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Assessment of integrated indoor environmental air quality parameters in selected church buildings of Faisalabad city: a statistical based comparative study

Key words: indoor air quality, church buildings, particulate matter, public health, air pollution

Introduction

The quality of air is the most vital insight that supports human existence on earth. Some cities of the world are facing the issues related with smog and imperceptible air pollution which are detrimental to the public's health (Al-Dabbous et al., 2019). For instance, particulate matter which is an arrangement of solid bits and liquid droplets measures 10 µm can easily inhaled deep into the respirational system (Shahid et al., 2019). The particulate matter size less than 2.5 µm are considered as fine particles. However, there may create a health risk, if a large portion of these particulates is inhaled (Aung et al., 2019). These particles patent from an assortment of different sources and may be emitted by the conversion of gaseous emissions. How these dangerous fine particles travel through the atmosphere is caused by dispersion creating a plume which spreads over a specific area, hence dropping the concentration of the air contaminants it covers (Behrooz et al., 2017). The common technique use for the gaseous diffusion is the Gaussian dispersion, in which air contaminants disseminated and are supposed to disclose ideal gas performance (Chang et al., 2019). The major force in air pollution transference is the wind causing the air pollutants to move downwind while the highest absorption of air contaminant molecules move laterally the plume centerline (Fernández, 2019). Since these molecules diffuse freely from upper to lower concentration regions, hence the air pollutants emitted constantly making the dispersion and emission process at a constant rate (Soudagar et al., 2019). Figure 1 shows the mechanism and arrangement of plume and wind sources related to the Gaussian dispersion. Looking through the Cartesian coordinate arrangement, the emission source is located at the starting point while the wind direction at the x-axis. Similarly, the vertical and horizontal dispersion are located the y-axis and z-axis respectively. For instance, as the plume travels downwind, it extents both crosswise and straight up away from the centerline allowing the air molecules to travel from upper to lower concentrations (Kelly & Fussell, 2019). Transection of the air pollutant concentration at both the y and z axes thus take the normal bell shape of Gaussian distribution curves as illustrated in Figure 1. The total effective height (H) is the sum of the vertical distance (h) and the symmetrical heap height (h_s) respectively. The cause of the pollutant spiral is in consequence a source raised above the ground at altitude follows Eq. (1).

$$z = H \tag{1}$$

The downwind attentiveness coming from this prominent source may be written using Eq. (2) (Filbet & Jin, 2010).

$$C(x,y,z) = \\ = \frac{Q}{2\pi \upsilon \sigma_y \sigma_z} e^{\frac{y^2}{2\sigma y^2}} e\left[\frac{-(z+H)2}{2\sigma x^2} + e^{\frac{-(z-H)2}{2\sigma x^2}} \right] \tag{2}$$

here:
$C(x, y, z)$ – concentration with coordinates x, y, z,
Q – emission rate [$gm \cdot s^{-1}$],
v – normal wind speed [$m \cdot s^{-1}$],
σ_y – standard non-conformity of the plume in the horizontal flow [m],
σ_z – standard non-conformity of the plume in the z trend [m] (Gao et al., 2017).

Since particulates matter concentration is normally restrained at earth level ($z = 0$) therefore, Eq. (2) diminishes to:

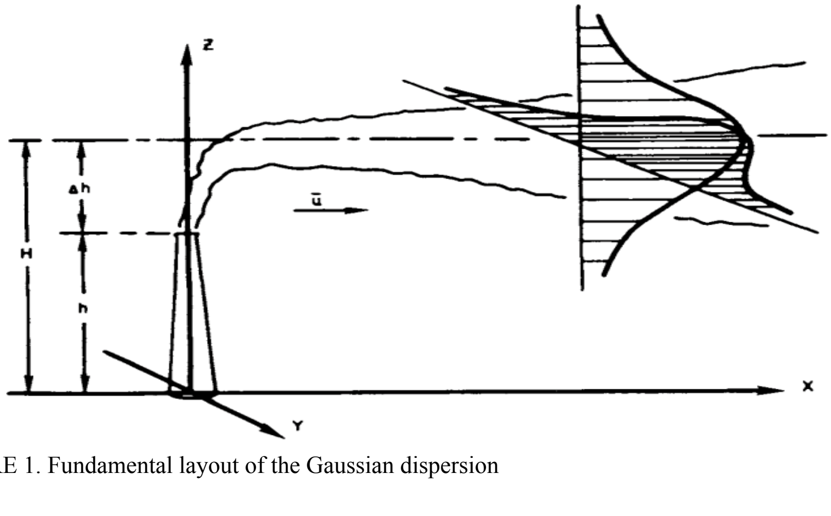

FIGURE 1. Fundamental layout of the Gaussian dispersion

$$C(x,y,0)=\frac{Q}{\pi \upsilon \sigma_y \sigma_z} e\left[\frac{y^2}{2\sigma_{y^2}}\right] e\left[-\frac{H^2}{2\sigma_{z^2}}\right] \quad (3)$$

