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Detecting the relations between meteorological elements and alpha and beta activity concentration at Al-Tuwaitha site, Baghdad

Key words: alpha activity, beta activity, airborne radioactivity, meteorology, Al-Tuwaitha site

Introduction

Al-Tuwaitha site is one of the nuclear places existing in Baghdad province, Iraq that was seriously damaged during the Gulf War 1991. This facility as the source of radioactive rays has a potentially significant amounts of wastes which cause radiological contamination of the site and surrounding areas around it by dispersing radionuclides attached on aerosols and water vapors (Interational Atomic Energy Agency [IAEA], 2012). Such contamination has adverse effects on human health, plants and animals especially when decaying radioactive materials which emit energetic charged particles such as alpha, beta, gamma or neutron radiation according to the radioisotope existing (Reiman, 2002; Shahbazi-Gahrouei, Gholami & Setayandeh, 2013; Nassif, Wahab, Al-Jiboori & Ali, 2020). Thus, their concentrations in surface air is mainly affected by emissions fine particles resulting from the variations of atmospheric conditions: strong solar insulation, high wind speed, wind direction changes and air stability.

In recent decade and based on the average bulk mass or surface concentration, some local and international studies were assessed the radioactive level at Al-Tuwaitha site by taking some samples for different places from its soil, plant and even air (Jarjies, Abbas, Fernandes, Wong & Coates, 2013; Mansour, Al-Bakhat & Karkosh, 2017; Salih et al., 2018; Nassif et al., 2020). In present research, we reanalyze alpha and beta activity concentration measurements published in the reference of (Salih et al., 2018) to explore the relationships between these concentrations and meteorological elements. Airborne radionuclides have high energy leading to large localized radiation doses inhaled the body whereas meteorology has significant effect in dispersion and transport of pollutants (Lazaridis, 2011; Al-Jiboori, 2015).

There was a few studies that investigated the quantitative relations between meteorological parameters and alpha and beta activity concentrations. For example, Dueńas, Fernández, Liger and Carretero (1999), Arkian, Salahinejad, Bidokhti and Meshkatee (2008), and Salih et al. (2018) showed that maximum concentration of alpha and beta were found during spring and summer seasons. Also these references illustrated that these concentrations were weakly inversely proportional with air temperature and wind speed while they were proportional with relative humidity. In this work, we focus to (1) study the variations of alpha and beta activity concentration with six meteorological elements: air temperature, solar radiation, wind speed, wind direction, air pressure, and relative humidity; (2) find the correlation coefficient among them with *p*-value; and (3) calculate air stability classes with their frequencies and then examine their relations with the concentrations above.

Description of Al-Tuwaitha site

At 18 km southeast of Baghdad, Al-Tuwaitha site is located as the foundation of Iraq's nuclear research center from 1967 until its final damage in 2003. It covers an area 1.3 km^2 and away about 1 km east of the Tigris river (Fig. 1). It is extended with latitude 33°10″ – 33°15″ N, longitude 44°29″ – 44°35″ E and 32 m above mean sea level.

