Analysis of Radon levels in Water from selected Boreholes and Shallow Wells in Mutomo Area, Kitui County-Kenya.

A.K Mutambu*[1], J. M. Linturi[1], J.M. Kebwaro[2], S.M. Matsitsi[1]

[1]*Department of Physical Sciences, South Eastern Kenya University, P.O BOX 170-90200 Kitui, Kenya*
[2]*School of Pure and Applied sciences, Karatina University, P.O BOX 1957-10101 Karatina, Kenya*
**Corresponding Author*

***Abstract*: This paper presents In-situ analyses of radon levels in water from Mutomo area located in the southeastern part of Kenya. The region is semi-arid and most resdents depend on water from boreholes and shallow wells for their domestic use. RAD 7 alpha detector was deployed in the In-situ measurements and geographical position of each water source sampled was determined and noted during the radon measurements. An average of 30 ± 1.5 Bq l^{-1} was determined from the measurements. This value is slightly higher than the maximum contamination levelof 11.1 Bq l^{-1} prescribed by USEPA but within the UNSCEAR recommended range of 4 – 40 Bq l^{-1}. Ngosini Springs reported the highest radon activity of 120 ± 6 Bq l^{-1} while Munyoki, Katuuni and Musila shallow wells had no detectable radon activity. Annual effective doses from water averaged 6.0 ± 0.03 µSv y^{-1} for radiation doses taken through ingestion which is well below the limits of 0.1 mSv y^{-1} for doses taken via ingestion. The correlational analyses between ^{222}Rn in water and ^{226}Ra in sediments sampled from the proximity of water sources reveal a weak positive correlation suggesting radium mineral has an insignificant influence on the radon level in the water. Based on the findings, water from the sampled wells and boreholes is safe for drinking without remediation measures.**

***Keywords*: Radon gas, RAD 7 detector, Mutomo area, Groundwater, Exposure.**

I. INTRODUCTION

Radon a tasteless, odourless, colourless gas that is chemically inert and radioactive is considered one of the major contributors to human exposure to ionizing radiation in the terrestrial environment. The gas has a half-life of 3.86 days and is normally present in various natural sources such as; air, water and sediments of geological origin. [1, 2]

Radon decays contribute to over 42 % of the total radiation dose from various sources [3]. Radon gas enters the human biological systems through various pathways where it may decay with the emission of alpha particles that damage the body. Studies on radon levels in water and associated radiation doses have reported a wide range of data from below detection limits to elevated levels where remediation measures have been recommended [4].

The United States Environmental Protection Agency recommends a maximum radon activity of 11.1 Bq L^{-1} (11 kBq M^{-3}) beyond which remediation measures such as boiling the water to degas it are recommended [5]. UNSCEAR, 2008 recommends radon concentrations ranging 4 - 40 Bq L^{-1} for water to be considered safe in the context of radiation. The recommended annual effective dose from radon activity via ingestion of water is 0.1 mSv y^{-1} [6, 7]. Radiation doses exceeding the recommended limit of 0.1 mSv y^{-1} via ingestion and 1 mSv y^{-1} via inhalation have been associated with increased cases of stomach and lung cancer respectively [8].

Radon in water used for domestic consumption contributes significantly to indoor air radiation doses, which might be taken via inhalation. Radon gas in the air enters the indoor dwelling via tapped water in bathrooms, kitchen or water reservoirs inside dwellings, building materials and cracks on the floor of the dwellings. Studies report that for every 1000 Bq L^{-1} in water, increases indoor air dose by 100 Bq L^{-1} [6]. The geological outline of a region influences the level of radon concentration in water and soils. The aquifers lying within granitic substratum or metamorphic rocks usually report enhanced levels of radon in water.

In this study, RAD 7 Alpha detector was used in the analysis of levels of radon in water from boreholes and shallow wells in the Mutomo area, Kitui County, located in south Eastern Kenya. The surveyed area is semi-arid and consists of a blend of geological materials. The relatively high population density of the area has exerted pressure on the limited water sources leading to over-reliance on the surface and sub-surface water systems whose radioactivity levels have not been documented. RAD-7 This detector was chosen for this study because of its portability, affordability and short turnaround time relative to other radon measurement techniques.