However, the higher value of the concentration in any desired direction is the point of interest hence when $y = 0$, then Eq. (3) reduces to:

$$C(x,0,0)=\frac{Q}{\pi \upsilon \sigma_y \sigma_z} e - \frac{H^2}{2\sigma_{z^2}} \quad (4)$$

As a final point, in case when $H = 0$ and the concentration at ground level for the air pollutants moving down along the centerline becomes equal to:

$$C(x,0,0)=\frac{Q}{\pi \upsilon \sigma_y \sigma_z} \quad (5)$$

Rendering to the surveys of the World Health Organization (WHO), people spend around 90% of their time indoors however according to the statement of the EPA, the level of unhealthy concentrations is complex than the outdoor (Chang et al., 2019). Those related to the human contribution include a variety of sources such as industrial processes, apparel of road dust into the air, burning of fossil and wood fuels, demolition and construction activities (Ramírez et al., 2019). The most significant in this case include nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), radon (Rn) and a variety of concentrations (Van den Heede & De Belie, 2012). In church buildings, pollutant matter from different sources affects the comfort, health and routine work of the people in a negative manner (Mitcham & Briggle, 2009). It is also noticeable that the rank of the quality of air in a church building is significantly influenced by the topographical latitude of the building (Ruffolo et al., 2015). The people who normally stay in the church buildings are pastors, administration staff, secretary, treasurer, Sunday schooling staff, music department staff, and visitors. Making sure that these individuals feel contented with the existing environment, a study on indoor air quality has been needed to be highlighted at church buildings where religious activities are performed (Wang et al., 2018). The environments of church buildings under this study are extremely polluted due to the reasons such as crowded halls, low ventilation during rituals, insufficiency in fresh air supply, lack of ventilation system, presence of impervious windows, and great levels of radon gas.

According to the 2018 world air quality reports based on air quality data from public monitoring sources, Pakistan had been placed at the next utmost contaminated country with an annual $PM_{2.5}$ average of 74.3 $\mu g \cdot m^{-3}$ (Sultan et al., 2019). There is quite a lack of investigations for studying the particulate matter contaminants in the church buildings located in Faisalabad-Pakistan. In 2019, Faisalabad's air pollution ranked number 3 while the recorded exposure of $PM_{2.5}$ is 274.7 $\mu g \cdot m^{-3}$ on averages (Alvi et al., 2019). There are additional factors which contribute to increasing the rate of air pollution including huge scale losses of forests and tree for new buildings and furniture (Behrooz et al., 2017). During the summer, the kinetics of O_3 with other organic compound increases which leads to minimizing the O_3 concentrations in indoor air. Conversely, the concentrations of NO_2, remain similar both in the summer and winter to the concentrations in the air surrounded by the church buildings (Stamp et al., 2020). However, the concentration was normally 2–3 times greater in the winter due to increased emissions from additional sources including agricultural fields' burning. The concentrations of NO_2 were also found higher due to the influence of burning candles inside the church buildings (Yin et al., 2019). During the study on air quality in church buildings, it was observed that the concentration of particulates matter is determined by establishing relationships between them.

Materials and methods

Faisalabad is the third largest city in Pakistan with latitude and longitude coordinates as (31°41'8.7"N, 73°4'35"E) (Ahmad & Nizami, 2015). Figure 2 shows the location of Faisalabad with the surrounding provinces of Pakistan (Muqaddas et al., 2019). Conversely, in January the average lowest and highest temperatures are 3.89°C (39.00°F) and 18.8°C (65.84°F), respectively. On the other hand, ranking between the topmost 10 peak contaminated cities in the world, the quality of air of Faisalabad is inferior to what is deliberated safe by worldwide standards for harmless air quality (Nawaz et al., 2020). The Jesus Pentecostal Church building is located in Faisalabad city. There is a light stream of traffic around the church building as it is located 15 km away from the main city. In the main hall, air circulation is done through electric fans and natural sources.