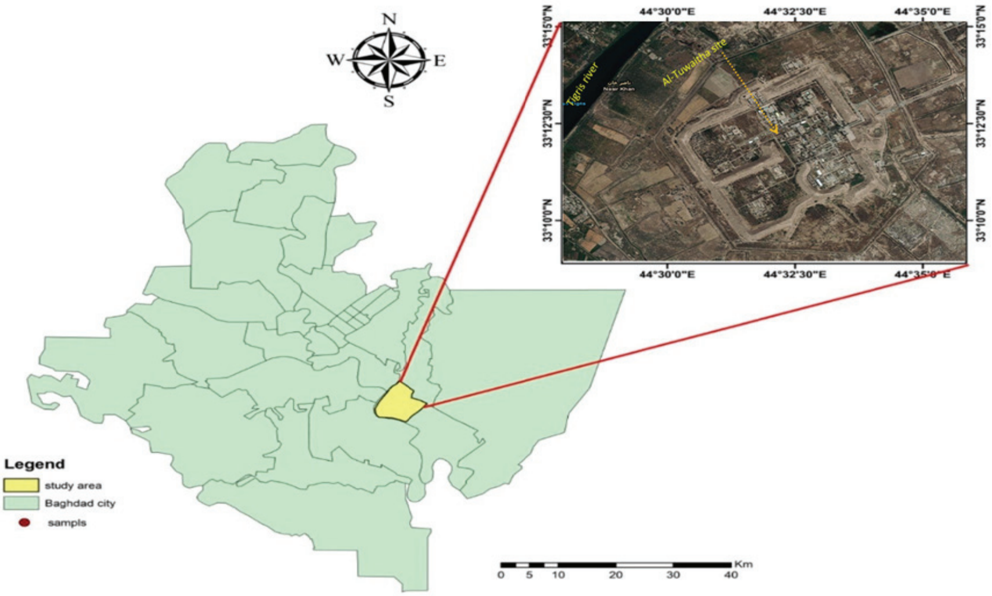

FIGURE 1. Map of Baghdad city including study area with its aerial photograph

There are large earthen beams that were placed around the key facilities to fortify them. In 1991, the Al-Tuwaitha had 90 buildings dedicated to nuclear fuel fabrication, radiochemistry, uranium enrichment, radioactive waste treatment and biological research (Zaboon, Al Obaidy & Al Sharaa, 2013). The famous reactors were Osiraq, 5-MW IRT-5000, 40-MW Tammuz-1 and 500-KW Tammuz-2, which suffered substantial physical damage since 1991 and then displayed to secret operations combined with the bombing of nuclear facilities and subsequent looting by dwellers. Therefore, Al-Tuwaitha and nearby villages suffered widespread radioactive contamination (Chesser, Rodgers, Bondarkov, Shubber & Philips, 2009).

Material and methods

Two different datasets were used to execute this study: (1) counting alpha and beta rates and (2) meteorological observations, which were measured at the same time at 50 places within and outside the Al-Tuwaitha site for worked 39 days with date starting from 28 December 2016 to 13 April 2017. The observation time was at daytime from 09:20 am and 12:20 am and for approximately 1 h. Airborne dust samples and drawn from ambient air at flow rate 10–15 $m^3 \cdot h^{-1}$ were daily collected in a glass-fiber filters with diameter 5.5 cm. To represent the radioactive contaminated air, the device was put 20 m far from the buildings with collection efficiency 99%. Later, using Ludlum 3030P scaler alpha/beta sample counter, the air filters analyzed to measure simultaneous alpha and beta particles. The structure and feature of this instrument can be found in more detail in reference (Ludlum Measurements, 2017). The device was daily calibrated and checked the quality control before using it to ensure the validation of measurements.

The activity concentration of radionuclides (alpha and beta) is the activity of these in a radioactive substance in an air divided by the volume of the air. The change in counting and background rates represents the number of spontaneous nuclear transformations taking place in the relevant number of radionuclides in a time interval (Δt) divided by this time.

$$AAC/BAC = \frac{\begin{array}{c}\text{counting rate (alpha/beta)} - \\ - \text{background rate (alpha/beta)}\end{array}}{\Delta t \cdot V \cdot E_f} \qquad (1)$$

where E_f is the filter efficiency. Thus the unit of activity concentration in SI system is the Becquered per cubic meter [$Bq \cdot m^{-3}$], whereas 1 Becquered equals 1 disintegration per 1 second. Becquered is a unit to express strength of radioactivity.

During the period of this study, meteorological parameters such as wind speed, wind direction, air pressure, and relative humidity were also recorded by portable devices at Al-Tuwaitha site, while only solar radiation measurements was supplied by the nearby automatic weather station located at Mustansiriyah University, which is far from the site with 21 km. The latter parameter is required in calculating air stability, which was determined using modified Pasquill–Turner (Table 1).

