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Research article

Levels of ionizing radiations in selected quarries in Nyamira County, Kenya

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ABSTRACT

It has been shown through a survey by World Health Organization and International Commission on Radiological Protection that certain materials (stones) sourced from quarries and used for the building are radioactive. In Kenya, underground stones which are sourced from embedded rocks are used in construction of most of the permanent buildings, yet Kenya has not adequately radio-profiled sources of building materials to determine whether the construction materials contain radionuclides that emit ionizing radiations yet are used for building. Consequently, Kenyans could be at risk of exposure to high levels of ionizing radiations by living in stone houses that are not radio-profiled. Health problems arise due to subjection to ionizing radiations. The study determined the levels of ionizing radiations in sampled quarries in Nyamira County by using Radiological survey dosimeters to show the radiation readings in milliRoentgen/hr then converted to milliSievert per year and the Global Positioning System device took note of the quarries' geographical positions. The study used Minitab version 17.0 software to establish the statistical differences of degree of exposure in sampled quarries. The sample size for the study was 40 quarries. It was revealed that Q-073 and Q-075 both had the lowest radiation readings of 0.64mSv while Q-079 had the highest reading of 3.46mSv equal to a deviation from WHO approved threshold of -35.71%,-36.29% and 245.7%, respectively. The results indicated that 89% of the sampled quarries had radiation emissions above the ICRP and WHO standard. However, within Borabu Sub County, only 5 and within Manga Sub-County 4 of the sampled quarries had radiation readings below ICRP and WHO recommended standards of 1mSv/yr. It was exhibited from the study results that there are higher levels of ionizing radiations in quarries going past recommended standards per year hence causing health risk to quarry workers and general public. Therefore, these results could guide in formation of the national construction policies by including regular surveying for the levels of ionizing radiation in building materials as well as in practicing appropriate mitigation strategies.

1. Introduction

Radiobiology is a basic medical and clinical science field entailing study of the activity of ionizing radiations on living organisms, mainly their detrimental effects [1]. In the earth, some areas have high levels of natural background radiation like France with 3.5mSv/yr among others. However, the published criterion should be 1mSv/yr above which could illicit undesirable biological effects hence it is very important to put forth mechanisms to reduce ionizing radiation exposure levels [2, 3, 4]. The estimates of risks produced by various National and International Scientific Committees suggest that normal levels of natural background radiation (1mSv/yr) are potentially responsible for about 0.5% of the total cancers and genetic diseases in general population [5] hence areas with radiation above 1mSv/yr are considered risky and mechanisms for radio-protection and safety should be adapted as much as possible.

Globally, cancers rank third among the main causes of death in the world after infections and cardiovascular diseases. It's approximated that the number of new cases of radiation-related illnesses especially cancers could arise from 10.1 million in 2000 to 15.7 million in 2025 thereby representing a 50% increase annually [6]. An estimate of five million persons worldwide are at risk of exposure to any kind of ionizing radiations for example; high energy UV light, X-rays, gamma rays, and particles given off by radioactive materials such as Beta particles, Neutrons and Alpha particles at levels above the natural background. Those people who mine are usually exposed to radon through inhalation; hence, they are exposed to gamma radiation and alpha particles. The air service staff can be exposed to neutrons as well as gamma radiation [7]. In medical field, radiations are used for treatment but the intensity and long-term exposure to the various types of radiations and radionuclides by medical practitioners and patients from diagnostic and treatment activities might elicit biological effects [8]. International Organizations have

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embraced the challenges imposed by exposure to ionizing radiations and are developing policies and reference levels for the ionizing radiations to enable the response to these exposure challenges hence aim at reducing exposure levels to ionizing radiations by the public. There are also almost no control programs and policies in place in developing countries [9].

In Africa, majority of the countries have no access to screening, diagnosis, treatment and palliative care for radiation-related disorders like cancers. This is due to insufficient resources and lack of basic facilities even though over a million new cancer cases annually are reported [9, 10].

In Kenya, the total effective dose is contributed by: 0.1–2.0 mSv/yr from terrestrial gamma radiation; 0.2–0.7 mSv/yr from cosmic radiation; and 0.4–6.0 mSv/yr from radon (222Rn) inhalation. When the distribution of the population as well as people's way of life, relief and geology are considered, it could be stated that the annual average effective dose in Kenya is higher than the mean globally (3mSv/yr) [11]. Most permanent buildings' construction in Kenya is done by using underground stones which are obtained from embedded rocks, yet there is no radio-profiling in the country. Considering that most building materials are never tested nor regulated prior to usage, it is therefore not clear what level of the radioactive particles are embedded in construction ballast, stones, rocks or sand many of which have been used in constructing various houses for residence. Moreover, as the exposure dose of radiation increases, the risk of radiation health problems increases as well [12, 13, 14, 15].

It was observed in Nyamira Hospital Health Records, 2016 that cases of radiation-related sicknesses such as cancers, respiratory diseases, eye, and skin problems, dehydration among the quarry workers and neighboring community members currently account for 21–23% of the disease burden. However, of the many postulated risk factors of radiation sicknesses, a genetic mutation that is accelerated by ionizing radiations has been validated as the major risk factor of sterility and cancers due to illiteracy about it by the public as indicated in the Nyamira County Health Statistics, 2014. As the County Environment Strategic plan 2018 indicates, the director of energy and mining in liaison with the staff regulates mining activities within the county quarries to reduce exposure levels. When cells are exposed to ionizing radiations such as when inhaled, leads to acute respiratory infections and cell mutations leading to cancers [16, 17, 18]. Radiation-related disorders especially cancer cases are on the increase. These ionizing radiations occur in trace levels in all rocks as Naturally Occurring Radioactive Materials [19, 20].

2. Materials and methods

2.1. Research design

The study used cross-sectional design since a sub-set representative of the total population of quarries in Nyamira County was used at one specific point in time and no follow-ups conducted after completion of the study since data don't change as rate of radionuclide decay is constant regardless of external influences such as temperature and pressure leading to constant amount of energy emitted. Analytical Design was then applied where data collected from sampled quarries was cleaned, coded and exported to the Minitab and Arch-GIS software for analyses.

The research protocols and procedures used were approved by the Ethics Committee of Kenyatta University and National Commission for Science and Technology (NACOSTI), Kenya.

2.2. Study variables

2.2.1. Independent variables

These are variables that are self-governed and aren't altered by other variables under measure. They included the ionizing radiations emitted, and exposure time as well as the duration to ionizing radiations and the geographical positions of quarries.

2.2.2. Dependent variables

A dependent or response variable is one that is influenced by other elements. This variable for this study was the radio-profiles for ionizing radiations because it depended on the factors stated as independent variables.

2.3. Study area

Nyamira County (latitude of 0º44′59.99″ N and longitude of 35º00′0.00″ E) is a county in the former Nyanza Province of Kenya with a total area of 912.5km^2. The area was selected for study since it has a larger number of quarries compared to other counties and a majority of the building stones are sourced in the area which is even sold to other counties (see Figure 1).

2.4. Study population

In Nyamira County there are more than 110 accessible quarries which were either private or community-owned and out of these, 40 quarries were sampled for the study.

2.5. Inclusion criteria

The study also included the selected quarries which were accessible. It also included those private-owned quarries whose owners gave consent.

2.6. Exclusion criteria

The study excluded those quarries which were inaccessible and the private owned quarries whose owners did not give consent to access them during the study.

2.7. Sampling techniques

Nyamira County was purposively selected for the study due to its large number of quarries which are major sources of building materials within and outside the county. Proportionate sampling was used to determine the number of quarries from each sub-county within Nyamira County. Random sampling was used to select the specific quarries in which to carry out the study.

