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Assessment of the Environmental Radioactivity Impacts and Health Hazards Indices at Wadi Sahu Area, Sinai, Egypt

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ABSTRACT

The natural radionuclide (\(^{238}\text{U}\), \(^{232}\text{Th}\), \(^{226}\text{Ra}\) & \(^{40}\text{K}\)) contents of soil and rock samples at various locations in Wadi Sahu area, Sinai, Egypt were studied using spectrometric techniques. The estimation of radioactivity hazard indices radium equivalent (\(\text{Ra}_{eq}\)), external hazards (\(\text{H}_{ex}\)) and internal hazards (\(\text{H}_{in}\)) beside European Commission index (\(\text{IEC}\)) in building materials have been derived. Also, integrated measurements for radon gas concentrations beside gamma dose exposure were taken at these locations. The concentration of radon-222 in unit of \(\text{kBqm}^{-3}\), gamma dose in \(\mu\text{Sv/h}\) and the annual effective dose rate (EDR) in \(\text{mSv/a}\) were estimated. The average of the radioactivity hazard indices and radium equivalent values are little more than restricted levels for the public. So, some precautions and recommendations should be follow and take into consideration for the public residences in this area. The effective annual dose rate (EDR) of the total area is ranging between 0.18 – 3.50 \(\text{mSv/a}\) with average value 1.84 \(\text{mSv/a}\). The etch track detector using CR – 39 for radon (Rn – 222) subsurface at the studied locations gives an indication and promising to uranium occurrence in some regions under study.

Key Words: Environmental Radioactivity Indices, Total Annual Dose, Dose Rate, Effective Dose Rate, Radon – 222, Radioelements, uranium

INTRODUCTION

Mining and milling of both nuclear and non-nuclear materials may cause significant environmental and occupational radiological impacts, and, typically, NORM in commercial and industrial products has the potential to expose workers and members of the public to some fraction of the recommended annual radiation exposure limit. The main external source of irradiation to the human body is represented by the gamma radiation emitted by naturally occurring radioisotopes, also called terrestrial environmental radiation. These radioisotopes, such as \(^{40}\text{K}\) and the radionuclides from the \(^{232}\text{Th}\) and \(^{238}\text{U}\) series and their decay products, exist at trace levels in all ground formations. Therefore, natural environmental radioactivity and the associated external exposure due to gamma radiation depend primarily on the geological and geographical conditions, and appear at different levels in the soils of each different geological region (UNSCEAR 1993, 2000 Reports).
The Nuclear Materials Authority (NMA) of Egypt has been developing a national program for radioactive mineral exploration, especially uranium mineralization. Wadi Sahu as a part of Sinai area is inhabited by Migrant Bedouins which used natural materials in building. Also, there is a quarry and manganese mine in this region that cause significant environmental and occupational radiological impacts. So, the present study is aiming to establish environmental baseline information on natural radioactivity and to prepare radionuclide maps for geological study and mineral resource assessment, also, to detect and record changes of environmental radioactivity and any anomalies in Wadi Sahu and surrounded mountains. Therefore our study includes collected samples from rocks and soil to determine the environmental radioactivity hazards indices and the exposure dose rate for the public and workers. Also, Solid state nuclear track detector (SSNTDs) of CR-39 is distributed in the subsurface of rocks and soil to study $^{222}$Rn emanation for $^{238}$U prospection.

**GEOLOGIC SETTING**

Wadi Sahu lies in southwestern Sinai, Egypt and limited by the latitudes 28º 58’ 54” to 28º 58’ 00” N and the longitudes 33º 25’ 00” to 33º 22’ 19” E (Fig.1). The area covered by the Paleozoic sedimentary succession, includes the following rock units starting from the oldest; Adedia formation. This is followed unconformably upwards by Um Bogma Formation unconformably overlain by Abu Thora Formation. Uranium mineralizations are mainly associated with Um Bogma Formation. The different lithologic units of Um Bogma Formation are the following:

**Lower member;**

It is mainly composed of mainly of dolostone, silt and clay beds manganese-iron concretions and lenses, sandstone and conglomeratic sandstone intercalation. Occasionally the sandstone grade into silty or conglomeratic size. These beds are varicoloured, where they show green to grey, red, yellow and brown colours. It is noteworthy to mention that more than one yellow secondary uranium minerals are detected in the silt of this member (Dabbour and Mahdy, 1988).

