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Archives of Earth and Environment Sciences
Research Article

Investigating the temporal variation in the frequency of air pollutant precursors in the ambient air of Lahore

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Citation: Rabia Shehzadi, Tahira Aziz Mughal, Moneeza Abbas, Amina Abrar, Ali Abbas (2021) Investigating The Temporal Variation in The Frequency of Air Pollutant Precursors in The Ambient Air of Lahore. Arch of Earth and Env Sci 1: 1-11

ABSTRACT

In present study the seasonal prevalence of smog precursors was analysed to investigate the temporal prevalence of air pollutant in the ambient air of Lahore. Data set of three years (November 2017- April 2020) was obtained from compact ambient air quality monitoring station, installed by Environmental Protection Department on Jail Road, Lahore. Statistical analysis of dataset of air pollutant revealed that in winter, the concentration range of PM_{10}, $PM_{2.5}$, NO, NO_2 was significantly higher than Punjab Environmental Quality Standards and WHO Air Quality Guidelines. while Seasonal impact on air pollutant concentration was further assessed by correlation analysis of weather component with air pollutants. According to statistical analysis, Ozone (O_3) was found to have high positive correlation with temperature >wind speed >relative humidity >sunshine hour while inverse relation with air pressure while NO, NO_2, SO_2, $PM_{2.5}$ showed positive corelation with air pressure and negative correlation with temperature, sunshine, and wind speed. These factual figures revealed that ambient air of Lahore has been experiencing reducive-type air pollution in winter which is acidic in nature and oxidative-type pollution in summer since 2017 because local weather conditions directly affect the air pollutant transportation behaviour.

Keywords: Ambient Air; PEQS; Photochemical; Air Pollutant; Smog

Introduction

Deteriorating air quality have become a major concern globally due to detrimental socioeconomic and environmental impacts. Pathogenicity of air pollutant depends upon their size, concentration, and origin. Although the biogenic and anthropogenic both sources contribute in the immense release of pollutants in ambient air [1]. But the empirical data on air revealed that industrial revolution has introduced the world to various types of toxic pollutants since 18th century [2]. The excessive use of low-quality fossil fuel in combustion processes, is found responsible for the emission of greenhouse gases beyond threshold level. Fossil fuel has become a major demand not only for domestic stove at micro level to power plant at macroscale for the provision of energy and this has given rise to concentration of greenhouse gases. According to [3] energy sector (25%), agriculture (24 %), industry (21%) transport (14%), energy related activities (10%) and buildings (6%), all contribute in the emission of GHG at global level. Increasing level of greenhouse gases in ambient air have been leading to the escalation of adverse environmental consequences in form of global warming, climate change and ozone depletion. World temperature has risen to 0.74 ºC since 1961 and temperature will further rise to 1.5 °C to 1.8 °C during 21st century [4]. These climatic changes have worsened the fate of air pollutant in photochemical transformation reactions and created extra-terrestrial hazard in form of Smog. The gaseous by-products combine with fog near ground surface under temperature inversion condition and produce tiny drops of acid aerosols to form Smog [29]. Mostly $PM_{2.5}$ is recognized as major agent for the formation of smog worldwide. Carbon, Nitrogen, and Sulphur , constitute the 70-80 % mass of PM2.5 , are responsible for their pollutant carrying capacity [5]. First incident of smog was experienced in London in 1952 that led to death of several thousand people from respiratory disorders. The London smog is also known as sulphurous smog as it originated due to the excessive use of sulphur-based coal [6]. Afterward Los-Angeles smog that was the product of photochemical smog and killed hundreds of people. Afterward, Beijing, Shangai, China, Cairo, Egypt, Brlgrade, Yogosalavia, Calcutta and India faced the worst impact of smog on population [7, 8, 9]. Hence Pakistan has also been facing the episodes of smog from last five years. Mostly the air pollution index of Pakistan remained at 77 but pollution index of Pakistan reached to 300 points and became 4th polluted country. Not only the internal sources of emission but the trans-boundary air pollution is also contributing to degrade the air quality of the country. Because moonsoons sweep all the haze and smog from india and china into Pakistan and north western states . Natural wind flow pattern shifts pollutant into downwind countries . in south asia , natural winds enters from south west ,flow over india turning west to enter into Pakistan [10]. Furthermore, natural process of air purification has become insufficient and created heat island effect in cities. Because Pakistan produce 60% electricity using gas and furnace oil. Out of which coal contribute (37%) , petroleum (39%), natural gas (24%).This fuel combustion release 158.10 MT of CO2 (54%) , 111.60 MT of CH4 (36%), 27.90 MT of N2O (9%) ,2.17 MT of CO (0.75) and 0.93 MT of Volatile organic compound in air (Ramay *et al*., 2011) when these emissions trap in the parcel of static cold air due to meteorological conditions , result in the formation of smog [11]. This human induced meteorological hazard has been occurring in Pakistan from last five years [12]. Especially in Punjab, thick cover of smog has caused the massive increase in the cases of allergies, itchy skins, sore throat, chest burns, respiratory hitches, eyes and nose irritations. Murky cloud of smog killed dozens in road accidents, hospitalized 1200 elders and 700 children during the year 2016 [13]. Thus, there is need to identify the factors responsible for smog formation. Therefore in current study, time series data of smog precursors e.g. nitrogen oxide, nitrogen dioxide, sulphur dioxide, particulate matter, ozone was deciphered and effect of weather components e.g., ambient temperature, air pressure, wind speed , relative humidity and sun shine hours on smog precursors was studied to characterize the frequently re-occurring smog event in the ambient air of Lahore.