TABLE 1. Modified Pasquill–Turner stability classes

Wind speed [$m \cdot s^{-1}$]	Daytime solar radiation [$W \cdot m^{-2}$]			Overcast
	> 600	300–600	< 300	
< 2	A	A–B	B	C
2–3	A–B	B	C	C
3–5	B	B–C	C	C
5–6	C	C–D	D	D
> 6	C	D	D	D

A – very unstable; B – moderate unstable; C – slight unstable; D – neutral.

Statistical analysis

First, sometimes, at the values for air pressure and wind speed, there were several different values of alpha and beta activity concentration. Thus, means were calculated with standard deviation – represent the dispersion around the mean values – plotted as vertical lines in some figures of this study. Second to identify the variations of these concentration affected by the meteorological parameters, linear and non-linear fitting lines were performed using Origin software (version 9.3). Other statistical analyses including maximum and minimum values, frequencies, wind rose, Pearson's correlation coefficients (*R*), and a significant level represented with *p*-value less than 0.05 were also computed.

Results and discussion

Daily alpha/beta activity concentrations were analyzed to derive the statistical relationships with meteorological elements measured at the same time. Table 2 displays their arithmetic means, standard deviation (*SD*), minimum and maximum values. *AAC* values were ranged from 0.42 to 4.18 $Bq \cdot m^{-3}$ and have a mean of 1.78 $Bq \cdot m^{-3}$ with $SD =$ $= 0.84$ $Bq \cdot m^{-3}$. While *BAC* values that are always larger than *AAC* range from 0.93 to

TABLE 2. Mean values for meteorological variables with their SD, minimum and maximum

Meteorological variable	Mean	*SD*	Minimum	Maximum
Alpha activity concentration [$Bq \cdot m^{-3}$]	1.78	0.84	0.42	4.18
Beta activity concentration [$Bq \cdot m^{-3}$]	3.9	1.8	0.93	9.21
Air temperature [°C]	20.8	4.1	15	30
Wind speed [$m \cdot s^{-1}$]	4.8	1.96	1	7.1
Relative humidity [%]	52.5	17.7	21	83
Air pressure [mmHg]	761.8	3.61	754.5	769.6
Solar radiation [$W \cdot m^{-2}$]	417.4	198.6	0	700

9.21 Bq·m^{-3} with an average 3.9 Bq·m^{-3} and SD = 1.84 Bq·m^{-3}. The above values in this study are approximately close to the measurements recorded at the air of university of Malaga, Spain which characterize with warm climate with little rain (Dueñas et al., 1999).

During the study period, there were also clear variations in meteorological elements. This can be verified in terms of their ranges, air temperature: 15–30°C, wind speed: 1–7.1 m·s^{-1}, relative humidity: 21–83%, air pressure: 754–769.6 mmHg and solar radiation: 0–700 W·m^{-2}. The means of these variables are 20.8°C, 4.8 m·s^{-1}, 52.5%, 761.8 mmHg and 417.8 W·m^{-2}, respectively.

Correlation coefficients between *AAC*/*BAC* and meteorological elements

To identify which meteorological element is effected on the fluctuations of *AAC* and *BAC*, thus we present the *AAC* and *BAC* measurements on Y-axis and meteorological observations on X-axis as shown in Figures 2–6. In general, there was high scatter in *BAC* values comparing to those of *AAC*. Also, according to observed behavior with respect to each figure, we could make the best fitting lines, solid and dashed lines plotted for *AAC* and *BAC*, respectively. They were obeyed to mathematical relations which have empirical constants deriving from the field measurements for all parameters in this study. We first calculate correlation coefficients which reported in Table 3 with p-value results.

Figure 2 presents *AAC* and *BAC* measurements against air temperature. The decreasing behavior for these concentrations is clear when increasing temperature, i.e. there has inverse relation between *AAC*/*BAC* and air temperature (T_a). Activity concentration of radionuclides (alpha and beta) could be expressed by the following equations:

$$AAC = 6.9 - 0.37 \cdot T + 0.006 \cdot T^2 \quad (2)$$

$$BAC = 15.4 - 0.84 \cdot T + 0.014 \cdot T^2 \quad (3)$$

This decreasing was also confirmed negative moderate correlation coefficient (R = –0.57 with p = 0.00002) for the relation between *AAC* and temperature, while R = –0.58 with p = 0.00001 when correlated with *BAC*.