The tables and benches in the main hall are made up of medium density fibers (MDF) concealed chipboards and two-fold glazed windows in size 140 × 45 cm. The windows are skylight models with an aluminum frame. The covered area of the building is 460 m^2 and for 270 publics. On the other hand, the St. Joseph's Cathedral church building is selected because it is located on the main mall road which is considered as one of the most crowded and commercial area of Faisalabad city. Hence, the church building is highly exposed to particulate matter, dust, smog and air pollution due to dissipating gases from traffic flow affecting the indoor air quality. The building has

FIGURE 2. Location of Faisalabad with the surrounding provinces

single glazed windows in size 120 × 50 cm. Tables and benches are made up of medium density fibers (MDF) concealed chipboards, wooden doors, classical skylight models windows with steel frame and precast slabs flooring. The covered area of the building is 445 m^2 and 250 publics. Based on study visits, different air quality parameters were investigated and analyzed to explore which specific church building has an extreme level of indoor contaminants.

Data collection and methodology

Comparing the air quality of Faisalabad city with the WHO guidelines, concentrations of different pollutant matter used in this work are represented in Table 1.

The measurements were performed in the middle of October–December 2019 which is the main smog period in Faisalabad city. The physical measurement was carried out in both church buildings at different time periods. The measurements were completed after acknowledged complaints associated with indoor air quality at the church buildings, based on the investigational process as shown in Figure 3. These values confirm that the hourly concentrations level of different pollutant matter reached 6–7 times the limit set by the WHO guidelines (Colbeck, Nasir & Ali, 2010). Similarly, the level of $PM_{2.5}$, which is mainly from combustion sources, has reached an alarming level, 8–9 times greater than the safe limit (according to the WHO guidelines annual mean of 10 $\mu g \cdot m^{-3}$and 24-hour mean of 25 $\mu g \cdot m^{-3}$). It further confirms that the air quality of Faisalabad city is very unhealthy. The methodical data collections are extended further by determining the contents of air pollutants and particulate matter accompanied by sampling progression. The specific equipment used includes PCE/RCM-12 for measuring temperature in the range between –20°C and +70°C, humidity level from 0–100%, volatile organic compounds (VOCs) level from 0.00–5.00 $mg \cdot m^{-3}$ and CO_2 level between 0 and 9,999 ppm respectively. Measurement point was selected near the main halls as the most significant to indoor air pollutants come from the outdoor air. Indicators were set aside at a distance of around 25 cm from the wall and 2.5 m high from the floor. Total numbers of 92 samples were obtained. The measurements were carried out in the course of the normal operating hour, starting from

TABLE 1. Comparison of air quality of Faisalabad with the World Health Organization guidelines

Data collecting time	Temperature [°C]	Humidity [%]	NO_2 [$\mu g \cdot m^{-3}$]	SO_2 [$\mu g \cdot m^{-3}$]	CO [$\mu g \cdot m^{-3}$]	O_3 [$\mu g \cdot m^{-3}$]	$PM_{2.5}$ [$\mu g \cdot m^{-3}$]
00.05–08.00	27	63	89	55	1 342	70	198
08.05–16.00	32	60	101	78	1 470	72	235
16.05–24.00	25	69	95	59	1 370	71	203
24-hour average	28	64	95	64	1 394	71	212
WHO values	–	–	70	20	20	60	25