Methodology

Temporal variation in the content of air pollutant and the impact of meteorological factors on their prevalence was studied in the ambient air of Lahore [14]. Lahore is the country's second-most populous city, lying between 31°15′—31°45′ N and 74°01′—74°39′ E. Its climate is five season semi-arid climate according to Koppen Classification [12]. The Lahore city experience combination of weather with hottest June (< 40°C), wettest July with heavy rainfall and coolest January with dense fog. Lahore has been facing the episodes of smog every winter since 2015 due to uncontrolled elevated level of air pollution (Haider *et al* ., 2017).To examine the prevalence of air pollutant in the ambient air, Jail Road (Figure 1) was selected. This 5km long road depicts the features of commercial zone and is located in the centre of Lahore. To characterize the emission sources, several visits to Jail Road were made for visual observations. Data set from November 2017 to April 2020 was obtained from compact ambient air quality monitoring station (CAAQMS: Air pointer MLU Recordum Austria Europe) installed by Environmental Protection Department in the premises of Meteorological Department on Jail Road. This CAAQMS was equipped with sensors and module in which UV-Absorption method,

chemiluminescence and NDIR were used to measure Particulate Matter ($PM_{2.5}$ µg/m³ and PM_{10} µg/m³), Nitrogen dioxide (NO_2 µg/m³), Nitric oxide (NO µg/m³), Sulphur dioxide (SO_2) and Ozone (O_3 µg/m³). Furthermore, preliminary (Table 2) on metrological parameters such as sunshine hours, temperature (ºC), wind speed (knot), air pressure (mb) and relative humidity (%) was obtained from meteorological department, Lahore and was subjected to statistical analysis to assess the impact of weather component on the prevalence of air pollutant in the ambient air of Lahore.

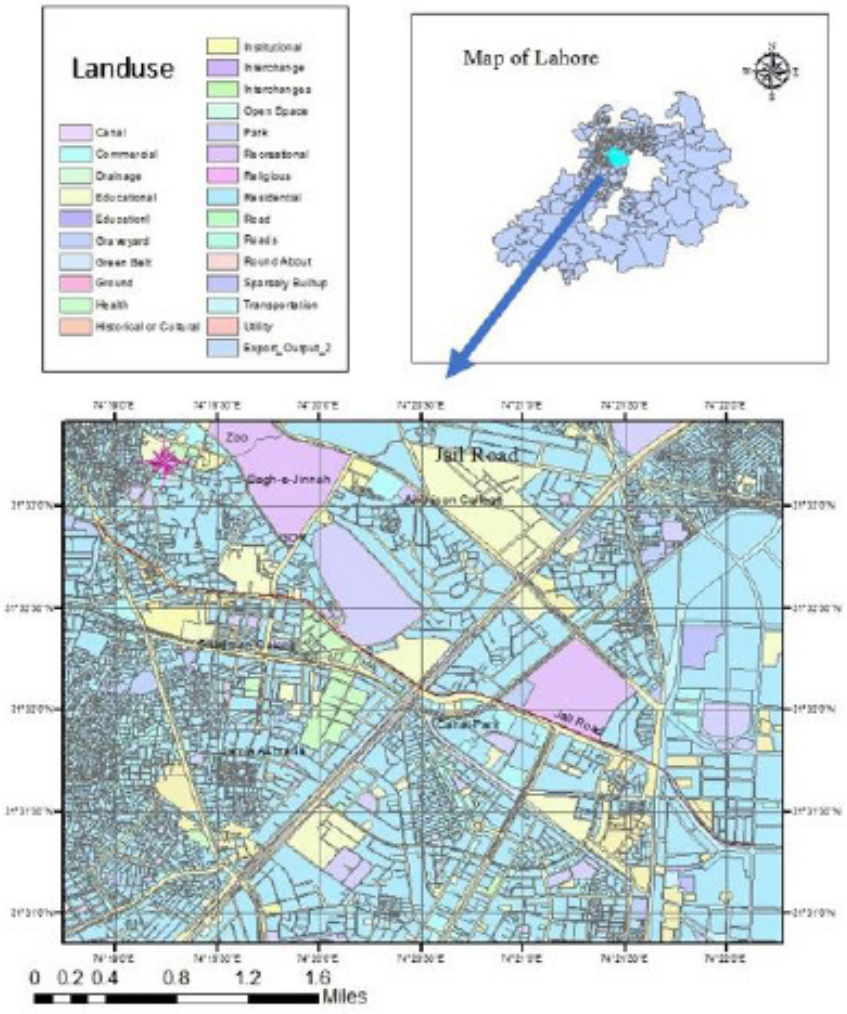

Figure 1: Commercial land use and Geographical coordinates of Jail Road, Lahore

Season	Month	Monthly Mean					
		Sunshine (Hours)	Relative Humidity %	Cloud Percentage (%)	Wind Speed(knot)	Ambient Air Temperature (ºC)	Atmospheric pressure (mb)
Spring	**February**	7.38	37.9	2.95	4.56	22.15	991
	March	8.3	54	2.675	2.5	27.9	988.05
	April	9.2	42.5	2.325	2.35	35	984
Summer	**May**	9.8	34	1.9	2.25	38.45	980.75
	June	8.1	40.5	2.075	2.3	39.5	975.8
Rainy	**July**	7	73.5	4.025	1.65	34.9	974.1
	August	8.1	68.5	3.975	2	35.5	976.3
Autumn	**September**	8.4	67	2.725	1.9	34.95	982
	October	8.7	64.7	1.05	1.1	31.65	988.75
Winter	**November**	6.1	62	2.425	0.65	26.2	991.05
	December	5.3	70	1.45	0.4	19.2	993.55
	January	5	28.6	2.175	3.78	19.85	992.3