Geology of the Area

The area of study is about 696 m above sea level and extends from Latitude $1^0$45'0" S to$1^0$54'0" S and Longitude $38^0$18'0" E to $38^0$28" E. The terrain is relatively rocky its geology is placed into the Tertiary Yatta Plateau system, Archean rocks of the basement system and the superficial deposits of

Pleistocene [9]. Within the same region are large limestone deposits.

The larger population of the Mutomo area depends on the surface-underground water systems that include; wells, hand pump waters from shallow wells and tap waters from boreholes, which mostly do not undergo prior treatment before consumption by the larger population. Figure 1 shows the studied profile of the Mutomo area with the sampled water sources marked in red.

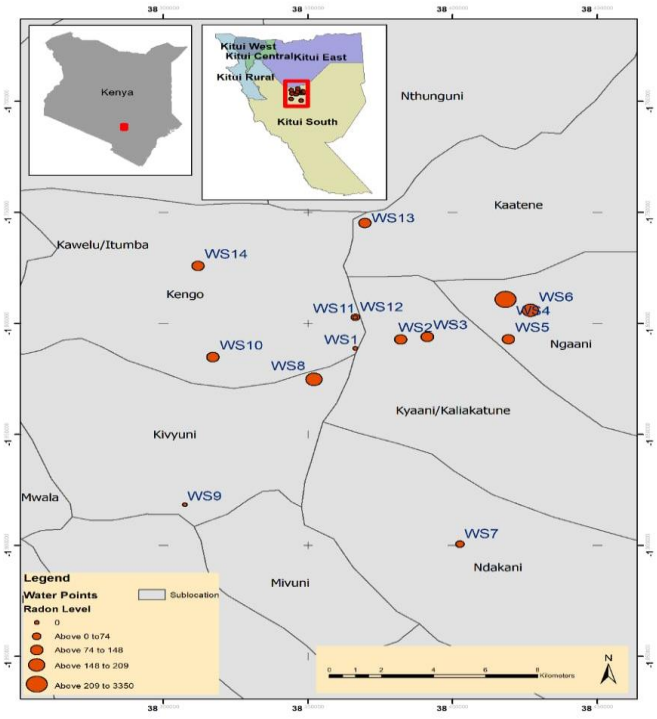

Figure 1: Sampling map of Mutomo Area in Kitui County, Kenya

II. MATERIALS AND METHODS

2.1 Water Sampling

The evaluation of radon levels in the water was done using water sampled from shallow wells, springs, hand pumps and boreholes. Fifteen (15) water samples were collected from dissimilar sampling water sources. Of the 15 water samples, 10 water samples were collected from shallow Wells, Hand pumps and water springs. The other 5 samples were collected from boreholes.

Before the water sample collection, the collection vials were first rinsed with water from the source to be sampled to increase the data quality. Gently, the 250 *ml* water vials were immersed into the bucket containing freshly collected water from the source and allowed to fill while completely under the surface of the water. The 5 water samples from the boreholes were collected by filling a 10 *l* bucket with water after allowing water from the faucet to drain for 5 minutes. The vials were filled through laminar water flow to minimize water disturbance which may enhance radon escape from the water. The samples were taken at least 10 minutes after the start of the water pump to ensure the water in pipes clears and the sampled water is right from the aquiver, which contains optimal radon content. For all water sources sampled, great care was taken not to disturb the water as poor sampling procedures are the major sources of errors in radon surveys. The bottles were capped while underwater to avoid radon desorbing. Each sample was thoroughly inspected to ensure it does not contain any air bubbles. The vials were given identity tags despite sample collection and counting being done onsite. Onsite measurements ensured a shorter delay time for optimal radon activity per sample.

2.2 Experimental Procedures

The activities of the eluted ^{222}Rn were done onsite using calibrated RAD 7 Alpha detector. RAD 7 is a solid-state detector that converts alpha radiation to an electrical signal for activity quantification using passivated implanted planar silicon as a semiconductor. The decay activities from ^{222}Rn were identified by the RAD H_2O accessory within the detector assembly. RAD 7 detector accurately distinguishes the alpha radiations with energies of 6.0 MeV and 7.9 MeV from ^{218}Po and ^{214}Po respectively.