TABLE 3. Correlation coefficients (R) and significance p-values for relation between *AAC*/*BAC* and meteorological variables

Variable	*AAC*		*BAC*	
	R	*p*	*R*	*p*
Air temperature	–0.57	0.000016	–0.58	0.00001
Wind speed	–0.72	0.0022	–0.76	0.001
Relative humidity	0.21	0.15	0.22	0.13
Air pressure	0.58	0.00083	0.58	0.00075
Solar radiation	–0.33	0.03	–0.34	0.025

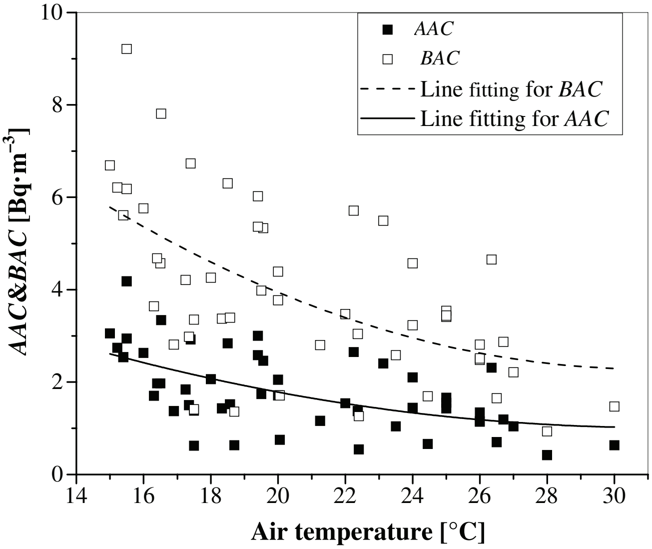

FIGURE 2. Variation of *AAC* and *BAC* with air temperature

The same behavior was also found when plotting *AAC*/*BAC* values with wind speeds (Fig. 3). The best fitting line passing through these data is described by the the following expressions:

$$AAC = 4.02 - 0.88 \cdot U + 0.007 \cdot U^2 \quad (4)$$

$$BAC = 10.06 - 2.22 \cdot U + 0.17 \cdot U^2 \quad (5)$$

The good inverse correlation coefficients between *AAC*/*BAC* values and wind speed were observed as shown in Table 3 where $R = -0.72$ with $p = 0.0022$ for *AAC* and wind and $R = -0.76$ with $p = 0.001$ for *BAC* and wind.

Because high scatter for *AAC*/*BAC* measurements with relative humidity, correlation coefficients were positive weak $R = 0.21$ and 0.13, respectively with $p > 0.05$. Although high scatter and weak correlation coefficient, the relations between them appear to have linear behavior which obeys to linear regression equations:

$$AAC = 1.24 + 0.88 \cdot RH\,\% \quad (6)$$

$$BAC = 2.71 + 0.02 \cdot RH\,\% \quad (7)$$

The values of *AAC* and *BAC* show a linear relation with air pressure (*P*) as illustrated in Figure 5, in which the plotted solid and dashed lines drawn are fitting for these values for these values followed by linear regression equations:

$$AAC = -75 + 0.1 \cdot P \quad (8)$$

$$BAC = -186.7 + 0.25 \cdot P \quad (9)$$

As stated in Table 3, both *AAC* and *BAC* values have the same moderate positive correlation coefficient with air pressure ($R = 0.58$ with $p = 0.0008$).

