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Evaluation of Gamma Radiation Exposure and Associated Health Risks for Visitors in Hormozgan's Hot Springs, Iran

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ABSTRACT

Introduction: Naturally occurring ionizing radiation is present throughout the Earth's environment, both on the surface, underground, and in the air. Hot springs, renowned for their therapeutic benefits, are popular destinations for hydrotherapy worldwide. However, these hot springs often contain radon and other radioactive elements in their water, sediments, and surrounding soil, making them potential sources of radiation exposure. Despite this, no prior research has assessed the radiation risks or estimated the annual effective doses to internal organs from Hormozgan's hot springs. This study aims to measure gamma radiation levels in these hot springs to fill this critical knowledge gap.

Material and Methods: In this cross-sectional study, radiation levels were measured using the RADDIGI 3000 C, a Geiger-Muller survey meter designed for environmental monitoring. Readings were taken at a height of 1 meter above the water surface, with dose rates recorded hourly.

Results: Our findings revealed that Khest hot spring 3 exhibited the highest gamma radiation dose rate, with values ranging from 2.31 to 4.2 µSv/h (mean: 3.2 µSv/h, SD: 0.17). In contrast, Momadi hot spring had the lowest recorded levels, ranging from 0.06 to 0.13 µSv/h (mean: 0.095 µSv/h, SD: 0.005). The results demonstrate that Khest hot spring 3 presents a significantly higher gamma radiation risk compared to all other hot springs examined in this study.

Conclusion: This gamma dose rate is comparable to levels recorded in Ramsar, northern Iran, a region globally recognized for its elevated natural background radiation. To mitigate potential health risks for swimmers and local populations, regulatory measures and protective policies should be implemented by regional authorities.

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Introduction

Natural ionizing radiation is omnipresent throughout various environmental compartments: terrestrial, subsurface, and atmospheric domains. Human populations are routinely subjected to environmental radiation exposure through dual pathways: external irradiation and internal incorporation via ingestion (food and water consumption) and inhalation. The studied hot springs are considered one of the world's hydrotherapy centers for their healing properties, inherently contain radioactive constituents, particularly radon and its progeny, within their aqueous, sedimentary, and pedological matrices [1, 2].

Humans are increasingly concerned about the stochastic effects of ionizing radiation from natural radionuclides. In the Earth's crust, natural radionuclides are widely distributed and have a significant influence on geological conditions. Two types of contamination can be classified. Internal radiation contamination consists of radon, and environmental gamma radiation consists of cosmic and terrestrial radiation [3, 4]. Human exposure to characteristic radiation sources, in particular radon and its constituents, is approximately 2.4 mSv (millisievert) per year, with nearly one mSv attributable. Moreover, a natural effect of 0.06 millisieverts per year is observed in food and water. Furthermore, it is interesting to note the variation in exposures between regions [5, 6].

The results of an indoor study of ^{222}Rn and ^{220}Rn in hot springs are presented, and the effective doses caused by inhalation of radon decay products are estimated. In the end, we measured gamma radiation from radionuclides in the hot spring of Hormozgan. In indoor air, radon emissions from water contribute to the total risk of inhalation of radon. In addition, there is radon in drinking water, which has been dissolved and will expose sensitive cells of the stomach or other organs when absorbed into the bloodstream to radiation generated by radon and its radioactive decay products [7]. Because of this concern, the EPA suggested that water around 11 Bq L^{-1} should be at

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the highest possible contaminant level for radon [8]. In the meantime, the IAEA stated that the radon concentration to which the public and workers are exposed is not more than 300 Bq.m and 1000 Bq.m according to the IAEA (International Atomic Energy Agency) safety series number GSR (General Safety Requirements) Part 3 [9, 10].

For years, people around the world have enjoyed natural hot springs for both tourism and health benefits. West Java, with its many volcanoes, is one of Indonesia's top destinations for hot spring tourism. Every year, around 1.8 million visitors come to the province to experience its hot springs [9]. Assessing radiation risks requires evaluating multiple factors, including calculating cancer risk a key consideration for hot springs. To ensure public safety from radiation exposure, it's essential to study how much ^{222}Rn (radon) from natural hot springs contributes to overall radiation doses [11]. Despite their popularity among locals, Hormozgan's hot springs have never been evaluated for radiation risks or the potential annual radiation doses their minerals may deliver to internal organs. Given this gap, conducting radiation measurements and expanding our understanding is crucial. This study focuses on assessing gamma radiation levels and predicting health risks for swimmers at select hot springs in Hormozgan, Iran.

