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Original paper

Establishing the range of background for radon variations in groundwater along the Serghaya fault in southwestern Syria

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Resumen

Se midió la presencia a largo plazo de radón en el agua en dos manantiales kársticos que salen de la zona de falla de Serghaya en el suroeste de Siria. El objetivo de este trabajo es determinar el rango ambiental del radón a lo largo de dicha falla, lo cual en la región representa una rama promimete en el sistema de fallas de Mar Muerto. Se analizaron los datos obtenidos de forma estadística y los valores medios de radón fueron estandarizados en términos de probabilidad de magnitud, con la finalidad de permitir distinguir entre las variaciones normales de radón y las de otros valores anómalos o geotecnónicos. Los resultados revelaron una gama ambiental general de la concentración de radón que varía entre 5.000 y 13.000 Bqm^{-3} y, por lo tanto, todos los valores de radón que se encuentran fuera de este intervalo se consideraron anómalos. Sin embargo, existen ramas de altas concentraciones de radón con valores pico de más del doble a nivel de fondo; pudieron observarse durante el monitoreo en ambos muelles durante el periodo de 1992 a 1994. Estos valores anormales de radón se correlacionaron positivamente al momento de altas precipitaciones, y no se registró actividad sísmica durante este período. Por lo tanto, los cambios en la tensión de la cortesa no parecen verse reflejados en las concentración de radón, sino que la mayoría se debe a las altas precipitaciones. Lo anterior confirma la utilidad de la aplicación de radón como un importante indicador natural en investigaciones hidrogeológicas.

Palabras clave: Radón ambiental, agua subterránea, primavera kárstica, Falla de Serghaya, Syria

Abstract

Long-term groundwater radon measurements were carried out in two selected karstic springs emerging from the Serghaya fault zone in southwestern Syria. The work is aimed at determining the range of radon background along the concerned fault, which represents a prominent branch segment of the Dead Sea Fault System in the region. The obtained data was statistically analyzed and the mean radon values have been standardized in terms of probability of magnitude in order to enable the separation between normal radon variations from other anomalous or geotectonic related values. The results revealed a general background range of radon concentration varying between 5000 and 13000 Bqm^{-3}, and thus all radon values lying outside this range were considered anomalous. However, remarkable clusters of high radon concentrations with peak values more than twice times the background level, were observed in both monitoring springs through the period (1992-1994). These abnormal radon values were positively correlated with simultaneous time of high precipitations, while no significant earthquake activities were recorded in the region during that period. Therefore, such radon signals do not seem to be a reflection of regional changes in crustal strain, but rather they mostly indicate evidences of radon response to the groundwater table fluctuations due to high precipitations. These consequences may confirm the usefulness of radon application as an important natural tracer in hydrogeological investigations.

Key words: Radon background, groundwater, karstic spring, Serghaya fault, Syria

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Introduction

The western margins of the Arabian Plate are represented by an active divergent boundary of the Red Sea and the left lateral Dead Sea Fault System (DSFS) that extends for about 800 km from the Gulf of Aqaba in the south to the Taurus Mountain in southern Turkey. The system ranks among the largest strike-slip faults in the world and represents a key element of the Eastern Mediterranean tectonic framework (Barazangi *et al*., 1993; Brew *et al*., 2001). As the (DSFS) continues its way towards Lebanon and western Syria, it follows a great restraining bend that consists of several outstanding active segments including the Yammouneh fault (YF) and the Serghaya fault (SF). This study focuses mainly on the (SF), a remarkable branch of the (DSFS) cutting through the Anti-Lebanon ranges, with local deflection towards northeast (Figure 1).

Radon isotope (^{222}Rn), for simplicity called "Radon" in the following, is a daughter nuclide of radium (^{226}Ra), which in turn is produced from the decay series of uranium (^{238}U). As a naturally occurring radioactive gas, radon is widely utilized in various fields of earth sciences, such as hydrogeological studies Pane et al., 1995; Han et al., 2006; Surbeck, 2007); detecting buried active faults (Baubron et al., 2002; Al-Hilal and Al-Ali, 2010) and monitoring seismic activities (Teng, 1980; Kuo et al., 2006; Erees et al., 2007). Furthermore, radon method is commonly used in most uranium exploration programmes due to its efficiency, low cost and simplicity (Dyck, 1975; Gingrich, 1984; Jubeli et al., 2000).

The first national programme for correlating radon variations with seismic records of Syria began in 1992 and the results of those studies have been reported (Al-Hilal and Mouty, 1994). Afterwards, periodical radon measurements, based on monthly intervals, were continued during the nineties of the last century in western Syria (Al-Hilal *et al*., 1998). Further groundwater radon measurements were resumed during the years from 2007 to 2009 with particular focus on the Serghaya fault as