2.8. Quarries' sample size determination

A third of the total 110 quarries were sampled as Mugenda and Mugenda (2003) [21] states that a third of a small population can be used for a study.

2.9. Data collection tools

A safety and health instrument called the Digilert 200 that is optimized to detect low levels of radiations was used in measuring the radiations from the selected quarries. Moreover, The Digilert 200 uses a Geiger-Mueller tube to detect radiation and displays the counts in various modes like milliRoentgen/hour, Gray and Sievert. The Global Positioning System machine (GPS MAPS 64s) was also used to collect coordinates of the various quarries within Nyamira County from where Ionizing Radiations were measured.

2.10. Pilot study and pretesting of study tools

Prior to the main study, the dosimeter was pretested at five different quarries in Kisii County due to its proximity and similarity in environmental conditions and economic activities. The essence of the exercise was to help in determining the machines' validity.

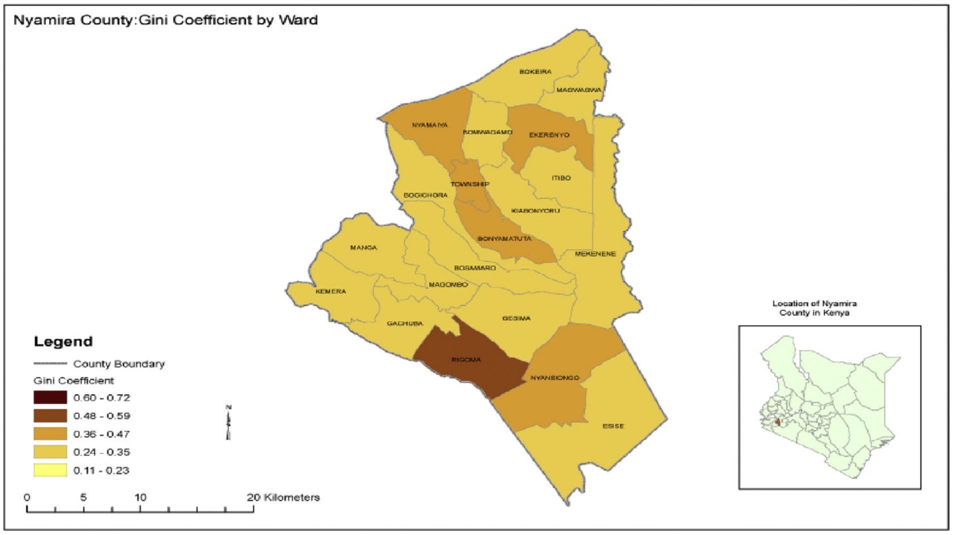

Figure 1. Map of study area (Nyamira county).

2.11. *Validity*

Validity is the ability of a research instrument to measure what it is intended to measure. Instrument validity concerns the level of accuracy to which the particular instrument actually measures what is meant to measure [22]. To enhance internal validity, a random sampling method was used to enhance homogeneity and representativeness of the selected population (limiting to quarries) and pretesting of the tools was done. To enhance content validity, expert opinion from supervisors and other researchers was sort.

2.12. *Reliability*

Reliability is defined as the degree to which the instrument can be depended upon to yield consistent results if used repeatedly overtime on the same study or if used by two researchers. It referred to the precision, consistency, and accuracy of the research instrument [23]. The test-retest technique to test the reliability of the machines twice over a period of time in the quarries respectively was adopted. The selection and training of the research assistant were properly and effectively done.

2.13. *Data collection procedures*

2.13.1. *Assessment of levels of ionizing radiations*

Data was collected from the selected accessible quarries. Measurements of the ionizing radiation exposure were carried out in units of MilliRoentgen per hour (mR/h) and the Quarries' geographical coordinates were measured using the Global Positioning System (GPS). A total of five different sections 1.5M apart, within a quarry were selected for radiation measurements and in each section, ionizing radiations at points 1 M from the researcher's standing position were measured and recorded in the sheets and the same procedure was repeated in other quarries. Since the normal background radiation levels often vary at different locations within and among quarries, a timed count was taken so as to establish the normal background radiation count rate for each point. In each section, a sample of three measurements was taken and the mean value calculated for that section. An average was found for the 15 points in that quarry to give one final average reading of the radiations for that quarry in mR/hr. which was converted to mSv/yr.

2.13.2. *Management and analysis of data*

The radiation readings were recorded on a worksheet in mR/hr. Average radiation readings were calculated for every sampled quarry then converted to mSv/yr using the equation below by UNSCEAR [24] based on the fact that quarry workers work for 8h per day for 6 days a week as required by the labor laws and an indoor occupancy factor of 0.8 is recommended:

$$R2 = M \times 2504 \times 1.7 \times 0.8 \times 0.01$$

R2 is the annual equivalent dose rate in mSv/y.
M radiation readings recorded in mR/hr.
2504 is the annual conversion factor in hrs. Per year.
0.8 is the indoor occupancy factor
0.01 is the conversion of mR to mSv.
1.7 is the calibration factor.

Collected data was transferred into the Microsoft Excel spreadsheet for analysis. The data was then exported to Minitab software version 18.0. In this software, the data was then put through the basic descriptive statistics and demonstrated as Means $\pm$ SEM. Inferential statistics were as well done using one-way ANOVA in the testing of the statistical significance of radiation means in selected quarries at 95% level of confidence. Tukey's Post Hoc test was used to determine the variance between radiation means from different quarries within Nyamira County. It was further computed based on the recommended WHO annual dose reference of 1mSv. If the P-value was less than or equal to 0.05, then the statistical differences were of significance. ArcGIS Software Version 10.3 was used to analyze distribution of spatial data and presented it visually in maps. The results were also presented in tables.

3. Results

3.1. *Profiles for annual exposure to ionizing radiations in quarries in Nyamira County*

3.1.1. *Profiles for annual exposure to ionizing radiations in quarries in Nyamira North sub-county*

The results indicated that the annual exposure to ionizing radiations in quarries within Nyamira North Sub-County were above the WHO recommended annual levels of exposure (1Msv/Yr). As revealed, there was no significant difference in quarry radiation readings among quarries Q-052 to Q-056 ($p > 0.05$; Table 1). The results exhibited that the percentage deviations from WHO standard in quarries within Nyamira North Sub-County were statistically similar ($p > 0.05$; Table 1).

3.1.2. *Annual radiation-profiles for Quarries in Manga Sub-County*

It was revealed that the radiation readings of all sampled quarries in Manga Sub-County with an exception of quarry Q-072 were below WHO

Table 1. Profiles for annual exposure to ionizing radiations in quarries in Nyamira North Sub-County.

Quarries	Quarry Readings (MSV/YR)	Percentage Deviation From WHO Recommended Standard (1mSv/Yr) in %	Global-Positioning System(GPS) Co-ordinates
Q-052	2.74 ± 0.186[a]	174.0 ± 18.56[a]	S00°33.136; E034°58.218
Q-053	2.27 ± 0.162[a]	126.7 ± 16.15[a]	S00°32.266; E034°58.909
Q-054	2.40 ± 0.369[a]	140.2 ± 36.90[a]	S00°32.062; E034°59.043
Q-055	2.35 ± 0.140[a]	134.9 ± 13.97[a]	S00°31.918; E034°59.118
Q-056	2.33 ± 0.434[a]	132.6 ± 43.40[a]	S00°32.385; E034°58.875

The readings are indicated as Mean ± SEM for 15 readings per quarry. The figures followed by the same superscript are statistically similar ($p \leq 0.05$; one-way ANOVA then Tukey's post hoc test).

recommended ionizing radiations' annual exposure levels (1Msv/Yr). It was also shown that there was statistical similarity in ionizing radiation readings among the sampled quarries within Manga Sub-County ($p > 0.05$). However, quarry Q-072 showed a significant difference in radiation reading when compared to the other quarries ($p < 0.05$) and also showed the highest radiation reading than all other quarries' radiations (1.01 Msv/yr). The results also showed a negative percentage deviation from the WHO standard in the other quarries apart from quarry Q-072 which indicated a positive percentage deviation of 1.16 from WHO-recommended annual exposure dose (see Table 2).