Materials and Methods

The equipment used for this cross-sectional study includes the RADDIGI 3000 C Geiger-Muller environmental radiation measurement device, which includes a digital display and can display the dose rate from 0-19.99 millisieverts. The dosimeter was calibrated by the Atomic Energy Organization's Standard Reference Laboratory, SSDL. It displays the dose rate in the air in real-time according to the specified µsv/h. To carry out this study and determine the dose in the hot springs of Hormozgan, it was measured at different stations. After choosing the station, the dosimeters were placed on tripods at a height of one meter from the surface of the water (in hot springs) and every minute for one hour, using the amount of received dose, the average dose rate was determined and recorded. After determining the dose rate, the effective dose for each organ is determined based on the sensitivity of different tissues. It should be noted that eleven hot springs were investigated, which are Bostano, Momadi, Angoran, Nimekar Siah Kosh, Khamir, Khest, Todroyeh Bastak, Anveh Bastak in the west of the province, Geno, and Khorgo hot springs in the north of the province, Raveng Minab in the east of the province (Figure 1).

Figure 1. The view of Bostano and Khest hot springs

Results

The results show that the gamma radiation dose rates varied across different sampling locations. At Khest hot spring, the measured dose rates were 0.6–0.94 µSv/h (mean: 0.85 µSv/h, SD (Standard Deviation): 0.1) for Site 1, 1.3–2.22 µSv/h (mean: 1.8 µSv/h, SD: 0.084) for Site 2, and 2.31–4.2 µSv/h (mean: 3.2 µSv/h, SD: 0.17) for Site 3. Similarly, at Bostano hot spring, the dose rates were 0.9–1.5 µSv/h (mean: 1.2 µSv/h, SD: 0.05) at the hot spring source, 1.23–1.37 µSv/h (mean: 1.32 µSv/h, SD: 0.01) at the water collection point, and 2.7–3.5 µSv/h (mean: 3.1 µSv/h, SD: 0.07) near the pool entrance. Meanwhile, Momadi hot spring exhibited significantly lower radiation levels, with dose rates ranging from 0.06–0.13 µSv/h (mean: 0.095 µSv/h, SD: 0.005). The measured gamma radiation dose rates across the studied hot springs were as follows: At Siahkosh Nimekar hot spring, dose rates ranged between 0.2-0.3 µSv/h (mean**:** 0.25, SD**:** 0.009) across various stations, while Angoran hot spring showed slightly lower levels of 0.15-0.25 µSv/h (mean**:** 0.2, SD**:** 0.009).

Table 1. The dose rate of hot springs in Iran

The name of the hot spring	Dose rate(µsv/h)	The name of the hot spring	Dose rate(µsv/h)
Mazandaran Province		Hormozgan Province	
Vazirgarma	0.32	Khest Bastak 1	0.85
Javaher deh	0.12	Khest Bastak 2	1.8
Estakhre tebbi	0.3	Khest Bastak 3	3.2
Larijan	0.32	Bostano 1	1.2
Ask	0.15	Bostano 2	1.32
Asterabko	0.3	Bostano 3	3.1
Larij	0.25	momadi	0.095
Emarat	0.12	Siahkosh Nimekar	0.25
Amolo	0.17	Angoran	0.2
Mozdaran	0.15	Todrouyeh Bastak 1	0.35
Ardabil Province		Todrouyeh Bastak 2	0.35
Sarein	0.17	Todrouyeh Bastak 3	0.65
Khorasan Province		Todrouyeh Bastak 4	1.1
Ferdos	0.2	Todrouyeh Bastak 5	0.2
Shahin garma	0.87	Anveh Bastak	0.27
Abtorsh Sarbisheh	0.27	Khamir	0.19
Ramsar Province		Raveng Minab	0.19
Bonyad	0.25	Khorgo 1	0.16
Sepid dasht	4.5	Khorgo 2	0.16
Ab Siah	2.3	Geno	0.22
Talesh Mahale	6.2		

