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Depositional characteristics of ^{7}Be and ^{210}Pb in Kuwaiti dust

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Abstract Dust fallout fluxes of ^{210}Pb and ^{7}Be were measured in Kuwait during October 2009–August 2011. The annual average depositional fluxes of ^{210}Pb and ^{7}Be were 134 and 422 Bq m^{-2}, respectively. The temporal variations of both radionuclides showed a maximum deposition during April of 2010 and 2011. A strong linear relationship between ^{7}Be and ^{210}Pb was found. The average dust depositional rate was about 50 mg m^{-2} h^{-1} with a maximum of 460 mg m^{-2} h^{-1}, while the extreme value of 664 mg m^{-2} h^{-1} was recorded in March 2011 when a massive dust storm hit Kuwait. The ^{210}Pb deposition has a strong correlation with dust deposition because of its terrestrial abundance. Whereas the ^{7}Be a radionuclide shows a weaker correlation with dust deposition.

Keywords Dust fallout · Temporal variations · Arid areas · Dry deposition

Introduction

Kuwait is an arid country with an extremely high level of dust loading. The rates of dust fallout in Kuwait had been reported to be among the highest in the world [1] with mean monthly concentrations as high as 1400 μg m^{-3} [2]. The ill effect of dust on human health are well established [3, 4]. There have been few studies conducted on gathering radiological data on dust fallout and its related species in the region. In Kuwait ^{210}Pb and ^{7}Be concentration in air were measured 15 years back [5, 6], but the radionuclide fluxes were not considered. Therefore, this study aims at collecting data on ^{7}Be and ^{210}Pb atmospheric fluxes in dust fallout over Kuwait. This will encourage applying nuclear techniques of fallout origin radionuclides in different environmental studies. This essentially includes the extensive use of several radioisotopes as radiotracers in atmospheric research, oceanography, and marine geology. Notably, the successful applications of fallout origin radioisotopes (e.g., ^{210}Pb, ^{137}Cs, and ^{7}Be) have been widely utilized for estimating sediment and soil redistributions, atmospheric supply and exchange, and applications to aquatic processes [7–12].

In general, dust fallout contains naturally occurring radioactive materials as radioisotopes of uranium, thorium series, and potassium 40, as well as cosmogenic radionuclides. In addition, anthropogenic radioisotopes were introduced by the application of nuclear technology in the last century. This study focuses on ^{7}Be and ^{210}Pb. ^{7}Be is a cosmogenic radionuclide produced in the atmosphere by spallation of oxygen and nitrogen with high-energy cosmic rays. About 75 % of ^{7}Be is produced in the lower stratosphere, while about 25 % is produced in the upper troposphere [13]. The mean tropospheric residence time for ^{7}Be at north temperate latitudes was estimated between 22 and 48 days [14]. It is removed from the atmosphere essentially by precipitation. ^{7}Be decays into ^{7}Li by an electron capture mode with a half-life of 53 days and emits 478 keV gamma energy. On the other hand, ^{210}Pb occurs naturally. It is produced through the gaseous radionuclide ^{222}Rn decay; the radiogenic ^{226}Ra in the ^{238}U series. A small portion of ^{222}Rn, which diffuses from soil, produces ^{210}Pb that

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binds to the aerosols in the atmosphere to become airborne and then is transported and deposited elsewhere on the surface soil and water bodies by fallout/precipitation. The half life of ^{210}Pb is 22.3 years compared to its parent's half lives of 3.8 days and 1600 years of ^{222}Rn and ^{226}Ra, respectively. It is assumed that the atmospheric ^{210}Pb fallout over a specific area is constant through the time [15] because of consistency in process. Nevertheless, the reported ^{210}Pb deposition rates showed significant global variability ranges from 23 to 367 Bq m^{-2} year^{-1} [16, 17].