3.1.3. Annual radiation-profiles for Quarries in Masaba North Sub-County

The results indicate that all the sampled quarries had radiation levels above the WHO recommended threshold (1mSv/Yr), with the lowest level of reading being in Q-083 (2.55 Msv/Yr) (Table 3). However, Q-079 recorded the highest radiation reading of 3.46 Msv/Yr among the sampled quarries. Additionally, Q-079 to Q-081 were not differently significant from each other ($p > 0.05$). It was shown that quarries Q-082 and Q-083 were as well not significantly different in their radiations but they showed a significant difference from Q-079, Q-080, and Q-081 ($p < 0.05$). The percentage deviation shown by Q-079 revealed to be the highest as compared to the rest, while Q-083 recorded the lowest percentage deviations from the WHO standard of 154.6. There was indication of statistical similarity in percentage deviations in Q-079 to Q-081 ($p > 0.05$). Similarly, there was statistical similarity in percentage deviations in quarries Q-082 and Q-083 ($p > 0.05$).

3.1.4. Annual radiation-profiles for Quarries in Borabu Sub-County

The results indicated that the radiation readings ranging from quarry Q-067 to quarry Q-071 were statistically similar ($p > 0.05$). Moreover, the radiation readings recorded were below the WHO recommended annual exposure standard of 1mSv.Similarly, there was a negative change in their percentage deviations and they were statistically similar as P-value was >0.05 (Table 4). Similarly, quarry Q-012, Q-013, and Q-015 were statistically similar in their radiation readings and percentage deviations ($p > 0.05$). It was also shown that radiation reading and percentage deviation of Q-025 were significantly different from the rest of the sampled quarries ($p < 0.05$) and its readings were above the WHO recommended threshold. However, their radiation readings were above the WHO recommended threshold (1Msv/Yr) and their percentage deviations were statistically similar as P-value was >0.05. It was also demonstrated that the radiations of sampled quarries ranging from Q-060 to Q-064 were statistically similar as P-value was >0.05. Besides, the same group of quarries recorded the highest radiation readings that were above the WHO recommended standard (1 Msv/yr) as compared to the other quarries ($p < 0.05$). The percentage deviations of Q-060 to Q-064 were statistically similar relative to the rest of the quarries within Borabu Sub-County ($p > 0.05$; 4).

3.1.5. Annual radiation-profiles for Quarries in Nyamira South Sub-County

The study showed that the annual exposure to ionizing radiations in all sampled quarries in Nyamira South Sub-County were above the WHO recommended threshold of 1 Msv/Yr. Quarry Q-037 recorded the highest radiation reading of 2.93 Msv/Yr and was significantly different from the rest of the quarries ($p < 0.05$). Similarly, it was found that quarry Q-037 had the highest percentage deviation from the WHO recommended standard (193.5) when compared to other sampled quarries within Nyamira South Sub-County. It was also shown that Q-027, Q-034 and Q-046 were statistically similar as P-value was >0.05 but were significantly different from the rest of the sampled quarries in Nyamira South Sub-County ($p < 0.05$). Similarly, the percentage deviations of Q-027, Q-034 and Q-046 were statistically similar as P-value was >0.05 although their percentage deviations were significantly different from the rest of the quarries sampled in Nyamira South Sub-County ($p < 0.05$). However, the other sampled quarries apart from Q-027, Q-034, and Q-046, were similar but were significantly different from the rest of the quarries ($p < 0.05$). Similarly, their percentage deviations were statistically similar as P-value was >0.05 (Table 5).

3.1.6. Annual radiation-profiles for Quarries among all sub-counties within Nyamira County

The readings of the annual radiation profiles in Manga sub-county were below the recommended annual radiation exposure dose by WHO while Nyamira North, Masaba North, Borabu and Nyamira South Sub-

Table 2. Profiles for annual exposure to ionizing radiations in quarries in Manga Sub-County.

Quarries	Quarry Readings (MSV/YR)	Percentage Deviation From WHO Recommended Standard (1mSv/yr) in %	Global-Positioning System (GPS) Co-ordinates
Q-072	1.01 ± 0.076[a]	1.16 ± 7.58[a]	S00°36.044;E034°50.350
Q-073	0.64 ± 0.106[b]	-35.71 ± 10.55[b]	S00°36.064;E034°50.377
Q-074	0.67 ± 0.076[b]	-33.38 ± 7.56[b]	S00°35.956;E034°49.887
Q-075	0.64 ± 0.196[b]	-36.29 ± 19.64[b]	S00°35.931;E034°49.903
Q-076	0.78 ± 0.130[ab]	-21.70 ± 12.98[ab]	S00°35.928;E034°49.915

The readings are indicated as Mean ± SEM for 15 readings per quarry. The figures followed by the same superscript are statistically similar ($p \leq 0.05$; one-way ANOVA then Tukey's post hoc test).

Table 3. Profiles for annual exposure to ionizing radiations in quarries in Masaba North Sub-County.

Quarries	Quarry Readings (MSV/YR)	Percentage Deviation From WHO Recommended Standard (1mSv/Yr) in (%)	Global-Positioning System(GPS) Co-ordinates
Q-079	3.46 ± 0.360[a]	245.7 ± 36.00[a]	S00°39.503; E034°51.527
Q-080	3.18 ± 0.263[ab]	218.0 ± 26.30[ab]	S00°39.506; E034°51.515
Q-081	3.06 ± 0.132[abc]	206.3 ± 13.19[abc]	S00°39.495; E034°51.520
Q-082	2.77 ± 0.413[bc]	177.4 ± 41.30[bc]	S00°39.456; E034°51.661
Q-083	2.55 ± 0.149[c]	154.6 ± 14.86[c]	S00°39.521; E034°51.484

The readings are indicated as Mean ± SEM for 15 readings per quarry. The figures followed by the same superscript are statistically similar ($p \leq 0.05$; one-way ANOVA then Tukey's post hoc test).

Table 4. Profiles for annual exposure to ionizing radiations in quarries in Borabu Sub-County.

Quarries	Quarry Readings (MSV/YR)	Percentage Deviation From WHO Recommended Standard (1mSv/yr) in %	Global-Positioning System(GPS) Co-ordinates
Q-067	0.81 ± 0.448[d]	-19.5 ± 44.80[d]	S00°48.812; E035°02.805
Q-068	0.94 ± 0.156[d]	-6.49 ± 15.61[d]	S00°48.716; E035°02.921
Q-069	0.82 ± 0.137[d]	-18.19 ± 13.70[d]	S00°47.762; E035°02.854
Q-070	0.92 ± 0.138[d]	-7.66 ± 13.81[d]	S00°47.636; E035°02.843
Q-071	0.71 ± 0.147[d]	-28.71 ± 14.71[d]	S00°48.635; E035°02.923
Q-012	1.72 ± 0.202[b]	71.81 ± 20.18[b]	S00°48.606; E035°02.916
Q-013	1.63 ± 0.314[b]	62.5 ± 31.40[b]	S00°48.652; E035°02.930
Q-015	1.56 ± 0.328[bc]	55.5 ± 32.80[bc]	S00°47.812; E035°02.887
Q-025	1.02 ± 0.284[cd]	1.7 ± 28.40[cd]	S00°47.778; E035°02.861
Q-060	2.60 ± 0.360[a]	159.5 ± 36.00[a]	S00°49.379; E035°01.241
Q-061	2.62 ± 0.218[a]	162.28 ± 21.80[a]	S00°50.020; E035°01.635
Q-062	2.78 ± 0.132[a]	177.53 ± 13.22[a]	S00°44.920; E034°53.806
Q-063	2.42 ± 0.190[a]	142.47 ± 19.96[a]	S00°46.021; E035°01.160
Q-064	2.67 ± 0.245[a]	166.5 ± 24.50[a]	S00°45.638; E034°54.846

The readings are indicated as Mean ± SEM for 15 readings per quarry. The figures followed by the same superscript are statistically similar ($p \leq 0.05$; one-way ANOVA then Tukey's post hoc test).