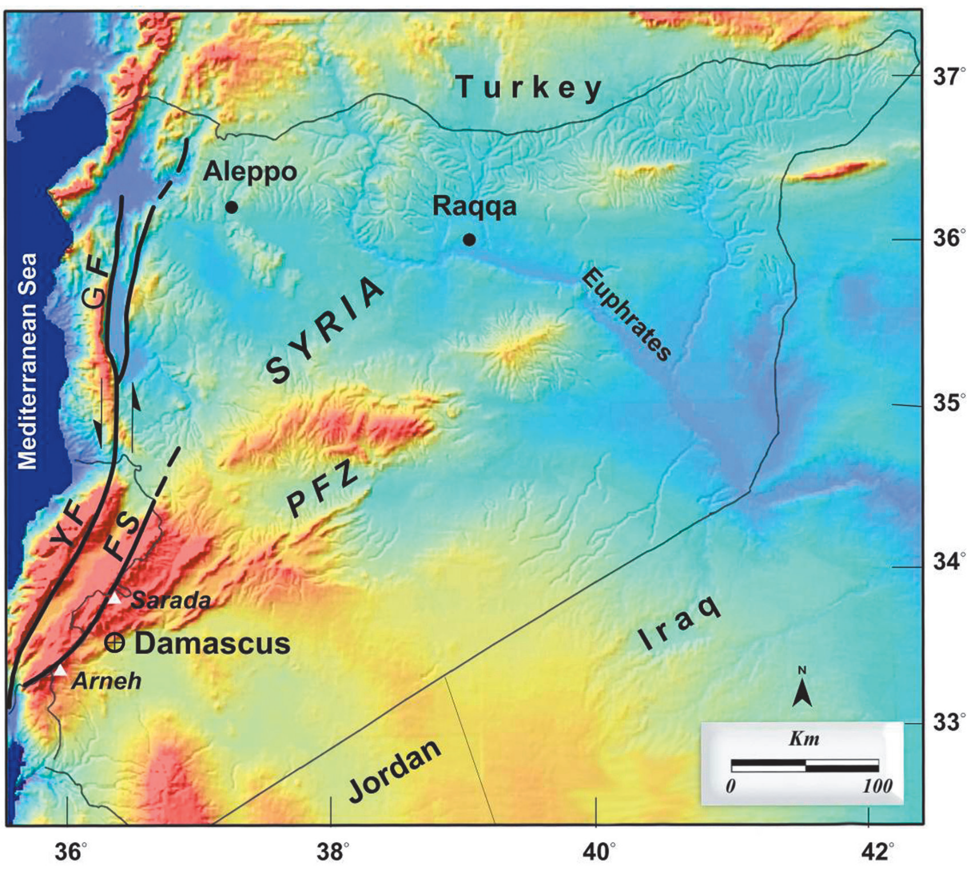

Figure 1 A location map showing the sites of *Arneh and Sarada* radon monitoring stations in southwestern Syria. Abbreviations; SF: Serghaya Fault, YF: Yammouneh Fault, GF: Ghab Fault, PFZ: Palmyride fold zone.

a unique active structural component of the (DSFS) in southwestern Syria. Considering the limited capability at this period of the radon monitoring programme in the country, it could be more reasonable to orient the efforts towards establishing the background of radon changes in groundwater as a range rather than as an absolute value. Such efforts would also help to set up an accessible data bank that may assist in evaluating the real potential hazard along the concerned fault and thereby reducing seismic risk in the region. Accordingly, the main objective of this study is to make use of the available set of radon data for setting the range of background for radon variations in groundwater along the Serghaya fault zone. The estimated range of background is regarded to be a significant step in the radon-monitoring programme, as it may assist the distinction of usual groundwater radon changes from other anomalous values that might be caused by either geotectonic disturbances or other hydrogeological and environmental factors.

Tectonic setting of the Serghaya fault zone

The Serghaya fault represents a major tectonic feature in Syria that can be traced approximately 120 km from the Golan Heights in southwestern Syria, traversing through the Syrian–Lebanese border to the eastern edge of the Bekaa Valley of Lebanon.

As a unique seismically active structure evinced by many historical catastrophic earthquakes, the northeast trending Serghaya fault attracted the interest of international earth scientists in the last decade who studied the tectonic evolution and the paleoseismicity of the region compiling various techniques (Ambraseys and Barazangi, 1989; Gomez *et al*., 2003). One of the main results of these researches reveals that the Serghaya fault is probably active and capable of generating large earthquakes in the future. These findings were based on extensive geologic observations and geomorphologic evidences of active

