Assessment of natural radioactivity hazards in selected water samples collected from northern regions of Oman

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Abstract: This study explores the radioactivity hazards in water samples collected from the Northern regions of Oman. The naturally occurring radioactive nuclides of the main series, $^{238}$U, $^{232}$Th, $^{235}$U and $^{40}$K have been studied by means of low level gamma spectroscopy. Majority of the studied valleys (wadis) are descending from Super Hajar Mountains either towards its east part (coastal area) or the west part (desert). Water samples were analyzed by applying the same analysis technique and ranges of concentrations of $^{238}$U, $^{232}$Th, $^{235}$U and $^{40}$K were found to be (0.35-1.7), (<DL-0.17), (0.01-0.18) and (0.26-0.91) all in Bq.L$^{-1}$ respectively. The radiological hazards, D, $H_{\beta}^{Gy}$ and $R_{\text{eq}}$ were calculated and found at ranges (0.21-7.94) nGy/h, (3.0-9.0)*10$^{-4}$ mSv/yr and (0.02-3.6) Bq.L$^{-1}$ respectively. The $H_{\text{in}}$, $H_{\beta}$ and $I_{\gamma}$ results were less than 1. The assessment of radioactivity in water samples showed values lower than world-wide average according to (WHO). The results indicate that the radiation hazard from naturally and artificially radionuclides in water samples from the area studied in this current work is barely significant.

Keywords: Radioactivity– Water – HPGe Detector- Gamma rays

1.Introduction

Radioactivity is the word used to describe the decay of atomic nucleus. It refers to the property of unstable atoms to move to a more stable. Earlier in 20th century, Radioecology started to be considered an individual natural science [1]. Since the creation of the earth radioactivity exit naturally everywhere, in air, soil, water, plants and food. Depending on the concentration of the radionuclides, the radiation doses delivered by these materials will [2]. The sultanate of Oman occupies most of the south east corner of Arabian Peninsula. The distribution of natural radioactivity in the environment depends basically on the geological and geographical properties. Most wadis in Oman are having headwaters descend from the mountains towards the coast or deserts. Majority of the studied valleys are descending from Hajar mountains either towards its east part (coastal area) or the west one (desert). Along these valleys, sub-surface water is available. In result, these regions are agricultural regions and therefore are populous too. Consequently, this study will provide a baseline data of radiation considering 15 locations from northern regions of Oman.
2. Materials and Methods

2.1 Water and Grass samples Collection and Preparation

In this study, decision was made to collect samples of water and grass from east and west of western Hajar Mountains. The sampling area considered in this study located at west of north Al Hajar Mountains where the influence of dust storms on the Arabian Peninsula takes place. Heavy rain drifts soil from mountains to the wadis and plain. Disturbed soils cause a decrease in the net surface radiation. Furthermore, the Ophiolites which are igneous rocks constitute the bulk of the geographical configuration of the northern regions of Oman. In terms of natural radioactivity; it is well known that igneous rocks are strongly enriched in thorium and uranium [3]. Some essential aspects were taken into consideration in order to obtain reliable results. Areas of agricultural activities were selected in order to investigate about probable radionuclides that might have eroded into the wadis by fertilizers. For each location, water samples were taken from an area distribution with the same Global Positioning System (GPS) readings to ensure precise comparison with other locations. Samples were collected from 15 different locations as shown in Table (1), Where 1 refers to the headwater of the wadi and 2 to the estuary of the same wadi. In the Lab, water samples were acidified with concentrated nitric acid (HNO₃) to bring the PH to 2 to avoid any adherence of radionuclide to the interior part of the containers and prevent the growth of organisms [4]. Then 1 L of each sample was stored into the Marinelli beakers for 4 weeks.