Table 5. Profiles for annual exposure to ionizing radiations in quarries in Nyamira South Sub-County.

Quarries	Quarry Readings (MSV/YR)	Percentage Deviation From WHO Recommended Standard (1mSv/yr) in %	Global-Positioning System(GPS) Co-ordinates
Q-004	2.55 ± 0.417[ab]	155.4 ± 41.70[ab]	S00°31.768; E034°54.930
Q-007	2.64 ± 0.207[ab]	163.5 ± 20.68[ab]	S00°31.790; E034°54.940
Q-009	2.47 ± 0.216[ab]	146.9 ± 21.58[ab]	S00°31.779; E034°54.958
Q-027	2.26 ± 0.210[b]	125.6 ± 20.99[b]	S00°31.529; E034°53.983
Q-030	2.47 ± 0.173[ab]	146.7 ± 17.30[ab]	S00°31.600; E034°53.994
Q-037	2.93 ± 0.065[a]	154.8 ± 87.7[a]	S00°31.637; E034°54.028
Q-018	2.65 ± 0.279[ab]	165.4 ± 27.90[ab]	S00°31.873; E034°54.489
Q-049	2.55 ± 0.362[ab]	155.3 ± 36.20[ab]	S00°31.584; E034°55.211
Q-034	2.28 ± 0.438[b]	127.9 ± 43.80[b]	S00°31.564; E034°55.196
Q-035	2.35 ± 0.259[ab]	134.9 ± 25.90[ab]	S00°31.511; E034°55.125
Q-046	2.29 ± 0.371[b]	129.1 ± 37.10[b]	S00°31.613; E034°55.109

The readings are indicated as Mean ± SEM for 15 readings per quarry. The figures followed by the same superscript are statistically similar ($p \leq 0.05$; one-way ANOVA then Tukey's post hoc test).

Counties recorded radiation annual exposure doses above the WHO standard of 1 Msv/Yr (Table 6). It was also shown that Nyamira North and Nyamira South Sub-Counties radiation readings were statistically similar ($p > 0.05$) but were of significant difference when compared to the other sub-counties ($p < 0.05$, Table 6). Percentage deviations of quarries within Nyamira North and Nyamira South Sub-Counties were significantly different from those of other sub-counties within Nyamira County ($p < 0.05$). Masaba North Sub-county recorded the highest radiation reading of 3.37Msv/Yr compared to other sub-counties ($p < 0.05$). Moreover, Masaba North Sub-County recorded the highest percentage deviation of 200.40 from the WHO recommended standard (Table 6). It was also indicated that Manga Sub-County recorded the lowest annual radiation reading and showed a negative percentage deviation of -25.18 as compared to other sub-counties ($p < 0.05$; Table 6).

Table 6. Profiles for annual exposure to ionizing radiations in quarries in Sub-counties within Nyamira County.

Sub-Counties	Quarry Readings (MSV/YR)	Percentage Deviation From WHO Recommended Standard (1mSv/yr) in %
Nyamira North Sub-County	2.42 ± 0.311^{b}	141.70 ± 31.07^{b}
Manga Sub-County	0.75 ± 0.184^{d}	-25.18 ± 18.44^{d}
Masaba North Sub-County	3.00 ± 0.416^{a}	200.40 ± 48.99^{a}
Borabu Sub-County	1.66 ± 0.816^{c}	65.65 ± 69.68^{c}
Nyamira South Sub-County	2.55 ± 0.270^{b}	145.96 ± 25.02^{b}

The readings are indicated as Mean ± SEM for 15 readings per quarry. The figures followed by the same superscript are statistically similar ($p \leq 0.05$; one-way ANOVA then Tukey's post hoc test).

3.2. Determining the association between geographical positions and levels of ionizing radiations in quarries within Nyamira County

As presented in Table 7, the results indicated that levels of ionizing radiations from various sampled quarries with different geographical positions were evenly distributed across the deviation clusters. It was shown that the quarries with different geographical positions had similar or closely related levels of ionizing radiation emissions which were high or low leading to them falling into similar deviation clusters. Hence a quarry at a higher altitude is not guaranteed to emit higher levels of ionizing radiations and vice versa. For instance, 9 quarries out of the 40 sampled quarries (22.50%) had different geographical positions but had ionizing radiation readings below the WHO recommended threshold of 1 mSv making them fall into a deviation cluster of ≤1% (See Tables 2, 4 and 7; Figures 2, 3, and 4). Further, 2 quarries that correspond to 5.0% were in the deviation cluster of 1–50 % (Table 7; Figures 4 and 5). Moreover, 7.50 % (3 quarries) of the sampled quarries in Nyamira County were in the deviation clusters of 51%–100% (Table 7; Figure 5). Of the sampled quarries, 11 quarries (27.50%) were in the radiation cluster of 101–150% (Table 7; Figures 6, 7, and 8). The highest number of the sampled quarries (12 quarries) which corresponded to 30.0% were in the ionizing radiation deviation cluster of 151–200% (Table 7; Figures 4, 6, and 9). The deviation cluster of 201–250% consisted of only 3 quarries (7.50%). The results thus showed that the levels of ionizing radiations emitted were not associated with the geographical positions of sampled quarries since quarries from different geographical positions could fall into similar or different deviation clusters since they had similar or different levels of radiation readings.

Table 7. Percentage deviation clusters from the recommended WHO standard of annual exposures to ionizing radiation in quarries in Nyamira County.

Deviation cluster (%)	Number of quarries	Proportion in percentage (%) of total number of quarries in various clusters.
≤1	9	22.50
1–50	2	5.00
51–100	3	7.50
101–150	11	27.5
151–200	12	30.00
201–250	3	7.50
TOTAL	40	

3.2.1. Percentage deviation clusters of annual exposure to ionizing radiations in quarries in Nyamira County

Moreover, as shown in Table 8, the levels of ionizing radiations emitted from the sampled quarries as arranged in the descending order to their geographical positions are not directly proportional. For instance, quarry Q-079 with radiation reading of 3.46 mSv/yr has an altitude of 1993M, followed by Quarry Q-080 with radiation reading of 3.18mSv/yr with 1999M. Besides, quarries Q-075 and Q-073 with the lowest radiation readings of 0.64mSv/yr had altitudes of 1789M and 1877M respectively which reveals that the levels of ionizing radiations from quarries are not associated with the quarries' geographical positions.