**Middle Member;**

This member is composed mainly of fossiliferous marly dolostone and shale. The dolostone is highly fractured and fissured with copper mineralization along fissures. It is grey to dark grey with Mn concretions. It is medium hard with caves near the base, which are often due to pre-existing Mn-Fe concretions or karstification processes, i.e dissolution features of carbonates (El Sharkawy, 1990). It is green with dark patches, contains green copper mineralization and is highly radioactive.

**Upper member;**

This member is composed mainly of dark grey to black sandy dolostone. The base of this member is more radioactive and composed of clay with sandstone lenses. Silt with shale intercalation are also present in this unit. The silt is grey, yellow and brown it contains
hematite with green copper minerals as grains and patches. Shale is soft, fissile and friable, grey to black; yellow and brown with patches of iron and manganese.
(Fig. 1) Location map of the studied area

(Fig. 2) Geologic map of studied Wadi sahu, southwestern Sinai, Egypt.
EXPERIMENTAL TECHNIQUE AND METHODOLOGIES

As shown in the geological map (Fig. 1), Wadi Sahu is divided into four regions RI, RII, RIII and RIV. The distribution of measurements takes place as follows;

1. Thirty-two samples from rocks and soil were collected from the stations under study for gamma spectroscopy whereas; samples from 1 – 10 at RI, 11 – 18 at RII, 19 – 26 at RIII and 27 – 32 at RIV.
2. Radon measurements and gamma survey are distributed as; 1 – 21 at RI, 22 – 50 at RII, 51 – 73 at RIII and 74 – 100 at RIV.

1. Estimation of gamma dose rate in air outdoors and effective dose rate

One handeried station was surveyed using RDS–100 Survey Meter, ALNOR, SF 20101, Finland for measuring the $\gamma$-ray dose rate in unit $\mu$Sv/h in air at 1 m above the ground surface. More than one gamma reading was taken at each station and averaged for estimation of $\gamma$-dose. The effective annual dose rate was calculated from the following equation;

$$\text{Effective dose rate (mSv}^{-1}) = D (\text{nGy} h^{-1}) \times 8760 \text{ h a}^{-1} \times 0.7 (10^3 \text{mSv/10}^9) \times 0.2$$

2. Radiometric measurement for U, Th, Ra and K concentration using $\gamma$-spectroscopy

The collected samples were analyzed for their $^{238}$U, $^{232}$Th, $^{226}$Ra and $^{40}$K content by gamma spectroscopic analysis. This was achieved using Multi-Channel Analyser (MCA) of gamma ray spectrometer including NaI (TL) Bicron scintillation detector. The rock samples were crushed to small pieces (~60 mesh). The crushed rocks were dried, mixed well and a representative rock sample (~250 – 300 g) was put on circular plastic containers of 10 cm diameter and 3 cm height. Every sample was then pressed manually in its container till it was completely filled and tightly closed. The prepared samples were stored for sealing about one month to reach the state of equilibrium and accumulate free radon.

The radiometric measurement for the radionuclides was carried out through four energy regions of interests (ROIs). Since uranium and thorium are not gamma-emitters, they were measured indirectly through the gamma-ray photons emitted from their daughters, Th-234 (81 – 108 keV) for U-238, Pb-212 (221 – 273 keV) for Th-232 and radium was measured from the gamma-ray photon emitted by Pb-214 (327 – 390 keV) whereas potassium was measured directly from the gamma-ray photon emitted by K-40 (1319 – 1471 keV). Consequently, they are expressed as equivalent (eU), equivalent thorium (eTh) and equivalent Radium (eRa).

Values of eU, eTh and eRa, in ppm, as well as K, in %, were converted to activity concentration, Bq kg$^{-1}$, using the conversion factors given by Polish Central Laboratory for Radiological Protection (Malczewski et al., 2004). The specific parent activity of a sample containing 1 ppm, by weight, of U is 12.35 Bq kg$^{-1}$, 1 ppm of Ra is 11.1 Bq kg$^{-1}$, 1 ppm of Th is 4.06 Bq kg$^{-1}$ and 1% of $^{40}$K is 313 Bq kg$^{-1}$. These data were used for calculation of some radiological parameters to estimate the environmental radioactivity impacts of the radionuclides.
3. Environmental radioactivity impacts of the radionuclides