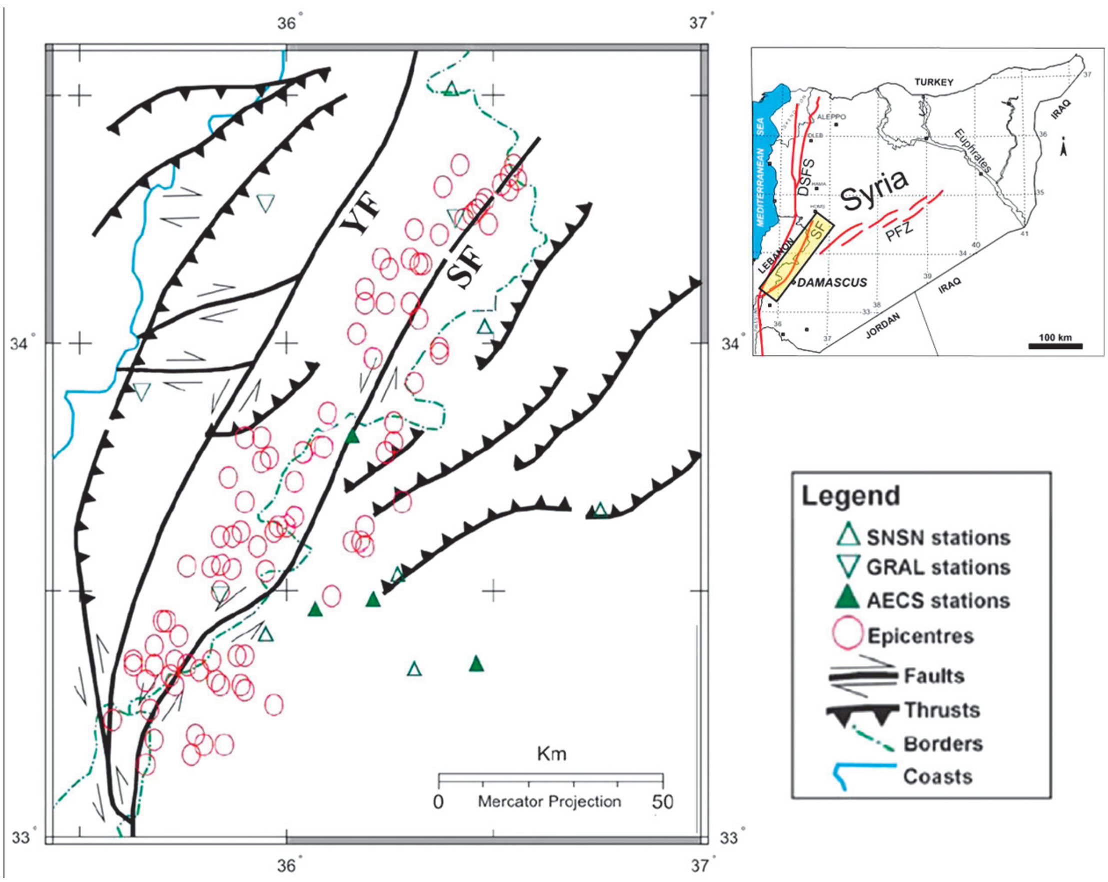

Figure 2. Distribution of earthquake epicenters (red circles) occurred on (SF) zone during the period 1995-2009. The triangles stand for the seismic stations of three networks: Syrian National Seismological Network (SNSN), Atomic Energy Commission of Syria (AECS), and Geophysical Research Arrays of Lebanon (GRAL). (Modified after Asfahani and Abdul-Wahed (2013)).

tectonics along the fault zone including large stream valley deflections, fault scarps and faulted recent alluvial deposits (Gomez *et al*., 2001). Thus, the concerned fault should be an essential element in any regional seismic hazard assessment, particularly with its close proximity to Damascus (30 km) and Beirut (60 km), two highly populated and cultivated cities.

On the other hand, Asfahani and Abdul-Wahed (2013) carried out a recent study based on the analysis of instrumentally observed earthquakes that occurred on Serghaya fault during the period (1995-2009). They found that little number of low magnitude events characterizes the Serghaya fault, with the biggest earthquake recorded during their study period not exceeding magnitude 3.9. Thus, they concluded that the fault might pass through a seismic quiescence extending from 1900 up to now, in comparison to other active branch segments of the (DSFS) such as the Yammouneh fault (Figure 2).

For that reason, there are only very limited data available on the application of radon measurement technique as an earthquake precursor along the concerned fault, except for the previous attempts made by the author (Al-Hilal and Mouty, 1994; Al-Hilal *et al*., 1998). The lack of such information is mostly due to the state of inactivity, which specifically characterized the (SF) zone at this current period. Nevertheless, radon monitoring technique has been extensively used elsewhere in the world for gaining additional information on precursory performance (Teng, 1980; Kuo *et al*., 2006). In addition, the tectonic influence of variable stress on underground radon concentrations has been successfully proved in several seismic regions throughout the world (Tansi *et al*., 2005). Radon concentrations may change in response to crustal motion, such as compression, expansion and tilting of the ground prior to and during an earthquake event. Such movements would be expected to form new microfractures and cracks and cause changes in the groundwater flow system with deformation of the water-bearing layers near the radon monitoring site (Choubey *et al*., 2007; Erees *et al*., 2007). These processes may enhance the release of radon from original rocks, and thereby increase its level in the groundwater. However, there is always a probability for false prediction, as radon increases do not conclusively prove a definite relation with earthquake activities. Therefore, radon changes in groundwater may be used only as an indicator of a regional stress build-up, and thereby a possible earthquake precursor.

Geological setting

Sedimentary and some volcanogenic rocks of Jurassic, Cretaceous, Paleogene, Neogene and Quaternary ages are the main geological formations exposed in the study area (Ponikarov, 1963). However, Jurassic and Cretaceous massive layers of limestone, dolomitic limestone and dolomite are the most common deposits that predominantly outcropped throughout Mount Harmon (2814 m. a. s. l) and Anti-Lebanon Chain Mountains in southwestern Syria. In view of that, two major lithological-stratigraphical successions of Jurassic and the Middle Cretaceous thick carbonate strata have extensively evolved into karstic aquifers in the region (Burdon and Safadi, 1965).

The general geology of the Sarada spring site consists mainly of a thin cover of sandy loams belonging to the Quaternary that underlain conglomerates and sands of Neogene age. The site is surrounded by a set of ring faults, separating the spring site from other older outcrops of karstified limestone and marl strata of Cretaceous age (Fig. 3).

The site of Sarada spring is also bounded from the south by the Zabadani Valley, which is characterized by flat and gently dipping alluvial pebble beds and sandy clays of the Quaternary. Thick Cretaceous and Jurassic calcareous sequences underlie these formations uncomfortably. On the other hand, the rock exposures in the site of Arneh spring are mainly represented by Jurassic fractured complex aquifer of intensively thick karstified limestone and dolomite formations. Besides, evidence of past tectonic deformations such as extrusive volcanic dikes and steeply dipping faulting and V-shaped valleys can be also observed at the vicinity of the site of Arneh spring (Figure 4).

