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Cancer Risk Assessment and Statistical Modeling of Particulate Matter and Toxic Metal Exposure in Air due to Metro Train Project in Lahore, Pakistan

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ABSTRACT

The air quality of metropolitan cities of developing countries is deteriorating rapidly. In Pakistan, Lahore city is a significant development hub (construction and industrialization). The current study deals with the quality of air due to anthropogenic activities. The sampling was conducted for four months during the Orange Line Metro Train construction. The parameters are particulate matter, toxic metals (Cu, Pb, Fe, Cr, Mn, and Cd), and anions (Sulphates and Chlorides). The analysis of these pollutants was performed using standard methods. The descriptive statistics showed that the particulate matter had the highest concentration (38.31 mg/m^3) while the lowest was for copper (1948 µg/m3). All parameters showed values above any guideline values of any agency or country. The parameters showed positively skewed data with symmetrical (toxic metals) and no-symmetrical (PM, Cl-1, and SO_4^{-2}) distribution. The ANOVA showed the Fcrit<F, which means the parameters have some correlation. Pearson correlation values were between 0.3 and 0.7, which indicates a moderate correlation. The enrichment (EF) factor showed high anthropogenic activities with a maximum EF value for Cd (7735). The PCA and CA showed construction work, wind-blown minerals, industrialization, and roadside dust. The risk analysis showed that the HQ and CR showed the following trend: Pb>Cu>Mn>Cd>Ni>Cr and Cr>Ni>Cd>Pb, respectively. The CI showed that 100 people/10,000 population were exposed to cancer risk, while HI (426) showed a severe threat. The results showed that the air quality of Lahore city is inferior and needs immediate government attention.

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INTRODUCTION

Every form requires fresh and clean air of life on this Earth for its well-being. However, due to anthropogenic sources, activities like automobile and industrial emissions, construction activities, and thermal power generation continuously deteriorate ambient air, significantly threatening living beings (Sanchez-Triana et al., 2014). Out of many, major air pollutants are particulate matter (PM), ozone (O_3), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), and volatile organic compounds (VOCs) (von Schneidemesser et al., 2010). Many toxic metals such as Pb, Cd, and Hg are common air pollutants in industrial emissions (Afzal et al., 1998). Generally, anions such as SO_4^{-2} and NO_3^- are said to be secondary pollutants and usually dominate air pollution (Tsitouridou et al., 2003). Particulate matter (PM) is a significant component in air pollution due to vehicular and industrial emissions in urban areas (Jafary &

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Faridi, 2006). The International Agency for Research on Cancer (IARC) has identified diesel engine exhaust as carcinogenic to humans (WHO, 2012).

The particles remain almost suspended in the air. It includes smoke, dust, soot, and tiny liquid droplets released into the air (Leghari et al., 2013). Their sources can either be natural or anthropogenic. PM composition may include organic and inorganic constituents (ions, metals, water, and polyaromatic hydrocarbons). The fine PM (0.1um-1um size) can stay in the air for several days to weeks and, therefore, can be used for long-range transboundary transport in the air. Higher concentrations of airborne particulate cause an increase in the number of deaths. According to an estimate by WHO, every year, approximately 800,000 premature deaths are due to particulate air pollution, ranking it the 13th principal cause of mortality around the globe (WHO, 2002). These PMs, classified as air toxins, have aerodynamic diameters of 2.5-10 (WHO, 2008). Particles of such size can enter the lung tissues and cause morbidity due to pulmonary and cardiovascular diseases like asthma and lung cancer. Around the globe, it is approximated that PM contributes to about 5% of deaths due to lung cancer and 3% due to cardiopulmonary diseases (Cohen et al., 2004). PM can cause visibility issues by lessening the visual range.

One of the components of PM composition is toxic metals. Most toxic metals are widely spread in our environment because of their extensive domestic, technological, agricultural, medical, and industrial applications (He et al., 2005). Toxic metals are also said to be trace metals because they are present in the environment in minimal concentrations (ppm or ppb) (Kabata-Pendias & Pendias, 2001). The different trace metals in airborne particulates, such as Cd, Cr, and As, are carcinogens. The high toxicity of As, Cd, Cr, Pb, and Hg is the reason for carcinogenesis (Tchounwou et al., 2012). Even low concentrations of these metals can cause damage to multiple organs (Afzal et al., 1998).

