A Study on the Radon Concentrations in Drinking Water in Kassala State (Eastern Sudan) and the Associated Health Effects

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Abstract: Radon and its radioactive progenies in indoor places are recognized as the main sources of public exposure from the natural radioactive sources. Exposure to radon occurs when breathing airborne radon while using water: showering, washing dishes, cooking and drinking water that contain radon. In the present research, number of (197) drinking water samples were collected from various places and supplies of public water used in Kassala State, Eastern Sudan, which has about 2 million population. Then radon concentration has been measured by using passive integrated solid-state nuclear track devices containing allyl diglycol carbonate plastic detectors. Results show that about 82.74% of water samples exceeded EPA (Environmental Protection Agency) recommendation for maximum contaminant level (MCL) for radon in drinking water of 11.1 Bq/l and have radon concentration gathered than 10 Bq/L, which advised EPA as a normal level. According to measurements data, the arithmetic mean of radon concentration for all samples was 15.94 ± 4.03 Bq/L. Similarly, the annual effective dose in stomach and lung per person has been evaluated in this research. According to the advice of WHO and EU Council, the total annual effective dose lowers than 0.1 mSv/y.

Key words: Radon • Drinking water • Radioactivity dose • CR-39

INTRODUCTION

Radon (222Rn) and its short-lived decay products (219Po, 214Pb, 214Bi and 214Po) in dwellings are recognized as the main sources of public exposure from the natural radioactivity, contributing to nearly 50% of the global mean effective dose to the public [1]. The interest in studying radon behavior is mainly due to the fact that it can accumulate indoors and in case of entering the body can be serious damage to human respiratory and gastrointestinal. Human respiratory tract due to radiation, radon and its daughter nucleus after entering the body are exposed to the most damage, producing an increase risk to the population. Therefore, after smoking, the second factor of lung cancer is radon [2]. Measure and analyze sources of drinking water and groundwater is important in health physics and in various countries has been done by researchers [3-7].

Radon contained in water is to some extent transferred into room air as a result of agitation or heating. UNSCEAR 2000 reported that radon concentration as a rule much lower in surface water than in ground water, radon concentrations in ground water are expected to be 40 Bq/L, the mean dose from radon in water from inhalation it was 0.025 mSv/year and 0.002 mSv when swallowed [1].

According to the WHO, mean the radon concentrations in tap water from surface waters equals 0.4 Bq/L and in well water is 20 Bq/L [8]. The release of radon from water to air depends upon circumstance in which the water is used, as the degassed fraction increases considerably with temperature. Recent reports of large radon concentration in drinking water in different places [9-12], has added a new element of deep concern to the problem of environmental health hazards.

Measurements of radon concentration in water have mostly been under taken in regions where high levels were suspected. It was tentitatively estimated in the UNSCEAR 1982 Report (Annex D, Paragraph 163) that between 1% and 10%of the world’s population consumes water containing radon concentrations of the order of 100 Bq/L or higher, drawn from relatively deep wells.
For the remainder, who consume water from aquifers of surface sources, the weighted world average concentration is probably less than 1 kBq/m³ [13].

This study of radon concentration in drinking water and the associated health effects is being carried out for the first time in Kassala State, Eastern Sudan, by using super grade quality of CR-39 solid-state nuclear track detectors (SSNTDs), which have proved to be a very economical and reliable method.