Finally, it is worth mentioning that the geological formations of the survey region, including the area of the Serghaya fault zone and its surroundings, are generally characterized by a notable decrease of radioactivity level due to the lack of any natural radioactive source such as igneous acidic rocks or other uraniferous formations. In view of that, radon concentration in soil gas measured in some geological outcrops in the close vicinity of Sarada and Arneh springs, were found to be generally low and varying between 3500 and 5000 Bqm^{-3} for the Quaternary sediments and recent soil cover; and from 1300 to 1500 Bqm^{-3} for limestone rocks. Furthermore, the result of chemical analysis, using γ-ray spectrometric

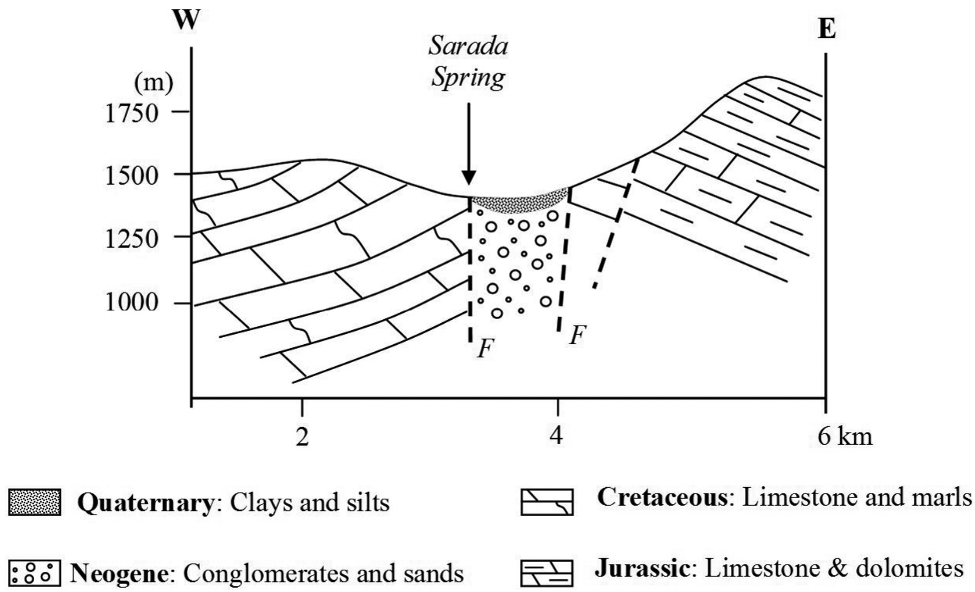

Figure 3. Geological cross-section through *Sarada* radon monitoring station. The dashed line is the position of the proposed fault (*F*).

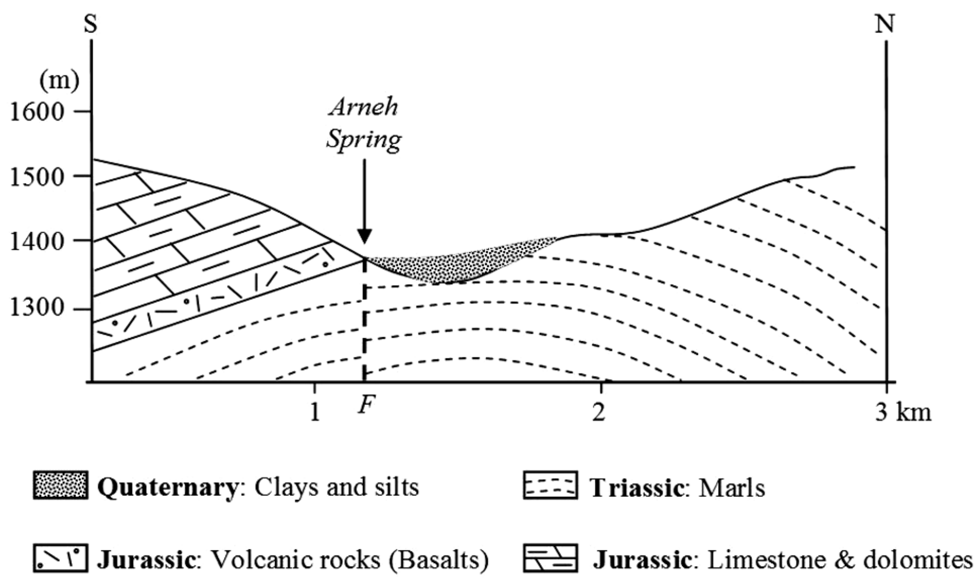

Figure 4. Geological cross-sections through *Arneh* radon monitoring station. The dashed line is the position of the proposed fault (*F*).

technique, for radium (^{226}Ra) concentration in water samples taken from Sarada and Arneh springs revealed low average values of 2±0.5 Bqm^{-3} and 2±1 Bqm^{-3} respectively.

Hydrogeochemical properties of the monitoring springs

Two main karstic springs, namely Sarada and Arneh were selected for long-term radon monitoring in groundwater along the Serghaya fault zone in southwestern Syria (Figure 1). The locations of these springs have been chosen according to data from the historical seismicity of Syria, (Sbeinati *et al*., 2005); geologic and geomorphologic evidences of active tectonics in the concerned area as reported by Gomez *et al*. (2003) as well as a detailed hydrogeological isotope survey in Damascus basin carried out by Kattan (1997).

Sarada monitoring station, (36°.16’E, 33°.80’N), represents a karstic spring emerging from Cretaceous carbonate strata on the northern side of the (SF) segment, 35 km northwest of Damascus, with altitude of 1380 meter above sea level (m.a.s.l). The Sarada aquifer exhibits circuit spring water that is characterized by a calcium-magnesium and bicarbonate water type (Ca-Mg-HCO_3). The hydrochemical properties of the Sarada spring revealed a quite fresh water since the total dissolved solids (TDS) equal 404 mg l^{-1}, the dominant pH value is 7.58, with average temperature of 13 °C and general electrical conductivity (E.C.) value of 473 μScm^{-1}.

