Influence of Meteorological Parameters on the Variations of Atmospheric Radionuclides Concentration in Dar es Salaam, Tanzania

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Authors' contributions

This work was carried out in collaboration between both authors DRS and YIK. Both authors read and approved the final manuscript.

ABSTRACT

Atmospheric concentrations of $^7$Be and $^{212}$Pb were measured for 11 years (2008 – 2018) in Dar es Salaam, Tanzania. The mean activity concentrations of $^7$Be and $^{212}$Pb were found to be within the range of 1.29 – 5.71 mBq/m$^3$ and 10.85 – 50.06 mBq/m$^3$, respectively. The annual mean activity concentrations of $^7$Be and $^{212}$Pb were $4.72 \pm 1.18$ mBq/m$^3$ and $29.76 \pm 13.63$ mBq/m$^3$, respectively. Distinct annual trends were depicted on $^7$Be and $^{212}$Pb, suggesting that the two radionuclides were affected differently with atmospheric conditions. Monthly atmospheric concentrations of $^7$Be showed a strong seasonal variation trend with the highest in January and February and lowest in April. $^{212}$Pb depicted the highest concentration during June and July and lowest in January and December. The regression analysis for $^7$Be and $^{212}$Pb activity concentrations together with number of meteorological parameters revealed that the relative humidity, rainfall, air temperature, absolute humidity and wind speed are the most significant parameters affecting radionuclides activity concentrations in the atmosphere. The sunspot numbers show 66.7% of its variability with $^7$Be activity concentration which further suggesting that other parameters may influence its variation. $^{212}$Pb, on the other hand, shows only 27.3% of its variability which clearly indicates that the existence of cosmic rays does not affect its activity concentration in the atmosphere.
Keywords: $^7$Be; $^{212}$Pb; CTBTO; meteorological parameters; sunspot numbers.

1. INTRODUCTION

The atmosphere, as part of our environment, provides for the need to be checked for radionuclides distribution. The radionuclides produced in the environment are introduced to the atmosphere through interactions of cosmic radiation or natural and man-made activities on the Earth’s surface [1,2,3]. Independent of the origin, the radionuclides produced enter the atmosphere. These then attach to sub-micron sized aerosol particles [4]. Radionuclides are in dynamic process which finds a place in short and long distances through diffusion or long range wind transport. The radionuclides normally redistributed vertically by gravitation, sedimentation and removed by dry and wet deposition in the troposphere [5,6,7]. Radionuclides behaviors can be used to examine aerosol particle movement, distribution governing their transport and also as tracers in geological and geochemical studies [3,8,9].

The radionuclides added to the environment results into worldwide concern in measurements [10]. The stations of radioactive aerosols and radioactive noble gases monitor various radioactive aerosols. The Beryllium-$^7$Be ($^{212}$Pb) are the most detected natural radionuclides on a daily basis. The radionuclides $^7$Be and $^{212}$Pb have been reported to be the major contributors to gamma counts spectra and are used for detection capability of radionuclides relevant to nuclear testing [11]. Furthermore, when combined with other radionuclides $^7$Be and $^{212}$Pb shows seasonality behavior in many places of the world [12,13].

$^7$Be ($T_{1/2}$=53.3 days) is a short lived radionuclide of cosmogenic origin formed due to spallation process of nitrogen and oxygen in the upper troposphere and lower, stratosphere [4,5]. Studies have shown that $^7$Be has been used as radiotracer for the environmental processes analyses including aerosol transit and residence times, long-range air mass transport and soil erosion studies [14,15,16]. It reaches the surface as a result of atmospheric production rate which is the function of latitude, altitude and solar activity. The amount of $^7$Be that reaches the surface is also affected by atmospheric production rate which is a function of air exchange between the stratosphere and troposphere [14,17]. The latitudinal dependence of $^7$Be fluxes and its annual production show the temporal variation related with solar activity on the earth’s surface [2,18].