Materials and methods

The meteorological conditions in Kuwait

The climate in Kuwait is hot and arid. The maximum temperature varies from 50 °C in summers to 2 °C in winters; on an average eight rainy days a year and the mean annual rainfall between 1996 and 2007 was about 118 mm. The precipitation data was collected during the period of this study. The mean annual rainfall in 2010 was 41.5 mm where as in 2011 was 73.0 mm. The prevailing wind direction in Kuwait is northwestern–southeast, about 60 % of the total wind throughout the year. The air mass during most dusty days originates from sub Saharan region, traveling over Jordan, Syria, Turkey, Iraq, reaches Kuwait. The gust recorded during these events is often exceeding 19.0 m s^{-1}.

In contrast, the southwestern winds, locally known as 'Koss', blows during the spring seasons at a speed of up to 30 m s^{-1}. Both sources of winds create critical dynamic weather that lifts up the fine desert sand and silt giving rise to severe dust storms. Topographically, Kuwait is a desert plain deposit with a maximum elevation of about 300 m in southwest (Fig. 1). The area is not having any structural feature with exception to north–south trending Ahmadi ridge and a north–east–southwest trending Jal Azour escarpment. The regional dip is towards north east. The topography provides no obstruction to the prevalent northwesterly wind resulting in high dust loading.

Sampling and sample preparation

Dust fallout samples were collected from nine locations in Kuwait during the period October 2009–August 2011 using a single-piece polyvinyl chloride bucket of 0.2 m diameter and 0.4 m depth. The bucket was partially filled with glass marbles to prevent the collected dust from being blown away. The dust traps were fitted with a metal strap looped in an inverted basket shape over the top to discourage birds from roosting. The traps were fixed at 240 cm above ground level. Four samplers were installed at each of the nine locations (Fig. 1). The samples are collected at end of each month to accumulate an adequate sample mass required for radioactivity determination. The accumulated dust of each trap was collected by repeated rinses of 1 M HCl-acidified distilled water, which were performed three times. The rinsings were collected in a 1-l beaker and the solution was heated to dryness. The dry dust was bottled in a vial of 2 cm diameter and 5 cm height for radioactivity measurements. The collected dry weights of the samples varied from 0.5 to 15 g at different stations.

Gamma spectrometry measurements and analysis

A gamma spectrometry system equipped with Canberra broad energy Ge series detectors was used to measure the gamma energy emissions from 30 to 3000 keV with an excellent low energy resolution (i.e., full width at high maximum at 122 keV is 750 eV). The essential imperative characteristic of this spectroscopic system is its effective and appropriate shielding design that enables to determine natural and man-made radionuclides, including low-energy gamma emitters, with extremely low detectable activity. The detector efficiency was calibrated using an in-house calibration source prepared by spiking a local dust sample with traceable gamma mixed standard solutions (QCYB-41 and QCYB-40) prepared by KDD Germany. The calibration source covers the energy range from 30 to 3000 keV. The specific activities of ^{210}Pb and ^{7}Be radionuclides were determined using the spectral lines of 46.5 and 477 keV of gamma intensities (branching ratio) 4.25 % and 10.52, respectively. The minimum detectable activity of ^{7}Be and ^{210}Pb was about 90 and 70 mBq, respectively, for a sample weight of about 1 g and 24 h counting. It should be noted that the necessary decay and buildup corrections during the sample collection period (30 days) have been implemented. This correction is critical, especially for the shorter half life radionuclide ^{7}Be ($T_{1/2}$ = 53.2 days). The correction factor ($1/K_s$) applied during the sampling time is defined as follows:

$$K_S = \frac{T_{1/2}}{\mathrm{Ln}(2) * t_S}\left[1 - e^{-\frac{\mathrm{Ln}(2)*t_S}{T_{1/2}}}\right], \quad (1)$$

where $T_{1/2}$ is the ^{7}Be half life and t_s is the sampling time (30 days).

The monthly deposition fluxes of ^{210}Pb and ^{7}Be were calculated on a unit of Bq m^{-2} by means of dust deposition rate (g m^{-2} month^{-1}).