**Measurement Technique:** In this work a variety of drinking water samples were collected from different locations in Kassala State (nine locations, in a number of 197 measurements). The samples were analyzed by using closed technique [11, 14]. Two liters of water samples were taken (from each source or region) in clean plastic bottles specially designed for $^{222}$Rn measurement. In order to prevent radon leakage, the bottles were closed tightly at the site and carried gently to minimize degassing. 150 g samples of water from each bottle were poured into plastic cups. Each sample cup was covered and glued tightly by an inverted cup dosimeter that described in a previous work [11, 15-17] to form a cylindrical can. A circular hole was made in the dosimeter lid and covered by a piece of sponge with dimensions of 5cm×5cm×0.5cm glued into the interior surface of the lid. This configuration was necessary to maintain the same calibration conditions, also to make sure that thoron (Rn-220; $t_{1/2}$=55.6s) cannot readily reach the detector and to minimize the evaporation from water samples. The prepared samples were kept inside special room into cabins prepared specially for this purpose; the samples were regularly checked to ensure that there are no losses. Ten detectors were prepared for calibration process and three for the background. After an exposure time of 90 days [11, 14], the dosimeter cups were collected and separated from the sample cups. The detectors were removed and chemically etched, using a 30% solution of KOH at temperature of $(70 \pm 0.1)^°C$ for nine hours. The resulting α tracks were counted manually under an optical microscope of magnification 400X.

The track density was determined and converted into activity concentration $C$ (Bq.m$^{-3}$) by using the following formula [11, 18]:

$$C = \frac{\rho}{K t}$$

where $\rho$ is the track density (tracks per cm$^2$), $K$ is the calibration constant ($K=3.2307\times10^{-3}$ tracks.cm$^{-2}$. h$^{-1}$/Bq.m$^{-3}$) $C$ is the Rn concentration in Bq.m-3 and t is the exposure time.

The radon activity density in water CW was calculated using the formula [11, 18]:

$$C_W = \frac{\lambda C h t}{L}$$

where $\lambda$ is the decay constant of radon-222, $h$ is the distance from the surface of water in the sample can to the detector, $t$ is the exposure time of the sample and $L$ is the depth of the sample.

**Evaluation of Radon Annual Dose:** Values reported for the dose to the stomach per unit radon activity ingested (a dose coefficient) vary widely and they are often based on assumptions that are not documented and very often, they are not based on contemporary dosimetric methods [19].

**The Central Issues Are:**

- The extent to which radon diffuses into the wall of the stomach and
- The behavior of radon and its decay products in the body.

Studies of the behavior in the body of inhaled and ingested radon indicate that radon is readily absorbed by blood and is rapidly eliminated from the body in exhaled air [20]. The radon concentration of drinking water is an important issue from the dosimetry aspect, because more attention is paid to the control of public natural radiation exposure.

Regarding radiation dose to the public, due to waterborne radon, it is believed that waterborne radon may cause higher risk than all other contaminants in water [21]. Radon enters human body through ingestion and through inhalation as radon is released from water to indoor air. Therefore, radon in water is a source of radiation dose to stomach and lungs. The annual effective doses for ingestion and inhalation were calculated according to parameters introduced by UNSCEAR report [1].

**For Ingestion, the Following Parameters Were Used:**

- The effective dose coefficient from ingestion equals 3.5 nSv/(Bq l);  
- Annual intakes by infants, children and adults are found to be about 100, 75 and 50 liters, respectively;
The annual effective doses, due to ingestion corresponding to 1 Bq/l, would be equal to 0.35 µSv/y for infants, 0.26 µSv/y for children and 0.18 µSv/y for adults.

RESULTS AND DISCUSSION

In the present research, a total number of 197 drinking water samples were collected and analyzed for radon concentrations.

Table 1 and Fig. 1 show the results of radon concentration for drinking water samples, which had been collected from various locations in Kassala state. The minimum average value was found in Aroma drinking water (10.91± 3.13) Bq/L. This water is drawn from wells located at Jammam area near Kassala while it is channeled from Kassala to Aroma through pipes; this may decrease the amounts of unsupported dissolved radon through decay and leakage. The minimum concentration value was recorded for Khashm Algirba drinking water to be (5.36 Bq/L), near values was recorded for Halfa Aljadida and Dugian drinking waters of (5.76 and 5.88 Bq/L) respectively, this may be due to the water source or to the type of treatment and transportation. Halfa Aljadida and Khashm Algirba towns are depending on the surface water sources for drinking water. The water is filtered and coagulated through many steps. At first the water is pumped (from the channel of the surface water) to the

For Inhalation, the Following Parameters Were Used:

- Ratio of radon in air to radon in tap water supply is in the range of 4 to 10;
- Average indoor occupancy time per person is about 7000 h/y;
- Equilibrium factor between radon and its progeny is equal to 0.4;
- Dose conversion factor for radon exposure is 9 nSv/(Bq h m^-3).