Deposition of $^7$Be to the land surface was a result of both wet and dry deposition, although it has been revealed that $^7$Be fallout is primarily associated with precipitation [13]. The significant decrease in $^7$Be concentrations was due to extreme wet deposition in the stations located within the Intertropical Convergence Zone (ITCZ) [6,19]. The increase in precipitations resulted to lower activities of $^7$Be [6,15]. In many studies, seasonal variations were reported to be one of the factors causing the variation of radionuclides in the atmosphere [12,20,21]. In Northern hemispheres, countries such as Thessaloniki, Greece and Switzerland, the higher concentrations of $^7$Be were observed during summer and lower during winter. Its concentration varies inversely with 11- year solar cycle [4,9]. In tropical and sub-tropical latitudes including Bombay, India, the peak $^7$Be concentrations occurred around spring time between March and April [22]. Due to higher temperature during those months causes the air masses rich of $^7$Be to be transported from the stratosphere to the troposphere through convective circulation [18]. Meanwhile in Philippines which is frequently affected by large scale atmospheric system including tropical cyclones and Intertropical Convergence Zone (ITCZ) has the highest concentration of $^7$Be between January to April and lowest concentration on October and November [12].

The radionuclides $^{212}$Pb ($T_{1/2}$=10.64 h) is the decay product of Rn 220 which emanates from the land, coastal sites and island sites can be attached to aerosol particles and remain in air [23,24]. Regardless of its short half-life, few studies have been reported so far using natural radionuclide $^{212}$Pb as atmospheric tracers in local and sub-regional scale due to its sensitivity to local emission [25]. Studies also reported that the concentration of $^{212}$Pb in the atmosphere varies due to local rainfall, wind speed and wind direction [26]. The activity concentration of $^{212}$Pb was observed to be higher during warm summer months (between March and July) and it was affected differently from that of $^7$Be by local atmospheric conditions and process [12].

In Tanzania, Dar es Salaam experiences a humid weather due to seasonal variation of winds from the ocean driven by general
circulation combined with the land and the sea [27]. Due to this there is a high possibility of the atmosphere to be contaminated with radionuclides released from natural sources from within and other countries. However, no studies have been conducted in Tanzania to assess the variation of radionuclides in the atmosphere until now. The main objective of this study is to assess the effect of meteorological parameters on the variation of radionuclides concentration. For this purpose, a monitoring program for $^7$Be and $^{212}$Pb for 11 years since January 2008 was carried out in the region of Dar es Salaam, Tanzania.

2. MATERIALS AND METHODS

2.1 The Description of the Study Area

Dar es Salaam is the region located on the eastern coast of Tanzania. It lies on the latitude 6.45°S and 7.25°S and longitude 39°E and 39.55°E, respectively and borders with the Indian ocean along the east and surrounded with the Coastal regions [28]. The map providing the sampling location of in Dar es Salaam station is given Fig. 1. Dar es Salaam experiences tropical climatic conditions with a warm and humid weather condition throughout the year. Dar es Salaam has a tropical wet and dry climate with two rain and dry seasons. Total rainfall per year is approximately 1,100 mm and in a normal year there are two distinct rain seasons: The long rains, which fall during March, April and May, and the short rains, which fall during October, November and December. During the dry season temperatures can easily rise to above 35°C. Dar es Salaam, experiences Northerlies, Easterlies, and Southerlies monsoon winds due to its humidity weather resulted from Indian Ocean [27].

2.2 Sample Collection and Analysis

The aerosol samples of diameter 0.2 μm and above were collected on daily basis for 24 h using high volume air sampler (Snow White JL-900, Senya Oy, Finland) with the flow rate ranging from 800 to 850 m$^3$/h. The air sampler has the ability of collecting air within the range of 1000 km - 10,000 km in three dimensions; vertically upward, downward and horizontally. The air sampler was positioned on the roof of the Physics department building 106 m above the sea level. Aerosols were separated by filtration through high - efficiency polycarbonate air filter (BMF5379-20F, 3 m, Mexico) with dimensions 57 cm × 46 cm with particulate efficiency of 80%. The collected air filter sample was then compressed for minimum of 4 minutes so as to produce a filter of a disc shape with diameter of 50 mm using a hydraulic press (3850, Carver Inc., USA) and placed on a plastic sample holder before being allowed to decay for 24 h to allow short-lived radionuclides to decay [29].