Among all South Asian countries, the urban air quality of Pakistan has been reported to be worse when measured as PM (Sanchez-Triana et al., 2014). According to a World Bank report published in 2014, the values reported for deleterious particulate matter in Pakistan (100$\mu g/m^3$) are much higher than those reported across South Asia, i.e., 20-80 $\mu g/m^3$ (Sanchez-Triana et al., 2014). Pakistan's air quality data indicates that ambient PM, SO2, and Pb concentrations in major urban centres are well above the National Environmental Quality Standards for Ambient Air and WHO guidelines. Pakistan is ranked as the most urbanized South Asian country, with rapidly increasing energy and transportation usage. Over the last two decades, the number of vehicles in Pakistan has increased from 2 million to 10.6 million, with an 8.5% average annual growth rate (Purohit et al., 2013). In addition, industrialization, where fossil fuel is used as an energy source, significantly damages air quality by releasing toxic metals into the air (Colbeck et al., 2010). According to an air quality analysis of Pakistan carried out in 2010, high concentrations of PM were reported in Karachi (88$\mu g/m^3$), Lahore (143$\mu g/m^3$), Islamabad (61$\mu g/m^3$), Peshawar (71$\mu g/m^3$) and Quetta (49$\mu g/m^3$) (Sanchez-Triana et al., 2014). Another study in 2007 showed that PM_{10} concentration in Pakistan frequently goes beyond 200$\mu g/m^{3,}$ which was considerably higher than the interim target of 70$\mu g/m^3$, as proposed by the World Health Organization (Ghauri et al., 2007).

Like other nations, Pakistan's construction sector contributes significantly to economic expansion, making for 2.53% of GDP. It employs 7.61% of Pakistan's working population, and private-sector investment has grown by 20.6% (Mubeen et al., 2023). The yearly rainfall in Pakistan, an arid and semi-arid nation, ranges from 90 to 1600 mm. Many cities have clouds of natural dust due to fine particles rising with hot air due to summer temperatures above 40°C. The fact that these dust clouds are over cities indicates that human activities like construction are to blame for their existence (Alam et al., 2015). The development of the country and local communities, especially in urban areas, is directly impacted by the construction of new highways, buildings, and megastructures. On construction sites, a large number of machines are in use.

Since combustion engines release copious amounts of CO_2, SO_2, and CO into the atmosphere, most of them are powered by diesel. Furthermore, heavy equipment such as excavators, cranes, dozers, and concrete mixers' trailers contribute to producing dust and particulate matter. Since most building projects are in highly populated areas, the local population is affected by air pollution brought on by construction operations (Jain et al., 2016).

Lahore, the megacity of Pakistan, is inflicted with very high concentrations of PM pollution. Lahore is located in an arid region, highly industrialized and densely populated (Stone et al., 2010). Suspended PM in Lahore city indicated the presence of toxins, as mortality is increasing due to inhalation of PM (Smith et al., 1996). Inhalation of the fine PM causes contact with toxins (e.g., toxic metals) (Rattigan et al., 2002). Many construction projects are underway in Lahore, contributing to particulate matter pollution. Unplanned industrialization and commercialization are considerable issues in the city. No preventive measures are being taken, and no mitigation is provided for the after-effects of such projects. No proper strategy for environmental protection against harmful industrial emissions is being implemented. Road traffic is increasing day by day, which is contributing to worsening the air quality of Lahore.

Consequently, the city faces real air pollution stress in terms of high concentrations of particulate matter and toxic substances. It is evident that if targeted interventions are not adopted, the air quality of Lahore will be impaired more severely soon and affect a larger number of people. This study is carried out to evaluate the air quality of Lahore by performing statistical analysis and cancer health risk analysis of PM-bound toxic metals and anions. It will help to exhibit the current conditions of the air quality of Lahore for PM, toxic metals, and anions. The study will also show the role of anthropogenic activities in degrading the environment.

MATERIAL AND METHOD

The roof of "The Institute of Environmental Engineering & Research," UET, situated at Grand Trunk Road, Lahore, was selected as the sampling site with coordinates as 31.5799° N and 74.3561° E. It is a hectic road because of the passage of heavy-duty vehicles and auto-rickshaws. This site was selected because of the intense air pollution caused by construction activities, and many industrial units are located around this area. Figure 1 shows the location map of the study area. The sampling was done during the construction of the Metro Train project. This project is named the Orange Line Metro Train. It is a part of four metro trains (Orange, Green, Red, and Blue), which will spread throughout Lahore. The project was initiated with the financial aid of the Government of China. The construction work of Orange Line was started in October 2015 and continued till Jan 2017, after which the mechanical work started. The air sampling was performed from September 2016 to December 2016.

Total suspended particle samples were collected on glass fibre filter papers (ADVANTEC) using a high-volume air sampler (SIBATA). Sampling was done thrice a week for 8 Hr/day for 04 months. The Air sampler flow rate was 1.6 m^3/hr. Before sample collection, the filters were placed in an oven at 110°C, cooled in a desiccator, and weighed. After collecting each sample, the filter paper was weighed again, and the difference in the weight of the filter paper before and after sampling was calculated to get the weight of PM. These filters were then wrapped in aluminium foil, placed in the zip-lock bag, and stored in the freezer for further analysis.

