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Atmospheric deposition fluxes of ^{137}Cs associated with dust fallout in the northeastern Arabian Gulf

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ABSTRACT

For many years, monitoring and determining the radioactivity of ^{137}Cs in the environment has considerable interest. This paper presents monitoring ^{137}Cs deposition fluxes during the period from 2009 to 2011. Dust fallout samples were collected from ten locations in Kuwait, and ^{137}Cs concentrations were determined using ultra low spectrometry system. The average of the annual atmospheric deposition fluxes of ^{137}Cs was 4.3, with an extreme value reaching 50 Bq m^{-2}. The monthly deposition rates of ^{137}Cs were attributed to seasonal increases in the spring. ^{137}Cs deposition fluxes showed a significant relationship with dust deposition and precipitation rates, where the correlation between the monthly dust fallout and the ^{137}Cs deposition fluxes and precipitation rates were approximately 0.95 and 0.81, respectively. The spatial monthly distribution of ^{137}Cs fluxes showed high rates in the southeastern part of Kuwait while the lowest rates were recorded along the coastlines. A strong correlation was observed between the annual ^{137}Cs and ^{40}K deposition rates considering that both radionuclides deposition were governed by similar conditions. It was concluded that long-range transport from the northwestern areas along with the effects from local dust washout and the site specify played a major role in controlling the rate of ^{137}Cs deposition. The estimated annual effective dose equivalent due to external and internal exposures was insignificant and can be ignored. It is worthwhile to continue investigating the source origin of ^{137}Cs in Kuwait to enhance understanding of the radiological hazards in the country.

1. Introduction

The majority of Arab countries in the Middle East suffer from the negative effects of dust, which directly affects air quality. The increasing occurrence of dust events and temporal changes in the region might be the result of global climate change (Taghavi et al., 2017). These events pose public health and economic concerns for the public and governments of the Middle East. The effect of dust on human health is of immense concern since it contains loads of organic and inorganic materials, some of which are toxic even at very low concentrations (e.g., Lead and Cadmium) (Al-Awadhi and AlShuaibi, 2013; Alolayan et al., 2013). It can be said that North Africa, Asia, and the Middle East are the primary global sources of dust worldwide (Middleton, 2017; Modaihsh et al., 2017; Tanaka et al., 2005; Prospero et al., 2002).

In general, dust fallout contains both natural and anthropogenic radionuclides. Monitoring and determining levels of ^{137}Cs in the environment has important relevance worldwide; detection of even a small amount of ^{137}Cs above background levels would raise questions about its source origin and potential radiological hazards. Presence of ^{137}Cs above certain environmental levels is most likely an indicator of nuclear activity and/or accidental releases from nuclear installations. In this regard, the Kuwait Institute of Scientific Research (KISR) has been cooperating with the preparatory commission for the Comprehensive Test Ban Treaty Organization (CTBTO) for many years to monitor atmospheric ^{137}Cs (Biegalski et al., 2001). The results obtained reveal that Kuwait had the highest ^{137}Cs concentration levels and the largest range of ^{137}Cs concentrations among the CTBTO monitoring stations from 1995 to 1999 (Tang et al., 2005). According to the reported results, the average concentration levels were almost constant (10 μBq m^{-3}) during the years 1995–1999 and 2004–2005, with extreme values reaching up to 270 μBq m^{-3}.

^{137}Cs, a man-made radionuclide with a half-life of 30 years, was produced during the atmospheric testing of thermonuclear weapons from the mid-1950s to the late 1960s. The global fallout of ^{137}Cs began in 1954, peaked in the early 1960s, and subsequently decreased to reach near zero levels in the mid-1980s (UNSCEAR, 2000). However, an additional amount of ^{137}Cs was injected into the atmosphere from the Chernobyl accident in 1986, when enormous amounts of fission products were released into the environment. In any case, ^{137}Cs fallout levels are globally variable, reflecting both annual precipitation and

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location relative to the main weapons tests (Walling, 2003). A temporal variation of derived ^{137}Cs bomb-testing over the northern and southern hemisphere is well-documented (UNSCEAR, 2000) and enables utilizing it as a radiotracer in environmental applications.

The baseline of the most natural and anthropogenic radioisotopes has been determined in different environmental compartments in Kuwait (Aba et al., 2014, 2016; Al-Azmi et al., 2001; Al-Zamel et al., 2005, 2006; Sayed et al., 2002; Uddin and Behbehani, 2018). However, limited data has been reported on concentrations of ^{137}Cs in dust fallout. In this work, we have monitored monthly ^{137}Cs deposition rates in ten locations in Kuwait for two years. The ^{137}Cs concentration in the small samples collected was determined using Ultra Low Background (ULB) spectrometry measurements. This type of monitoring is aligned with the objectives of the crisis decision support program to support the decision makers for responding to radiological emergencies. The radiological data will provide useful inputs to support the stakeholders involved in the national emergency plan whom responsible to make accurate decision in case of emergency. Such radiological data will enhance understanding of the ^{137}Cs source apportionment in Kuwait and its radiological hazards. In addition, it will encourage application of the nuclear techniques using ^{137}Cs in different environmental studies.