Quality assurance

A quality control procedure using an in-house prepared control sample containing a known amount of uranium ore was used to continuously monitor the performance of the ultra low background (ULB) gamma spectrometry system.

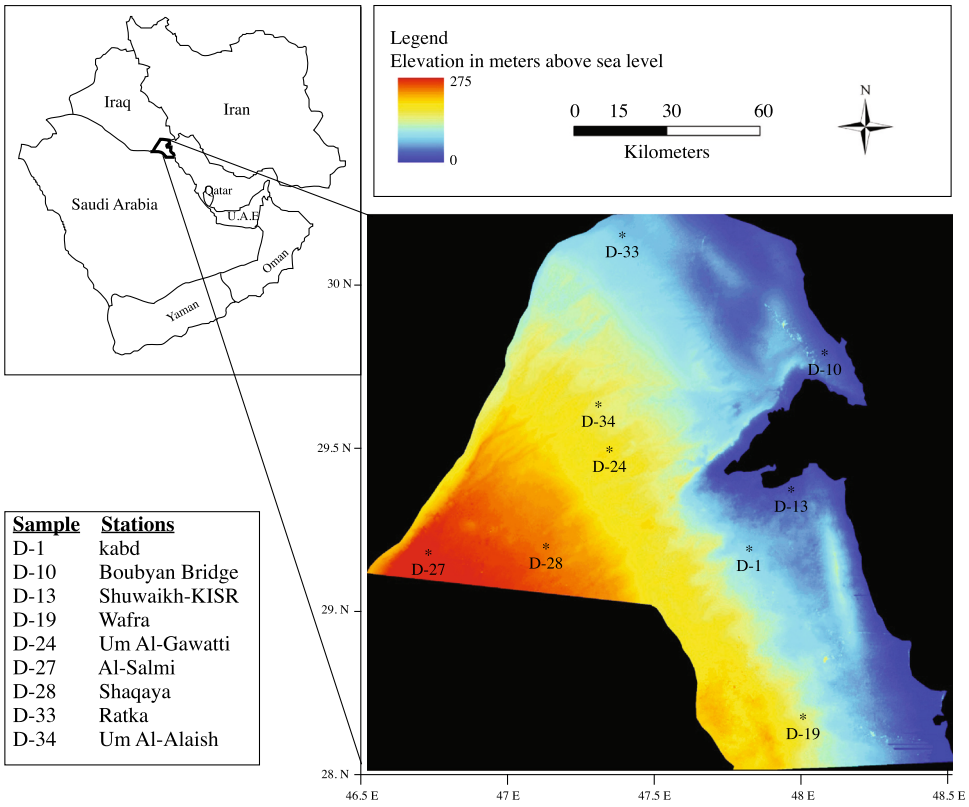

Fig. 1 Sampling locations of dust fallout and digital elevation model of Kuwait [44]

The spectral gamma lines of ^{210}Pb, ^{214}Pb, and ^{214}Bi were used as controlling parameters to generate a Shewhart quality control chart. In addition, background variations and changing environmental conditions within the laboratory were also monitored and controlled. Moreover, a control sample with a known radioactivity concentration was used in each batch of samples. Good laboratory procedures of sample preparation and handling were also implemented to avoid any cross contamination or loss of sample.

Results and discussion

Variations of dust deposition rates

The calculated annual bulk (wet and dry) dust fallout varied from 2.5 to 460 mg m^{-2} h^{-1}, with an average (arithmetic mean) of 50 mg m^{-2} h^{-1}. This range of measurements is comparable with the recent results obtained by Al-Awadhi and AlShuaibi [18] on the dust fallout in Kuwait City in 2013. However, the rate of dust deposition across the globe would reach a level of 51.4 mg m^{-2} h^{-1} [19], which matches the average deposition in Kuwait. Nevertheless, an extreme value of 664 mg m^{-2} h^{-1} was recorded on March 2011, during a strong dust storm in Kuwait that was a local phenomenon. This extreme dust loading were comparable to sites primarily that are affected by a local dust sources [20]. The temporal variations of the deposition rates showed seasonal tendency, as presented in Fig. 2. This trend demonstrated a peak during the spring seasons in Kuwait where the frequency of dust storm events and precipitation was high. During these events, the windy conditions develop resulting in high dust loadings (both locally and regionally) often accompanied by thunderstorms and rain (in a short period of time).