The sample after 24-h decay was then analyzed for gamma-emitting radionuclide using a P type high-purity Germanium high resolution gamma ray spectrometry with relative efficiency ≥ 40% and resolution of < 2.5 keV at 1332 keV of model GEM70P4-95S with sample geometry DISC50MMX5. The generated gamma spectra data were then automatically sent to CTBTO’s International Data Centre (IDC) for analysis and categorization. Daily data for activity concentrations of $^{212}$Pb and $^7$Be from 1st January 2008 to 31st December 2018 were retrieved from the CTBTO Concentration Reporting Tool (CRTTool) for further analysis [30].

The daily precipitation/ Rainfall data, air temperature, relative humidity, and the zonal and meridional wind components were retrieved from the Climate Hazards Group Infrared Precipitation with Station (CHIRPS) at grid resolution of 0.05 degree from the European Centre for Medium - Range Weather Forecasts (ECMWF) Re-Analysis data fifth generation (ERA5) covering the duration from 2008 to 2018 were indulged into the analysis [31].

2.3 Statistical Data Analysis

The time series for $^7$Be and $^{212}$Pb activity concentration were plotted and changes in their values were analyzed in terms of their meteorological data. The regression analysis was employed to examine the influence of air temperature, relative humidity, rainfall, absolute humidity and wind speed on variability of $^7$Be and $^{212}$Pb activity concentrations by using R statistics based package for test analysis. The coefficient of correlation ($r$) between the variables in Linear Regression was examined using critical probability ($P$) value with significance level ($\alpha$) = .05 such that for $P < .05$ the statistic modal was significant and for $P > .05$ the modal was not significant. The $P$ - values which were less than 0.001 were not reported as 0.000 instead as $P < 0.001$ because the $P$-values can never be equal to zero [32,33].
3. RESULTS AND DISCUSSION

3.1 Statistical Representation of Radionuclides Data

The radionuclides (⁷Be and ²¹²Pb) data for eleven years (2008-2018) are presented in the box with whisker plots in Figs. 2 and 3 respectively. The vertical boxes contained the middle 50%. The horizontal line represented the median concentrations while the vertical lines (Whiskers) were plotted as individual points. Outside the box, the outliers were distinguished with the black round balls which are the points more than 1.5 interquartile range below the lower quartile or above the upper quartile.

From the graphical view of data in the box plots, the data were not normally distributed. The radionuclides data only show skewedness. This is in agreement with [24] that natural radioactivity always shows a skewed distribution and they are often described in Log-normal or gamma distribution. For normal distributions, data in the box plots should display whiskers of the same length as box or marginally longer. Also the median line should be closer to the center of the box.

The measurement of the activity concentration of ⁷Be and ²¹²Pb in aerosols samples started effectively in January 2008. The mean activity concentration level for ⁷Be and ²¹²Pb for the duration of 11 years (2008 - 2018) are represented in Table 1. This shows the average concentrations, the standard deviation (σ) and the range of both radionuclides. The mean activity concentration of ⁷Be and ²¹²Pb in the atmosphere were 4.72 ± 1.18 mBq/m³ and 29.76 ± 13.63 mBq/m³, respectively. The ⁷Be activity concentration in Dar es Salaam was found to be within the range of 1.29 – 5.71 mBq/m³ while ²¹²Pb were in the range of 10.85 – 50.06 mBq/m³, respectively. The results are in agreement with the earlier results reported by [21, 25].