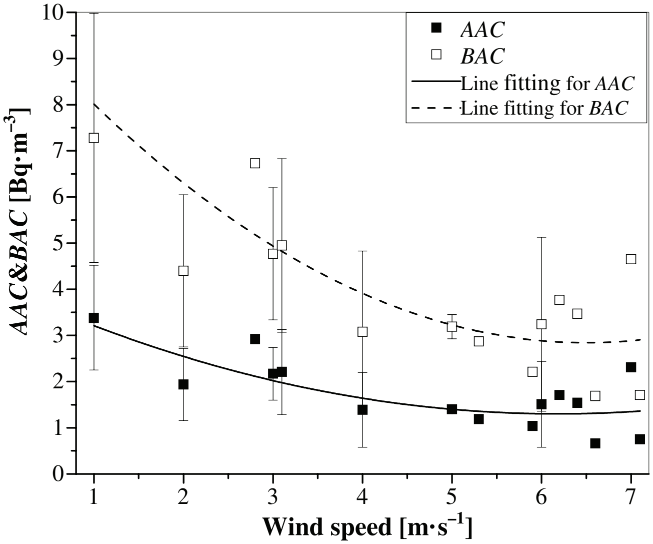

FIGURE 3. Variation of *AAC* and *BAC* with wind speed

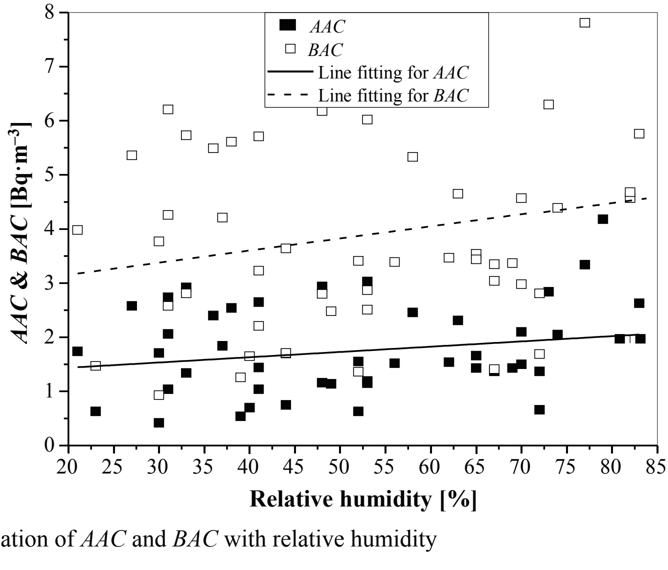

FIGURE 4. Variation of *AAC* and *BAC* with relative humidity

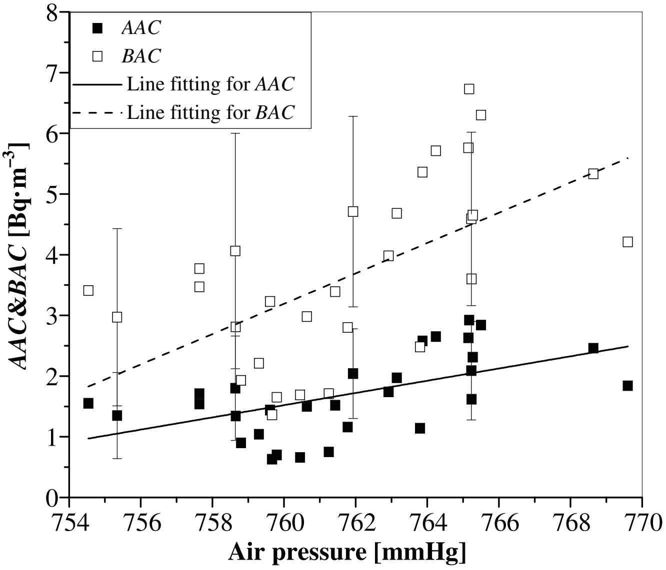

FIGURE 5. Variation of *AAC* and *BAC* with air pressure

Lastly, when solar radiation (*SR*) values were less than 300 $W \cdot m^{-2}$, the *AAC* and *BAC* values have constant behavior and then continuously decrease when $SR > 300$ $W \cdot m^{-2}$ as shown in Figure 6. These non-linear behaviors could be represented by the the following expressions:

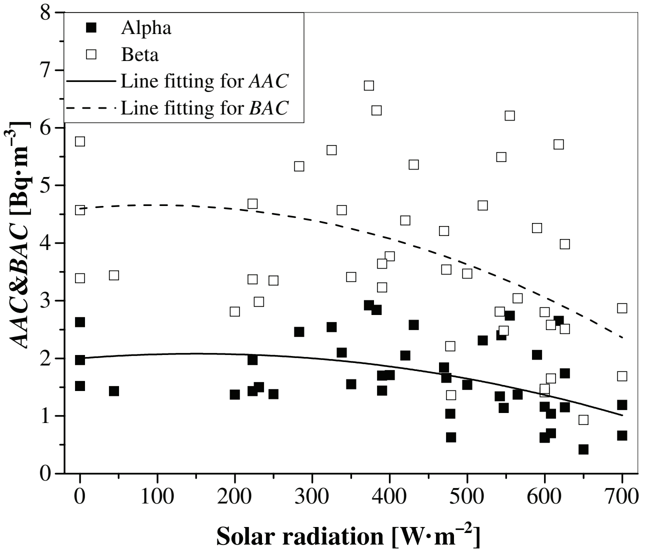

FIGURE 6. Variation of *AAC* and *BAC* with solar radiation

$$AAC = 4.02 - 0.88 \cdot SR + 0.07 \cdot SR^2 \quad (10)$$

$$BAC = 10.06 - 2.22 \cdot SR + 0.17 \cdot SR^2 \quad (11)$$

The overall correlation coefficients for both *AAC* and *BAC* with solar radiation data were negative weak, $R = -0.33$ with $p = 0.025$.

Effect of wind direction on *AAC*/*BAC*

To study the potential effect of daily wind direction, we presented wind rose shown in Figure 7, in which the main direction is at northwest that represents prevailing wind direction with frequency ratio (46%) during the study period. The other prevailing direction with ratio 23% is north. These two directions roughly forms 70% of total number of measurements.

Through both prevailing directions, the mean concentration activity for *AAC* and *BAC* with *SD* was calculated. The frequency with its percentage and mean with *SD* were reported in Table 4. When the northwesterly wind dominates the mean *AAC* and *BAC* values arise as high

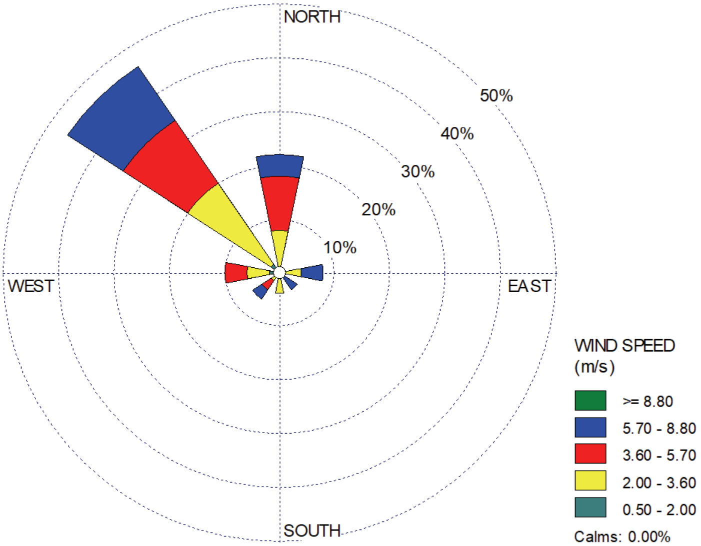

FIGURE 7. Wind rose at Al-Tuwaitha site during the studied period

TABLE 4. Frequencies of *AAC* and *BAC* and their means for prevailing wind directions in this study

Wind direction	Number of frequencies	Activity concentration	Mean [Bq·m^{-3}]	*SD*	Minimum	Maximum
NW	23	*AAC*	2.05	0.88	0.6	4.18
		BAC	4.52	1.92	1.41	9.21
N	10	*AAC*	1.4	0.73	0.63	2.74
		BAC	3.15	1.63	1.36	6.21

as from north. Although minimum values for both *AAC* and *BAC* are approximately similar for both above directions, the maximum *AAC* and *BAC* at northwest is higher than those at north.