For analyses of radon concentration in water samples, the radon detector was connected to a bubbling kit and powered. The inbuilt pump automatically ran for 5 minutes aerating the sample to an equilibrium state after which no more radon could be purged out of the water. The degassed radon from the water was circulated to the detection chamber. The system took a counting period of 5 minutes and the numerical data on radon activities along with the respective bar plots and entire cumulative spectra for each sample were printed out on the printer coupled to the detector. The counting procedure outlined was repeated for four, 5 min cycles to obtain consistent results. The minimum detactable activity was deterimined by running distilled water sample assumed to be radon free to get the background count.

2.3 Uncertainty analysis and Method Validation

To achieve reproducible and accurate data, all the factors which could compromise the quantitative aspect of data were well factored in as follows;

The water sampling was done following the procedures proposed by the RAD7 manufacturer (RAD7 RAD H2O). The manufacturer recommends the use of a 250 ml vial and Wat-250 protocol for radon concentrations less than 100 Bq l1 and a 40 ml vial and Wat-40 protocol for radon activity exceeding 100 Bq l1 was used.

The radon measurements were done in situ to minimize degassing of radon gas, which lowers radon concentration. In cases where the measurements were delayed by 1 hour, the radon level activities correction were made using equation 3.1

$$DCF = e^{-\lambda.T} \qquad 3.1$$

Where T is the time lapse between the sample's collection and counting while λ (0.00756 h^{-1} is the constant decay of 222_{Rn}

The RAD 7 alpha detector was calibrated regularly for efficiency to ensure it meet the manufacturer's protocols for optimal radon activity detection. To minimize radon gas dissolution which is temperature dependent, water samples were collected and analyzed early in the morning when the dissolved gases and air were optimal [10]

The radon minimum detectable activity (MDA) was evaluated using distilled water assumed to be radon free sample using the equation 3.2 [11]

$$MDA(Bq.l^{-1}) = \frac{LLD}{\varepsilon_\gamma . P_\gamma . t . V} \quad 3.2$$

Where ε_γ is the detector counting efficiency, P_γ is the decay transition probability,t is the time lapse between sample collection and counting, V is the sample volume and LLD is lower limit of detection which was evaluated using equation 3.3

$$LLD = 2.71 + 4.65\sqrt{B} \quad 3.3$$

Where B is the background count

III. RESULTS AND DISCUSSION

3.1 Radon Estimation in Drinking Water

The individual level of radon activity for water sources exceeding the maximum contamination level of 11.1 Bq l^{-1} was calculated using the analytical equation 4.1 and the results are presented in Table 1. The average and range of radon activity concentration in water samples from various water sources were evaluated and presented in Table 2 [12].

$$C = \frac{EMR}{V} \quad (4.1)$$

Where; C is the radon concentration (Bq/m^3), E is the emanation coefficient; M is the total mass of the sample (kg); R is the radium activity concentration (Bq/kg) and V is the effective volume of the sampling device (m^3).

Table 1: Water sources reporting radon levels above MCL suggested in USEPA reports

Sample Name	Temprature	Geo-Reference	Water source	Radon in Bq.l^{-1}
Munyoki B	30.2	38.37 S 1.80E	Well	11±0.5
Kwa Nzalu	29.1	38.40 S 1.79E	Well	14±0.7
Kyanga	28.8	38.36 S 1.79E	Hand Pump	17±0.8
Kawambemba	29.3	38.42 S 1.79E	Borehole	18±0.9
Muliluni	27.4	38.38 S 1.80E	Hand Pump	23±1.2
Kwithima	30.3	38.31 S 1.77E	Hand Pump	27±1.4
Kavuse	30.2	38.39 S 1.80E	Hand pump	28±1.4
Yimikoongoo	30.2	38.35 S 1.82E	Hand pump	32±1.6
Kasiluni	29.1	38.38 S 1.80E	Borehole	47±2.4
Makutano	29.3	38.36 S 1.75E	Borehole	52±2.6
Mutha town	30.4	38.42 S 1.80E	Borehole	54±2.7
Ngosini	27.3	38.41 S 1.79E	Spring	120±6.0

Generally, on average, water sampled from boreholes had higher radon activity as compared to water sampled from hand pumps and shallow wells. This is in agreement with other studies as most aquivers are hosted by rocks with high radium content [13]