After collecting all samples, the PM was for toxic metals (Fe, Cu, Cr, Pb, Ni, Mn, Cd) and anions (SO_4^{-2}, Cl^-) using standard methods (Lodge Jr, 1988). The filter papers were placed in the desiccator to remove moisture content. Each filter paper was cut into tiny pieces and transferred to 100mL conical flasks. A 100ml of 2% HNO_3 was added to each flask. These flasks were placed in a sonic bath 45°C for 1 hour. The resultant solution was filtered using pre-weighted filter paper. The filtrate was used for the analysis of anions and cations. The samples were subjected to an atomic absorption spectrometer (Perkin Elmer, 8000 AAS) for toxic metals. The

Fig. 1. Figure showing the construction activities and location map of the study area

samples were run in triplicate, and all quality checks were performed. The average values of the toxic metal concentrations were used for further analysis.

After experimentation, statistical analysis of all the experimental data was performed using SPSS (v20). These include Descriptive Analysis, Pearson's correlation, Analysis of Variance (ANOVA), Principal Component Analysis (PCA), and Cluster Analysis (CA). In addition, the enrichment factor of toxic metals was also calculated. Meteorological parameters were also considered, and the Pakistan Meteorological Department provided daily data for temperature, wind speed, wind direction, and humidity.

The effect of exposure to toxic metals and anions was also determined using the methodology derived by the Environmental Protection Agency (US). The following mathematical models (Jalees et al., 2021) were used to calculate the lifetime average daily dose, hazard quotient, hazard index, cancer risk, and cancer index.

$$LADD = \frac{CxETxEFxED}{AT} \quad (1)$$

LADD: Lifetime Average Daily Dose
C: Concentration of contamination (µg/m³)
ET: Exposure Time
EF: Exposure Frequency (days/year)
ED: Exposure duration (years)
AT: Average time (days)for noncancer: EDx365x24; Average time for Cancer: 70x365x24

$$HQ = \frac{LADD}{R_f D} \quad (2)$$

HQ: Hazard Quotient
$R_f D$ is the standard reference daily dose for each metal

$$HI = \sum_i HQ_i \quad (3)$$

HI: Hazard index

$$CR = LADDxSF \quad (4)$$

CR: Cancer Risk
SF: Slop Factor is upper bound (95% percentile) cancer risk due to lifetime exposure to toxic metals (USEPA, 1997).

$$Cancer\ Index = \sum_i^n Cancer\ Risk_i \quad (5)$$

Where *n* is the number of metals and *i* represents the respective metal.

RESULTS AND DISCUSSION

The concentration of various pollutants from air samples was determined using the standard method. The values of pollutants are given in Table-1. Except for Fe, all other pollutant concentrations were above WHO guidelines for air quality. Descriptive data analysis showed the amount of dispersion in the data by calculating the range, standard deviation, and skewness of the parameters under study (Table-2). Skewed data shows that the values are not symmetrically distributed above and below the mean. A zero value of skewness means data is symmetrical. A positive skewness value indicates that the mean is greater than the median, and the data is positively skewed. A negative skewness value indicates that the mean is less than the median value, and thus, data is negatively skewed (Gaur & Gaur, 2006). The Fe shows negative skewness, while all other parameters show positively skewed data (Table-2). The PM, Fe, $SO_4^{-2,}$ and Cl^- show the symmetrical distribution of data due to little skewness values, whereas Cu, Cr,

Table 1. Master table showing the concentration of all the parameters analyzed during the study period.