Table 2: Temporal extent of weather component in Lahore

Result

Temporal variation in the content of air pollutant and the impact of meteorological factors on their prevalence was studied in the ambient air of Lahore. For compliance, permissible limits of ambient air quality from Punjab environmental quality Standards [15] and WHO Air Quality Guidelines,2005 were used (Table 1)

Sr. no	Parameters	Air Quality Standards / Guidelines	
		WHO, 2005	PEQS,2016
1.	Particulate matter (PM 10)	50 µg/m³ 24-hour mean	150µg/m³ 24-hour mean
2.	Particulate matter (PM 2.5)	25 µg/m³ 24-hour mean	35µg/m³ 24-hour mean
3.	Nitrogen Dioxide (NO2)	40 µg/m³ annual mean 200 µg/m³ 1-hour mean	80µg/m³ 24-hour mean
4.	Nitrogen Oxide (NO)	-	40µg/m³ 24-hour mean
5.	Sulphur Dioxide (SO2)	20 µg/m³ 24-hour mean	120µg/m³ 24-hour mean
6.	Ozone (O3)	100 µg/m³ 8-hour mean	130µg/m³ 1-hour mean

Table 1: Ambient Air quality limits prescribed by Punjab Environmental Quality Standards (2016) and WHO Air Quality Guidelines (2005)

Concentration range of temporally prevailing Air pollutant in Ambient Air

The temporally prevailing concentration range of air pollutant were subjected to Box and whisker analysis (Fig. 2) and Result showed that temporal concentration extent of PM_{10} was (min:21.98µg/m³ to max:307.76µg/m³) was higher than NO (min:04µg/m³ to max:250µg/m³), $PM_{2.5}$(min:10.49µg/m³ to max:176µg/m³), NO_2(min:9.85µg/m³ to max:127µg/m³), and O_3(min:20.7µg/m³ to max:107µg/m³), SO_2(min:9.4µg/m³ to max:99.17 µg/m³).

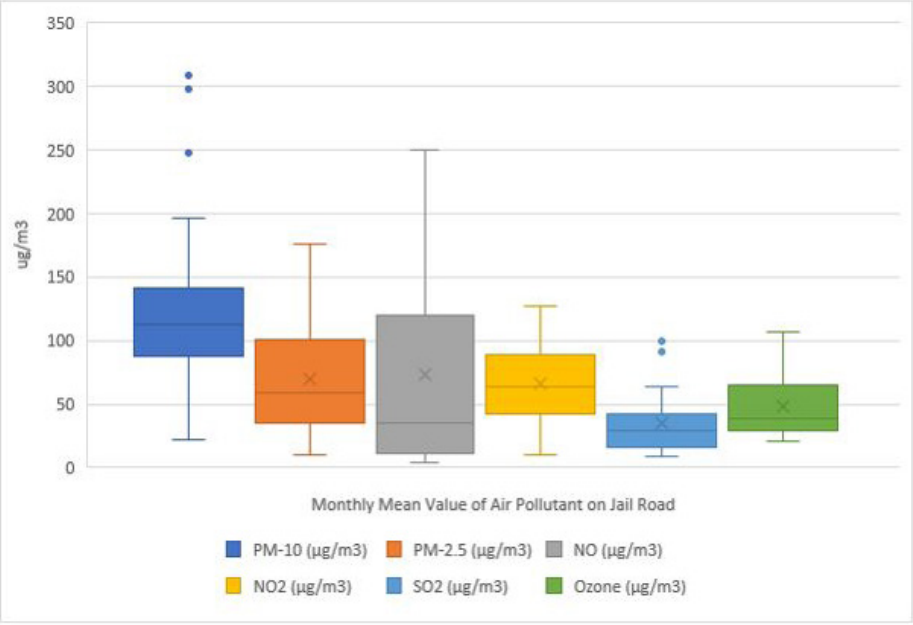

Figure 2: Box and whisker is showing the Temporal concentration range of air pollutant in the ambient air of Jail Road

Temporal Variability trend of Air pollutant in Ambient Air

Trend analysis of temporal concentration range of PM_{10}(figure 3), $PM_{2.5}$(figure 4), NO (figure 5), NO_2 (figure 6), SO_2 (figure 7) showed a significant cyclic rise in cold season and fall in hot season in the ambient air of Jail Road, Lahore. Whereas tropospheric ground level ozone (figure 8) showed a significant periodic rise in summer and fall in cold season in the ambient air. Compliance of results

showed that concentration range of PM_{10}, $PM_{2.5}$, NO, NO_2 from November to February had been significantly above and the temporal concentration range of SO_2 and O_3 was found below the limits prescribed by PEQS. However temporal concentration range of PM_{10}, $PM_{2.5}$, NO, NO_2 and SO_2 was found significantly above and temporal concentration range of tropospheric ozone was found below the WHO air quality guideline.