Arneh station, (35°.88’E, 33°.36’N), is also a natural karstic spring emerging from Jurassic massif fissured rocks on the southern part of the (SF), at the centre of the Mount Hermon, 45 km southwest of Damascus, with altitude of 1358 (m.a.s.l). A calcium-magnesium and bicarbonate type also distinguishes the groundwater of Arneh spring, which is typically characterized the karstic aquifers in the area. The main hydrochemical parameters of the spring reveal fresh water with total dissolved solids (TDS) of 141 mg l^{-1}, 7.58 pH value, average temperature of 12 °C and general E.C. value of 222 μScm^{-1}.

Studying some major karst springs in Damascus limestone aquifer systems, Kattan (1997) found that groundwater bodies of most karst springs emerging from Anti-Lebanon mountain chain in southwestern Syria are mainly originated from direct infiltration of meteoric precipitation in the exposure zones with a strong positive relationship between infiltrated water of rainfalls and discharges. Further, the karstic aquifers in the region, including Sarada and Arneh springs, are characterized by the occurrence of fractures, conduits, sinkholes, caves and other karstified calcareous layers with high flow velocities of and relatively short transit time for the infiltrated rainwater to approach chemical equilibrium with rocks (Burdon and Safadi, 1965; Bakalowicz, 2005). Such extensive network of solution cavities would provide pathways for facilitating the movement of significant bulk flow of soil gases including radon, which is naturally released from rock surfaces and moves into the surrounding fluids where it can migrate by the mechanism of diffusion and fluid transport due to the influence of pore-fluid circulation processes. Thus, groundwater that is in contact with the radium-bearing rocks and soil will be a receptor of radon emanating from the surroundings geological environment by means of permanent alpha recoil in micro-pore or fracture walls. Although the radium activity in groundwater seems to be very low in both monitoring sites, as mentioned previously, the surface rainwater may possibly remove the available radon produced in the surficial soil cover and transport it down into the karst aquifer. Additional source of probable radon feeding could be due to the mechanism of pushing out old waters, after a long dry period, by the new arrival of fresh waters taking a considerable amount of radon during its passage through permeable layers at shallow depth.

Materials and methods

The apparatus used for degassing radon in groundwater was “Model WG-1001 Vacuum Water Degassing System” manufactured by Pylon Electronics, Canada. The instrument is designed for accurate and rapid extraction of radon from water samples. In practice, a 190 ml water sample is transferred to a graduated cylinder with the bubbler valve closed. The system is evacuated with a hand pump and the gas is drawn through a closed-circuit from the water sample into a scintillation cell coated internally with silver-activated zinc sulphide (Figure 5). Five minutes bubbling period was found to remove about 75 % of the dissolved radon from a 190 ml sample. The radon sample must be allowed to decay inside the scintillation cell for about three hours after sampling so that the radon daughters come into equilibrium with the radon gas. After that, the scintillation cell is placed into the counter (RM-1003 Radon Detector), where the alpha activity is measured in counts per minute, and then converted to radon concentration. The counter was frequently calibrated during the survey, using a standard test cell containing a source of ^{226}Ra with known activity. The calibrations ensured an acceptable detection limit, and thus it is believed that the measurements may give reasonable determinations of radon concentration in groundwater. Additionally, it is important to point out that the noticeable low values of radon concentration in groundwater of the study area could be justified in general by the low corresponding values of radium (^{226}Ra) content found in water samples taken from the same springs. The chemical analysis for ^{226}Ra was performed using γ-ray spectrometric technique, and the results revealed concentration values of 2±0.5 Bqm^{-3} and 2±1 Bqm^{-3} for Sarada and Arneh spring waters respectively. As mentioned previously, the reason for the general decrease of radioactivity levels over the surveyed geological area is mostly referred to the lack of any natural radioactive source such as granites or other igneous acidic rocks.

Results and discussion

Table 1 summarizes the basic statistical characteristics of radon data, which were performed along the Serghaya fault during the nineties of the last century, besides the years 2007 and 2009. The analysis includes the main hydrochemical properties of the monitoring springs, besides the mean value of radon concentration ($\bar{x}$), standard deviation (σ) and the coefficient of radon variability (CV %), which reflects the degree of homogeneity, the higher the coefficient of variability, the lower the homogeneity of the radon values. The (CV %) value is examined for the degree of radon variability in each monitoring station separately through the following formula:

$$CV\% = (\sigma / x) \times 100 \qquad (1)$$

Where *CV* is the coefficient of variability, x is the mean value and σ is the standard deviation.

Radon concentration was sampled monthly for 89 and 70 times at Sarada and Arneh springs respectively. As the level of the measured radon concentration seemed to be quite variable, it was more realistic to view the radon background as a range rather than as an absolute value. For that reason, the abnormal radon values in both monitoring stations have been isolated, and the rest of the ordinary data were statistically analyzed in order to recognize a possible range of normal radon fluctuations in groundwater. In principle, the level of common

Table1. Radon and radium concentrations, besides some hydrochemical properties of two karstic springs emerging from the Serghaya fault zone, a branch of the Dead Sea fault system in southwestern Syria. Abbreviations; EC: electrical conductivity, TDS: total dissolved solids.