The annual effective dose due to inhalation corresponding to the concentration of 1 Bq/l in tap water is 2.5 µSv/y.

Therefore, waterborne radon concentration of 1 Bq/l causes total effective dose of about 2.68 µSv/y for adults. The mean annual effective dose per person for adults caused by different water samples are reported in Table 2.

Table 1: Statistical summary of radon concentration from drinking water samples (Bq/L) in Kassala State locations.

<table>
<thead>
<tr>
<th>No.</th>
<th>Location</th>
<th>Min. C</th>
<th>Max. C</th>
<th>(mean ± s.d) Bq/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Alsawgi public drinking water(private wells)</td>
<td>12.86</td>
<td>34.02</td>
<td>20.56 ± 5.01</td>
</tr>
<tr>
<td>2</td>
<td>Dugain drinking water</td>
<td>5.88</td>
<td>19.26</td>
<td>10.98± 3.02</td>
</tr>
<tr>
<td>3</td>
<td>Kassala drinking water</td>
<td>8.84</td>
<td>85.32</td>
<td>21.59 ± 4.89</td>
</tr>
<tr>
<td>4</td>
<td>Algera drinking water</td>
<td>7.98</td>
<td>72.34</td>
<td>16.97 ± 3.91</td>
</tr>
<tr>
<td>5</td>
<td>Makali drinking water</td>
<td>8.57</td>
<td>48.35</td>
<td>19.88 ± 4.78</td>
</tr>
<tr>
<td>6</td>
<td>Aroma drinking water</td>
<td>6.43</td>
<td>17.14</td>
<td>10.91 ± 3.13</td>
</tr>
<tr>
<td>7</td>
<td>Wad Alhilalio Drinking water</td>
<td>8.02</td>
<td>17.89</td>
<td>12.93 ± 3.67</td>
</tr>
<tr>
<td>8</td>
<td>Halfa Aljadida drinking water</td>
<td>5.76</td>
<td>29.47</td>
<td>16.76 ± 3.89</td>
</tr>
<tr>
<td>9</td>
<td>Khashm Algirba drinking water</td>
<td>5.36</td>
<td>18.48</td>
<td>12.89 ± 3.97</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>5.36</td>
<td>85.32</td>
<td>15.94 ± 4.03</td>
</tr>
</tbody>
</table>

Table 2: Statistical summary of dose to lung (µSv/y) from radon in drinking water samples (Bq/L) for adults, children and infants and the effective dose to stomach (µSv/y) and the total effective dose in Kassala State locations.