3.1 Exposure and dose rate

The concentration of U-238 and Th-232 in ppm and K-40 in percent was used to estimate the dose rate in (nGy/h) as the following relation (IAEA-TECDOC-1363, 2003)

\[
\text{Dose Rate (nGy h}^{-1}\text{)} = 5.675 \text{ U (ppm)} + 2.494 \text{ Th (ppm)} + 13.078 \text{ K (\%)}
\]

Where 5.675, 2.494 and 13.078 are the conversion factors for U, Th and K, respectively. To estimate annual effective doses, account must be taken of the conversion coefficient from absorbed dose in air to effective dose. The average numerical values of those parameters vary with the age of the population and the climate at the location considered. In the UNSCEAR 1993 Report, the Committee used 0.7 Sv Gy\(^{-1}\) for the conversion coefficient from absorbed dose in air to effective dose received by adults. The occupancy factors of time spent outdoors is 0.2. So, the annual effective dose for outdoor occupancy is determined as follows:

\[
\text{Annual Effective Dose (mSv a}^{-1}\text{)} = \text{Dose (nGy h}^{-1}\text{)} \times 8760 \text{ h} \times 0.2 \times 0.7 \text{ Sv Gy}^{-1}\times 10^{-6}
\]

3.2. The radium equivalent (Ra\(_{eq}\))

Radium equivalent activity (Bq/kg) is an index which is convenient to compare the specific activities of samples contains of different concentration of \(^{226}\text{Ra}, ^{232}\text{Th}, \text{ and } ^{40}\text{K}\. It is defined based on the assumption that 10 Bq/kg \(^{226}\text{Ra}, 7\text{Bq/kg }^{232}\text{Th} \text{ and } 130 \text{ Bq/kg }^{40}\text{K} produce the same gamma dose rate. Therefore radium equivalent activity depends on activities of Ra, Th and K radionuclides. It is defined as;

\[
\text{Ra}_{eq} = \frac{10}{7} A_{Ra} + \frac{10}{130} A_{Th} \leq 370
\]

where Ra\(_{eq}\) is the radium equivalent activity and A\(_{Ra}\), A\(_{Th}\) and A\(_{K}\) are the specific activities of Ra, Th and K, in Bq kg\(^{-1}\), respectively (Tufail et al., 1992).

3.3. External and internal hazard indices

The external hazard index (H\(_{ex}\)) was used to measure the external hazard due to the emitted gamma radiation. It was calculated by the equation from Tufail et al. (1992):

\[
H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_{K}}{4810} \leq 1
\]

where H\(_{ex}\) is the external hazard index and A\(_{Ra}\), A\(_{Th}\) and A\(_{K}\) are the specific activities of Ra, Th and K, in Bq kg\(^{-1}\), respectively. In addition to external hazard index, radon and its short – lived products are also hazardous to the respiratory organs. So, the internal to radon and its daughter products is quantified by the internal hazard index H\(_{in}\) which is given by ;

\[
H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_{K}}{4810} \leq 1
\]
3.4. The raw materials used in building and covering materials

It is also possible to use an activity utilization index proposed by UNSCEAR 1993 and/or EC 1999 that facilitates the derivation of dose rates in air from different combinations of these three radionuclides.

\[ I = \frac{C_K}{3000\text{Bqkg}^{-1}} + \frac{C_U}{300\text{Bqkg}^{-1}} + \frac{C_{Th}}{200\text{Bqkg}^{-1}} \]

Where \( C_K, C_U \) and \( C_{Th} \) are the uranium, thorium and potassium-specific activities in \( \text{Bqkg}^{-1} \) in building material, respectively. The index \( I \) is correlated with the annual dose due to the excess external gamma radiation caused by superficial material. Values of index \( I \leq 2 \) correspond to 0.3 mSv\( \text{a}^{-1} \), while \( I \leq 6 \) correspond 1 mSv\( \text{a}^{-1} \). Thus, the activity concentration index should be used only as a screening tool for identifying materials which might be of concern to be used as covering material. According to this dose criterion, materials with \( I \geq 6 \) should be avoided. dose (EC, 1999, UNSCEAR, 1993, 2000).