Sample	PM	Fe	Cu	Cr	Pb	Ni	Cd	Mn	SO_4^{-2}	Cl^-	WS	Max Temp	Min Temp	RH.
	(mg/m^3)	(µg/m^3)	(µg/m^3)	(µg/m^3)	(µg/m^3)	(µg/m^3)	(µg/m^3)	(µg/m^3)	(µg/m^3)	(mg/m^3)	(Km/hr)	(ºC)	(ºC)	(%)
1	17.74	396.69	1948.38	247.91	178.39	6.83	1.89	47.54	184.22	4.61	2	34.5	25.5	62
2	19.46	357.51	1282.12	15.04	71.3	0	0.94	42.53	210.94	3.48	3	35.5	26.5	67.5
3	33.45	268.62	588.25	8.41	35.32	0.29	0.95	38.4	94.94	1.85	2	36.2	26	60
4	14.9	410.64	932.44	3.42	316.86	4.6	21.35	56.44	163.24	6.56	2	35.3	23	58.5
5	20.73	305.23	523.72	0	147.23	3.65	2.96	51.26	11.64	4.62	2	35	22	53.5
6	24.15	340.97	1159.56	263.14	326.25	1.52	17.76	53.14	83.42	3.05	1	34.2	19	54
7	27.56	345.34	744.48	54.55	41.22	0	0.46	56.52	30.99	2.39	2	34.5	18.5	50.5
8	25.93	290.24	562.96	32.22	44.98	1.11	0.09	40.25	53.36	3.23	1	34	20	57.5
9	18.71	295.13	498.21	23.23	74.37	2.51	0.51	39.76	0	4.16	1	32.5	18	57.5
10	25.88	418.39	274.42	10.78	604.17	2.19	83.43	47.69	83.25	3.85	1	31.6	17.5	57.5
11	30.45	255.18	1105.21	153.72	77.06	3.82	1.6	30.87	153.09	2.82	2	29.2	13	69
12	38.31	205.21	295.68	26.8	44.03	1.79	1.48	23.55	206.48	3.8	1	28.5	16	77.5
13	32.45	269.53	296.8	15.41	49.88	1.7	0.69	31.06	198.02	3.81	2	28.5	15.5	73.5
14	23.95	358.87	160.83	19.08	66.95	0	2.56	40.08	117.1	3.58	1	28	14.5	61.5
15	11.41	428.19	369.65	28.64	140.29	0	3.14	53.24	12.21	9.96	1	29.4	14.5	54
16	8.81	340.14	1031.26	70.11	257	3.26	6.06	43.24	0	5.43	1	27	12	54
17	15.02	347.8	349.92	19.53	147.78	0	4.67	40.61	0	6.64	1	26.7	10	60.5
18	12.9	308.08	234.68	11.06	99.54	2.04	3.27	37.44	0	5.72	1	27	12.5	59
19	18.1	402.07	162.76	23.39	211.56	0.93	5.81	43.08	69.26	4.63	1	26.7	13	68.5
20	16.51	429.91	194.89	26.46	183.16	0	7.24	42.2	0	4.59	3	28.8	11.5	46.5
21	15.35	289.88	503.67	23.43	339.74	0	8.73	35.22	96.19	5.33	3	24.5	10	61
22	18.69	355.44	453.47	46.54	117.7	6.65	4.01	59.68	164.95	5.55	2	25	9.7	67
23	28.11	275.06	159.28	15.15	61.49	0	1.3	31.23	208.77	4.19	2	25	11	78.5
24	18.37	358.36	226.84	17.49	83.86	0	0.87	32.08	73.81	8.58	3	23.5	11	83.5
25	19.47	372.58	1382.07	35.04	114.3	9.05	8.35	84.5	58.17	5.94	2	21	8.6	59.5
26	20.49	307.5	359.79	20.97	227.55	0	4.08	50.93	109.65	5.64	3	23	7.3	73
27	20.6	350.22	450.11	33.55	140.99	11.96	3.6	74.11	50.03	5.42	3	23.2	7.4	61
28	17.39	378.69	381.57	40.38	575.22	15.26	27.68	50.97	79.01	6.53	1	25.3	9	61
29	22.94	340.46	193.17	20.33	76.63	2.71	1.98	36.53	51	4.43	1	26	8.7	63

Table 2. Descriptive statistics for the pollutant under study and comparison with WHO guidelines

Parameters	Mean	Std. Error	Std. Dev.	Skewness	Range	Min.	Max.	WHO Guidelines
PM (mg/m^3)	21.30	1.28	6.87	0.60	29.50	8.81	38.31	$0.045 mg/m^3$
Fe ($\mu g/m^3$)	338.00	10.40	56.02	-0.26	224.70	205.21	429.91	$10000\ \mu g/m^3$
Cu ($\mu g/m^3$)	580.21	82.54	444.51	1.47	1789.10	159.28	1948.38	$100\ \mu g/m^3$
Cr ($\mu g/m^3$)	45.03	12.02	64.75	2.76	263.14	0.00	263.14	$0.012\ \mu g/m^3$
Pb ($\mu g/m^3$)	167.41	27.19	146.43	1.81	568.85	35.32	604.17	$0.5\ \mu g/m^3$
Ni ($\mu g/m^3$)	2.82	0.71	3.83	1.91	15.26	0.00	15.26	$0.025\ \mu g/m^3$
Cd ($\mu g/m^3$)	7.84	2.96	15.93	4.16	83.34	0.09	83.43	$0.005\ \mu g/m^3$
Mn ($\mu g/m^3$)	45.32	2.41	13.00	1.17	60.95	23.55	84.50	$1.0\ \mu g/m^3$
SO_4^{-2} ($\mu g/m^3$)	88.40	13.20	71.08	0.41	210.94	0.00	210.94	---
Cl^{-1} (mg/m^3)	4.84	0.33	1.75	0.98	8.11	1.85	9.96	---
WS (Km/hr)	0.69	0.19	1.00	1.14	3.00	1.00	3.00	---
Max Temp (°C)	28.95	0.83	4.47	0.18	15.20	21.00	36.20	---
Min Temp (°C)	14.87	1.07	5.75	0.66	19.20	7.30	26.50	---
Humidity (%)	62.41	1.61	8.67	0.68	37.00	46.50	83.50	---

Cd, Pb, Ni, and Mn show more variation in their data by giving high values for skewness. The concentrations observed for PM, toxic metals, and anions are above WHO guidelines. Even the minimum concentrations observed during the sampling period were significantly higher than guideline values.