Although the precipitation is scanty the correlation coefficient between the precipitation and the dust fallout was 0.64, providing an insight that the windblown component is not insignificant. Similar observation has been made in other arid and low precipitation areas, where the dry depositional fluxes could be more than 50 % of the total deposition [21]. Considering the low rainfall in 2010 and 2011 corresponding to 41 and 73 mm, this assumption is very valid in Kuwait. The spatial distribution of annual dust depositional shows highest deposition rates at station D-28 and D-24. These stations are located within a major wind corridor that passes across Kuwait.

Temporal variations of ^{210}Pb, ^{7}Be depositional fluxes and ^{7}Be/^{210}Pb ratio

The monthly measurements of ^{210}Pb in dust samples collected during October 2009–August 2011 showed a range of 24–520 Bq m^{-2}, with an average annual deposition flux

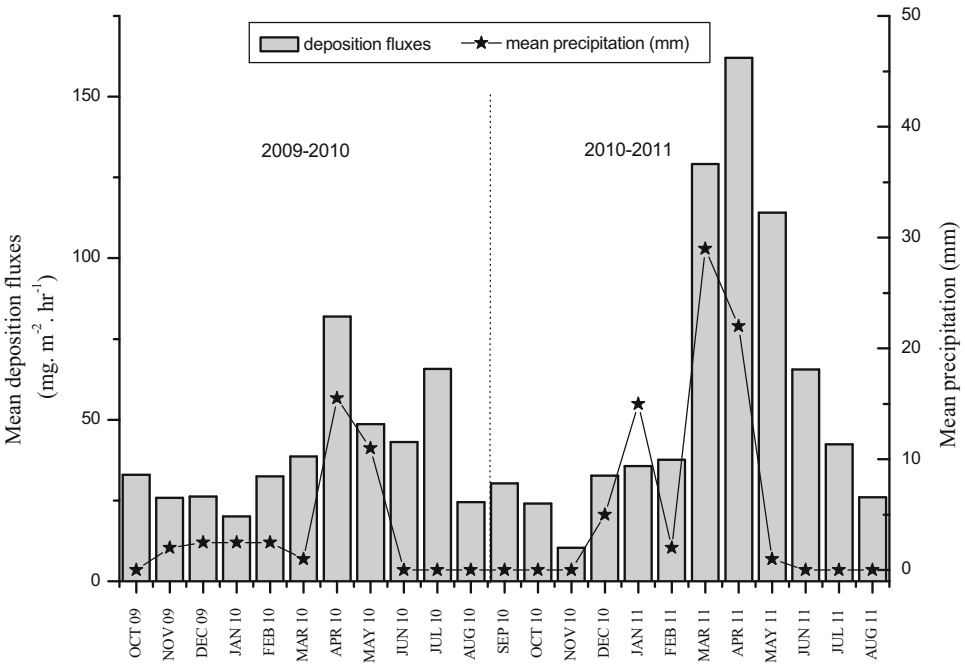

Fig. 2 Temporal monthly variations of dust deposition fluxes in Kuwait