4. Estimation of Radon Gas Concentrations in the Subsurface at the Studied locations

To estimate \(^{222}\text{Rn}\) gas concentrations over the studied area, a total of 100 monitoring stations in the four regions that wadi sahu is included were chosen. After 60 days, CR-39 detectors were collected, cleaned with distilled water and etched at the optimum conditions (Fig.3). The resulting \( \alpha \)–tracks on each detector were counted under the optical microscope at total magnification of 400X. The number of \( \alpha \)–tracks per field was average over fields counted for each detector and the track density (Tcm\(^{-2}\)d\(^{-1}\)) was obtained. The calibration factor (CF) of the CR-39 detector used in this study was obtained to have the value; \( \text{CF} = 0.131401 \pm 0.022 \) (T.cm\(^{-2}\).d\(^{-1}\)/Bq.m\(^{-3}\)).

\[ C_{Rn} = \frac{\text{TrackDensity(Tcm}^{-2}\text{d}^{-1})}{\text{CalibrationFactor(Tcm}^{-2}\text{d}^{-1}/\text{Bqm}^{-3})} = \text{RadonConcentration(Bqm}^{-3}) \]
RESULTS AND DISCUSSION

1. Radio-elements distribution

Results of the radiometric analysis for the collected rock and soil samples using gamma-ray spectrometry are listed in Table (1). It is clear that Variegated Shale-middle Um Bogma and Siltstone of L.Um Bogma have the highest concentration of uranium, thorium, radium and Potassium. So, Shale and Siltstone is highly enriched in uranium and thorium concentrations comparing with that of sediments published by (IAEA, 1979) but with lesser K contents.

In addition some uranium content is adhered to and/or adsorbed on the Fe oxide cement (Ahmed, 2003). On the other hand, ferruginous siltstone with clay intercalations shows wide range of uranium contents starting from 4 to 212 ppm with average 30.36 ppm. Also, the average concentrations of, radium, thorium and potassium are 34.10 ppm, 16.19 ppm and 0.78%, respectively. Middle member of Um Bogma is composed mainly of marl, siltstone and sandy dolostone intercalations.

This member was subjected to laterization process resulted in the formation of gibbsite mineral. This mineral in the hosting siltstone represents a good adsorbent for uranium from later carrier solutions (El Aassy et al., 1998). This is very clear in the anomalously uranium contents in these sediments. El Agami (1996) and Ahmed (2003) stated that the anomalous uranium contents in gibbsite are attributed to the presence of discrete uraniferous green mineral grain-like metabernte, which is associated with kaolinite mineral.

The equilibrium factor, which was defined by Hussein,(1992) as P-factor and expressed as the ratio between radiometrically measured equivalent uranium and equivalent radium ($eU/eRa$) was calculated in all rock and soil samples. This factor is more or less than unity indicating state of disequilibrium, while P-equal unity indicate the state of equilibrium. From the estimated values, illustrated in Fig.5 we note that the composition (Rocks & Soil) of wadi sahu area in equilibrium state within experimental error. Also, The average of the radioactivity hazard indices and radium equivalent values are little more than restricted levels for the public. So, some precautions and recommendations should be follow and take into consideration for the public residences in this area.
Fig. 5: The average values of the P-Factor at the studied area.

Fig. 6: Total averages of radium equivalent (Ra_{eq}) at Wadi Sahu beside the average of R_{eq} at each region, Sinai, Egypt.
Table (1): radioelements content in the collected soil and rock samples from the four regions of Wadi Sahu area at Sinia