The box and whisker plot is the graphical representation of how symmetrical the data is or how the data is distributed around the median value. In Figure-2, the rectangles are called the boxes, and lines extended outside the rectangles are called whiskers. Boxes show the first, second, and third quartiles. The line inside the box is the median value of the data. The 50th percentile or second quartile is the median, showing that 50% of the values are at or below the median. The first quartile (lower limit of the box) is the 25th percentile, and similarly, the third quartile (upper limit of the box) is the 75th percentile. The box's first half shows data values between the first and second quartiles, and the second half shows values between the second and third quartiles. The whiskers extend to the lowest and highest observations in the data set. Figure-2 shows an almost symmetrical distribution for PM, Fe, SO_4^{-2}, and Cl^- and non-symmetrical distribution was observed for Cu, Cr, Pb, Ni, Cd, and Mn as the values before the median are closer to each other and the values that lie after the median are more dispersed from each other.

For ANOVA calculation, the 1st step is the formulation of *null* and *alternative* hypotheses. The null hypothesis is based on the assumption that the parameters do not correlate with each other, i.e., r=0, while the alternative hypothesis assumes that the parameters correlate with each other r≠0. For ANOVA, *SS* is the sum of squares, giving the variance in the observed data. Groups here are the parameters considered in the analysis. The *df* is the degree of freedom calculated by '*n-1*', where 'n' is the number of parameters. The *MS* is the mean square value giving average variation in the data. The *"F"* is frequency. Suppose the values of *"F*>F_{crit}'" then the *null* hypothesis can be rejected, while if "F<F_{crit}'" then the *null* hypothesis can be accepted. As the study deals with PM, toxic metals, and anions, the ANOVA was performed in combination with any two types of parameters. The results of ANOVA are in Table-3. Below are the details of each ANOVA measurement.

i. ANOVA between PM and Toxic metals: Table-3 shows that 'F' is more significant than

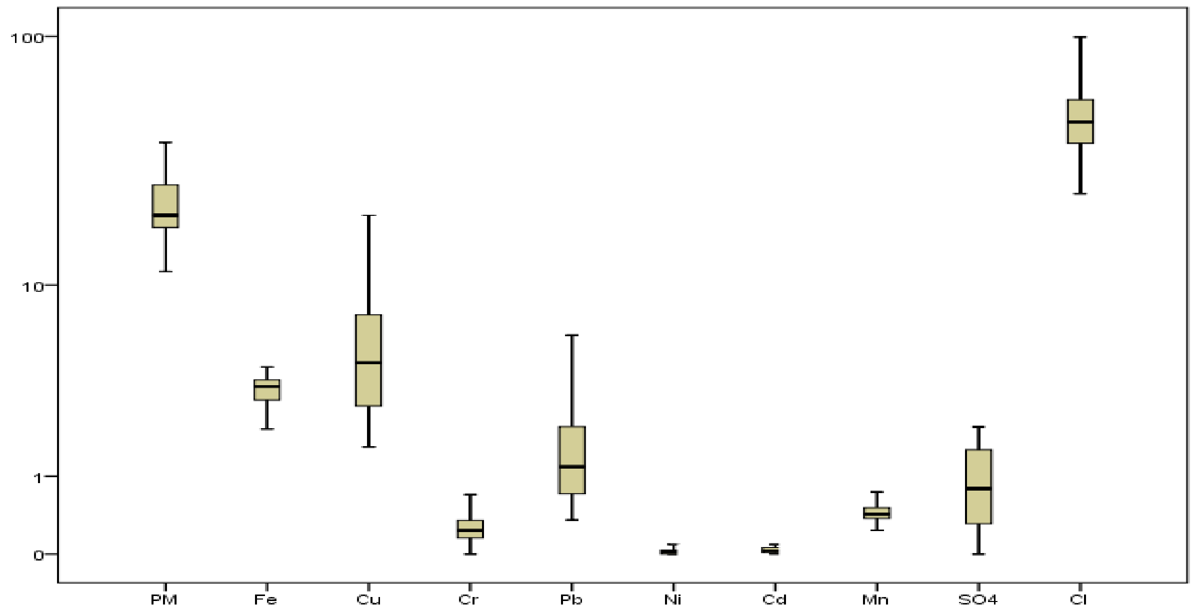

Fig. 2. Box Whisker Plot for pollutants under study

'F_{crit}'; therefore, the null hypothesis is rejected, which means the PM and toxic metals have some correlation.

ii. ANOVA between PM and Anions: Table-3 showed that the 'F' is more significant than 'F_{crit}.' Therefore, PM and anions have some correlation.

iii. ANOVA between Anions and Toxic metals: Table-3 shows that 'F' values are more significant than 'F_{crit}'; therefore, anions and toxic metals have some correlation.