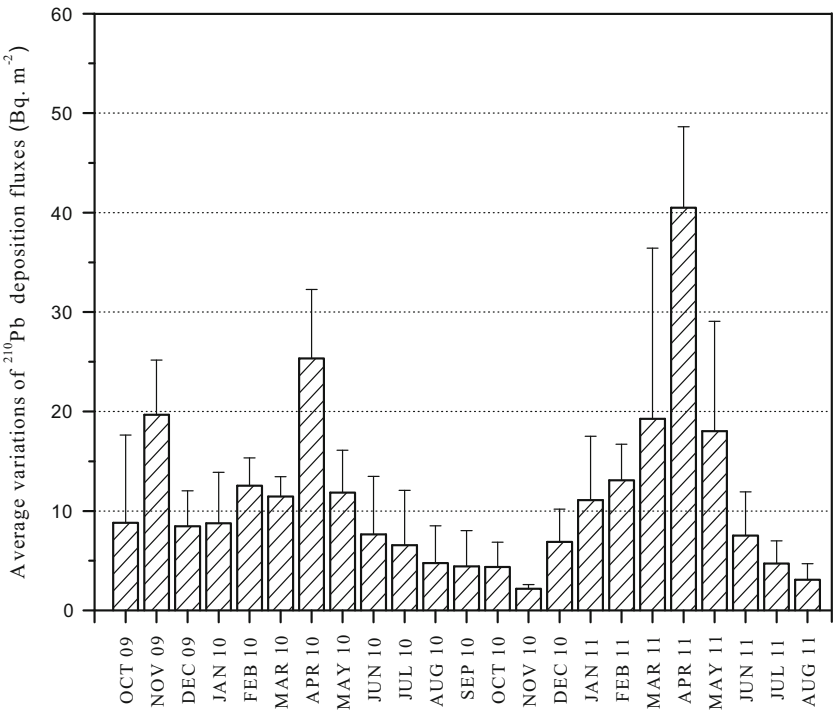

Fig. 3 Temporal monthly variations of ^{210}Pb depositional fluxes from October 2009 to August 2011

of 134 Bq m^{-2}. This range of measurements is consistent with the global compilation data of ^{210}Pb depositional fluxes in the northern hemisphere, where the reported ^{210}Pb annual depositional rate on continents between 10° and 30° N latitude was about 160 Bq m^{-2} [21, 22]. The highest ^{210}Pb concentrations were observed in April each year and lowest in October–November. About 50 % of the measurements lay between 46 and 165 Bq m^{-2}. The monthly ^{210}Pb depositional rates are quite consistent with the dust loadings in the corresponding months. A strong correlation between dust fallout and the ^{210}Pb depositional rates has been found ($r = 0.79$) and can be explained by the effect of

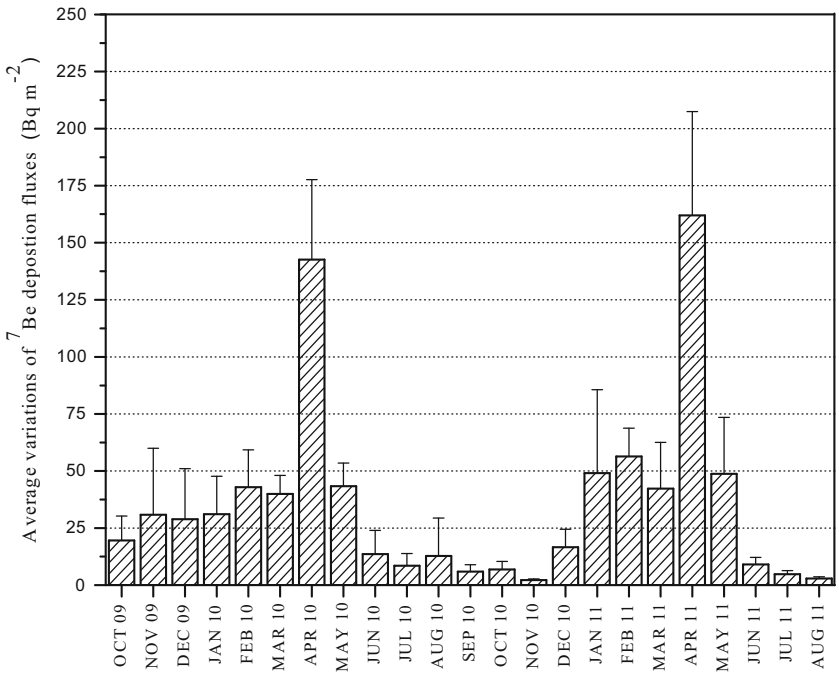

Fig. 4 Temporal monthly variations of ^{7}Be deposition fluxes from October 2009 to August 2011 in Kuwait