Monitoring Site	**Sarada Spring (33˚.80N, 36˚.16E)**	**Arneh Spring (33˚.36N, 35˚.88E)**
Geology of the aquifer	*Middle Cretaceous complex: karstified limestone, conglomerates and sands*	*Upper Jurassic complex: karstified dolomitic limestone, marls and basalts*
Altitude (m.a.s.l)	1380	1358
Number of radon samplings	89	70
Coefficient variability CV (%)	26	32
^{222}Rn mean value (Bqm^{-3})	8000±1500	9000±2000
^{226}Ra mean value (Bqm^{-3})	2±0.5	2±1
Water temperature (˚C)	13	12
PH value	7.58	7.96
E.C. (μScm^{-1})	473	222
TDS (mg l^{-1})	404	141

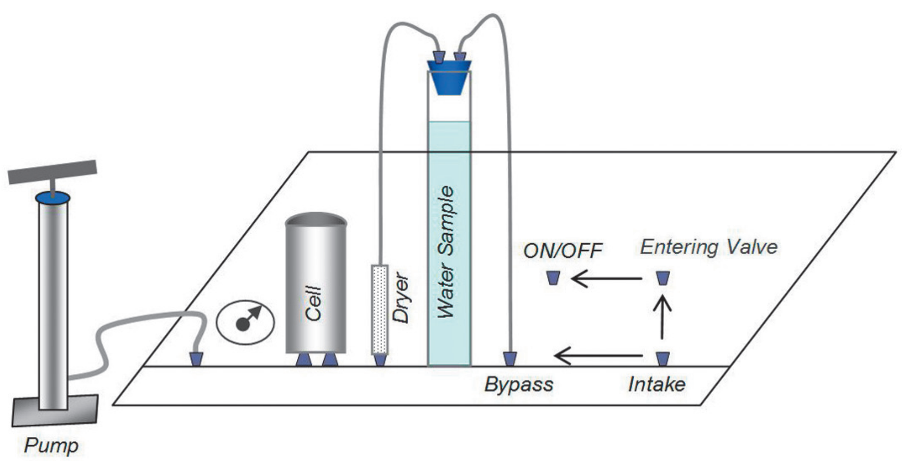

Figure 5. Schematic diagram showing the main parts of the Pylon WG-1001 Water Degassing System.

radon changes was estimated to be at the mean value plus or minus two standard deviations ($\bar{x}$ ±2σ), and any value of radon concentration out of this range could be assumed an anomaly. In view of that, the mean of normal radon value ($\bar{x}$) at Sarada station was determined as 8000 Bqm^{-3} with a standard deviation of 1500, compared to a mean value of 9000 Bqm^{-3} and a standard deviation of 2000 for Arneh station. As a result, it can be inferred that the majority of the normal radon data were concentrated within the range 5000-11000 Bqm^{-3} for Sarada spring (Figure 6a), and 5000-13000 Bqm^{-3} for Arneh spring (Figure 7a), which may be considered as the background values. According to these results, it can be noticed that a distinct number of anomalous radon signals were appeared in both monitoring stations, particularly during the time span from1992 to 1994. In other words, the radon time-series shown in Figures 6 and 7 revealed periods of synchronized radon anomalies, which occurred at a certain time but at no other times during the overall radon-monitoring period. One point of importance is the remarkable occurrences of these anomalously high radon values through the period 1992-1994, which represents the most wet duration in the study region during the 1990s (Abou Zakhem and Hafez, 2010). Besides, no significant seismic activities were recorded in the region throughout the same period (Asfahani and Abdul-Wahed, 2013). Thus, the noticeable increases of radon concentrations are most likely attributed to coincident increases of groundwater table due to high rainfalls, which normally leads to increasing the rate of discharge in the monitoring springs. These consequences may provide evidences of probable radon response to the oscillation of the groundwater table due to high precipitations, and thereby indicate the possible application of groundwater radon measurement as a useful tracer in hydrogeological studies.