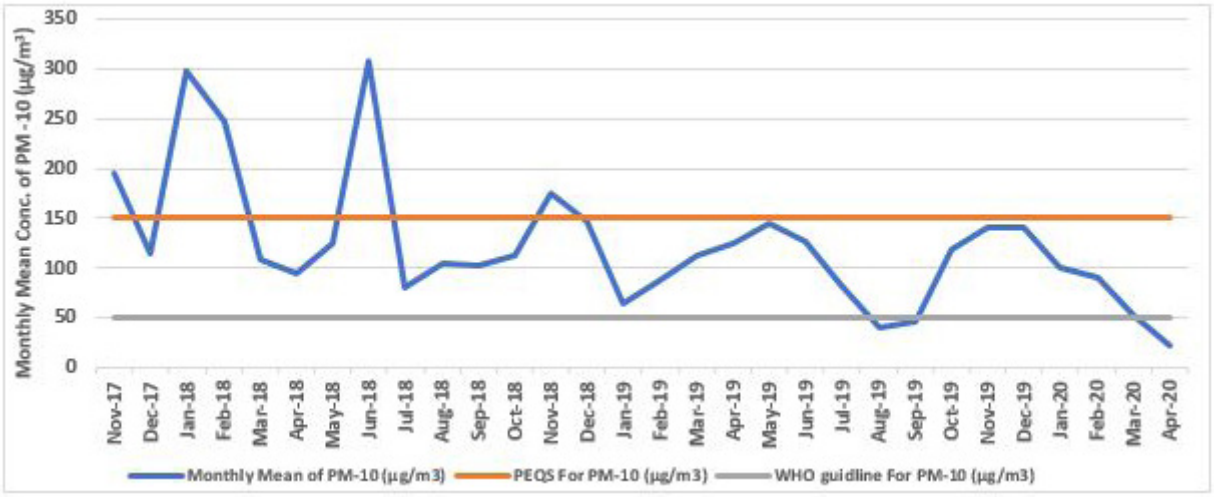

Figure 3: Temporal prevalence of PM10 in the ambient air of Jail Road and its compliance with PEQS,2016 and WHO Air Quality Guidelines,2005

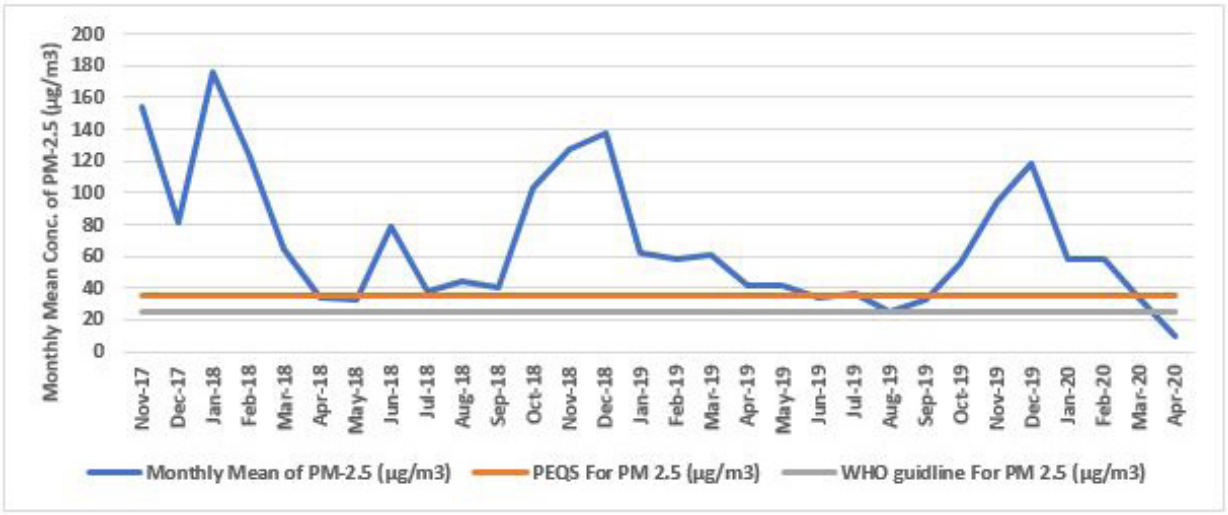

Figure 4: Temporal prevalence of PM2.5 in the ambient air of Jail Road and its compliance with PEQS,2016 and WHO Air Quality Guidelines,2005