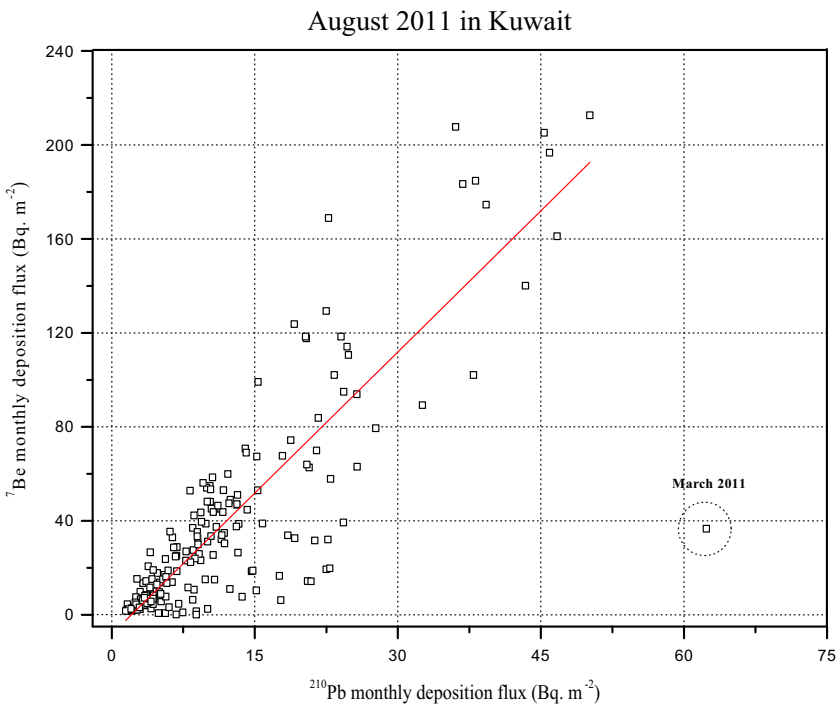

Fig. 5 The linear relationship between ^{210}Pb and ^{7}Be

the wet precipitation associated with Sarrayat and Koss. Beks et al. [23] also concluded that the related thundery and heavy rainfall could scavenge a greater volume of air than with normal precipitation, which could lead to large depositional fluxes of ^{210}Pb. Large uncertainty of the average measured ^{210}Pb depositional rate in March 2011 was mainly due to the impact of the exotic dust storm where the dust depositional rate had exceeded 664 mg m^{-2} h^{-1} (Fig. 3).

The monthly measurements of ^{7}Be in dust samples collected during October 2009–August 2011 showed a range of 30–1954 Bq m^{-2}, with an average annual deposition flux of 422 Bq m^{-2}. The mean of the annual deposition flux obtained in the present work is consistent with that derived from the