4. Discussion

Most often, natural background radiation exposure to the public is inevitable. Based on the ACGIH 1996 and ICRP, 2007, it was reported that quarry workers are considered as general public who are exposed to natural background radiation while personnel are mainly exposed to artificial sources during medical radiological procedures and in industries. In the earth, some areas have high levels of natural background radiation like France with 3.5mSv/yr among others. However, the American Conference of Governmental Industrial hygienists set levels of 1mSv/yr above which could elicit undesirable biological effects. Moreover, occupational exposure limits of 20mSv/yr adopted by many jurisdictions as guidelines for effective dose per year for radiation workers with planned exposures averaged over 5yrs hence it is very important to put forth mechanisms to reduce ionizing radiation exposure levels [2, 3, 4]. The estimates of risks produced by various National and International Scientific Committees suggest that normal levels of natural background radiation (1mSv/yr) are potentially responsible for about 0.5% of the total cancers and genetic diseases in general population [5] Moreover, the occupational exposure limits for radiation workers subjected to ionizing radiation's artificial origin like medical radiography and in nuclear plants is 20mSv/yr averaged over 5yrs [4]. For any health hazard, exposure levels should be limited as much as possible as any dose above zero there is higher risk of eliciting the effects.

The results of this study indicated that radiations were significantly different, for instance, the lowest dose of annual ionizing radiation exposure levels in Nyamira County was recorded in quarries Q-073 (0.64mSv) and Q-075 (0.64mSv) in Manga Sub-County. Moreover, the highest ionizing radiation levels were recorded in quarry Q-079 in Masaba North Sub-County with a reading of 3.46mSv. This may be attributed to the difference in concentrations of naturally occurring radionuclides among the various quarries.

This research's findings concur with several radiological studies. For instance, according to a study by Onwuka [25], elevated levels of natural background radiations were reported in a quarry within Ebonyi State in Nigeria. A study by Ononugbo [26] states that, "The equivalent dose had an annual average range of 1.056 mSv–2.871 mSv, which is much lower than the International Commission on Radiological Protection recommended 20 mSv dose limit for radiological workers, but above the permissible level of 1 mSv/yr recommended for the general public" [27, 28].

Past research findings show that natural radio-active materials get confined in the earth's crust through the process of rock breakdown. These studies reveal that the radioactive particles may reveal a variation in the radiation level in the surroundings depending on geographical and local geological factors of the concerned study area [29, 30]. The rise in degree of ionizing radiation may be ascribed to the quarrying activities which can raise the natural background radiation levels by letting out a buried materials containing naturally occurring radioactive materials onto the surface of the environment [25, 26, 27, 28, 29, 30, 31, 32, 33, 34]. However, most of the quarry sites selected for this study had their annual radiation exposure above the normal acceptable annual limits of 1 mSv for the general public set up by the International Commission for Radiological Protection (ICRP)and World Health Organization (WHO),

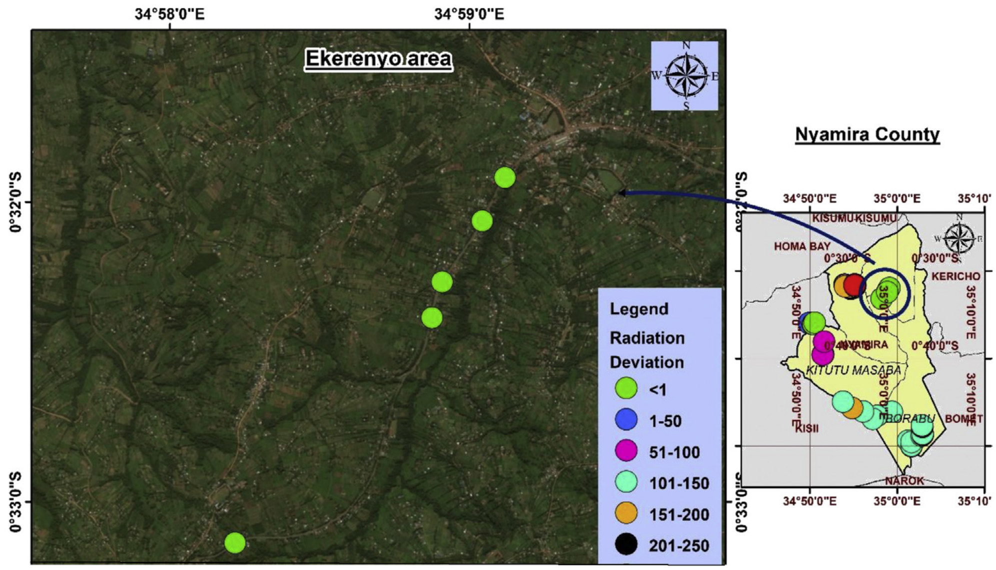

Figure 2. Clusters of radiation deviations from WHO approved exposure levels of ionizing radiation (1mSv/yr) in Nyamira North Sub-County quarries.

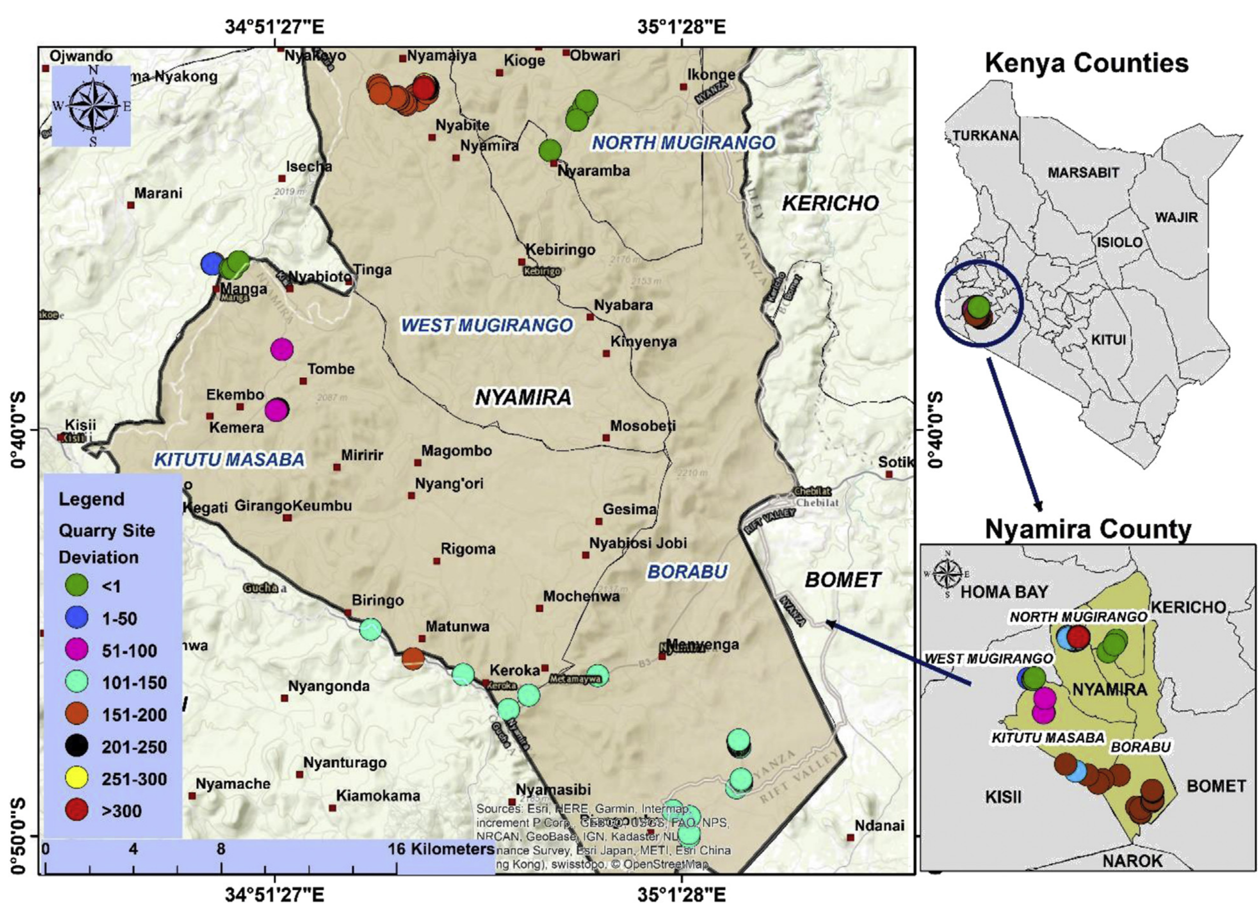

Figure 3. Clusters of radiation deviations from WHO approved exposure levels of ionizing radiation (1mSv/yr) in Manga Sub-County within Nyamira County.

while very few of the quarries had their exposure levels below the standard. Only nine quarries out of the 40 selected quarries had exposure levels below the acceptable standards, representing a dismal 22.5% compliance.