Table 2: The range and mean activity concentration of Radon from water sources

Water Source	Range (Bq l-1)	Average (Bq.l^{-1})
Boreholes	(18 ± 0.9) – (52 ± 2.6)	(42.75 ± 2.1)
Hand Pumps	(17 ± 0.85) – 32 ± 1.6	(25.4 ± 2.6)
Wells	(0) – (11 ± 0.55)	(5.25 ± 0.26)
Springs		(120 ± 6.0)

Radon activity in water ranged from below the detection limit for well waters to 52 ± 2.6 Bq.l^{-1} in borehole water. The minimum detectable activity of RAD 7 alpha detector was 0.074 Bq.l^{-1} for the distilled water sample assumed to be radon free. The undetectable radon levels in most shallow water wells were inferred to degassing of water due to constant disturbances and desorption due to the surface temperature changes. The highest average radon level of 120 ± 6.0 Bq l^{-1} in water was recorded from water sampled from Ngosini water springs followed by water from Kasiluli, Mutha town, Makutano and Kawambemba boreholes. Elevated radon levels in water from Ngosini Spring were attributed to a blend of geology in the area, as it is located in the eave of the rocky Mutha hill.

The average radon level of 42.75 ± 2.1 Bq l^{-1} in borehole water is above the safety level of radon in drinking water of 11 Bq l^{-1} or 11 Bq/L (300 pC/L) suggested by the United States Environmental Protection Agency [14].The overall

mean radon level of 30 Bq l^{-1} from various water sources sampled is well below the EU recommended level of 100 Bq l^{-1} for remediation measures like boiling the water to be adopted. The overall mean activity concentration of 30 ± 1.5 Bq l^{-1} well fits in the recommended safety range of 4 - 40 Bq l^{-1} [15]. The Commission of European Communities sets the consumer population exposure below 100 Bq l^{-1} [16] . Figure 2 presents a comparison of mean radon activity in various water sources.

3.2 Annual Effective Dose

The risks of developing stomach cancer by population have been reported to increase with intake of water whose annual effective dose exceeds 0.1 mSv y^{-1}. The annual radiation doses to water users through ingestion (D_{ig} and inhalation (D_{in}) of radioactive radon gas from water were estimated using equations 4.2 and 4.3 respectively, as suggested by UNSCEAR 2000.

$$D_{ig}(mSv.year^{-1}) = C_{R_nW} \times C_w \times EDC \qquad (4.2)$$

$$D_{in}(mSv.year^{-1}) = A_{R_nW} \times C_{aw} \times F \times I \times DCF \qquad (4.3)$$

Where; C_{R_nW} is the radon concentration in water (Bq l^{-1} or kBq m^{-3}), C_w is the weighted estimate of water consumption of 2 litres per day (60 l y^{-1}), EDC is the effective dose coefficient for ingestion (3.5 nSv Bq^{-1}). A_{RnW} is the radon concentration in water (Bq l^{-1}or kBq/m^{-3}), C_{aw} is the radon in the air to the radon in water ratio (10^{-4}), F is the equilibrium factor between radon and its progenies (0.4), I is the average indoor occupancy time per individual (7000 ha^{-1}) and DCF is the dose conversion factor for radon exposure (9 nSv (Bq.h.m^{-3})$^{-1}$.

Figures 2 and 3 show comparative plots for the annual radiation dose contributions from the sampled water sources and the corresponding indoor air dose from the sampled water sources.