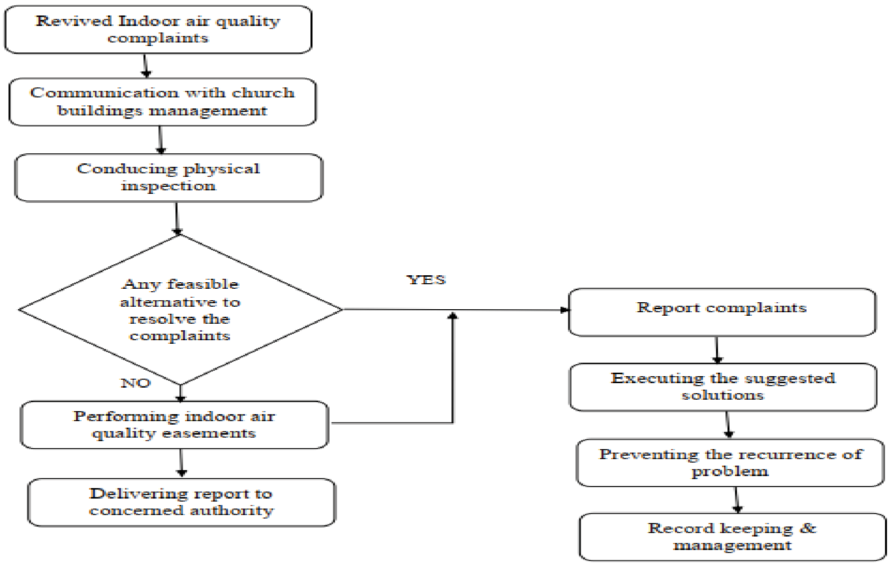

FIGURE 3. Indoor air quality complaints and exploration process flow chart

8 am and finished at 5 pm, for six days. The data were analyzed considering different air quality parameters.

For data analysis, Minitab 18 and Statgraphics Centurion XVII mathematical software packages were used accordingly. For establishing a mathematical comparison between air quality factors, the Pearson correlation coefficient (r) is used using Eq. (6). This comparison is helpful to scrutinize the existence of a linear correlation among different parameters given that positive norms around the data are contented (Koo & Li, 2016).

$$R_{xy} = \frac{\sum_{i=1}^{n}[y(x_i - \bar{x})]}{[\sum_{i=1}^{n}(y_i - \bar{y})\sum_{i=1}^{n}(x_i - \bar{x})^2]} \quad (6)$$

Being a quantitative extent of the strength of the correlation between the two random variables x and y, if the parameters have a linear correlation with a positive slant, then $R_{xy} = 1$ however $R_{xy} = -1$ will show a negative correlation among the two parameters (Larsen et al., 2007).

Results and discussion

Table 2 shows the descriptive statistics of the measured data. The descriptive statistics parameters based on 92 counts, the mean, standard deviation, minimum, median, maximum and range values were determined. Mean indoor temperature of both the church buildings was recorded as 19.71°C as well as the corresponding range was 9.00°C (such that 24.00 – 15.00 = 9.00°C).

Figure 4 shows that these values are lower than the standards specified by the American National Standards Institute (ANSI) and the American Society of Heating, Refrigerating and Air-Con-

TABLE 2. Descriptive statistics of the measured data

Parameter	Mean	Standard deviation	Minimum	Median	Maximum	Range
Temperature [°C]	19.71	2.71	15.00	20.00	24.00	9.00
Relative humidity [%]	41.61	15.01	19.00	40.00	75.00	56.00
Carbon dioxide [ppm]	1 459.5	714.3	490.00	1300.0	2 900.00	2 410.00
Nitrogen dioxide [ppm]	215.98	36.86	105.00	215.00	300.00	195.00
Sulphur dioxide [ppm]	125	64.73	5.00	110.00	350.00	345.00
$PM_{2.5}$ [$\mu g \cdot m^{-3}$]	69.04	28.42	10.00	70.00	130.00	120.00

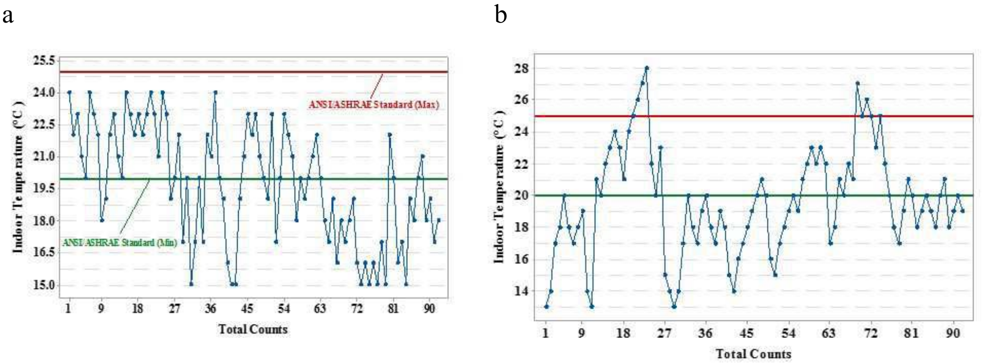

FIGURE 4. Mean indoor temperature: a – Jesus Pentecostal Church building; b – St. Joseph's Cathedral church building

ditioning Engineers (ASHRAE). Mean indoor relative humidity was measured as 41.61% and the corresponding range was 56.00% (such that 75.00 – 19.00 = = 56.00%). According to the Figure 5, it was established that the relative humidity conforms with the ASHRAE standards which take a range of 30–60%.