Based on the results described in Table 1, the annual changes of ⁷Be and ²¹²Pb in the atmosphere were commonly regarded to be caused by different atmospheric stability due to increase or decrease of different meteorological parameters including rainfall, humidity, air temperature or wind speed and direction.
Fig. 2. Box with whisker plots showing annual variations of (a) $^7$Be and (b) $^{212}$Pb activity concentration from 2008 – 2018

Fig. 3. Box with whisker plots showing mean monthly values of (a) $^7$Be and (b) $^{212}$Pb activity concentration from 2008 – 2018
3.2 Trend Analysis for $^7$Be and $^{212}$Pb Activity Concentration

The time series and the trend lines for both $^7$Be and $^{212}$Pb are shown in Figs. 4(a) and (b). Fig. 4(a) depicted linear trend of decrease in activity concentration for both radionuclides while in Fig. 4(b) the trend is nonlinear on activity concentration of the $^7$Be and $^{212}$Pb in the Dar es Salaam during 2008–2018. It was observed that the higher activity concentrations of $^{212}$Pb occurred during the months of June ($38.02 \pm 9.56$ mBq/m$^3$) and July ($38.16 \pm 6.58$ mBq/m$^3$) while the lowest occurred in two phases.

The first phase started between January ($21.61 \pm 4.48$ mBq/m$^3$) and February ($25.29 \pm 8.24$ mBq/m$^3$) and lastly between November ($22.3 \pm 4.40$ mBq/m$^3$) and December ($21.54 \pm 5.22$ mBq/m$^3$), respectively. On the other hand, the activity concentration of $^7$Be indicated to have high concentrations during the months of January ($5.84 \pm 0.91$ mBq/m$^3$) and February ($5.38 \pm 1.22$ mBq/m$^3$) while the low concentrations was observed in April ($2.63 \pm 0.84$ mBq/m$^3$). A slight increase of $^7$Be concentration was observed in June and July before decreases in November. This is in agreement with the results observed from Tayan, Philippines where the seasons are different. The highest activity concentrations of $^7$Be in Tayan, Philippines observed between January to April ($3.76 \pm 0.95$ mBq/m$^3$) with the concentration range of 10.10-11.20 mBq/m. and those of $^{212}$Pb observed in warmer months between April and July. The maximum concentration was in May ($32.29 \pm 6.46$ mBq/m$^3$) with activity concentration ranging from 8.67–106.62 mBq/m$^3$ [5].

3.3 Correlation between Meteorological Data with $^7$Be and $^{212}$Pb Activity Concentrations

The relationship between air temperature, absolute humidity, relative humidity, wind speed and rainfall with activity concentrations of $^7$Be and $^{212}$Pb in the atmosphere were investigated. The Spearman correlation coefficient was employed. In Fig. 5, the correlation between the activity concentrations of $^{212}$Pb and $^7$Be activity for 11 years (2008–2018) is shown. The results revealed that no correlation was observed between $^7$Be and $^{212}$Pb activity concentration was found ($r = 0.15$, $P > 0.05$). This suggests that the atmospheric activity concentration of $^{212}$Pb, a terrestrial radionuclide and $^7$Be cosmogenic radionuclide are affected differently by local atmospheric process and weather conditions.

A series of correlations of $^7$Be activity concentrations with meteorological parameters in Fig. 6 reveal that relative humidity has the significant correlation compared to others (Fig. 6(d); $r(132) = -0.662, P < 0.001$). This is in agreement with the study conducted by [19] of which the IMS stations located in ITCZ revealed similar correlation. The results also indicated that there was a moderate correlation with rainfall (Fig. 6(a); $r(132) = -0.436, P < 0.001$), weak positive correlation with temperature (Fig. 6(b); $r(132) = 0.160, P = 0.2243$), with wind speed (Fig. 6(c); $r(132) = 0.339, P < 0.001$) and with absolute humidity (Fig. 6(e); $r(132) = -0.323, P < 0.001$).