The high radiation profiles recorded in several quarry sites in Nyamira County could be ascribed to the radionuclides that occur naturally on earth (uranium-238, potassium-40 and thorium-232) that could be exposed to the environment due to quarrying activities. These radionuclides decay and emit ionizing radiations hence the high radiation levels. Similarly, a survey was done in Ilorin Industrial Area in Nigeria and the levels of radiation levels was above the approved limit of 1 mSv/yr by 50% [25]. According to international recommendations, the public's annual exposure levels should not be higher than 1 mSv [27, 28].

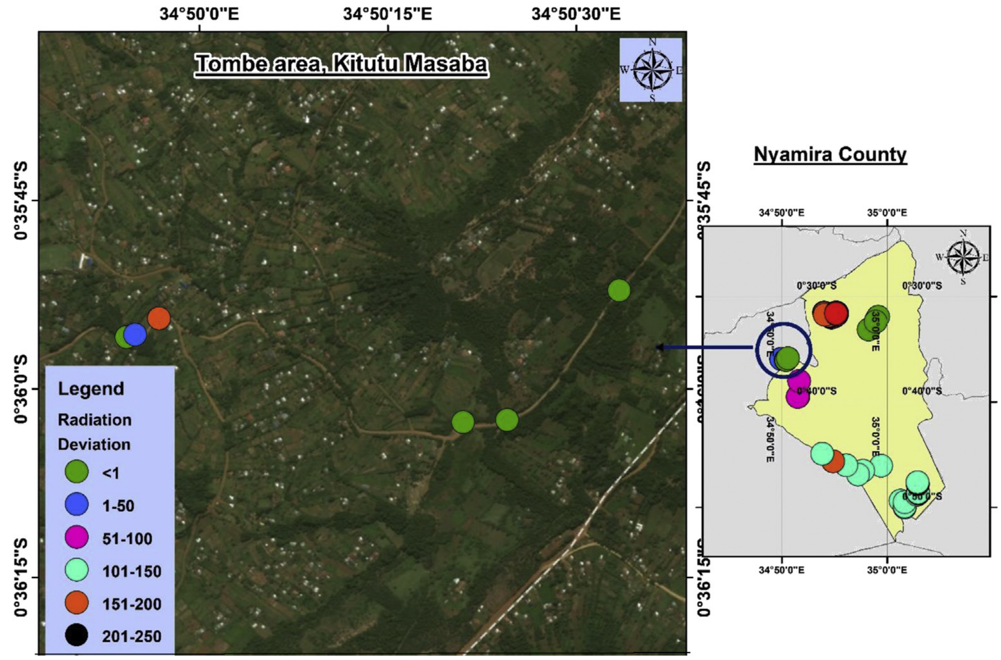

Figure 4. Clusters of radiation deviations from WHO approved exposure levels of ionizing radiation (1mSv/yr) in Masaba North Sub-County quarries.

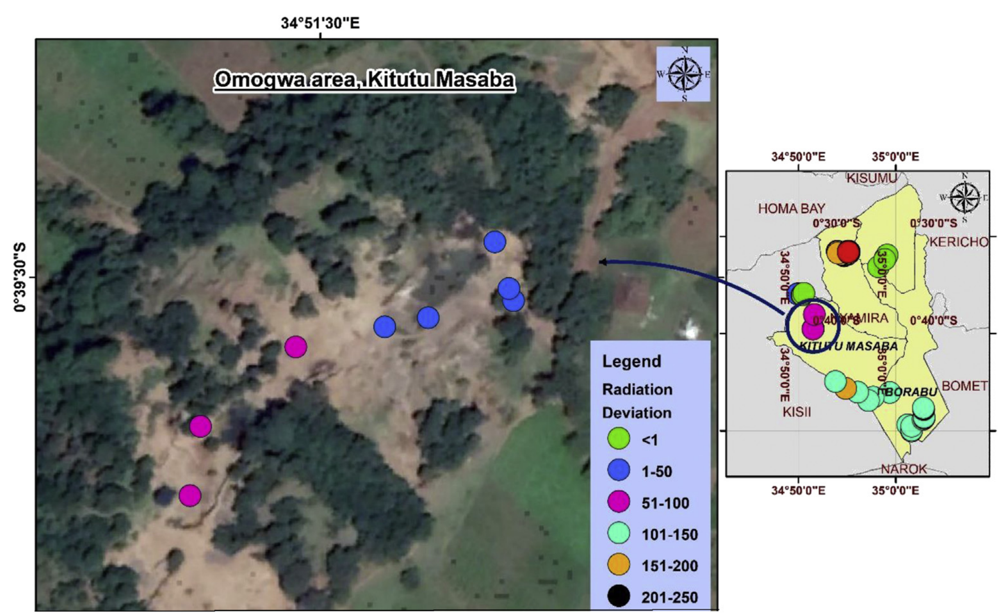

Figure 5. Clusters of radiation deviations from WHO approved exposure levels of ionizing radiation (1mSv/yr) in Masaba North Sub-County quarries.

Consequently, this study's results have shown that only 22.5% of the quarries had exposure rates below the recommended threshold. ICRP states that, "Dose limits are intended to serve as a boundary condition that will prevent deterministic effects and limit the probability of stochastic effects" [35, 36, 37, 38, 39, 40, 41, 42].

Therefore, the implication is that the quarry workers are exposed to elevated levels of ionizing radiation. The baseline risk of radiation disorders' occurrence in the quarry workers that were sampled could result from long term exposure to ionizing radiation. This may, in turn, signify some health problems to the people around the quarries. All forms of ionizing radiations constitute a danger to biological tissues depending on level of exposure. At 70 rem, it can lead to hair loss and vomiting. At 100 rem it can cause hemorrhage while doses between 400-2000 rem can constitute death. Data indicate that radiation disorder risks like cancers among miners are associated with exposure rate, and also is influenced by the presence of other carcinogens such as arsenic in the mine environment. Exposure to ionizing radiation tends to alter the way human bodies are composed and end up in illnesses enhanced by radiations like cancers in the long run [43].