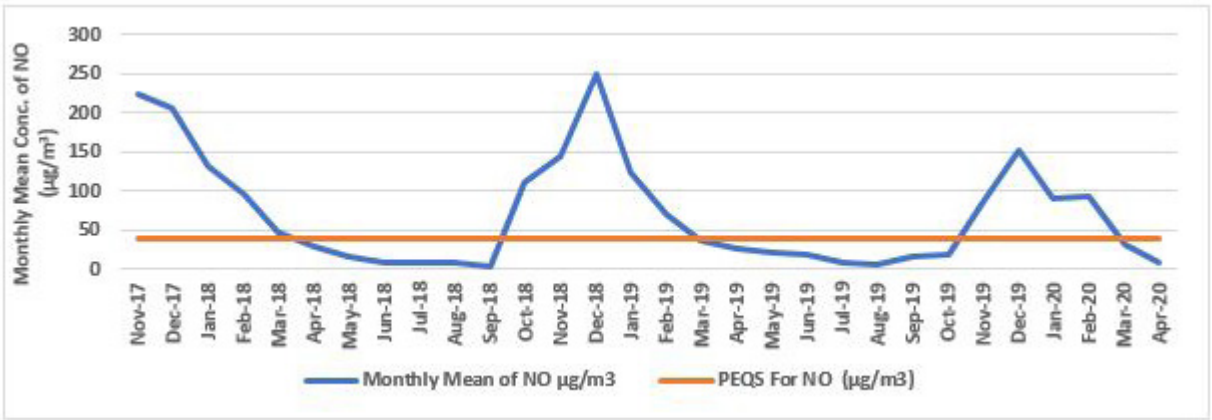

Figure 5: Temporal prevalence of NO in the ambient air of Jail Road and its compliance with PEQS,2016

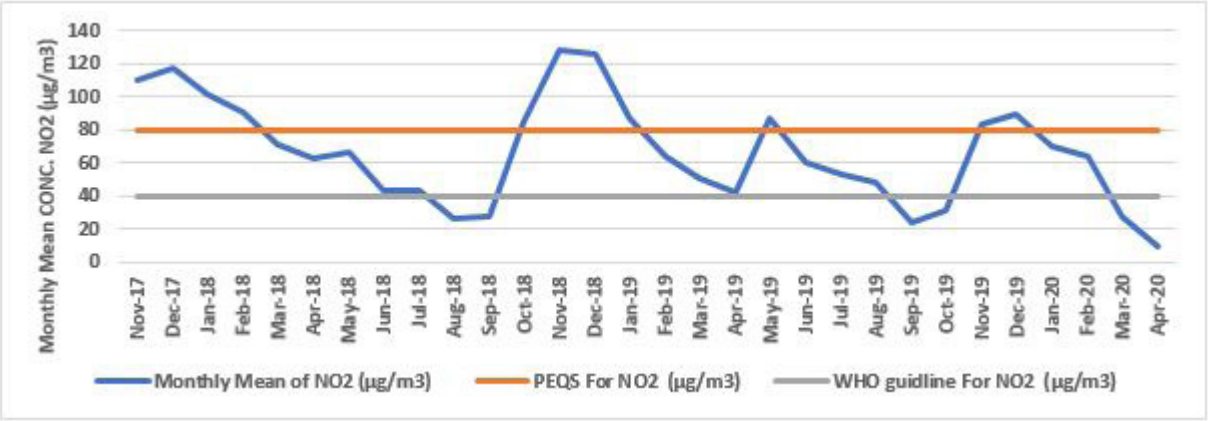

Figure 6: Temporal prevalence of NO_2 in the ambient air of Jail Road and its compliance with PEQS,2016 and WHO Air Quality Guidelines, 2005

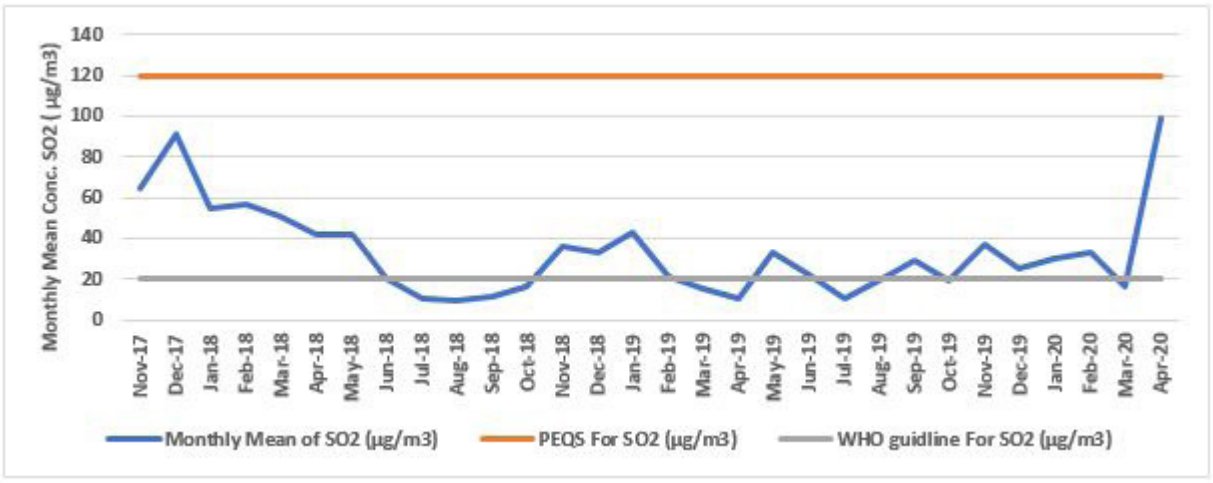

Figure 7: Temporal prevalence of SO_2 in the ambient air of Jail Road and its compliance with PEQS,2016 and WHO Air Quality Guidelines, 2005