The results of spearman correlation in Fig. 7 show that, a series of correlations of the $^{212}$Pb activity concentration values with meteorological data indicate a significant negative correlation with the absolute humidity (Fig. 7(e); $r(132) = -0.551, P < 0.001$) and air temperature (Fig. 7(b); $r(132) = -0.541, P < 0.001$), a significant negative correlation with rainfall (Fig. 7(a); $r(132) = 0.412, P < 0.001$), a weak positive correlation with wind speed (Fig. 7(c); $r(132) = 0.358, P < 0.001$) and very weak negative correlation with relative humidity (Fig. 7(d); $r(132) = -0.177, P < 0.001$).

The results of regression analysis do not indicate strong effect of air temperature on $^7$Be and that the inclusion of air temperature did not improve the fit ($r = 0.106, P = 0.2243$) which further indicates only 1% on its variability. Relative humidity had significant influence since it has 44% of its variability to $^7$Be. $^7$Be also indicates its variability with rainfall 19%, wind speed 12% and only 7% with absolute humidity. On the other

| Radionuclide | Mean ± σ (mBq/m$^3$) | Range (mBq/m$^3$) |
|--------------|----------------------|------------------|
| $^7$Be       | 4.72 ± 1.18          | 1.29 – 5.71      |
| $^{212}$Pb   | 29.76 ± 13.63        | 10.85 – 50.06    |

Table 1. Mean activity concentrations for $^7$Be and $^{212}$Pb for the years 2008 - 2018 at Dar es Salaam, Tanzania
hand, absolute humidity and rainfall had significant influence on the $^{212}$Pb measurements. They indicate 31% and 41% on their variability with $^{212}$Pb, respectively.

Fig. 4. (a) Yearly time series and (b) Monthly time series of the $^7$Be (in black) and $^{212}$Pb (in red) activity concentration from 2008 to 2018

Fig. 5. Correlation between $^{212}$Pb and $^7$Be activity concentration from 2008 – 2018
Fig. 6. Correlation between $^{7}$Be activity concentrations with: (a) rainfall, (b) air temperature, (c) wind Speed, (d) relative Humidity and (e) absolute humidity from 2008 – 2018

3.3.1. Variation in $^{7}$Be and $^{212}$Pb with rainfall

Dar es Salaam region experiences rainfall in all seasons regardless of being a rain season or dry seasons but mostly between March, April and May due to humid weather caused by winds from Indian ocean. The mean monthly activity concentration of $^{7}$Be and $^{212}$Pb presented in Fig. 8 clearly demonstrated a significant season variation the radionuclides in the atmosphere of which rainfall was considered to be one of the factor for the variation. In all MAM seasons the activity concentrations of $^{7}$Be were low when compared to other seasons as illustrated in Fig. 8 (a). When the amount of rainfall increased a sharp decrease in activity concentration of $^{7}$Be occurred. This was clearly observed during the MAM season in 2014, 2017 and 2018 when the total rainfall was about 917.884 mm, 1378.447 mm and 1263.552 mm, respectively. This is associated with radionuclides washout from the air by rain, which in turns reduced their concentration in the airborne particulate [28]. Based on the results of Fig. 8 (b), rainfall was not the only parameter affecting $^{212}$Pb activity concentration in the atmosphere. This is because the variation of the $^{212}$Pb activity concentrations during dry and rain seasons was not high.
3.3.2 Variation in $^7$Be and $^{212}$Pb with humidity

The results revealed from Figs 9 (a - b) clearly shows that, the decrease in $^7$Be and $^{212}$Pb activity concentration was due to the increase in relative humidity and absolute humidity during rain season. High amount of humidity was observed during MAM months (2013, 2014, 2017 and 2018) resulting higher deposition of $^7$Be and $^{212}$Pb in the surface air. Mean while, the effect of humidity in dry seasons was low. The increase in absolute humidity caused more $^{212}$Pb to be removed from air by rainfall via the wash out process. This results to lower measured activity concentrations to the surface air.