The mean CO_2 values were determined as 1,459.5 ppm and the corresponding range was 2,410 ppm such that (2,900 – 490 = 2,410 ppm). As per findings of Figure 6, for short-term exposure, the acceptable CO_2 concentration is 1,000 parts per million (ppm). It is observed that the mean CO_2 value is above the ASHRAE standards. Consequently, the air quality standards in St. Joseph's Cathedral church building was more aggressive than that of Jesus Pentecostal Church building. In this regard, human respiration and combustion are joint sources of CO_2 ranks. St. Joseph's Cathedral church is also a prevalent destination for tourists. Due to its prime location and historical background, the church build-

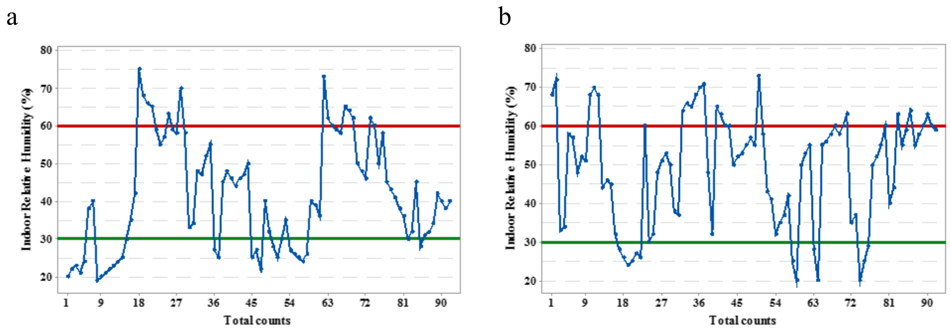

FIGURE 5. Mean indoor relative humidity: a – Jesus Pentecostal Church building; b – St. Joseph's Cathedral church building

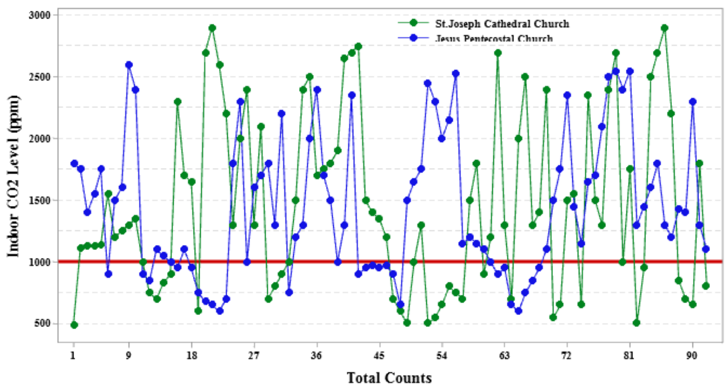

FIGURE 6. Carbon dioxide indoor concentration comparison

ing receives fairly a massive number of visitors every year. As a result, the CO_2 concentration for St. Joseph's Cathedral church building is much higher and extra polluted as compared to the indoor air quality of carbon dioxide for Jesus Pentecostal Church building.

The mean NO_2 values were determined as 200 μg·m^{-3} and the corresponding range was 195 μg·m^{-3} such that (300 – 105 = 195 μg·m^{-3}). Based on Figure 7 rendering to the WHO, for a short-term exposure for an hour, the acceptable NO_2 concentration is 200 μg·m^{-3}. It is noticeable that both church buildings had surpassed the acceptable range of concentration. However, the NO_2 concentration for St. Joseph's Cathedral church building is much greater and more contaminated compared to indoor air quality levels for Jesus Pentecostal Church building. Due to its central location, a heavy traffic flow is observed all the time. Moreover, the church building is much closer to the main road while Jesus Pentecostal Church building is located about 250 m from the main road. Hence it is confirmed that the distance of building from the roadway can affect the quality of air with respect to the levels of NO_2.