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Rock Type lithology</th>
<th>Radionuclide concentration (ppm)</th>
<th>Specific Activity concentration (Bq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>eU (ppm)</td>
<td>eRa (ppm)</td>
</tr>
<tr>
<td>1</td>
<td>Variegated Shale-middle Um Bogma</td>
<td>78</td>
<td>103</td>
</tr>
<tr>
<td>2</td>
<td>Variegated Shale-middle Um Bogma</td>
<td>212</td>
<td>153</td>
</tr>
<tr>
<td>3</td>
<td>Shale of middle Um Bogma</td>
<td>35</td>
<td>43</td>
</tr>
<tr>
<td>4</td>
<td>Variegated Shale-middle Um Bogma</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>Variegated Shale-middle Um Bogma</td>
<td>20</td>
<td>24</td>
</tr>
<tr>
<td>6</td>
<td>Shale of middle Um Bogma</td>
<td>11</td>
<td>29</td>
</tr>
<tr>
<td>7</td>
<td>Shale of middle Um Bogma</td>
<td>45</td>
<td>48</td>
</tr>
<tr>
<td>8</td>
<td>Siltstone of Um Bogma</td>
<td>28</td>
<td>25</td>
</tr>
<tr>
<td>9</td>
<td>Shale of Um Bogma</td>
<td>35</td>
<td>33</td>
</tr>
<tr>
<td>10</td>
<td>Dolostone of Um Bogma</td>
<td>19</td>
<td>8</td>
</tr>
<tr>
<td>11</td>
<td>Shale + Mn of L. Um Bogma</td>
<td>uLD</td>
<td>139</td>
</tr>
<tr>
<td>12</td>
<td>Shale + Mn of L. Um Bogma</td>
<td>uLD</td>
<td>18</td>
</tr>
<tr>
<td>13</td>
<td>Mn / ore</td>
<td>uLD</td>
<td>18</td>
</tr>
<tr>
<td>14</td>
<td>Gibbsite L. Um Bogma</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>15</td>
<td>Shale + gibbsite</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>16</td>
<td>Soil in the track</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>17</td>
<td>Sandstone L. Um Bogma</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>18</td>
<td>Sandy dolomite L. Um Bogma</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>19</td>
<td>Shale of Um Bogma</td>
<td>38</td>
<td>56</td>
</tr>
<tr>
<td>20</td>
<td>Gibbsite of Um Bogma</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>21</td>
<td>Variegated shale + white shale</td>
<td>17</td>
<td>49</td>
</tr>
<tr>
<td>22</td>
<td>Siltstone of L. Um Bogma</td>
<td>64</td>
<td>40</td>
</tr>
<tr>
<td>23</td>
<td>Ferro-manganese (Fe-Mn)</td>
<td>102</td>
<td>26</td>
</tr>
<tr>
<td>24</td>
<td>Gibbsite L. Um Bogma</td>
<td>27</td>
<td>32</td>
</tr>
<tr>
<td>25</td>
<td>Gibbsite L. Um Bogma</td>
<td>22</td>
<td>26</td>
</tr>
<tr>
<td>26</td>
<td>Adedia sandstone</td>
<td>uLD</td>
<td>1</td>
</tr>
<tr>
<td>27</td>
<td>Hashash siltstone</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>28</td>
<td>Hashash siltstone</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>29</td>
<td>Hashash siltstone</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>30</td>
<td>Abu thora sandstone</td>
<td>uLD</td>
<td>1</td>
</tr>
</tbody>
</table>

Min.  | 4.00   | 1.00   | 2.00   | 0.06   | 49.4   | 11.1    | 8.12    | 18.78   |
Max.  | 212    | 153.00 | 33.00  | 2.73   | 2618.2 | 1698.3  | 133.98  | 854.49  |
Ave.  | 30.36  | 34.10  | 16.19  | 0.78   | 360.53 | 378.47  | 65.75   | 243.05  |
Table (2) : The average of environmental radioactivity indices, effective annual dose and P-Factor at the regions of Wadi Sahu, Sinai, Egypt

<table>
<thead>
<tr>
<th>Region</th>
<th>Ra_{eq}</th>
<th>H_{ex}</th>
<th>H_{in}</th>
<th>I_{EC}</th>
<th>ED (mSv\textsuperscript{-1})</th>
<th>P-Factor eU/eRa</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI</td>
<td>672.98</td>
<td>1.82</td>
<td>3.25</td>
<td>2.58</td>
<td>3.34</td>
<td>1.12</td>
</tr>
<tr>
<td>RII</td>
<td>446.16</td>
<td>1.21</td>
<td>2.12</td>
<td>0.60</td>
<td>1.02</td>
<td>1.15</td>
</tr>
<tr>
<td>RIII</td>
<td>510.69</td>
<td>1.38</td>
<td>2.52</td>
<td>1.18</td>
<td>2.09</td>
<td>0.90</td>
</tr>
<tr>
<td>RIV</td>
<td>189.31</td>
<td>0.51</td>
<td>0.84</td>
<td>0.64</td>
<td>0.91</td>
<td>0.92</td>
</tr>
<tr>
<td>W.Sahu</td>
<td>454.79</td>
<td>1.23</td>
<td>2.18</td>
<td>1.25</td>
<td>1.84</td>
<td>1.02</td>
</tr>
</tbody>
</table>

Fig.7: Total averages of annual effective dose rate, AED, (mSv\textsuperscript{-1}) at the studied area

2. Radon concentration and its significance

Uranium (U-238, U-235) and thorium (Th-232) decay over the geological time periods through their respective well known decay series generate a wide spectrum of daughter products. Uranium and thorium, as well as their daughter products, except Rn-222, Rn-219 and Rn-220, are solids, and therefore, do not easily migrate from one place to another under normally conditions.