![Fig. 7. Correlation between $^{212}$Pb activity concentrations with: (a) rainfall, (b) air temperature, (c) wind speed, (d) relative humidity and (e) absolute humidity from 2008 – 2018](image-url)
3.3.3 Variation in $^{7}$Be and $^{212}$Pb with air temperature

Air temperature as one of the meteorological parameter seems to affect differently $^{7}$Be and $^{212}$Pb activity concentration in Dar es Salaam station as compared to other station in the world. Based on the correlation results it is in agreement that the production rate of $^{7}$Be is not influenced by the air temperature. This is due to the fact that the increase in temperature influences the mixing rate of air masses as a result of increase in $^{7}$Be from higher altitude to lower attitude. Since Dar es Salaam is located near the equator, the tropical climatic condition is experienced. For that case warm air, weak horizontal pressure gradient and lighter easterlies were expected which are in association with ITCZ at the boundary of Southeast and Northeast trade winds [34]. Due to deflection of warm air by Coriolis force in Northern hemisphere causes the winds to blow from northeast. Based on the results of this study, an increase in $^{7}$Be at the surface level is an indicator of a vertical downward flux of air masses in January and February which was associated with warm air from the northeast. This result is in agreement with earlier study carried out by [6].

The highest and lowest activity concentration for $^{7}$Be corresponds with the dry season (JF) and the rain seasons (MAM), respectively. The absence of enough rainfall during dry season causes a build-up of $^{7}$Be concentration due to the solar heating of the air. From the correlation results, it was observed that the increase in air temperature tends to decreases activity.
concentration of $^{212}$Pb. It was observed that also the effect of temperature on $^{212}$Pb is significant during dry seasons (January - February). An increase in temperature during JF was related with the decrease in $^{212}$Pb activity concentration while during JJAS there is a sharp decrease in temperature resulting to an increase of $^{212}$Pb activity concentration as shown in Fig 10.

3.3.4 Inter annual variability of $^7$Be and $^{212}$Pb related to sunspot cycle

Solar activity varied inversely with the galactic cosmic-ray intensity at the earth’s orbit as reported by [17]. This result explains the cause of solar winds that shield the earth’s orbit from the galactic cosmic rays and the possible associated changes within the 11 years’ circle. That is an increase in the number of sunspots or solar activity causes decrease in cosmic-ray intensity at the earth’s orbit which leads to the decrease in the production rate of cosmogenic radionuclide $^7$Be. The year to year variability of annual mean activity concentration of $^7$Be, $^{212}$Pb and Sunspot numbers for the years 2008 – 2018 shows that, the yearly variation of $^7$Be and sunspot numbers agrees with the observation made by [17]. The months which have high $^7$Be activity concentration corresponded to low sunspot numbers. The variability of the annual average solar activity (sunspot numbers) was seen to be negatively correlated with the atmospheric concentration of $^7$Be. The beginning of the solar cycle from 2008 - 2009, the sunspot numbers were low because of high production rate of cosmic rays in the atmosphere which in turn causes the increase in $^7$Be activity concentration.

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**Fig. 9.** Seasonal distribution (left axes) of (a) $^7$Be and (b) $^{212}$Pb with the average relative humidity and absolute humidity (right axes) from 2008 to 2018
A sharp increase in sunspot numbers during 2013 – 2014 was observed which further resulted into the decrease of $^7$Be activity concentration in Dar es salaam, Tanzania. This is in agreement with previous results in literatures and solar cycle observed by NOAA/ Space weather prediction center. From 2016 - 2018 a sharp decrease in $^7$Be does not fit the hypothesis of higher sunspot number lower $^7$Be activity concentration since both of them show a decreasing trend. On the other side, the annual trend of $^{212}$Pb variability was not influenced by the solar activity. It was noted that, only 27.3% was observed as a decreasing variability trend for $^{212}$Pb over the 11-years period and 66.7% on the variability of $^7$Be. These are shown in Fig. 11 where the annual mean variation in activity concentration of (a) $^7$Be and (b) $^{212}$Pb along with variation of Sunspot Numbers are drawn.