The mean SO_2 values were determined as 125 μg·m^{-3} and the corresponding range was 345 μg·m^{-3} (such

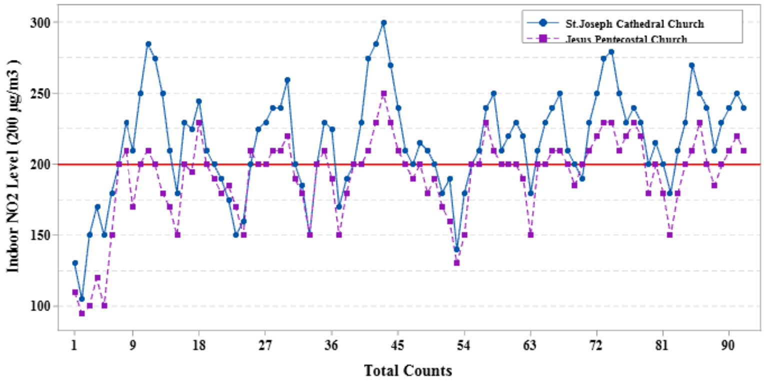

FIGURE 7. Nitrogen dioxide indoor concentration comparison

that 350 – 5 = 345 µg·m^{-3}). According to the WHO and based on Figure 8 for a short-term SO_2 exposure is 10 min, the acceptable concentration for SO_2 is 500 µg·m^{-3}. It is observed that both the church buildings are quiet safe and deliver a well indoor atmosphere. It is due to the fact that the church buildings are located in the city area where no power generation stations and industries are located close to these buildings. Conversely, there still exists the presence of SO_2 pollutants in the indoor atmosphere owing to the means of transportation factor. Considering the distance of the church buildings from roadside and different means of transportations, it is confirmed that the SO_2 concentration at St. Joseph's Cathedral church building are higher compared to indoor air quality levels of SO_2 at Jesus Pentecostal Church building because a heavy flow of traffic is experienced throughout the day due its prime location in central part of the Faisalabad city.

The mean indoor $PM_{2.5}$ concentration values were determined as 69.04 µg·m^{-3} and the correspond-