Todrouyeh Bastak hot spring exhibited particularly interesting variations, with Station 1 and 2 both measuring 0.3-0.4 µSv/h (mean**:** 0.35, SD**:** 0.009), Station 3 showing increased levels of 0.6-0.7 µSv/h (mean**:** 0.65, SD**:** 0.009), and Station 4 recording the highest readings of 0.9-1.3 µSv/h (mean**:** 1.1, SD**:** 0.03). The water collection point at this hot spring measured 0.2 µSv/h. Anveh Bastak hot spring's Station 1 registered 0.2-0.3 µSv/h (mean**:** 0.27, SD**:** 0.009), while Khamir hot spring's Station 1 showed the lowest radiation levels among all sites at 0.11-0.22 µSv/h (mean**:** 0.19, SD**:** 0.01). At Raweng Minab hot spring, Station 1 showed radiation levels ranging from 0.13 to 0.22 µSv/h, with a mean of 0.19 µSv/h (SD**:** 0.008). Khorgo hot spring exhibited similar radiation at both its water collection point (0.11-0.19 µSv/h; mean**:** 0.16, SD**:** 0.007) and pool outlet (0.13-0.19 µSv/h; mean**:** 0.16, SD**:** 0.005). The Geno hot spring pool displayed slightly elevated radiation compared to these sites, measuring 0.19-0.25 µSv/h (mean**:** 0.22, SD**:** 0.005) (Table 1).

Discussion

This study showed that the radiation level of Khest and Bostano hot springs is higher than all of the other hot springs of Iran that have been studied so far, except the hot springs of Sepid Dasht and Talesh in Ramsar. The high background radiation of these hot springs is caused by the elements of radium, radon, thorium, and uranium. These hot springs have second place in the country in terms of radiation after the two hot springs of Ramsar hot spring. The reason for the radiation of the hot spring is the passage of water through different layers of the earth and the deposition of radioactive substances in it.

Radon dissolves in water that passes through soil and rock containing the natural radioactive substance [12, 13]. Moreover, the increased levels of radon and other natural radioactivity are drawn up by water flowing from deep inside the earth's crust. When the temperature and pressure in geothermal systems rise sufficiently to allow these waters to flow out of cracks and fissures, they reach the earth's surface as hot springs. High concentrations of ^{222}Rn are normally found in hot spring water under these conditions. This could be explained by at least one of two natural processes: when ^{226}Ra is absorbed into water after interaction with rock and soil in the ground, ^{222}Rn enters groundwater originating from rocks that contain ^{226}Ra [13, 14].

Hot springs, even those found in non-volcanic regions, are primarily the result of water interacting with deep hot rocks beneath the Earth's surface. This interaction is facilitated by the geothermal gradient, which indicates that the temperature of rocks increases with depth. When water penetrates sufficiently into the Earth's crust, it encounters these hot rocks and can rise to the surface, forming hot springs. The heat generated by these hot springs is large due to the decay of radioactive isotopes such as Uranium 238, 235, Potassium 40, and Thorium 232, which are found within the mantle. These isotopes are responsible for 90 percent of the Earth's interior heat. However, the radioactivity of hot springs is not solely a result of the mantle's radioactive elements [15]. The crust, where hot springs are more commonly found, contains higher concentrations of uranium, thorium, and potassium compared to the mantle. These elements are strongly attracted to solid rock, and their concentrations in the crust are higher in the mantle. In certain specific areas, hot springs exhibit elevated radiation levels due to the presence of radium, thorium, and uranium. For instance, the hot springs of Ramsar, Iran, with radiation levels ranging from 55 to 200 times higher than the norm, marking it as the highest natural radiation site globally. This high radiation is attributed to radium dissolved in the mineral water, elevated thorium levels in travertine deposits, and the presence of uranium. Radon gas, originating from granite rocks containing uranium, can also be detected in hot spring water. Although radon is a major radiation source, it typically appears in minuscule amounts and is quickly lost from the water [16].