Table 1: Water samples codes and locations

| Sample Code | location         | Willayat   | LatitudeN (Deg.Min.S) | longitudeE (Deg.Min.S) |
|-------------|------------------|------------|-----------------------|------------------------|
| AW1         | WADI ASWAD1      | Shinas     | 24 52 43.1’           | 56 17 03.3’            |
| AW2         | WADI ASWAD2      | Shinas     | 24 52 17.0’           | 56 19 46.8’            |
| HW1         | WADI HIBI1       | Sohar      | 24 54 33.4’           | 56 33 23.5’            |
| HW2         | WADI HIBI2       | Sohar      | 24 02 58.1’           | 56 33 25.8’            |
| IW1         | WADI HILTI1      | Sohar      | 24 03 29.9’           | 56 29 05.3’            |
| IW2         | WADI HILTI2      | Sohar      | 24 05 26.9’           | 56 29 05.3’            |
| BW          | BURAIMI          | Buraimi    | 24 01 16.8’           | 56 11 55.3’            |
| FW          | WADI ALFATH      | Yanqul     | 23 40 45.6’           | 56 15 03.4’            |
| DW1         | WADI DHUNK(FEDA)1| Dunk       | 23 31 48.3’           | 56 35 15.8’            |
| DW2         | WADI DHUNK(FEDA)2| Dunk       | 23 32 29.0’           | 56 18 05.9’            |
| SW          | WADI ALSAIFA     | AlSinaina  | 23 44 45.6’           | 55 53 07.1’            |
| WW1         | Wadi WAHRA 1     | Ibra       | 23 18 10.8’           | 56 42 28.6’            |
| WW2         | Wadi WAHRA 2     | Ibra       | 23 29 05.0’           | 56 40 27.3’            |
| MW          | Wadi bani Gahafir(MAHBAB) | Rustaq   | 23 27 28.5’           | 57 04 59.0’            |
| KW          | Wadi bani Gahafir(KHADA) | Rustaq   | 23 25 20.9’           | 57 17 56.2’            |
2.2 Gamma-Ray spectroscopy

The most common detectors in gamma spectroscopy systems are Thallium activated Sodium Iodide (NaI), Lanthanum Bromide (LaBr) and High Purity Germanium (HPGe). The resolution of each detector is different. Resolution of the spectra refers to the sharpness of peaks in a spectrum. The HPGe detector shows narrow and sharp energy lines as shown in figure (1) [5].

![Figure (1): Resolution of most common detectors](image)

A Germanium detector is a semiconductor diode in which the intrinsic region is sensitive to ionizing radiation. The digital signal or spectrum can be analyzed using a personal computer and a Software program called (GENIE 2000). The schematic sketch in figure (2) shows the detection System of γ radiation.

![Figure (2): The detection System of γ radiation.](image)

3. Results and Discussions

The maximum activity concentrations of main radionuclides in water $^{238}$U, $^{235}$U, $^{232}$Th and $^{40}$K were found all at maximum levels in HW1 sample with values $(1.69 \pm 0.10 \text{ Bq.L}^{-1})$, $(0.18 \pm 0.01 \text{ Bq.L}^{-1})$, $(0.17 \pm 0.02 \text{ Bq.L}^{-1})$ and $(0.91 \pm 0.01 \text{ Bq.L}^{-1})$ respectively. Whereas the lowest activity concentrations of
$^{238}$U (0.35±0.06 Bq.L$^{-1}$) was found in DW2, and the lowest concentrations of $^{235}$U, $^{232}$Th were found in (HW2) with (0.010±0.001 Bq.L$^{-1}$), (<DL) in 6 locations respectively. The results of the water samples showed that the activity concentrations of uranium were higher than thorium in all water samples figure (3). HW1 is a falaj sample where radionuclides have been presented in the water for long time and contaminated significantly from the soil comparing with sub-surface water which exists temporarily during the heavy rain only and for a short time.

Figure(3): Activity concentrations of main radionuclides in water samples

The values of the concentrations of the present study to be in the range of other studies and is below the recommended values by WHO [6] as shown in Table (2).