The radioactive daughters Rn-222, Rn-219, and Rn-220 being gaseous and can thus move away from their respective source materials (U-238, U-235 and Th-232), through the process of forced and/or natural migration. They may also be carried away owing to the convectional flow of fluids in the earth’s crust.

The radon isotope Rn-219 is insignificant because of the low abundance of U-235 and very short half life (4s), while Rn-220 is of less importance due to its very short half-life (55 s). So, the radon isotope (Rn-222) will be our main task. The radon profile is combined with locations of the faults, joint and cracks. The radon coming from the uranium source collects
inside the cup and creates tracks on the surface of CR-39. So, it can safely be assumed that the area of high track density and so, high radon-222 concentration underlies uraniferous ore-body. Fig. 6 shows two different samples a) high radon concentration and (b) low radon concentration of alpha-track selected from the studied locations.

The difference in concentration values between U-238 & Ra-226 with Rn-222 in the location site is attributed to the diffusion of Rn-222 through the soil and rocks that depend upon the geology of the transmitting medium. Factors, which affect the passage of radon, include lithology, compaction, porosity and cementation (Borreto et al., 1972). So, a porous sandstone or fractured rock allows a high penetration of radon than the crystalline rocks. The overall picture emerging from this study shows that a radon build up occurs in the area of active fault zones. So, radon could be transported more rapidly than by diffusion or ground water movement in fracture zones.

One is that radon is transported with geogas (e.g. CO\textsubscript{2}, CH\textsubscript{4} and N\textsubscript{2}) finding its way towards the surface (Hermansson et al, 1991a&b) A reason for increased concentrations over fracture zones is that uranium ions and/or daughter nuclides dissolved in the ground water have been precipitated close to the ground surfaces, and that radon emanates from the radium formed in their disintegration. However, it is perfectly clear that increased radon concentrations in rock air that can be formed by surrounding layers of rock, occur over certain fracture zones. In these cases, they occur together with enhanced levels of CO\textsubscript{2} and often of helium. CO\textsubscript{2} has been shown to act as carrier in transporting radon from the fracture zones to the surface. So, the values of the exposure dose rate are different from the radon gas concentration.

This is due to that the record $\gamma$-rays are for the all radioelements in the soil and rocks, while CR-39 record $\alpha$-particle emitted from radon (Rn-222) restricted in the cup. Also, both radon-222 and $\gamma$-exposure dose are represented in contour maps, whereas the concentration increase in the more color (darkness) locations.
Fig. 9: Average of Rn-222 gas concentration (kBq m$^{-3}$) at the four regions beside the total average of all regions of Wadi Sahu, Sinia, Egypt.
Fig.10 the contour map for both radon and gamma rays at Wadi Sahu area, Sanai, Egypt.

CONCLUSION

The average of the radioactivity hazard indices and radium equivalent values are little more than restricted levels for the public. So, some precautions and recommendations should be followed and taken into consideration for the public residences in this area. The effective annual dose rate (EDR) of the total area is little more in some regions due to public and most Wadi Sahu region are valued for construction and covering materials.

This study has been carried out to compare the gamma activity at the surface and the radon measurements in the subsurface. The results show that, there was no direct comparison between the two sets of measurements. One observation which particularly favors the alpha-track method is that at points where the gamma method did not predict any active zone, while the alpha-track method did indicate their presence. The etched track detector technique has been found to be fairly successful for U-mineralization, so it is frequently applied to areas where other methods and favorable geological criteria have identified them as possessing potential for subsurface ore.
The obtained data are used to identify raw materials which might be of concern to be used as covering material. Also, to establish environmental baseline information on natural radioactivity and to prepare radioelement maps for geological study and minerals resources assessment.

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