3.3.5 Variation of $^7$Be and $^{212}$Pb with wind speed and direction

Wind is known to be the main mechanism of aerosols transport. In general, the high speed of wind resulted to high aerosols transport and vice versa which finally affect aerosols deposition (as a wet or dry deposit) to the surface air. The decrease and increase in activity concentrations of $^7$Be and $^{212}$Pb were observed during rain seasons and dry seasons in vicinity of Dar es Salaam (Fig. 12). During the period of 2008 – 2018, the average wind speeds were different from season to season.
Fig. 11. Annual mean variation in activity concentration of (a) $^7$Be and (b) $^{212}$Pb along with variation of sunspot numbers.

Fig. 12. Seasonal distribution (left axes) of (a) $^7$Be and (b) $^{212}$Pb with average wind speed from 2008 to 2018.
Fig. 13. Seasonal distribution of wind directions covering the period from 2008 to 2018
Table 2. Atmospheric activity concentration of $^7$Be and $^{210}$Pb in various locations

| Site                        | Coordinates                  | Elevation (m.a.s.l) | Study period       | $^7$Be (mBq/m$^3$)                     | $^{210}$Pb (mBq/m$^3$)          | References |
|-----------------------------|------------------------------|---------------------|-------------------|----------------------------------------|---------------------------------|------------|
| Dar es Salaam (Tanzania)    | 6°S, 39°E                    | 102                 | 2008 - 2018       | 4.72 ± 1.18 (Annual mean)             | 29.76 ± 13.63 (Annual mean)     | This study |
| Nouakchott (Mauritania)      | 18.1°N, 15.9°W               | 20                  | 2009 - 2015       | 5.755 ± 1.807 (Annual mean)           | -                               | [29]       |
| University of Málaga (Spain) | 36.7°N, 4.5°W                | 2000 - 2006         | 2.47 – 14.9       |                                        | -                               | [21]       |
| Tanay (Philippines)          | 14.6°N, 121.4°E              | 642                 | 2012 - 2017       | 2.17 ± 1.8 (Annual average)           | 14.08 ± 3.67 (Annual average)   | [12]       |
| Barcelona (Spain)            | 41°N, 2°E                    | 2001 - 2005         | 3.6 ± 1.11 μBq/m$^3$ (mean) | 2.1 ± 1.1 μBq/m$^3$ (mean) | [35]   |
| Kanazawa University (Japan)  | 36°26’N, 136°32’E            | 40                  | 2004              | 0.77 – 6.28                           | 9.04 – 97.4                     | [25]       |
| Shishiku Plateau, Ishikawa   | 36°27’ N, 136°39’ E          | 640                 | 2004              | 0.72 – 7.44                           | 6.57 – 23.2                     | [25]       |
| (Japan)                     |                              |                     |                   |                                        |                                 |            |
| Hegura Island (Japan)        | 37°51’ N, 136°55’E           | 10                  | 2004              | 0.72 – 6.81                           | 3.58 – 44.0                     | [25]       |
Fig. 13 shows that during JF the winds blow with an average speed of 3.6384 m/s from North to East as a result of high activity concentration of $^7\text{Be}$. Meanwhile during JJAS, Dar es Salaam experienced South East winds blown with an average speed of about 4.1364 m/s. In that particular time the concentration of $^{210}\text{Pb}$ was particularly high but low in other stations (Table 2) where the main contribution of its activity concentrations were the air masses coming from the soil of the Southern part of Tanzania, coastal sites, islands and from Madagascar. During rain seasons low wind speed of 2.93 m/s and 2.97 m/s were experienced when compared to other seasons of which the main contributors of air masses containing $^{210}\text{Pb}$ were from coastal sites and Island including Cocos Island in Australia.