As all the parameters have some correlation with each other, the Pearson Correlation was studied to check the extent of correlation.

The most common correlation coefficient is the Pearson correlation coefficient 'r.' It measures the linear correlation between two variables, *X* and *Y.* It is the covariance of the two variables divided by the product of their standard deviations (Cohen et al., 2013). This coefficient can be calculated as:

$$r = \frac{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)\left(Y_i - \bar{Y}\right)}{\sqrt{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)^2 \sum_{i=1}^{n}\left(Y_i - \bar{Y}\right)^2}} \quad (6)$$

Where;

r = Pearson's correlation coefficient

n = number of observations

$\bar{X}$ and $\bar{Y}$ are the sample means of $X1, X2, \ldots, X_n$ and $Y1, Y2, \ldots, Y_n$, respectively.

Pearson's correlation coefficient is applicable when variables are quantitative, i.e., ratio or interval scale variables. This correlation can be weak, moderate, or strong. If the 'r' value is between 0-0.3, it is a poor correlation. If the 'r' value is between 0.3 and 0.7, it is a moderate correlation. If the 'r' value is greater than 0.7, it shows a strong correlation (Jalees & Asim, 2016a).

Table 4 shows that PM has a moderate to strong correlation with Fr, Pb, and Cl^{-1}. The correlation values were negative, which means the relationship is inverse. In comparison, other metals and anions showed poor correlation with PM. The Fe has a poor to moderate correlation with Pb, Cd, Mn, SO_4^{-2}, and Cl^{-1} for toxic metals. Copper has a poor to moderate correlation

Table 3. Analysis of Variance (ANOVA) for PM, toxic metals, and anions under study

Source of Variation	SS.	Df	MS	F	F_{crit}
PM and Toxic Metals					
Between Groups	8732816	7	1247545	43.99	2.05
Within Groups	6351752	224	28356.04		
Total	15084568	231			
PM and Anions					
Between Groups	113646.5	2	56823.24	33.41	3.10
Within Groups	142875.8	84	1700.902		
Total	256522.3	86			
Toxic Metals and Sulphate					
Between Groups	8342363	7	1191766	41.12	2.05
Within Groups	6491888	224	28981.64		
Total	14834251	231			
Toxic Metals and Chloride					
Between Groups	8863545	7	1266221	44.66	2.05
Within Groups	6350507	224	28350.48		
Total	15214051	231			

Table 4. Pearson Correlation Coefficient for the parameters under study

	PM	*Fe*	*Cu*	*Cr*	*Pb*	*Ni*	*Cd*	*Mn*	SO_4^{-2}	Cl^-
PM	1.0									
Fe	**-0.6**	1.0								
Cu	-0.1	0.1	1.0							
Cr	0.0	0.1	**0.7**	1.0						
Pb	**-0.3**	**0.5**	0.0	0.1	1.0					
Ni	-0.2	0.2	**0.3**	0.2	**0.4**	1.0				
Cd	0.0	**0.4**	-0.1	0.0	**0.8**	0.2	1.0			
Mn	-0.3	**0.5**	**0.4**	0.1	0.2	**0.6**	0.2	1.0		
SO_4^{-2}	0.5	**-0.3**	0.2	0.2	-0.1	0.0	0.0	-0.2	1.0	
Cl^-	**-0.7**	**0.5**	-0.2	-0.2	0.2	0.2	0.0	0.2	**-0.3**	1.0

with Ni and Mn. Lead has a moderate to strong correlation with Ni and Cd. Nickel has a moderate correlation with Mn. The extent of correlation indicated that these pollutants may have the exact emission source (Jalees & Asim, 2016a). Principal component analysis (PCA) and cluster analysis (CA) were performed to check the sources of these pollutants.

Principal component analysis (PCA) is a statistical tool used to reduce the dimensionality of a data set consisting of many interrelated variables while retaining as much of the variation present in the data set as possible. It is achieved by transforming a new set of variables, the principal components (PCs), ordered so that the first few retain most of the variation in the original variables (Jolliffe, 2003). This tool is handy when many variables are involved in the data, and those variables may have some redundancy (Kline, 2014). PCA aims to reproduce as much information in original variables as possible with as few principal components. It separates different groups of related variables. Table-5 shows the principal component loadings

Table 5. Principal Component Analysis (PCA) of all the parameters under study

Eigenvalue	3.3	2.1	1.6
Proportion	0.3	0.2	0.2
Cumulative	0.3	0.5	0.7
	PC1	PC2	PC3
PM	**-0.4**	-0.2	**0.3**
Fe	**0.5**	0.0	0.0
Cu	0.1	**-0.6**	**-0.3**
Cr	0.0	**-0.5**	-0.2
Pb	**0.4**	-0.1	**0.5**
Ni	**0.3**	**-0.3**	0.0
Cd	**0.3**	-0.1	**0.6**
Mn	**0.4**	-0.2	-0.2
SO4-2	-0.2	**-0.3**	0.2
Cl-	**0.3**	**0.3**	-0.2