The study revealed that radiation exposure levels were distributed across the deviation clusters. The majority of the sampled quarries' annual radiations fell in the deviation cluster of 151–200% which is above the recommended standard threshold. Moreover, nine quarries fell in the percentage deviation cluster of less than or equal to one and it was revealed that 4 were in Manga Sub-county while 5 were in Borabu Sub-county. These quarries had radiation

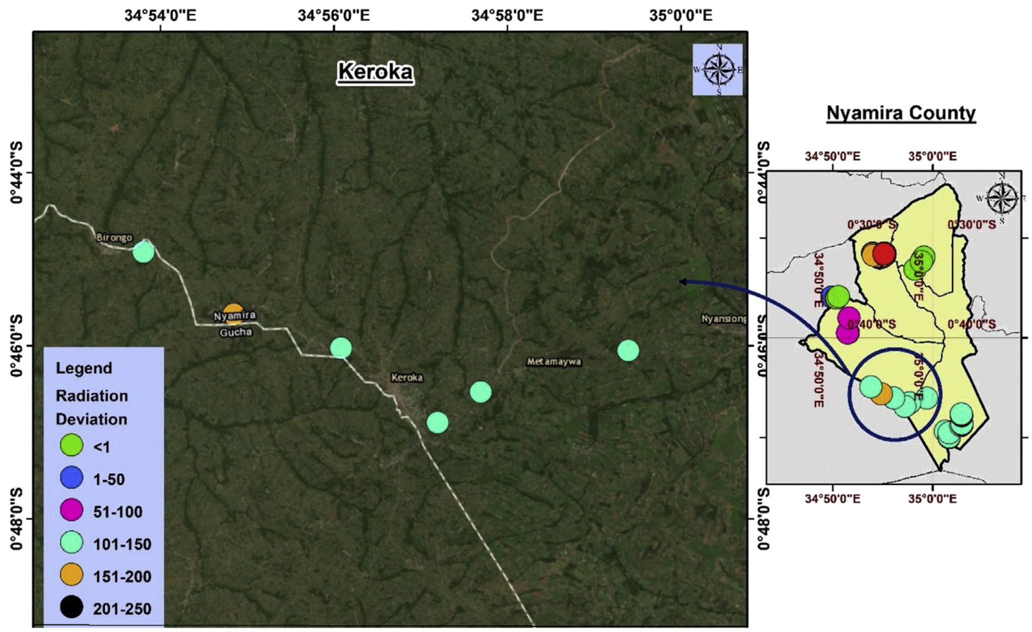

Figure 6. Clusters of radiation deviations from WHO approved exposure levels of ionizing radiation (1mSv/yr) in Borabu Sub-County quarries.

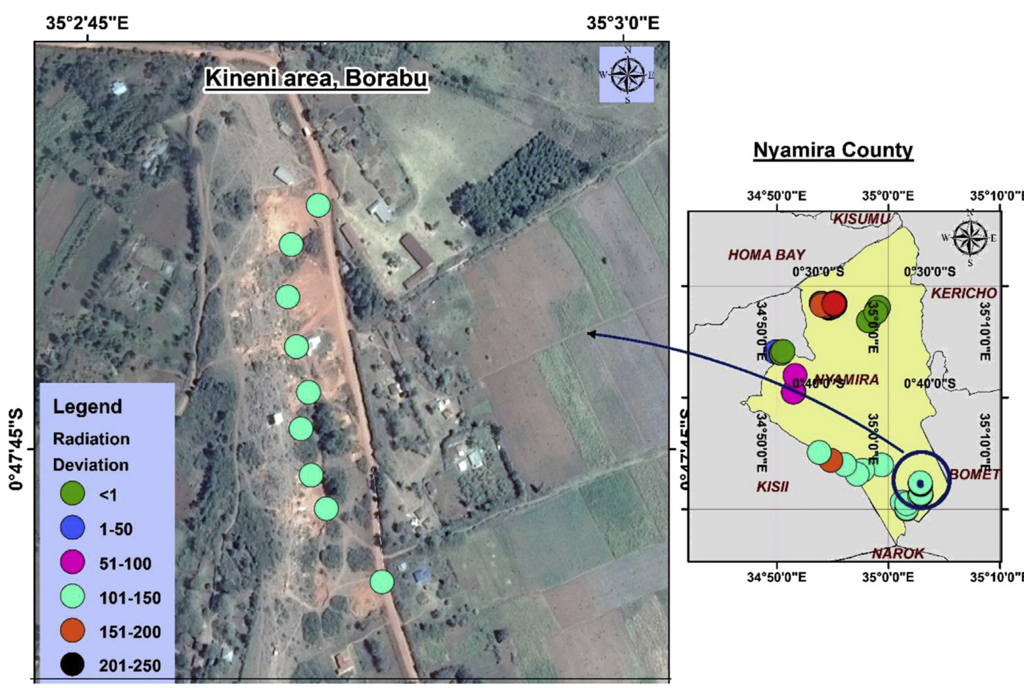

Figure 7. Clusters of radiation deviations from WHO approved exposure levels of ionizing radiation (1mSv/yr) in Borabu Sub-County quarries.

exposure levels below the acceptable annual limits of 1mSv for the public as per the International Commission for Radiological Protection. Additionally, the majority of the sampled quarries in Nyamira County had annual radiation exposure levels above the recommended standard and were evenly distributed throughout the county. Therefore, it was noted that the quarries could have different geographical positions but fell into a similar deviation cluster since the levels of ionizing radiations emitted could be low or high. Similarly, some quarries were at high altitudes but recorded low levels of ionizing radiations while others with low altitudes recorded high levels of ionizing radiations.

The study was in agreement with a radiometric assessment done by Ademila O [44]. in Ondo State, to evaluate the radiations and distribution of radionuclides associated within those areas. It showed that the concentrations varied from one location to another and that no association was noted between the levels emitted by the sampled quarries and their geographical positions. The significant difference in the radiation profiles between the sampled quarries may be attributed to the differences in concentration of the naturally occurring radionuclides per quarry. Radioactivity in the environment and other related external disclosures from ionizing radiations depend on the geological and geographical conditions which are presented in various

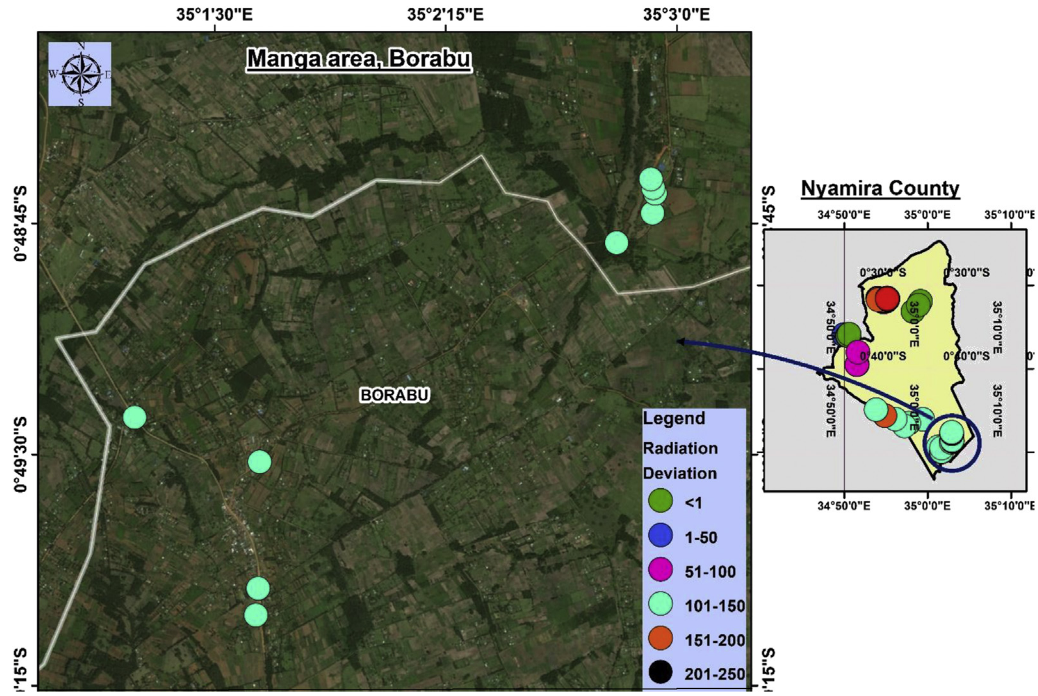

Figure 8. Clusters of radiation deviations from WHO approved exposure levels of ionizing radiation (1mSv/yr) in Borabu Sub-County quarries.