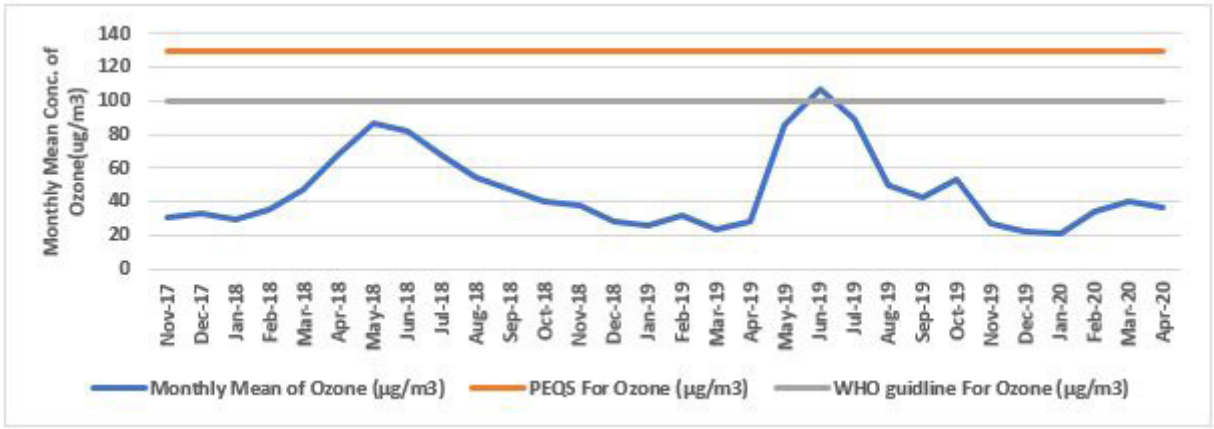

Figure 8: Temporal prevalence of O_3 in the ambient air of Jail Road and its compliance with PEQS,2016 and WHO Air Quality Guidelines, 2005

Impact Assessment of meteorological Factors on air pollutant prevalence

Effect of metrological parameters such as sunshine hours, temperature(ºC), wind speed(knot), air pressure(mb)and relative humidity (%) were studied on air pollutant prevalence and result (Figure 9) showed that windspeed have positive association with Ozone(r=0.8099) >SO_2(r=0.7284) >PM_{10}(r= 0.7127) >$PM_{2.5}$(r= 0.0183). Null association was found with NO(r= 0.051) whereas highly negative correlation was found with NO_2(r= -0.714). Air pressure have positive association with $PM_{2.5}$(r=0.8422) >PM_{10}(r= 0.8067) >NO_2(r= 0.7) >NO(r= 0.603) >SO_2(r= -0.3565) whereas highly negative correlation was found with O_3(r= -0.9834).Cloud Percentage have positive association with O_3(r= 0.5788) >NO(r= 0.4) > SO_2(r= 0.1553) whereas highly negative correlation was found with PM2.5(r= -0.7333) >PM10(r= -0.6599) >NO_2(r= -0.0542).Relative Humidity have positive association with O_3(r= 0.8074) >SO_2(r=

0.8008) >PM_{10}(r= 0.2479) whereas highly negative correlation was found with NO(r= -0.3942) >NO_2(r= -0.385) >$PM_{2.5}$(r= -0.284). Temperature have positive association with O_3(r= 0.8873) whereas highly negative correlation was found with PM_{10}(r= -0.6032) >NO_2(r= -0.584) >$PM_{2.5}$(r= -0.476) >NO(r= -0.3601) >SO_2(r=-0.1303).Sunshine hours have positive association with the Ozone(r = 0.7) >SO_2(r= 0.4) in the ambient air of Jail road whereas $PM_{2.5}$(r= -0.769) >PM10(r= -0.76) >NO(r= -0.67) >NO_2(r= -0.32) have negative correlation with sunshine hours.