The maximum level of $^7\text{Be}$ in Dry season (JF) were attributed to more efficient vertical transport of air masses between the upper and lower layer of troposphere. The concentrations of $^7\text{Be}$ were observed to be low during rain season (MAM) especially in April when the station experienced South East (SE) winds prevailed from March to October. This is in agreement with the observation made by [27]. The higher the concentration of $^7\text{Be}$ was associated to high production rate with low deposition rate [4, 6].

The low values are suggesting that the deposition was significant due to washout of aerosols particles from the atmosphere to the subsurface air. This is due to the low temperature and low rainfall in vicinity of Dar es Salaam which is influenced by the North East (NE) winds which were the lighter and predominantly Northerly [20] that prevailed in the country from October to March [27]. The airborne $^{210}\text{Pb}$ reaches a maximum level in dry season (JJAS) with a minimum in the rain seasons (MAM and OND) but its variation was affected by wind speed and direction. The high activity concentration observed during JJAS was a result of South East (SE) winds which were normally strong and predominantly southerly prevailing in Dar es Salaam [20]. The winds are associated with episodic events including Storms and Cyclones.

3.3.6 Comparison of the activity concentrations of radionuclides with the values reported in the literature

Generally, the high temperature and air humidity mediated convective rising of air masses dominates the Inter Tropical Convergence Zone (ITCZ). It enhances the cumulus and cumulonimbus clouds formation which leads to highest precipitation rate. Since the radionuclide $^7\text{Be}$ distribution is characterized by latitudinal distribution, to some extent symmetrical about the Equator [20]. The results of $^7\text{Be}$ and $^{210}\text{Pb}$ measurements in Dar es Salaam were compared with measurements for similar range of latitudes, both in Northern and Southern Hemispheres. The mean activity concentration of $^7\text{Be}$ and $^{210}\text{Pb}$ in this study are higher than those of Tayan, Philippines and Barcelona, Spain [12, 35]. Meanwhile, for the stations located in Africa, Mauritanian depicts to have high concentration of $^7\text{Be}$ when compared to the results of this study [29]. Furthermore, the range of activity concentration of $^7\text{Be}$ and $^{210}\text{Pb}$ in this study is similar to those of radionuclides stations located in Japan and in Spain [25,35] as shown in Table 2.

Based on the findings of this study it is evident that effect meteorological parameters on radionuclides concentrations vary from one location to another. This is due to different climatic conditions, altitude and latitude position and even the source location.

4. CONCLUSION

The activity concentrations data of radionuclides $^7\text{Be}$ and $^{210}\text{Pb}$ from CTBTO radionuclides monitoring station located in Dar es Salaam were for the first time measured and analyzed. In Tanzania, the data were used together with the meteorological one to investigate the mechanism that governs radionuclides concentration level in the atmosphere. The two radionuclides of different origin showed different periodic pattern of atmospheric concentration for the past 11 years (2008 – 2018). No correlation was found between $^7\text{Be}$ and $^{210}\text{Pb}$ activity concentration. This suggests that the surface air concentration between $^{210}\text{Pb}$ (was a terrestrial radionuclide) and $^7\text{Be}$ (was cosmogenic radionuclide), was affected differently by local conditions of atmospheric processes. The mean values of both $^7\text{Be}$ and $^{210}\text{Pb}$ were higher in dry seasons and lower in rain seasons due to vertical mixing and greater deposition of radionuclides. It was also observed that, both $^7\text{Be}$ and $^{210}\text{Pb}$ decrease with the increase in rainfall and humidity. The annual average solar activity (sunspot numbers) was seen to be varied with the atmospheric concentration of the $^7\text{Be}$, of which 66.7% of its variations where observed from 2008 – 2018.
The present study is restrained to a simple interpretation of the atmospheric concentrations of $^{7}$Be and $^{210}$Pb and its variations with meteorological parameters as well as the ecological, geological and demographic condition in Dar es Salaam, Tanzania. The predicted statistical relationships are also useful for environmental risk protection and decision making for planning human settlement or societal infrastructure development in large-scale activities of the people in Tanzania and the region.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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