2. Materials and methods

2.1. Sampling and sample preparation

Ten locations present the majority of landscape and land use in the country were chosen (Table 1). A single-piece polyvinyl chloride (PVC) bucket of 0.2 m diameter and 0.4 m depth was used to collect dust fallout samples from ten locations in Kuwait (Fig. 1). The bucket was half-filled with glass marble (1 cm diameter) to prevent dust, which had deposited in the bottom of the pan, from being blown away. All dust traps were fitted with a metal strap looped in an inverted basket shape over the top to discourage birds from roosting (Fig. 2). The dust collectors were installed 2.4 m above ground, far from buildings or other infrastructure. To accumulate the adequate sample mass required for radioactivity analysis, a composite sample was collected from 4 dust traps deployed at each location for almost a month. The accumulated dust was rinsed with 0.2 M HCl acidified distilled water and collected in a 1 L can. The rinsings were collected in a 1-L beaker and the solution was heated to dryness. The weight of dry samples (ranging between approximately 0.5 g and 15 g) was bottled in a small vial (1 cm diameter and 3 cm length).

In addition to dust samples, 2 cm top soil samples were collected using a scraper of 20 × 20 cm six samples were randomly collected from the vicinity of each station to form a composite sample according to slightly modified recommended by IAEA procedure (IAEA, 1989). The composite samples were dried overnight at 105 °C, sifted through a 0.5 mm sieve, bottled in a 200 ml container, and counted using the ULB spectrometer. The radioactivity concentrations of ^{137}Cs and ^{40}K were determined using the efficiency calibration curve.

2.2. Gamma spectrometry measurements and analysis

A gamma spectrometry system, equipped with a Canberra Broad Energy Germanium (BEGe) detector, was used to measure the gamma emissions of 5–3000 keV with excellent low energy resolution (i.e., FWHM @ 122 keV is 750 eV). The most significant characteristic of this spectroscopic system is its effective and appropriate shielding design, which enables it to determine natural and man-made radionuclides, including low-energy gamma emitters, with extremely low detectable activity. Detector efficiency was calibrated using an in-house calibration source prepared by KDD Germany and the dust sample was spiked with a traceable gamma mixed standard solution (QCYB-41 and QCYB-40). The calibration source covered an energy range from 30 keV to 3 MeV. The efficiency correction due to different sample masses and cascade summing was performed by Canberra-Genie (2000) analysis software. The prepared samples were counted for a long time (more than 100,000 s) to achieve an accurate statistical peak area calculation (less than 10% area error) of the radionuclides of interest. And the radioactivity calculation of ^{137}Cs and ^{40}K was based on its high intense gamma lines (660 keV (0.85) and 1460 keV (0.105)), respectively.

2.3. Quality assurance

Quality control procedures using an in-house control sample (Aba and Ismaeel, 2013) and the IAEA 375 soil sample were used to monitor the performance of the ULB gamma spectrometry system. The in-house control sample contained a known amount of uranium ore, with gamma lines of ^{210}Pb, ^{214}Pb and ^{214}Bi, while the IAEA 375 sample contained a high concentration of ^{137}Cs. Peak centroids, full width at half maximum and counting efficiency were used as control parameter in the Shewhart quality control chart (Eisenhart, 1990).

3. Results and discussion

3.1. Spatiotemporal atmospheric of ^{137}Cs and ^{40}K deposition fluxes

^{137}Cs and ^{40}K were regularly found in the dust fallout samples collected from different locations in Kuwait during the October 2009 to August 2011 study. The average of the annual atmospheric deposition fluxes of ^{137}Cs and ^{40}K were 4.3 and 143 Bq m^{-2} respectively, with a broad range of measurements. The scatter and lognormal distribution plots (Fig. 3) showed extreme values extending to about 50 and 1800 Bq m^{-2} for ^{137}Cs and ^{40}K correspondingly. These extreme values were associated with the exotic dust storm that hit Kuwait in March 2011 (Al-Awadhi and AlShuaibi, 2013). A strong correlation was observed between the annual ^{137}Cs and ^{40}K deposition rates (Adj. R-Square 0.79), provided that both radionuclides deposition were governed by similar conditions. Thus, the discussion and conclusions of the man-made radionuclide ^{137}Cs behavior will also be drawn on the naturally

Table 1
Locations and specifications of the collected dust samples.

St. No.	Coordinates (Long., Lat.)	Local name	landscape	Land use	Vegetation
S1	47.689333, 29.158333	Kabd	Mobile sand	Fenced area	Rhanterium epapposum
S2	48.150766, 29.588533	Sabiya	Sabkha	Open/grazing area	Haloxylon salicornicum
S3	47.902733, 29.349166	KISR	Sabkha	Urban area	Tamarix aucheriana
S4	47.998233, 28.610233	Wafra	Inland Sabkha	Farms	Nitraria retusa
S5	47.416805, 29.511388	Um Eish	Sand dunes	Open/grazing area	Haloxylon salicornicum
S6	46.683722, 29.101666	Um Umara	Mobile sand	Open/grazing area	Stipagrostis plumosa
S7	47.267222, 29.154277	Salmi	Mobile sand	Open/grazing area	Stipagrostis plumosa
S8	47.459601, 30.051566	Hushan	Fluvial deposits	Fenced area	Haloxylon salicornicum
S9	47.373883, 29.649916	Um Urta	Sand dunes	Grazing area	Cyperus conglomerates
S10	48.336446, 29.746924	Bubiyan	Sabkha	Preserved area	Salicornia europaea