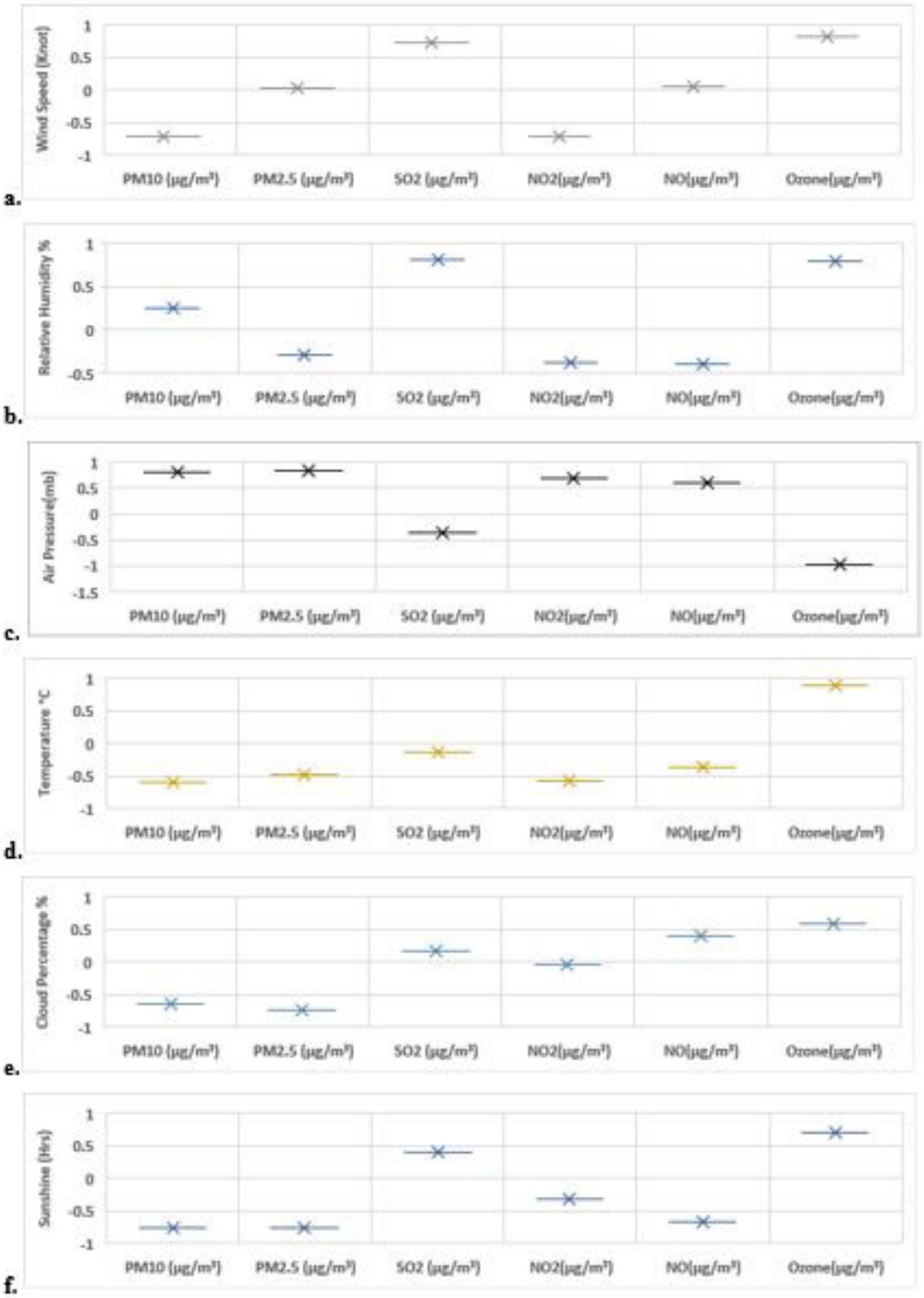

Figure 9: Correlation of air pollutant prevalence with weather components

Discussion

Study on the variation in the prevalence of smog precursors species in the ambient air of Lahore was carried out to assess the temporal extent of gaseous by-product in air and impact of meteorological factors on their recurring trend. Major pollutants selected for current study were oxides of nitrogen, sulphur, ozone, and particulate matter as they are identified as instigator for smog with substantial evidence. Sources of the release of these air pollutants are dust generating activities, burning of biogenic material and combustion of low-quality fossil fuel which are well apportioned on roads with heavy traffic load, Industries, and agricultural sites near and around Lahore.In present study, the Data set of three years for scrutiny was obtained from the air quality monitoring station that was installed in meteorological department on Jail Road. Jail Road, Lahore is a 5 km long 3 lane road that scored the features of commercial zone e.g., hospitals, educational institutes, police station, departmental stores, restaurants, recreational parks, car showrooms, Fuel pumps stations and housing societies on roadside. This road is located almost on the centre of Lahore city. The intense agglomeration of high grade public and private services cause the high influx of vehicles (>0.1 million) in this area, often create traffic congestion in daytime. Therefore, in current study, temporal monthly mean extent of PM_{10} (21.98 µg/m^3 - 307.76 µg/m^3) , $PM_{2.5}$ (10.49 µg/m^3 - 176 µg/m^3), NO (04 µg/m^3 - 250 µg/m^3), NO_2 (127 µg/m^3 - 9.85 µg/m^3) was found to be higher than the permissible limits of PEQS . Whereas SO_2 (99.17 µg/m^3 - 9.4 µg/m^3) and ozone (107 µg/m^3 -20.7 µg/m^3) was found below standards in the ambient air of Jail road .

First Reason is attributed to type of fuel used in vehicles. Large proportion (> 70 %) of vehicles use petrol followed by Compressed natural gas (CNG) on second, Liquified petroleum gas (LPG) on third and diesel on fourth . while scientific evidences proves that CNG is more cleaner in term of CO_2, CO and SO_2 , LPG is cleaner in term of NO_2, NO and petrol is cleaner in term of hydrocarbon [16] . Along with the quality and type of fuel, increase in number of point sources further aggravate the emission factor as the rise in city traffic has reached to 6.2 million vehicles at 10% annual increase rate since 2005. Out of which, 4.2 million motorcycles , 2.4 million non-commercial cars, 0.24 million rikshaw, 0.004 million motorcycle rikshaw are on road while the rest are delivery vans ,buses and trucks [17, 18]. Therefore, 70% air pollution in city is attributed to Traffic pollution .Out of which 40% is from poorly maintained auto rikshaws, pickups and diesel buses. Hence further decline in recurring content of air pollutants could be attributed to the initiative taken by Government in 2016 after worst episode of smog in city [16]. Which include the import and supply of low sulphur fuel to local markets . Fuel sector imported first environmental friendly low sulphur diesel of 500 ppm in 2017 , LNG in 2015 and higher 92/95 grade gasoline in November 2016. Sulphur dioxide is formed by the oxidation of sulphur compound in petroleum /coal as fuel which further lead to acid rain [19]. This minor change in fuel quality has led to visible decrease in sulphur emission. Further governmental actions include the strict implementation of smog policy reforms at provincial level since 2016 which involved shutting down dust generating activities , banning of stubble burning , municipal solid waste burning , closure of brick kiln in winter season for three months fine/challan on pollution generating vehicles and industries every year all over the province. Other structural measures include the widening and construction of signal free roads in Lahore Which contributed in the minimization of fuel combustion emission [20].