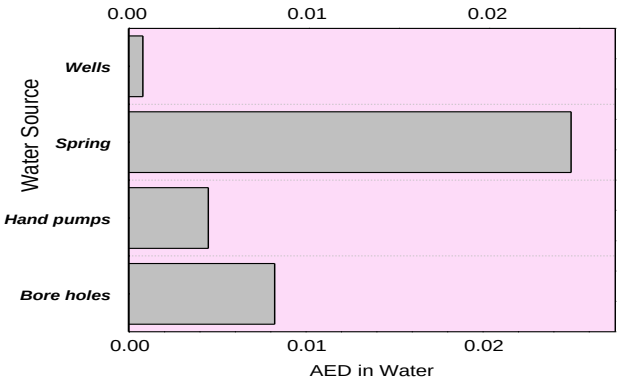

Figure 2: Mean radon activity for various water sources

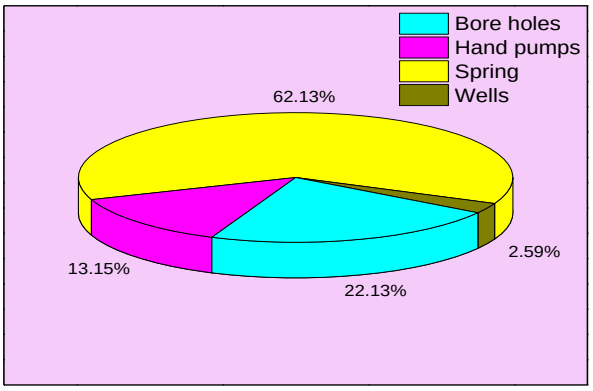

Figure 3: AED in the air due to contributions from various water sources

The annual effective dose taken via ingestion varied correspondingly as radon with a range of 0 to 25 ± 1.2 µSv y^{-1} and a mean of 6.0 ± 0.03 µSv y^{-1} which is far below 0.1 mSv y^{-1} for the water to be termed unsafe for drinking [6, 7] . The average and range of radiation doses from sampled water sources were well below the reference levels and the data from this survey guarantees the safety of the population using the water for drinking purposes from excessive radiation. Figure 3 is a presentation of various water sources and their contribution to indoor air. Such analysis was necessary as researches document that elevated radon levels in water significantly increase indoor air doses. Studies by European Commission show that for every radon concentration of 1000 Bq l^{-1} in water, a contribution of 100 Bq m^{-3} is made to indoor air [6] . The annual indoor dose from water reports a minimum of 0 mSv y^{-1} to a maximum of 0.3 ± 0.015 mSv y^{-1} with an average of 0.07 ± 0.003 mSv y^{-1} which is less than the recommended threshold of 1 mSv y^{-1} suggesting that radon in water contributes to annual indoor air doses for sampled water sources is insignificant in this area. The comparison of data from this research is in a reasonable range with similar radiometric surveys on water. Table 3 gives a summary of radon activity reported by this work and by scholars from Europe, China, Nigeria and other parts of Kenya.

Table 3: Comparison of ^{222}Rn Activity concentration of this work with other similar radon surveys

Region	Radon activity	Reference
Kenya (Kitui County)	30 ± 1.5 Bq l^{-1}	Present work
Kenya	37.1 (Bq l^{-1})	[17]
Nigeria	13.77 ± 1.05 Bq L^{-1}	[18]
Pakistan	0.94 ± 0.05 Bq L^{-1}	[19]
India	4.42 Bq L^{-1}	[20]
China	41 kBq m^{-3}	[21]
Europe	9.03±1.03 Bq l^{-1}	[22]

IV. CONCLUSION

The levels of radon in water used for drinking purposes in Mutomo Sub County, Kitui County were empirically evaluated. Generally, the highest radon activity was reported in water from the underground system, which was ascribed to high radium levels in bedrock containing the aquifer. Similarly, the low radon concentrations from shallow wells were due to desorption and evaporation of ^{222}Rn isotopes due to constant disturbance of water and high surface temperatures, which favours the dissolution of gases. Such observations, however, have been reported in similar radon surveys. This work reported a mean radon activity of 30 ± 1.5 Bq l^{-1} which is above the safety level of 11.1 kBqm^{-3} suggested by US-EPA but well within the range of 4 – 40 Bq L^{-1} recommended by UNSCEAR reports. The estimation of the annual effective dose to the population via ingestion in the sampled area reports an average of 6.0 ± 0.03 µSv y^{-1} which is below the WHO's recommendations of 0.1 mSv y^{-1} for the remediation measures to be taken. The data on contributions of radon in water to annual indoor air doses in this study was insignificant. The study recommends elemental analyses in water as this work did not consider that. Therefore, the study concludes that radon levels and annual effective doses via ingestion or inhalation emanating from water lie well within the proposed ranges and limits by WHO, ICRP and US-EPA report.

CONFLICT OF INTEREST

None to declare

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