Table 6. Table showing industries surrounding the sampling location in the study area

Industries	**Emissions**	**References**
Ishtiaq Steel Industry	Fe, Mn, Ni, Pb, Cu, Cr, SO_4^{-2}	(Jalees & Asim, 2016a)
Ashraf fabrication & engineering *(Steel fabrication, storage tanks, vessels*)	Fe, Mn, Ni, Pb, Cu, Cr, SO_4^{-2}	(Jalees & Asim, 2016a)
Bajwa agro industries *(Automotive parts)*	Fe, Mn, Ni, Pb, Cu, Cr	(Shah et al., 2012), (Jalees & Asim, 2016a)
National battery industries	Pb, Cd	(Awan et al., 2011; Tchounwou et al., 2012)
Ok electric industry *(Centrifugal pumps, sprinklers, aerators)*	Fe, Mn, Ni, Pb, Cu, Cr	(Shah et al., 2012), (Jalees & Asim, 2016a)
M. Ramzan sewing machine industry	Fe, Mn, Ni, Pb, Cu, Cr	(Shah et al., 2012), (Jalees & Asim, 2016a)
Emco industries *(Floor tiles, porcelain insulators, pigments, clays)*	Pb, Cd, Fe, Cr, Cu. Mn, Ni, PM	(Skinder et al., 2014)
Fiber craft industries *(Fiberglass materials)*	PM, Cd, Pb, Cr, SO_4^{-2}	(Passant et al., 2002)
Breeze frost industries *(Air conditioning parts)*	Cu, Fe, Mn	(Vermette & Landsberger, 1991)
Textile mills	PM, SO_4^{-2}	(Meenaxi & Sudha, 2013)
Quaid-E-Azam industrial estate	PM, Pb, Cd, Fe, Cr, Cu. Mn, Ni, SO_4^{-2}	(Jalees & Asim, 2016b)

for PM, toxic metals, and anions using the Varimax rotation method. Three components having eigenvalues>1 were extracted, and these components combined explained 69.35% of the cumulative variance in the given data. The first component *(PC 1)* showed higher loadings for PM*, Fe, Pb, Mn,* Cl^- *and Ni*, which indicates that these pollutants may originate from the same source as they fall in the same group. The close association of these metals in PM reveals that their sources would be wind-blown mineral dust (Shah et al., 2012) and steel and iron industries. The Earth's crust primarily contributes Fe and Mn as they are abundant in the Earth's crust.

Continuous construction activities and vehicular movements cause the re-suspension of road dust, and this re-suspended road dust is mainly composed of particulate matter, along with Fe, Mn, Pb, and fine Cl^- (Vermette & Landsberger, 1991). Previous studies in Lahore regarding source apportionment of trace metals reported that steel and iron industries are responsible for high Fe, Mn, Ni, and Pb concentrations(Jalees & Asim, 2016b). Many industrial units of steel and iron are located near GT road and at Quaid-E-Azam Industrial Estate, Lahore (Table-6), which release these trace metals into the air, and wind contributes the emissions from these sources to the sampling site. Secondly, construction activities near the sampling