Furthermore the trend analysis of temporal concentration range of PM_{10}, $PM_{2.5}$, NO, NO_2, SO_2 showed a significant cyclic rise in cold season especially from November to February and fall in hot season from April to august in the ambient air of Jail Road, Lahore.

The reason is attributed to behaviour of air pollutant to meterological factors e.g., In summer, wind convection due to high temperature cause vertically upward movement of pollutant and disperse them in air . The dilution effect of wind speed on pollutant rises at first and then tends to be gentle. Because the particles can be carried out over long distance by wind and then settle on the ground, vegetation or water where they further begin/trigger the disruptions of ecological processes and damages to aesthetic damages [21] high wind speed (>12 m/s) cause more dispersion and dilution. while positive association of PM2.5 > PM10 > NO_2 > NO > SO_2 and negative correlation O_3 with air pressure is due to the fact that under the low-pressure circulation situation mostly in summer, there are more rainy days and the wind direction changes more frequently, which helps the diffusion and dilution of particulate matter; while the high-pressure circulation situation brings more sunny days and the weather system is relatively stable, forcing the particulate matter to be stagnate in the near-surface layer. In this way, an inversion can prevent the rise and dispersal of pollutant from lower layer cause a localized air pollution problem and the response of Pollutants to air pressure appears to be positive on a large time scale.while high relative humidity in the air cause agglomeration of PM 2.5 mostly in winter . High sulphur produces high concentration of sulfuric acid when combine with fog droplets. formation of these acidic particles

aggravated by dampness and high concentration of particulate matter in air [22] and produce more sulphate aerosol. According to [23] NOx concentrations are more elevated during the wet season. Because the frequently recurring thunder storm flashes produce oxide of nitrogen. Temperature and sunshine hours have positive association with O3 and highly negative correlation with PM10 >NO_2 > PM2.5 > NO > SO_2 .According to [24] higher heat deficit is associated with less turbulence thus cause high concentration of Particulate matter while low heat deficit associated with high turbulence that cause low particulate matter in summer . Hence high temperature (>24C) cause more dilution than dispersion which is observed more in summer than winter where under strong temperature inversion condition, wet ground due to precipitation trap more pollutant near to their sources. Whereas [28] reported that temperature, high UV index and sunshine hours strongly influence the amplitude of ozone cycles . Thus variation at inter month scale in meteorological factors further trigger the different intermediate gaseous reactions in ambient air and lead to the formation of Particles smaller than 2.5 µm that originate from secondarily formed aerosols, (gas-to- particle conversion) combustion particles, recondensed organic and metal vapours. This fact is in compliance with work reported by [25] that sulphur dioxide oxidise in atmosphere form sulphuric acid (H_2SO_4) which can be neutralized by NH_3 to form ammonium sulphate. Sulphate aerosols mostly makes the 6%-28% of $PM_{2.5}$. while Nitrogen dioxide is oxidised to nitric acid (HNO_3) which in turn can react with ammonia to form ammonium nitrate (NH_4NO_3). These secondary particles are the dominant part of fine particles produced from the intermediate reaction of gases mostly in winter and make the medium of atmosphere more acidic by giving rise to the formation rate of suspended tiny acid droplets. whereas the higher concentration of Ozone in summer is attributed to the fact reported by [26] that oxidation of carbon mono-oxide, nitrogen dioxide , hydroxide and VOCs triggered by photochemical reactions result in elevated ground level tropospheric ozone in summer .Because in summer , high sunshine time, UV index and temperature trigger the high occurrence rate of photochemical reaction in which result in brownish oxidative air pollution [27].

Conclusion

Current studies revealed that the winter maximum mean values of PM_{10}(307.76±54.9µg/m^3), $PM_{2.5}$(176±89µg/m^3), NO(250±35 µg/m^3), NO_2(127±07µg/m^3) was found significantly higher than Punjab Environmental Quality Standards [15] Whereas (O_3) tropospheric ozone recurrence was higher in summer .while Ozone (O_3) was found to have high positive correlation with temperature >wind speed >relative humidity >sunshine hour while inverse relation with air pressure while NO, NO_2, SO_2, PM2.5 showed positive corelation with air pressure and negative correlation with temperature, sunshine and wind speed.These findings were in compliance with the studies done by [14] and [7]. These facts are evident that ambient air of Lahore is experiencing reducive-type air pollution in winter which is acidic in nature and oxidative-type air pollution in summer [30-35].

Funding

Publication funding provided by Lahore College for Women University

Acknowledgements

We acknowledge the support of Environmental Protection Department, Punjab and Meteorological Department Lahore, Pakistan

Consent for publication

All authors participated in this research work have consented to the submission of this research article and relevant research data

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