Table (2) Comparison of activity concentrations of natural radionuclides in this study with other studies from different countries

| Country                  | $^{232}$Th | $^{40}$K | $^{226}$Ra | $^{238}$U | References |
|--------------------------|------------|----------|------------|-----------|------------|
| Present study            | <DL - 0.17 | 0.26 - 0.91 | <DL - 3.25 | 0.35 - 1.69 | Present study |
| Oman, A'Dhahira          | 0.087      | 0.379    | 0.73       | 0.287     | [7]        |
| Oman, A'Dhahira          | 0.094      | 0.469    | 0.775      | 0.311     | [7]        |
| Yemen                    | 1.26       | -        | 3.5        | -         | [8]        |
| Saudi Arabia Western province | <DL - 3.3 | DL - 3.392 | <DL - 11.33 | 0.001 - 0.170 | [9]        |
| Saudi Arabia, Arar city  | 9 - 27     | 63 - 250 | 11 - 33    | -         | [10]       |
| Egypt                    | 0.05       | -        | 0.1        | -         | [11]       |
| Sudan                    | 9.19       | -        | 11.6       | -         | [12]       |
| Yemen-Ahomria            | 1.81       | <DL      | 4          | -         | [8]        |
| Bangladesh               | 0.256      | 9        | -          | 0.157     | [13]       |
| Bangladesh, Tarakandi    | 8.0E-04    | -        | -          | -         | [14]       |
| WHO                      | 0.6        | 10       | 1          | 10        | [6]        |
3.1 Variation of $^{238}$U series activities in water

The concentrations of this radionuclide are higher than WHO limit ($1\text{Bq.L}^{-1}$) in four water samples (figure 4). It reflects the geochemical controls on solubility and adsorption, its physical, chemical properties and variation of $^{226}$Ra formation in the terrestrial environment [7].

![Activity concentrations of radionuclides in $^{238}$U series in water samples](Figure 4)

The radionuclide $^{210}$Pb concentrations were recorded to be less than concentrations of $^{226}$Ra in all locations with a range of (DL – 0.72) Bq.L$^{-1}$. This occurred due to the mobility and short half-life of $^{210}$Pb compared to $^{226}$Ra. The isotopes $^{214}$Bi and $^{214}$Pb have the shortest half-lives which cause the fastest decay among all radionuclides in the series and this interpreted their lowest concentrations.

3.2 Variation of $^{232}$Th series activities

Two significant isotopes from $^{232}$Th series were observed in water samples, $^{232}$Th ($^{228}$Ac) and $^{212}$Pb. The minimum levels are less than the detection limit (figure5).
Figure (5): Activity concentrations of radionuclides in $^{232}$Th series in water samples

The concentrations of $^{40}$K were found to be higher than $^{232}$Th ($^{228}$Ac) concentrations in all water samples. This may be due to the very short half-life of $^{228}$Ac (6.13 hours). The activity concentrations of $^{235}$U are consistent with that of soil samples. Table (3) compares the activity concentrations of natural radionuclides in this study with other studies from different countries. It showed the values of the concentrations of the present study to be in the range of other studies and is below the recommended values by WHO.

Table (3): A comparison of different activity concentrations of water between different countries.

| Country                        | $^{232}$Th | $^{238}$U | $^{235}$U | References |
|--------------------------------|------------|-----------|-----------|------------|
| Present Study                  | <DL - 0.17 | <DL - 3.25| 0.35 - 1.69| Present study |
| Oman, A’Dhahiria               | 0.087      | 0.379     | 0.73      | 0.287      | [7] Ass | 3.3 |
| Oman, A’Dhahiria               | 0.094      | 0.469     | 0.775     | 0.311      | [7] ess |
| Yemen                           | 1.26       | -         | 3.5       | -          | [8] men |
| Saudi Arabia Western province  | <DL - 3.3  | DL - 339.2| -         | 0.001 - 0.170 | [2] ts of |
| Saudi Arabia, Arar city        | 9 - 27     | 63 - 250  | 11 - 33   | -          | [10] haxard |
| Egypt                          | 0.05       | -         | 0.1       | -          | [11] s in |
| Sudan                          | 9.19       | -         | 11.6      | -          | [12] wat |
| Yemen-Ahomria                  | 1.81       | <DL       | 4         | -          | [8] er |
| Bangladesh                     | 0.250      | 9         | -         | 0.157      | [13] |
| India                          | 8.0E-04    | -         | -         | -          | [14] |
| Bangladesh, Tarakandi          | 1.76       | 11.43     | 1.59      | -          | [17] |
| WHO                            | 0.6        | 10        | 1         | 10         | [6] |
Exposure to radiation can be defined in terms of many parameters, such as absorbed dose rate, annual effective dose, radium equivalent activity, Gamma representative level and internal and external hazard indices.

