849126	1604.178
Athi River mining	149.4645715	334.8612
Industrial area	514.2813511	1383.275

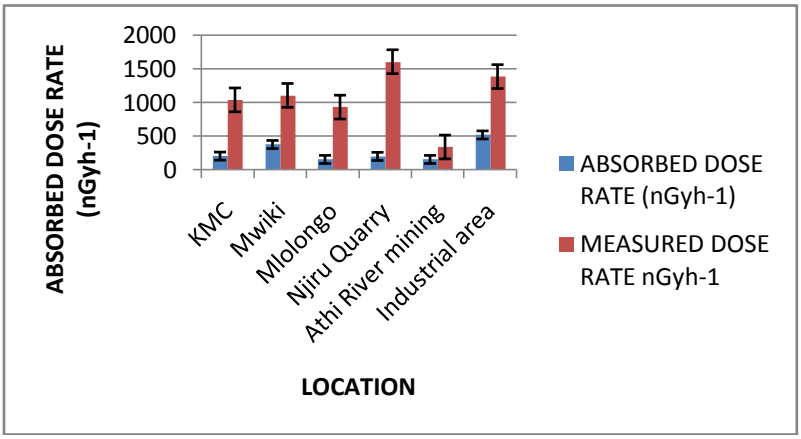

Figure 1: Graph showing a comparison of the calculated and measured absorbed dose rates.

Table 5: External and Internal hazard indices

PLACE	EXTERNAL HAZARD INDEX (H_{ex})	INTERNAL HAZARD INDEX (H_{in})
KMC	0.676907	0.854012
MWIKI	1.240544	1.500854
MLOLONGO	0.470423	0.527688
NJIRU QUARRY	0.660586	0.832941
A.R MINING	0.497729	0.630472
INDUSTRIAL AREA(T.P)	1.739202	2.17035

The external and internal hazard indices were calculated and the values obtained were as indicated in Table 5. The values ranged from 0.470423 to 1.739202 and 0.527688 to 0.527688 respectively. The mean values were 0.880899 and 1.086053 respectively. The highest indices were found in Mwiki and Industrial Area (TetraPak) which were greater than the recommended unity value.

1.4 CONCLUSIONS

The mean activity concentrations values of ^{232}Th, ^{226}Ra and ^{40}K were 117.137764, 75.90704 and 1074.915 $Bqkg^{-1}$ respectively. The activity values were higher than the world wide average activity concentrations which are 30, 35 and 400 $Bqkg^{-1}$ respectively. In all samples, ^{40}K had the highest activity concentration. The average value of air absorbed gamma radiation dose rate (D) was 156.1788366 $nGyh^{-1}$**,** which is approximately 4 times higher than the world average value of 43 $nGyh^{-1}$ (UNSCEAR, 2000). The average annual effective dose (E) was 0.957689 $mSvy^{-1}$. These values vary from 334-1604 $nGyh^{-1}$, the lowest dose being experienced at Athi River Mining and the Njiru quarry. The average measured absorbed dose rate for the six sampled sites is 1064.9229 $nGyh^{-1}$, which is 17 times higher than the world average value of 60 $nGyh^{-}1$. The mean values were 0.880899 and 1.086053 respectively. The highest indices were found in Mwiki and Industrial Area (Tetrapak) which were greater than the recommended unity value. The data provides some of the comprehensive radiation exposure levels that the inhabitants of the biggest city in East and Central Africa experience on daily basis. It also shows the need for urgent and comprehensive measures to minimize this radiation as well as awaken the concerned authority's to consider radiation exposures as an emerging occupational health and safety concern.

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