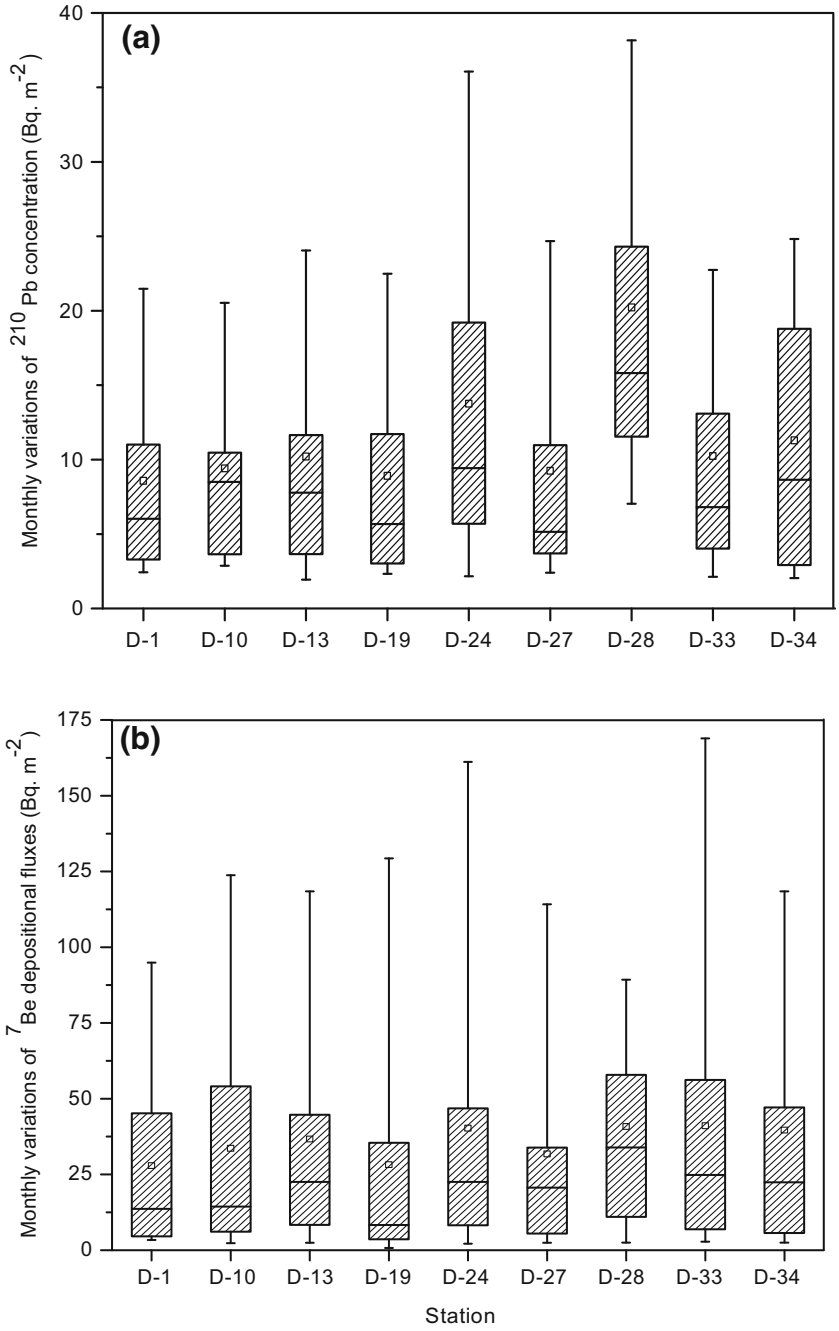

Fig. 6 **a** Spatial monthly variations of ^{210}Pb depositional fluxes. **b** Spatial monthly variations of ^{7}Be depositional fluxes

global model (about 400 Bq m^{-2}) [24]. About 50 % of the obtained results lay between 74 and 542 Bq m^{-2}. The highest deposition of ^{7}Be was observed during April. This is in agreement with the precipitation data. The ^{7}Be removal from the atmosphere is influenced by rainfall rates [25, 26], due to extremely low precipitation in the region the mean annual ^{7}Be fluxes showed no significant differences. The correlation coefficient of ^{7}Be with the dust fallout was $r = 0.67$. For the reason that all dusty days are not accompanied by rain event.

The high concentration during April of 2010 and 2011 was due to rainfall during the period supporting the theory of wet precipitation commonly associated with the mixing of stratospheric and tropospheric air masses [27]. In spring time a rapid removal from lower polar troposphere to the troposphere at the northern hemisphere is well known [28] and possibly due to folding of the troposphere during April and May at the mid-latitude (30–50) enhances the removal of the stratospheric ^{7}Be into the troposphere [29, 30]. It is worth mentioning that the ^{7}Be deposition rate in March 2011 was considerably lower in spite of a massive dust event suggest limited dry deposition of ^{7}Be in the study area (Fig. 4).