The external absorbed dose rate in air at a height of about 1 m above the ground was calculated by:

\[ D (\text{nGy.h}^{-1}) = 0.0417A_R + 0.462A_{Ra} + 0.604A_{Th} \quad \text{......... (1)} \]

According the annual effective dose received by a member in mSv.y\(^{-1}\) unit, the values obtained for the water samples were calculated using equation:

\[ H_R (\mu\text{Sv.y}^{-1}) = 8760 \times 0.2 \times 0.7 \times 10^{-6} \times D \quad \text{...............(2)} \]

The radium equivalent activity (Raeq) was calculated by equation:

\[ R_{eq} = 1.43A_{Ra} + 0.077A_K \quad \text{................................................. (3)} \]

The external, internal and gamma representative level hazard indices which are on concern due to their impact on people health were calculated using:

\[ H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad \text{.................................................................(4)} \]

\[ H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad \text{.......... (5)} \]

\[ I_{yr} = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \leq 1 \quad \text{......... (6)} \]

formulas respectively. Where \(A_{Ra}, A_{Th} \text{ and } A_K\) are the activities of \(^{226}\text{Ra}, ^{232}\text{Th} \text{ and } ^{40}\text{K}\) in Bq.kg\(^{-1}\), respectively [16].
Table (4): A comparison of different hazard parameters in water between different countries.

| Sample Code | D (nGy/h) | $H_{R,10^4}$ (mSv/yr) | $R_{aq}$ (Bq/L) | $H_{ex,10^3}$ (mSv) | $I_{p,10^{-3}}$ (Bq/L) | Category of water |
|-------------|-----------|------------------------|-----------------|---------------------|------------------------|------------------|
| Aw1         | 0.36      | 4.0                    | 0.53            | 3.0                 | 2.0                    | Rain water       |
| Aw2         | 0.26      | 3.0                    | 0.83            | 4.0                 | 2.0                    | Well water       |
| Hw1         | 7.94      | 9.0                    | 3.56            | 180                 | 460                    | Falaj water      |
| Hw2         | 0.32      | 4.0                    | 0.44            | 2.0                 | 2.0                    | Rain water       |
| Iw1         | 0.44      | 5.0                    | 0.93            | 5.0                 | 3.0                    | Rain water       |
| Iw2         | 0.26      | 3.0                    | 0.51            | 3.0                 | 2.0                    | Rain water       |
| BW          | 0.24      | 3.0                    | 0.81            | 4.0                 | 1.0                    | Rain water       |
| Fw          | 0.46      | 6.0                    | 0.11            | 1.0                 | 3.0                    | Rain water       |
| Dw1         | 0.50      | 6.0                    | 1.85            | 9.0                 | 3.0                    | Rain water       |
| Dw2         | 0.22      | 3.0                    | 1.14            | 6.0                 | 1.0                    | Rain water       |
| Mw          | 0.21      | 6.0                    | 0.02            | 5.0                 | 1.0                    | Rain water       |
| Kw          | 0.27      | 3.0                    | 1.25            | 6.0                 | 2.0                    | Rain water       |
| Oman, A’Dhahira[7] | 0.04 | 5.1                    | 0.87            | -                   | 2.4                    | well water       |
| Oman, A’Dhahira[7] | 0.418 | 6.2                    | 1.06            | -                   | 0.10                   | Tap water        |
| Oman, A’Dhahira[7] | 0.26 | 3.2                    | 0.53            | -                   | 1.5                    | Falaj water      |
| Saudi Arabia[10] | 30   | 370                    | -               | 230                 | 170                    | Well water       |
| Yemen[8]    | -         | 36                     | 6.6             | -                   | -                      | Well water       |
| NorthMalaysia [12]| 13.7 | 21.78 | - | - | Tap water |
| Bangladesh[14]| -       | 254.14 | - | - | Tap water |
| Egypt[13]   | -         | 7.13                   | -               | -                   | -                      | Well water       |
| Worldwide[6] | 18 - 93  | 0.1                    | 370             | <1                  | <1                     | WHO              |

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