Salt domes are a fascinating geological feature found across various regions in Iran, including Kerman, Azarbaijan, and Semnan provinces. These formations are not confined to a single area but are widespread. Some salt domes contain radioactive materials that are indicated by their natural radiation levels. Among the over 100 salt domes in the North-East of Bandar Abbas to the West of Kazerun, only a few have been researched. The Gachin salt dome, located in the southern part of this area, is particularly noteworthy for its radioactive content. It spans approximately 100 square kilometers and rises about 300 meters above sea level. The primary rock type in this dome is rhyolite, and the active minerals are concentrated within the slate layers. A cross-sectional analysis reveals a block layer containing rhyolite. The region has been found to contain various radioactive minerals, including Uraninite (UO_2), Pitchblende (UO_2), Compreignacite ($H_2U_60_{19}$.11 H_{20}), Becquerelite (CaU_6O_{19}.11 H_{20}), and Schopeite (UO_3•2H_{20}) [17].

Hot springs are widespread around the world, with some containing warm water rich in radon. These hot springs are often utilized by the public for both medical and recreational purposes. However, radon gas from these water sources can easily escape into the atmosphere, leading to higher radon concentrations indoors and outdoors compared to normal conditions. Whether seeking therapeutic benefits or simple relaxation, hot spring users receive radiation both externally and through inhaling radon gas. The radioactive particles from radon decay can accumulate in lung tissue, creating cancer risks that warrant serious attention [18, 19, 20]. Ramsar's hot springs attract many visitors seeking their therapeutic benefits. The region boasts more than 50 hot springs, with radium concentrations varying from 1 to 130 Bq/liter. These hot springs maintain comfortable temperatures between 25-45°C. Notably, the local drinking water comes from a Ramsar reservoir containing minimal radium, just 2-3 mBq/m³ [21, 22, 23].

The research presents detailed gamma radiation dose rates and associated health risk assessments for tourists. It underscores the necessity of tracking radiation levels in frequently visited tourist destinations to safeguard visitor well-being. A study in South Khorasan revealed that the average gamma radiation dose in outdoor hot springs was considerably less than in indoor hot springs, with mean values falling below international safety thresholds. Specifically, the mean effective dose was determined to be under 0.5 mSv/year, suggesting a relatively secure environment for visitors [24]. Research conducted in Gachine indicated that the outdoor gamma radiation dose rates exceeded the global average, with particular locations such as Gachine Bala measuring rates as high as 78.87 nGy/h. This finding implies a possible health hazard for residents and visitors resulting from the increased radiation levels (1). A comprehensive investigation conducted in the Caspian coastal provinces revealed an average background gamma radiation dose of approximately 60.37 nSv/h (0.53 mSv/year). This is consistent with global averages; however, it exhibits considerable variation when compared to regions such as Ramsar, which are recognized for their elevated natural background radiation levels [25]. In the mineral hot springs of Ardabil, gamma dose rates were recorded to range from 103.0 ± 3.1 to 201.0 ± 6.0 nSv/h in outdoor environments, whereas indoor measurements peaked at 260.0 ± 7.8 nSv/h. These findings indicate that exposure levels are influenced by both the particular location and the characteristics of the spring [27]. Research conducted in various countries reveals significant differences in background radiation levels. In Nigeria, studies indicate an average background radiation of approximately 0.53 mSv/year, which aligns with findings from Iran. Additionally, investigations in Egypt have shown that natural background radiation levels are lower than those observed in Iranian hot springs, implying that geological factors may contribute to regional variations [27].

Haghparast M, et al, and Bahreyni Toossi MT et al showed that Vazirgarma, Javaher deh, Estakhre tebbi, Larijan, Ask, Asterabko, Larij, Emarat, Amolo, and Mozdaran hot springs of Mazandaran city were 0.32 µsv/h, 0.12 µsv/h, 0.3 µsv/h, 0.32 µsv/h, 0.15 µsv/h, 0.3 µsv/h, 0.25 µsv/h, 0.12 µsv/h, 0.17 µsv/h, and 0.15 µsv/h. The Sarein hot spring of Ardabil city was 0.17 µsv/h. Ferdos, Shahin garma, and Abtorsh Sarbisheh hot springs of Khorasan city were 0.2 µsv/h, 0.87 µsv/h, and 0.27 µsv/h. Bonyad, Sepid dasht, Ab Siah, and Talesh Mahale hot springs of Ramsar city in Mazandaran were 0.25 µsv/h, 4.5 µsv/h, 2.3 µsv/h, and 6.2 µsv/h. In this study, it has been found that, except for Sepid Dasht and Talesh's hot spring in Ramsar, the radiation from Khest and Bostano is higher than any of the rest of Iran's hot springs investigated so far [1, 2] (Figure 2).