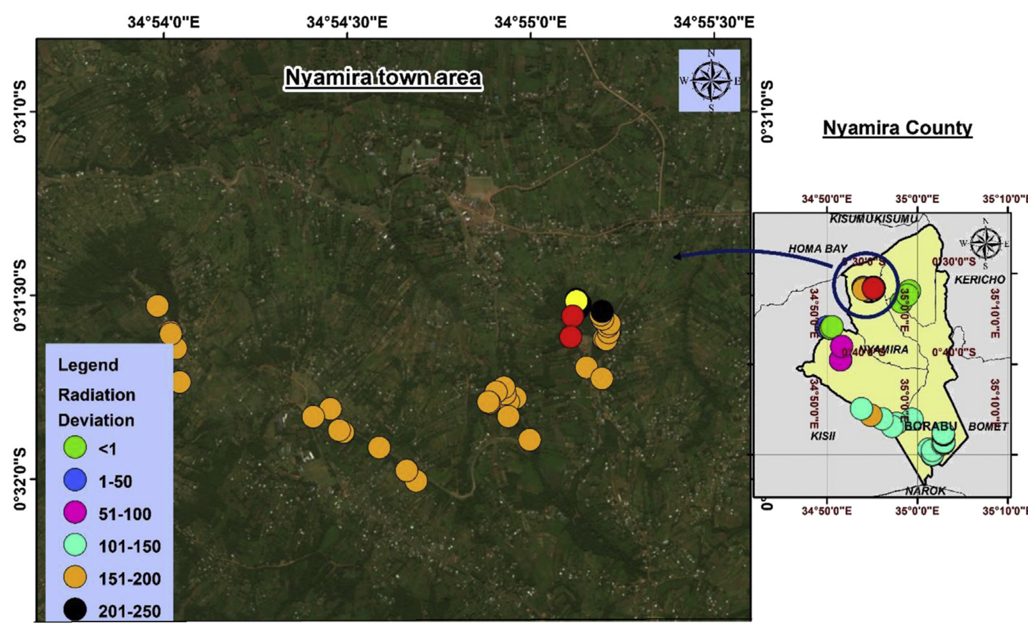

Figure 9. Clusters of radiation deviations from WHO approved exposure levels of ionizing radiation (1mSv/yr) in Nyamira South Sub-County quarries.

levels in the soils for every individual zone in the world [45, 46]. As observed from the study, Q-073 and Q-075 quarries both had the lowest annual radiation readings of 0.64mSv which was similar despite their difference in geographical positions. This similarity in annual radiation emissions by these quarries could be due to similarities in their geological conditions.

This means that the quarry workers and even the public within and around the various sampled quarries in different geographical positions are subjected to raised radiation levels. This might result in health effects following long term exposure [47, 48, 49, 50].

5. Conclusion

Only 22.5% of selected quarries had their annual ionizing radiation below the recommended threshold. Therefore, most of quarries release radiation in elevated levels. Continuous exposure to the low levels of ionizing radiations may lack instant effects but after a long time of exposure to the doses, they can become hazardous. Therefore, it's commended that regular evaluation of ionizing radiation levels be done within quarries for assessment of the health hazard to the quarry workers and even community at

Table 8. Geographical positions for the radio-profiled quarries in Nyamira County.

Quarries	Quarry Readings (MSV/YR)	Global-Positioning System (GPS) Co-ordinates	G.P.S. Quarries' Altitudes in Meters (M)
Q 079	3.46 ± 0.360[a]	S00°39.503; E034°51.527	1993
Q 080	3.18 ± 0.263[ab]	S00°39.506; E034°51.515	1999
Q 081	3.06 ± 0.132[abc]	S00°39.495; E034°51.520	1996
Q 037	2.93 ± 0.065[a]	S00°31.637; E034°54.028	1956
Q 062	2.78 ± 0.132[a]	S00°44.920; E034°53.806	2030
Q 082	2.77 ± 0.413[bc]	S00°39.456; E034°51.661	1994
Q-052	2.74 ± 0.186[a]	S00°33.136; E034°58.218	1986
Q 064	2.67 ± 0.245[a]	S00°45.638; E034°54.846	2054
Q 018	2.65 ± 0.279[ab]	S00°31.873; E034°54.489	1932
Q 007	2.64 ± 0.207[ab]	S00°31.790; E034°54.940	1864
Q 061	2.62 ± 0.218[a]	S00°50.020; E035°01.635	2087
Q 060	2.60 ± 0.360[a]	S00°49.379; E035°01.241	1898
Q 004	2.55 ± 0.417[ab]	S00°31.768; E034°54.930	1875
Q 049	2.55 ± 0.362[ab]	S00°31.584; E034°55.211	1971
Q-083	2.55 ± 0.149[c]	S00°39.521; E034°51.484	1995
Q 009	2.47 ± 0.216[ab]	S00°31.779; E034°54.958	1856
Q 030	2.47 ± 0.173[ab]	S00°31.600; E034°53.994	1922
Q 063	2.42 ± 0.190[a]	S00°46.021; E035°01.160	2019
Q-054	2.40 ± 0.369[a]	S00°32.062; E034°59.043	1859
Q 035	2.35 ± 0.259[ab]	S00°31.511; E034°55.125	1942
Q-055	2.35 ± 0.140[a]	S00°31.918; E034°59.118	1845
Q-056	2.33 ± 0.434[a]	S00°32.385; E034°58.875	1897
Q 046	2.29 ± 0.371[b]	S00°31.613; E034°55.109	1967
Q 034	2.28 ± 0.438[b]	S00°31.564; E034°55.196	1943
Q-053	2.27 ± 0.162[a]	S00°32.266; E034°58.909	1894
Q 027	2.26 ± 0.210[b]	S00°31.529; E034°53.983	1917
Q 012	1.72 ± 0.202[b]	S00°48.606; E035°02.916	1857
Q 013	1.63 ± 0.314[b]	S00°48.652; E035°02.930	1862
Q 015	1.56 ± 0.328[bc]	S00°47.812; E035°02.887	1860
Q 025	1.02 ± 0.284[cd]	S00°47.778; E035°02.861	1842
Q 072	1.01 ± 0.076[a]	S00°36.044; E034°50.350	1872
Q 068	0.94 ± 0.156[d]	S00°48.716; E035°02.921	1816
Q 070	0.92 ± 0.138[d]	S00°47.636; E035°02.843	1852
Q 069	0.82 ± 0.137[d]	S00°47.762; E035°02.854	1848
Q 067	0.81 ± 0.448[d]	S00°48.812; E035°02.805	2000
Q 076	0.78 ± 0.130[ab]	S00°35.928; E034°49.915	1793
Q 071	0.71 ± 0.147[d]	S00°48.635; E035°02.923	1859
Q 074	0.67 ± 0.076[b]	S00°35.956; E034°49.887	1902
Q 075	0.64 ± 0.196[b]	S00°35.931; E034°49.903	1789
Q 073	0.64 ± 0.106[b]	S00°36.064; E034°50.377	1877

The readings are indicated as Mean ± SEM for 15 readings per quarry. The figures followed by the same superscript are statistically similar ($p \leq 0.05$; one-way ANOVA then Tukey's post hoc test).

large and make sure that quarries of potential risks are spotted early enough and safety strategies put in place. Moreover, concerned stakeholders should create public awareness on the background ionizing radiations, their risks and mitigation measures. Therefore, the study findings can be pre-owned during the formation of the national building policy to carry out survey for levels of radiation of building materials.

Declarations

Author contribution statement

Kerubo Makori Ruth: Performed the study; Wrote the paper.

Peterson Njogu Warutere, Jackim Nyamari: Conceived and designed the study; Wrote the paper.

Wycliffe Arika: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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