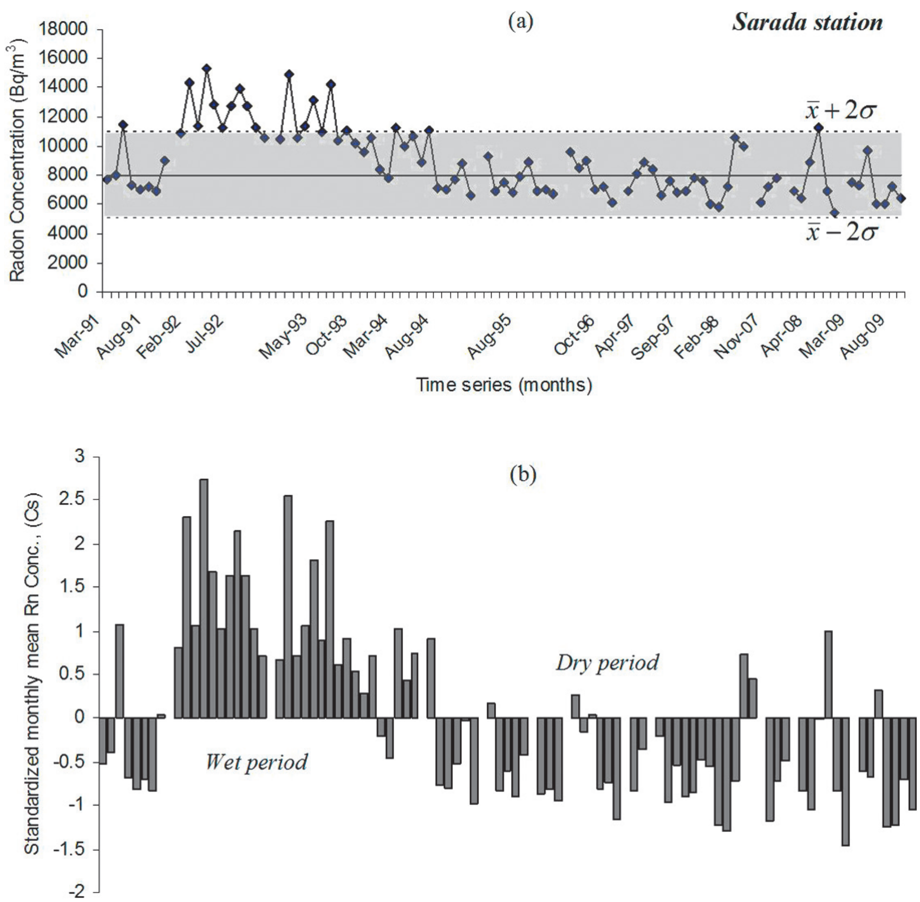

Figure 6. (a) Time series of groundwater radon concentration recorded monthly in Sarada station. The gray stripe indicates the range of normal radon background, (b) Standardized radon index, where positive values are correlated with the wet period, while negative values are related to the dry period..

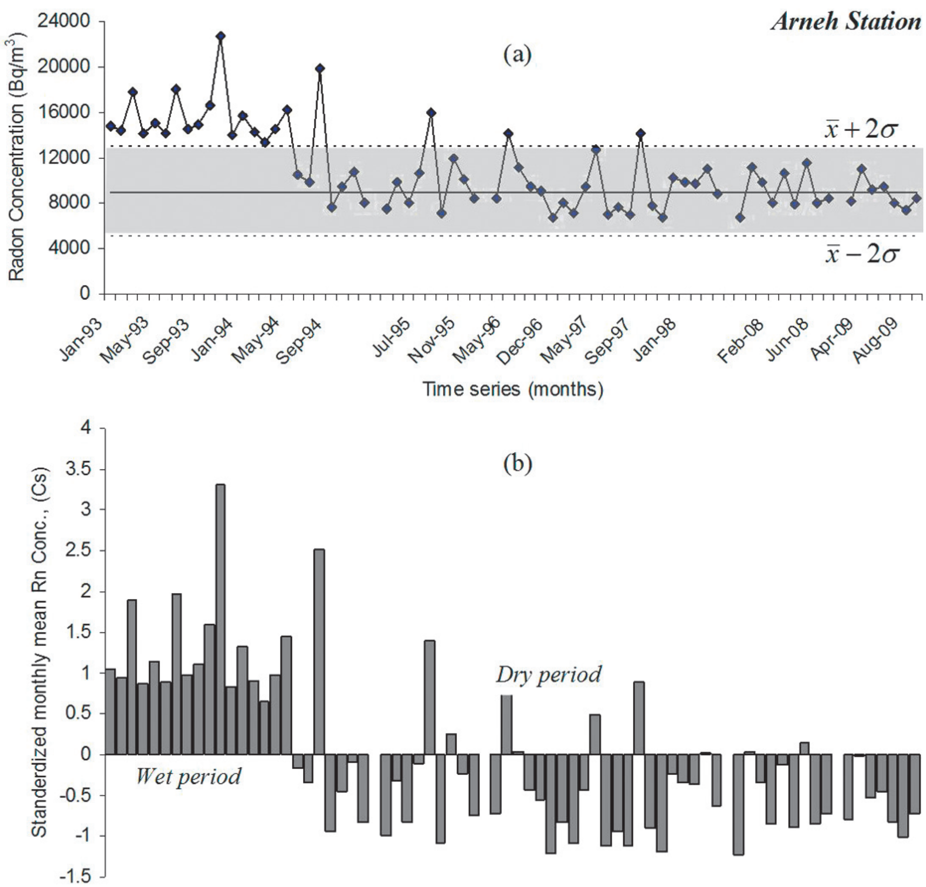

Figure 7. (a) Time series of groundwater radon concentration recorded monthly in *Arneh* station. The gray stripe indicates the range of normal radon background, (b) Standardized radon index, where positive values are correlated with the wet period, while negative values are related to the dry period.

In view of the prevailing climate of Syria, which is characterized by semi-arid to arid conditions, the country has undergone a sequence of dry periods since the early 1980s. These environmental circumstances caused a strong trend towards hydrological drought with a clear decline of the groundwater resources. According to the record of rainfall data from the meteorological station of Damascus region during the period 1919-2008, the annual precipitation varied from 60 to 360 mm/year, with mean annual precipitation of 202±15 mm/year. However, a remarkable wet time with annual mean value of 315 mm/year, appeared through 1992-1994, and it is regarded as the most rainy period in the concerned area during the 1990s (Abou Zakhem and Hafez, 2010). Considering the previously mentioned results, it can be deduced that the exceptional groundwater radon signals, which have been recognized through this study appear to be well related with the average rate of precipitations in the area. Additionally, the Syrian Irrigation Ministry (2003) completed a study of water resources in Damascus basin through the 1982 to 2004. The study includes the average of annual period discharge values for most of the springs emerging from the basin, and the results revealed average annual discharge values of ~0.03 m^3s^{-1} and ~0.6 m^3s^{-1} for Sarada and Arneh springs respectively. This may explain the differences in the general level of radon concentration in both monitoring stations, where the average of normal radon content in Arneh spring (9000 Bqm^{-3}) seems to be relatively higher than the normal radon average (8000 Bqm^{-3}) in Sarada spring. Besides, the coefficient of radon variability in Arneh spring shows a higher value (CV = 32 %), compared to a relatively lower value of (CV = 26 %) in Sarada spring (Table 1). This discrepancy might be due to the hydrogeological nature of the concerned aquifers and the differences in the average volume of groundwater discharges. Arneh spring flows from thick fractured Jurassic formations with relatively higher discharge rate, compared to poor discharge of groundwater from Cretaceous carbonate rocks in Sarada spring.