Table 1 Global ^{7}Be and ^{210}Pb deposition

Sites/locations	Deposition flux (Bq m^{-2})		Rainfall (mm year^{-1})	References
	^{7}Be	^{210}Pb		
Kuwait (29.3N, 48E)	30–1954[a]	24–520[b]	41.5–73	Present study
Murree, Pakistan	4832	271	1450	[33]
Islamabad, Pakistan	3801	1137	1140	[33]
Stillpond, USA	2167	130	120	[34]
Detroit, Michigan, USA	1900	235	183	[35]
Galveston, USA	2450	172	1167	[36]
Brisbane, Australia	1070–1362		718–1056	[37]
Dun Coillich, UK		98	1300	[38]
Izmir, Turkey		48	645	[39]
Rokkasho, Japan	2160–3300	563–967	1340–1637	[40]
Fukuoka, Japan	1737	273	1703	[41]
Shanghai, China	2070	479	1140	[42]
Xiamen, China	599	186	1135	[43]

[a] Average 422 Bq m^{-2}

[b] Average 134 Bq m^{-2}

Finally, as found by other workers [31, 32], a strong correlation between the monthly depositional fluxes of ^{210}Pb and ^{7}Be has been observed, where the ^{7}Be/^{210}Pb slope was about 4 with an adjusted R^2 of 0.77 as shown in Fig. 5. The extreme ^{210}Pb value shown belongs to station D-28 where the dust monthly fallout reached a level of 478 g m^{-2} during the dust storm of March 2011. This extreme dust fallout reduced the specific activity of the short lived ^{7}Be to the long lived ^{210}Pb; hence deposition fluxes of ^{210}Pb reached the extreme monthly average of 62.3 Bq m^{-2}.

Spatial variations of ^{210}Pb, ^{7}Be depositional fluxes

The spatial variation plots of the monthly measurements of ^{210}Pb in dust samples collected during October 2009–August 2011 showed a range of 2.0–38.0 Bq m^{-2}. Highest ^{210}Pb deposition was observed at stations D-24 and D-28 (Fig. 6a). These stations are located within the major dust corridors that pass through the study area.

The monthly measurements of ^{7}Be in dust samples collected during October 2009–August 2011 showed a range of 0.7–213 Bq m^{-2}. The highest concentration of ^{7}Be was observed at stations D-24 and D-33 (Fig. 6b). The spatial consistency in ^{7}Be concentration across the stations is related to quite uniform low precipitation in the study area.

Conclusions

The annual average dust deposition in Kuwait is about 50 mg m^{-2} h^{-1}, which is in agreement with the global average of 51.4 mg m^{-2} h^{-1}, being an arid country it often has severe dust storms, where an extreme value of 655 mg m^{-2} h^{-1}, was recorded. The average annual deposition rates of ^{210}Pb and ^{7}Be were 134 and 422 Bq m^{-2}. The ^{210}Pb values are in agreement with those reported from northern hemisphere and similar climatic milieu (Table 1). The ^{7}Be mean annual deposition is order of magnitude less than reported elsewhere and can be very well linked to the precipitation. The ^{7}Be is essentially deposited due to wet deposition. Its spatio-temporal distribution in Kuwait suggests a correlation with dust deposition. The ^{7}Be is essentially transported with dust from trans boundary sources where it is deposited in much higher concentration with precipitation. In addition, the variations of these fluxes showed a seasonal pattern which peaked during April and was minimal during October–November. The ^{210}Pb deposition has a strong correlation with dust deposition because of its terrestrial abundance. Whereas the ^{7}Be a cosmogenic radionuclide shows a weaker correlation with dust deposition.

This study sets the first baseline for ^{7}Be and ^{210}Pb in dust samples in Kuwait. The 0.5 g sample was sufficient to detect the activity of these radionuclides using the ULB gamma spectrometry system along with the necessary corrections of the efficiency calibrations. The future study will focus on size fractionated dust to determine the inhalable fraction of these radionuclides, which may be an important input for dose and risk assessment.

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