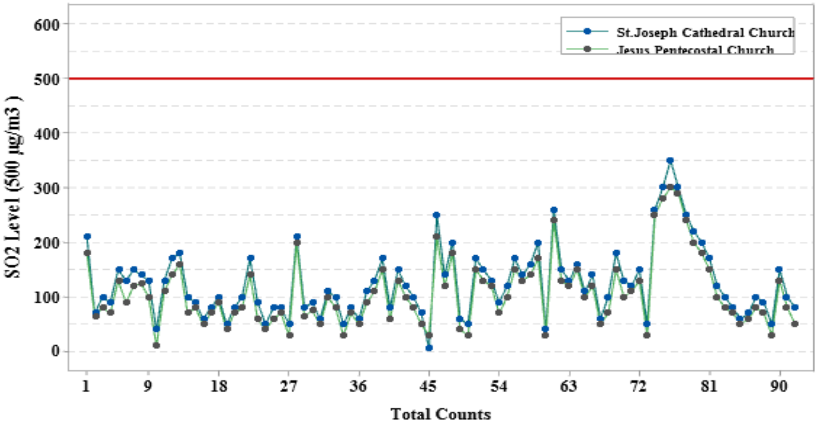

FIGURE 8. Sulphur dioxide indoor concentration comparison

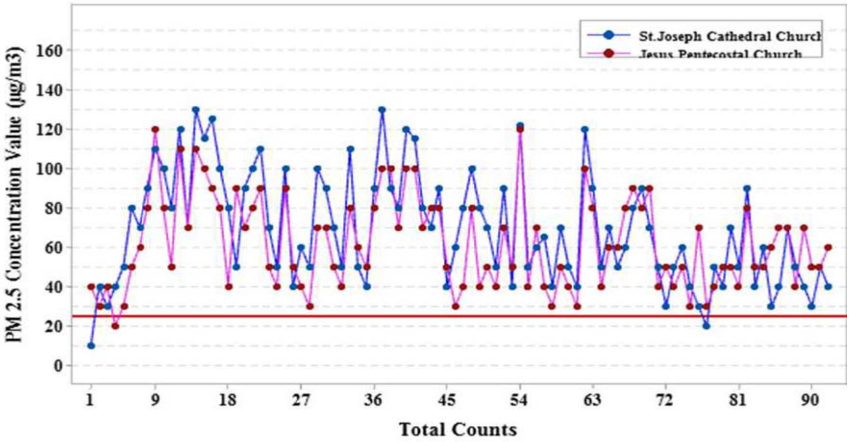

FIGURE 9. Particulate matter PM2.5 concentration comparison

ing range was 120 µg·m^{-3} (such that 130 – 10 = 120 µg·m^{-3}). According to the WHO and based on Figure 9, for a limited $PM_{2.5}$ vulnerability for a 24-hour period of the adequate $PM_{2.5}$ concentration is 25 µg·m^{-3}. However, it observed that the $PM_{2.5}$ concentration for both the church buildings is higher than the satisfactory level. Rendering to the WHO, there are several bases of particulates matter connected with natural means which differ in conformation, concentration, and size. Still, there are human activities, for example, source gain from manufacturing, infrastructure, construction spots, landfills, agricultural fields and transportation means which intensely affect human health, visibility, climate, and biogeochemical cycling. Indoor air quality levels of environmental pollutants are usually a function of outdoor and indoor causes, where great outdoor portions are initiating from different combustion means and indigenous traffic sources impact indoor air quality. This factor and also considering the distance of church buildings from roadside, it revealed that $PM_{2.5}$ concentration for St. Joseph's Cathedral church building are higher and more contaminated compared to indoor air quality levels of $PM_{2.5}$ for Jesus Pentecostal Church building because a heavy flow of traffic is experienced throughout the day due its prime location in central part of the Faisalabad city. Yet, there was some likelihood that indoor $PM_{2.5}$ may be generated through inadequate ventilation, combustion events such as the use of fireplaces, burning of candles, use of unvented and space-heaters and pulverized dust that added to indoor air quality levels of $PM_{2.5}$ in both church buildings.

Establishing statistical significance of parameters

To confirm whether the correlation among variables is significant, comparing the *p*-value to the significance level (α). The significance level (α) is chosen as 0.05 which will show that the risk of concluding that a correlation occurs while, essentially, no correlation exists is 5%. Similarly, the *p*-value confirms whether the Pearson correlation coefficient (*r*) is significantly different from 0. Pearson correlation coefficient (*r*) between indoor CO_2 extent and general public is 0.640 which indicates a strong positive correlation between the two variables. It is observed that since door and windows are closed especially in the winter season, there is a substantial growth in CO_2 concentration reliant on the number of people. Pearson correlation coefficients (*r*) between the number of people and indoor $PM_{2.5}$ values is 0.278. It can be understood that different actions of people and their movement increase the percentage of particulates matter. It means that the church buildings are not ventilated adequately. Pearson correlation coefficients (*r*) between indoor CO_2 extent and indoor temperature is –0.567. It is because there is normal ventilation when the doors and windows are open. There is a slight increase in temperature generally in spring season hence carbon dioxide concentration declines which generates graphical instabilities. Pearson correlation coefficients (*r*) between indoor air temperature and indoor relative humidity is –0.6332. It is because as the concentrated humidity extent increases with an increase in air temperature, relative humidity rate decreases when air temperature increases. These different correlations among the parameters are given in Figure 10.