In order to get a better insight into the variability of radon content in groundwater, both radon time-series were standardized in terms of probability magnitude, which could help in representing the data in terms of probability of occurrence, and thereby assist recognizing anomalous radon signals (Crockett and Holt, 2011). The monthly mean values of radon concentration, *Ci*, have been standardized, *Cs*, by using the following formula:

$$Cs = (Ci - x)/\sigma \quad (2)$$

Where $\bar{x}$ and σ, are the mean and the standard deviation of the series, respectively. The Standardized Radon Index (SRI) is a dimensionless index that is comparable to the Standardized Precipitation Index (SPI), where negative values indicate drop in the radon level, probably due to drought conditions (dry period) and positive or anomalous radon values may point to wet periods due to high precipitations (Figures 6b and 7b). The result of the standardized radon data shows synchronized peaks of similar durations corresponding to the wet period of 1992–1994.

Nevertheless, and apart from the influences of the wet period (1992-1994), the curves of radon concentration at both monitoring stations appear to fluctuate more or less around the mean value, except for some cases in which the radon level crosses the limits of the estimated range of normal radon variations, especially in Arneh spring (Figure 7). This reveals that radon concentration, during this monitoring period, does not appear to remain steady within a certain range, but rather it shows some changes with some abnormal peak values that appear in particular times through the dry period. These infrequent radon signals are most likely associated with the flood times that commonly occur at the end of the annual rainfall seasons, where groundwater table usually increases in the region during April and early May each year. Many researchers (e.g. Pane *et al*., 1995; Han *et al*., 2006; Surbeck, 2007) discussed the hydrogeological control of radon variations in karstic aquifers and the spatial correlation with changing groundwater levels of the monitoring site due to decreasing or increasing precipitations. In view of their results, it has been found that occasional radon changes in groundwater usually appear in a restricted time of the year announcing the arrival of the new percolating rainwater after the rainfall season. Such increases of radon concentration in groundwater are most likely related to the effect of rainfall events, which cause the water table to rise up driving radon gas toward the surface. In addition, the infiltration of rainwater could also remove a considerable amount of radon from the ground during its passage through permeable layers at shallow depth. Subsequently, any radon input from the shallow layers covering the aquifer would be evidently detectable in the spring waters. Thus, radon concentration level and the discharge rate are usually correlated for most springs (Eisenlohr and Surbeck, 1995). Therefore, it is quite essential to consider such observations especially when measuring radon in seismically active areas. In fact, the radon signals, which are caused by hydrogeological processes, represent occasional and isolated changes that are usually confined to a wet period or a certain time of the year, commonly after high rainfall season. Whereas the seismic-induced radon variations represent a gradual increase followed by sudden changes with sharp peaks, and they are normally related to stress build-up or ground motion due to tectonic disturbances, which may occur at any time of the year.

From the seismic point of view, although the seismic record of the Serghaya fault reveals that the fault is historically active (Gomez *et al*., 2001; Sbeinati *et al*., 2005), the present earthquake activity along the fault zone is quite low, with no coincident occurrences of any major seismic events during the time of this monitoring period (Dakkak *et al*., 2005). Moreover, Asfahani and Abdul-Wahed (2013) have performed a comprehensive evaluation of earthquake activity along the (SF), including the establishment of an earthquake catalogue for the concerned fault through the period from 1995 to 2009. They found that the earthquake activity along the (SF) produces little number of low-magnitude events. Therefore, it is thought that the fault passes currently through a relative quiescence, in comparison to other active seismic parts of the (DSFS), such as the (YF) of Lebanon and the Gulf of Aqaba. Accordingly, hydrogeological processes rather than seismic activities are presumably the main factors controlling the variations of radon concentration in groundwater of both monitoring springs, particularly through the wet period 1992–1994.

Conclusion

Based on statistical analysis of long-term radon measurements data from two karstic springs located on the Serghaya fault zone, the range of background for radon variations were found to be varying between 5000 and 13000 Bqm^{-3}, and all values of radon concentration beyond this range are assumed to be anomalous. Radon time-series revealed periods of synchronized anomalies, which appeared at a certain time during the overall radon monitoring period. These anomalous radon signals were positively correlated with a remarkable wet period prevailed through the years (1992-1994), whereas no significant seismic activity occurred in the region during that period. The correlation between the level of radon concentration and the rate of precipitation has been interpreted using the Standardized Radon Index (SRI), which enhanced the comparison process of data, and showed simultaneous radon peaks of similar durations corresponding with the above mentioned wet period. These observations clearly indicate that hydrogeological processes and the rate of groundwater discharge are the main factors controlling the variations of radon level in groundwater in both springs through the time window of this monitoring. On the other hand, the present study proved also the importance of establishing the range of background for radon changes in groundwater, which may assist the separation between common radon fluctuations from other anomalous values. Determining such range of background would be a useful step in the ongoing research programme for future monitoring of the Serghaya fault, which represents a prominent seismic segment of the (DSFS) in southwestern Syria, in order to evaluate its seismic hazard and behavior.

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