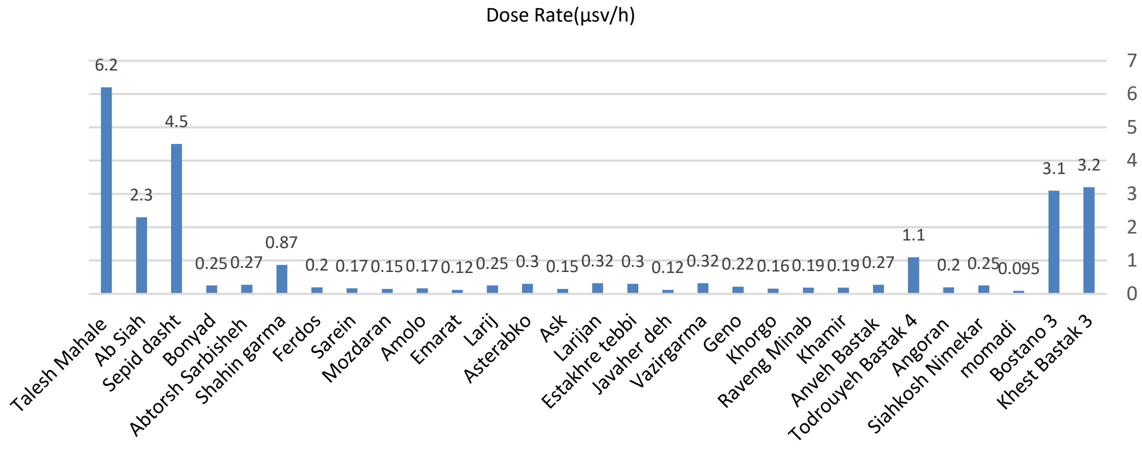

Figure 2. The comparison of hot springs in Hormozgan province and other hot springs in Iran

In addition to these, the presence of salt domes and diverse radioactive substances in the west of Hormozgan province caused high-level background radiation, and due to the presence of these salt domes and diverse radioactive substances, the hot springs in the west of the province, such as Khest and Bostano, compared to the hot springs in the north and east of Hormozgan province, such as Geno, Khorgo, and Raweng, show much higher values. Due to the presence of sulfur and other minerals, people usually use these hot springs for skin and joint diseases.

In addition, some of these hot springs are used as a recreational complex, which can increase external and internal radiation. The effective dose of red bone marrow and gonad were 2.56 µsv/h and 2.59 µsv/h for Khest hot spring. Also, the effective dose of red bone marrow and gonad were 2.48 µsv/h and 2.51 µsv/h for the Bostano hot spring.

The evaluation of gamma radiation in the hot springs of Hormozgan uncovers a multifaceted array of exposure risks that differ markedly across various regions in Iran and from international benchmarks. Certain locations demonstrate minimal radiation levels deemed safe for visitors, whereas others pose elevated risks that require continuous monitoring and attention to public health. It is crucial to conduct localized research to guarantee the safety of visitors and to manage health risks effectively in these natural settings.

The limitation of this study is the limited number of studies on the radioactivity of the hot springs in Iran and in the world, which makes it difficult to compare the gamma radiation level of the hot springs in Hormozgan province and other hot springs. Most of the local people consider the hot springs as sacred and a place of healing, and they are used to treat most diseases, including back pain, muscle cramps, lumbar disc protrusion, Rheumatoid arthritis, skin disease, disk rupture, etc. It is suggested that more studies will be conducted in the field of gamma radiation of hot springs in all regions of Hormozgan, all of the city of Iran, and even the world, so that the residents of the neighborhood are aware of its radioactive nature and reduce its exposure.

Conclusion

This study revealed that Khest Hot Springs 3 exhibited the highest gamma radiation levels among all studied sites. The measured dose rates were comparable to those found in Ramsar, northern Iran, a region globally recognized for its naturally high background radiation. Given these findings, local officials should implement protective measures to minimize health risks for swimmers and visitors exposed to these radiation levels.

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