<table>
<thead>
<tr>
<th>No.</th>
<th>Location</th>
<th>dose to lung (µSv/y)</th>
<th>effective dose to stomach (µSv/y)</th>
<th>total effective (mSv/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>adults</td>
<td>Children</td>
<td>infants</td>
</tr>
<tr>
<td>1</td>
<td>Kassala public drink fountain</td>
<td>3.70</td>
<td>5.35</td>
<td>7.20</td>
</tr>
<tr>
<td>2</td>
<td>Dugain drinking water</td>
<td>1.96</td>
<td>2.84</td>
<td>3.82</td>
</tr>
<tr>
<td>3</td>
<td>Makali drinking water</td>
<td>3.58</td>
<td>5.17</td>
<td>6.96</td>
</tr>
<tr>
<td>4</td>
<td>Algera drinking water</td>
<td>3.05</td>
<td>4.41</td>
<td>5.94</td>
</tr>
<tr>
<td>5</td>
<td>Kassala drinking water</td>
<td>3.89</td>
<td>5.61</td>
<td>7.56</td>
</tr>
<tr>
<td>6</td>
<td>Aroma drinking water</td>
<td>1.98</td>
<td>2.85</td>
<td>3.84</td>
</tr>
<tr>
<td>7</td>
<td>Wad Alhilalio Drinking water</td>
<td>2.33</td>
<td>3.36</td>
<td>4.53</td>
</tr>
<tr>
<td>8</td>
<td>Halfa Aljadida drinking water</td>
<td>3.02</td>
<td>4.36</td>
<td>5.87</td>
</tr>
<tr>
<td>9</td>
<td>Khashm Algirba drinking water</td>
<td>2.32</td>
<td>3.35</td>
<td>4.51</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>2.87</td>
<td>4.14</td>
<td>5.58</td>
</tr>
</tbody>
</table>
unit pump (intake), then it is drawn through pipes to a primary sedimentation tank called Lagoon, after that it is passed to another sedimentation tank built from concrete in which it is processed and coagulated by aluminum sulphide in order to reduce its turbidity, then to the filters which consist from many layers of gravel, large size sands and fine sand and lastly to the reservoir in which the chlorine dose is added, to be ready for distribution to the network and for human consumption. However, where the reduction of turbidity in the source water is a concern, the coagulation/ filtration method can be very effective for this purpose. It is also one of the technologies capable of removing uranium from source water supplies and it is compatible with other water treatment processes in different regions [22]. Removal by coagulation appears to be low at pH 8 due to stability and charge characteristics uranyl species in solution [23]. While Dugian water is drawn from wells located at Jammam area and Kassala town and channeled to Dugian village through pipes, this may decrease the amounts of unsupported dissolved radon through decay and leakage.

The maximum average value of radon concentration for drinking water samples was measured from wells in Kassala town which located near Algash river (the main building of Kassala University) to be (21.59 ± 4.89) Bq/L. The highest individual value was measured in water sample collected from the main building of Kassala University (85.32 Bq/L). This may be due to the source of water as it is mixed water from both the main tank near Al-Gash River and the private well situated in a porous sedimentary basement aquifer. Higher porosity might allow the radon gas to escape easily while the lower porosity of the soil and intact rocks above the aquifer reduces the probability of gas escape [24-26]. Groundwater movement, water table depth and its ability to leach radioactive materials from underlying bedrock during this movement is considered one of the important factors in the variation of radon concentration in water [27]. The lower concentration in Khashm Algirba town because the source of water supply is surface water that is treated (coagulated and filtrated) and conserved in a reservoir situated above the surface of the ground. An important aquifer in Kassala State is replenished by delta of Gash River downstream from Kassala town [28, 29]. The gravel and sands are usually up to 75 m thick and they provide considerable quantities of water during dry season, recharge being from rainfall from Ererarian highlands south of Asmara [30]. Menin et al. reported that, the low concentration of radon in water may depend on the type of soil in which aquifer is situated [31]. There are many underground wells with depths ranging from 21 to 41m used for drinking water in Kassala town. These wells are connected with a pipe network leading to the large reservoir from which the water is pumped to the main distribution system after treatment by addition of chlorine. It is clear that, in autumn period the turbidity and the total dissolved solids of the water are relatively higher, unless the routine treatment of water is done. Thus, it may contain trace elements affecting the probability of changing the concentration values; this may also depend on the radium concentration in the water sample. It was reported that, heavy rainfalls induce a decrease in radon concentration in water, which could be explained by the dilution of radon in a water table whose volume has increased. On the other hand, low or moderate rainfalls induce an increase of the radon concentration considering that the infiltrating water is charging the radon of the ground itself without increasing noticeably the water volume [32].