Effect of air stability on *AAC*/*BAC*

According to daily data for wind speed and solar radiation, the air stability classes have been determined using Table 1. All of observations (50 runs) were mostly found to be in two major classifications that are unstable (37 runs) and neutral (13 runs) conditions as shown in Table 5. Here, only two runs with ratio 4% at class A cannot be reliable, so they were not discussed. Most runs were in moderate unstable classes (23 runs with 46%), slight unstable classes (12 runs with 24%). Meanwhile only 13 runs with ratio 26% were obtained under neutral conditions class D.

The mean values for both *AAC* and *BAC* at each class were calculated with their standard deviations, as reported also in Table 5. The large values for *AAC* (> 2 $Bq\cdot m^{-3}$) were found at classes B and B–C and also the same result was for ABC but with a large value (~ 4.5 $Bq\cdot m^{-3}$). At class C, the smallest values for both *AAC* and *BAC* were 1.27 ±0.7 $Bq\cdot m^{-3}$ and 2.83 ±1.5 $Bq\cdot m^{-3}$. As an overall result, mean *AAC* in stable air has a value of 1.67 $Bq\cdot m^{-3}$ which are slightly less than 1.71 $Bq\cdot m^{-3}$ for neutral air. This result was changed for ABC, where its mean value is 3.78 $Bq\cdot m^{-3}$ in unstable air that is slightly larger than the value 3.71 $Bq\cdot m^{-3}$ in neutral conditions.

Conclusions

This study detects the effects of daily meteorological variables of air temperature, wind speed and its direction, air pressure, relative humidity, and solar radiation on gross alpha and beta activity concentration at Al-Tuwaitha nuclear site for period from 28 January 2016 to 13 April 2017. In general, although *AAC* values are less than *BAC*, they have often the same behavior over all ranges of these variables. Both wind speed, temperature, and solar radiation negatively correlated with *AAC* (R = –0.72, –0.58 and –0.33) and *BAC* (R = –0.76, –0.58, –0.33, respectively). Meanwhile, air pressure and relative humidity were positively correlated with *AAC* (R = 0.58 and 0.21) and *BAC* (R = 0.58 and 0.22). All these relations were found to obey nonlinear regression equations, except for *AAC*/*BAC*

TABLE 5. Frequencies of stability classes and mean values of *AAC* and *BAC*

Stability classes	Frequency	Ratio [%]	*AAC* [$Bq\cdot m^{-3}$]		*BAC* [$Bq\cdot m^{-3}$]	
			mean	*SD*	mean	*SD*
A	2	4	1.39	0.49	3.28	0.99
B	17	34	2.1	0.93	4.71	2.09
B–C	6	12	1.92	1.0	4.32	2.28
C	12	24	1.27	0.72	2.83	1.57
D	13	26	1.71	0.63	3.71	1.2

with air pressure and relative humidity, which follow the linear equation. Lastly, wind direction has significant effect on *AAC* and *BAC* whereas their mean values were found to be large in prevailing wind (northwest) compared to other direction (north).

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Summary

Detecting the relations between meteorological elements and alpha and beta activity concentration at Al-Tuwaitha site, Baghdad. In this study, 50 samples of air particulates collected from different places in- and outside the Al-Tuwaitha nuclear site, south of Baghdad were used to measure daily gross alpha and beta activity concentrations (*AAC* and *BAC*) for the period from 28 January 2015 to 13 April 2017. At the same time, several meteorological factors such as air temperature, wind speed, wind direction, air pressure, relative humidity, and solar radiation, were also measured. Air stability classes were also derived from wind speed and solar radiation. *AAC*/*BAC* variations in the surface air layer were discussed in relation to these factors. The results show that there are inverse relations between *AAC*/*BAC* and wind speed and temperature, linear relations between *AAC*/*ABC* and air pressure and weak relations between *AAC*/*BAC* and relative humidity and solar radiation. Lastly, *AAC*/*BAC* measurements in unstable air are as large as in neutral air.

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