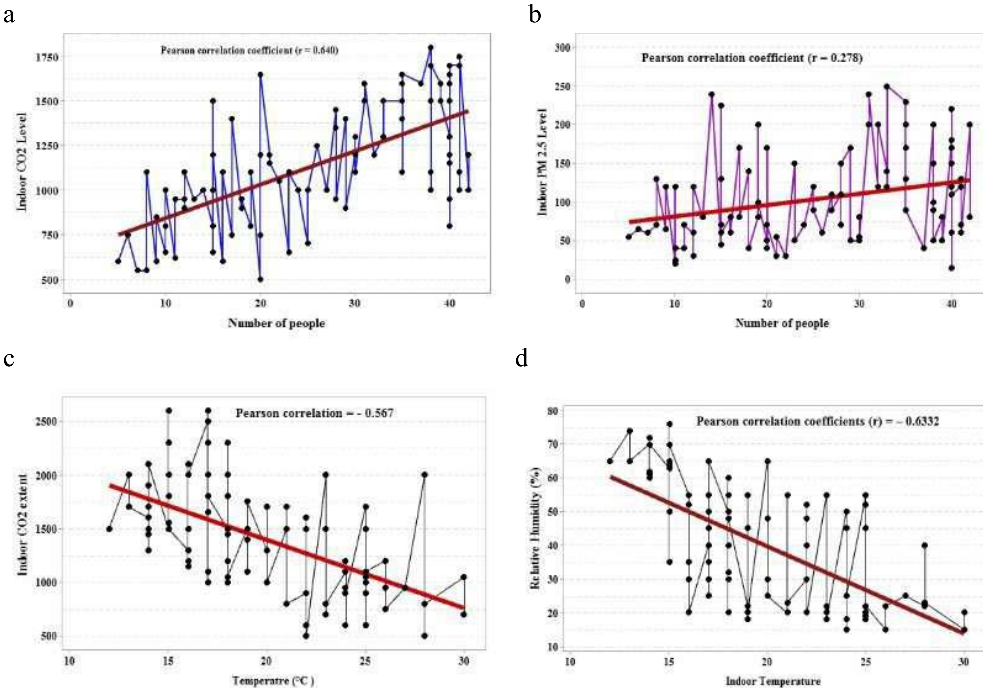

FIGURE 10. Parameters comparison: a – carbon dioxide indoor concentration and number of public; b – particulate matter $PM_{2.5}$ indoor concentration and number of public; c – carbon dioxide indoor extent and indoor temperature; d – indoor relative humidity and indoor temperature

Conclusions

This study seems to be innovative in Pakistan because the air quality of church buildings under study was not safe to the public as it may take harmful impact towards them. The result of this study specified that the distance of building from roads performs to have an impression on indoor air quality levels, particularly for CO_2, SO_2, NO_2, and $PM_{2.5}$. It was recognized that only gaseous particulates matter such as SO_2 did not surpass the satisfactory level compared to other particulates matter. It can be established that St. Joseph's Cathedral church building is more contaminated for indoor air quality parameters of CO_2, SO_2, NO_2, and $PM_{2.5}$ compared to Jesus Pentecostal Church building since location of St. Joseph's Cathedral church building is much nearer to the main road compare to Jesus Pentecostal Church building. The average indoor CO_2 level is greater. This is normally affected due to closed doors and windows especially in winter. The reduction in CO_2 level in spring confirms that there is typical air ventilation in church buildings although it is not adequate, hence a proper ventilation system should be installed to stop the exceeding indoor CO_2 levels. For determining the relationships among indoor air quality parameters, Pearson correlation coefficients (r) and significance level ($\alpha = 0.05$) were considered. Pearson correlation coefficient (r) of 0.640 acknowledged that there is a solid progression between the indoor CO_2 level and number of people. Pearson correlation (r) coefficients between number of people and indoor $PM_{2.5}$ values of 0.278 confirmed a moderate positive relationship. It can be concluded that different activities of people upsurge the percentage of particulates matter. At present, the average $PM_{2.5}$ concentrations in Faisalabad city is 69.04 $\mu g \cdot m^{-3}$, hence for controlling the extent of indoor particulates matter some necessary measures of ventilation must be taken into consideration. A value of Pearson correlation coefficients (r) is –0.567 established that due to the increase in temperature in the spring season, the concentration of CO_2 decreased. Pearson correlation coefficients (r) value of –0.6332 indicated that as the air temperature increases relative humidity rate decreases as well. It is also noticeable that at significance level ($\alpha = 0.05$) the relationship between other parameters and radon values could not be established. Since the concentration of indoor radon is likely changing from place to place. Additionally, the radon concentration level is continuously below a definite value. This difference may be recognized as climatic conditions, temperature, humidity, air circulation, ventilation, and soil penetrability.

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Summary

Assessment of integrated indoor environmental air quality parameters in selected church buildings of Faisalabad city: a statistical based comparative study. The objective of this study is to control the air quality parameters for a selected range of different particulate matters. A comprehensive experimental approach is established to regulate the quality of air about a selected range of different air pollutants being investigated in the indoor atmosphere of the church building. Relative humidity, temperature, carbon dioxide, particulate matter and radon were considered as the factors of air quality extents. For establishing the association among the selected parameters, the data were mathematically analyzed. The correlation coefficient confirmed a strong relationship between the indoor CO_2 level and the number of public. A negative relationship between the indoor CO_2 extent and indoor temperature confirmed that due to the increase in temperature the concentration of CO_2 decreased as well. A solid adverse connection among indoor relative humidity and indoor air temperature showed that due to the increase in air temperature, the level of the relative humidity decreased. Some recommendations were proposed for the treatment of air quality in church buildings for human well-being.

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