The concentration value of Alsawgi public drinking water (private wells) was measured to be (20.56±5.01)Bq/L, the source of water at Alswagi area in Kassala town is a
shallow dug wells essentially used for plant irrigation and for house uses, so the water is not subjected to any treatment or filtration before pumping, thus its composition is observed to be mixed with visible particles. This may enhance the amount of probability of its ability to carry a sizable load radioactive material. We may recall several hydro-geological reasons that might cause variations in water radon concentration from place to another. The degree of aeration would be the first reason, where gases like radon will escape from collected rainfall water as of Toteil much easier more than for dug wells such as Sagia. The deeper wells hold most of the radon, while open water is closer to the earth surface allows gases to escape easily [11, 24]. Hess et al., has shown that well water has higher concentration of radon than the water from the public utility systems [33]. Seidel et al., reported that, higher radon concentrations in wells are correlated with low transmissivity or low permeability and inversely [34]. In Finland it was found that, the mean concentration of radon in drilled wells to be 460 Bq/L and in wells dug in the soil is 50 Bq/L [35].

The descending order ordering of Radon concentration in drinking water samples collected from the water supplies at different locations can be arranged and ordered as follows: Kassala drinking water > Alswagi drinking water > Makali drinking water > Aljera drinking water > Halfa Aljadida drinking water > Khashm Algirba drinking water > Wad Alhilaio drinking water > Dugain Drinking water > Aroma drinking water.

Although the underground water is known with fewer problems, Halfa Aljadida and Khashm Algirba towns are poor from underground water tables and/or aquifers. This fact seems to be true, because they are situated in a deep clayey geological formation, which reduces the probability of finding the economical amounts of water. Thus, the surface water sources are in use at these towns.

The size of data obtained for pH and T.D.S. for drinking water samples is statistically small to give meaningful correlation with radon concentration. It is also true for other water types.

Water supplies containing high-unsupported levels of radon have been found in some countries such as in Maine (U.S) [36]. Such water might contribute to indoor radon levels [1]. An important source of indoor radon is radon rich-water. In fact it has been estimated that approximately 104 kBq/m³ in water would result in 1 kBq/m³ in air. The ratio of radon concentration in air to that in water, however, depends on water use and room ventilation [37, 38].

The total average of radon concentration from all types of water samples in Kassala State was found to be $(15.94 \pm 4.03)$ Bq/L. Which is under the maximum allowable radon concentration from water as recommended by EPA [23, 39].

Table 2 and Figs. 1-2 summarize the annual effective dose to lung and stomach with the type of drinking water.

![Fig 2: Annual effective dose to lung for adults, children and infants due to radon concentration from water samples in Kassala State locations.](image)
It is clear that dose is strongly related to the concentration value, the infants can receive a large dose than children and adults. Fig.3 summarizes the total dose from drinking water sample with respect to the sample's location. From the figure (4), the higher dose is recorded with the higher concentration value.

**CONCLUSIONS**

From the study, we can conclude the followings: radon concentration from water samples is affected by: type of water; we found that underground water having larger values of concentration more than surface water. The situation of the aquifer, the type of rocks and soils on which the aquifer is situated. The movement of water and the drift velocities of the water flow. The source of water and the type of control for the water flow. It is correct to say that if the aquifer were situated in base (ground) rich with radium the radon concentration would be higher in values. Also if the water is in a hard bulk rocks (easy to be dissolved) the rates of dissolved particles will be minimum to decrease (may increases) the concentration values. The flow with higher velocities may help on drift the soils or crush the rocks through which the water pass and this
may increase the concentration values depending on the mixer content of radium element. From our survey, we can conclude that about 82.74% of water samples exceeded Environmental Protection Agency recommendation for maximum contaminant level (MCL) for radon in drinking water of 11.1 Bq/l and have radon concentration. In this work the annual effective dose to stomach and lung per person has been evaluated. According to the advice of WHO and EU Council, the total annual effective dose lowers than 0.1 mSv/y.

Finally, it is very important to mention that, this is the first measurement ever carried out in Kassala State for radon concentration from water samples, so further works is recommended.

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REFERENCES