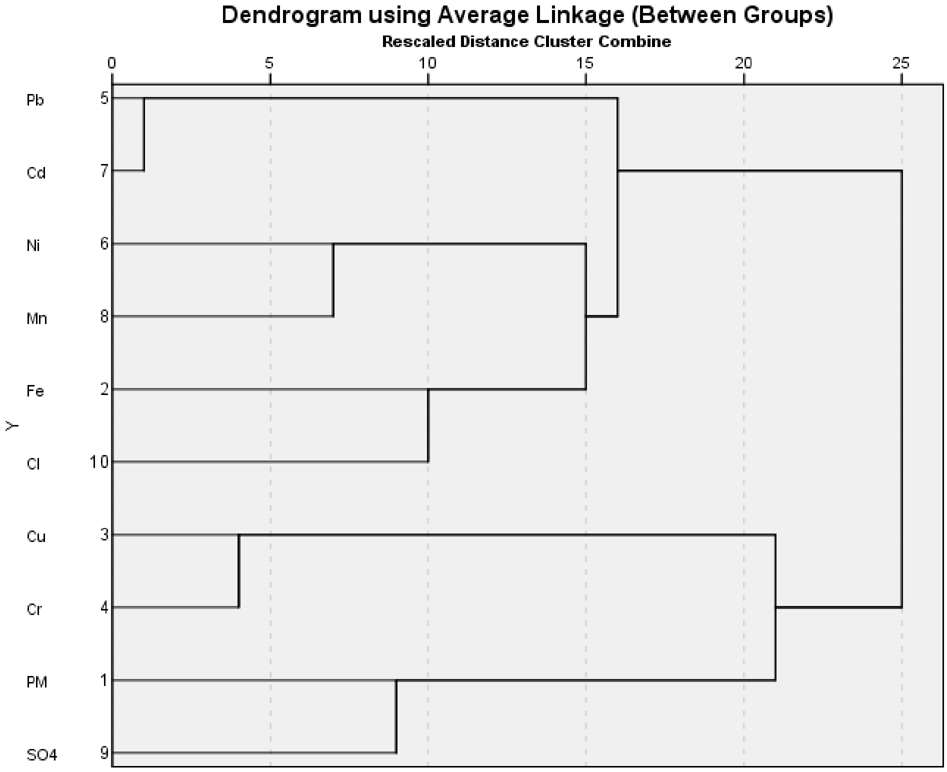

Fig. 3. Cluster analysis (Dendrogram) showing the different linkages between pollutants with the same origin source

site also contributed significantly to the increased concentration of TSP and other pollutants. *PC 2* is showing higher loadings for *Cu and Cr*. This association mainly indicates industrial sources for copper and chromium. Industrial processes, especially metallurgical operations and electroplating units are responsible for Cu and Cr (Shah et al., 2012). Cu and Cr are produced mainly in many industries, such as paints and pigment, tannery, stainless steel welding, copper smelters, and refractory industries (Tchounwou et al., 2012). Cu and Cr are also present in brake wear dust and linings (Grigoratos & Martini, 2015). *PC 3* is showing higher loadings for *Pb and Cd*. This group reveals two sources, i.e., automobile emissions and industrial processes. Pb and Cd are present in the brake linings of vehicles (Hjortenkrans, 2008). The industrial processes responsible for Pb and Cd in the air are metals processing, ores extraction, alloys, automobile batteries, and pigment production (Awan et al., 2011; Tchounwou et al., 2012).

A dendrogram is a hierarchical tree diagram that shows the linkage points. This technique, called cluster analysis, forms clusters linked at increasing dissimilarity levels. It starts with each case as a separate cluster, i.e., there are as many clusters as cases, and then it combines the clusters sequentially, reducing the number of clusters at each step until only one cluster is left. The clustering method uses the dissimilarities or distances between different parameters when forming clusters, which is the principal statistical method for finding relatively homogeneous clusters of cases based on measured characteristics. Cluster analysis gave the linkage or correlation between different parameters. Figure-3 shows five clusters that are formed. Among these**,** Pb and Cd formed the strongest cluster, linked to the clusters formed by Ni-Mn and Fe-C^{1-}. Then, Cu and Cr formed the next more robust cluster. Lastly, PM and SO_4^{-2} fall into one group. All these linkages between groups show that they supported PCA findings. The linkage between PM and $SO_4^{-2,}$ as in cluster analysis (Figure-3) and Pearson's correlation (Table-4), shows that automobiles and power plant emissions are sources of pollution.

The PM is mainly produced from diesel engine vehicles, i.e., trucks and buses (Kheirbek et

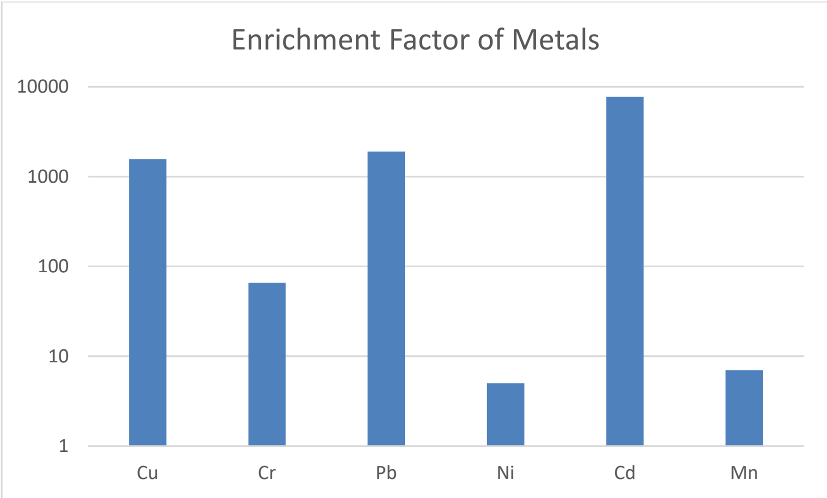

Fig. 4. Enrichment Factor of metals showing the extent of toxic metals pollution in the air

al., 2016), and fuel combustion at power plants. SO_2 released from automobiles and thermal power plants is oxidized to SO_4^{-2} due to chemical reactions in the atmosphere and becomes a part of particle pollution (Rattigan et al., 2002). Sulfates constitute much fine particulate matter (Stone et al., 2010). Many industries surround the study area, and Table-3 summarizes the sources identified for respective pollutants considered in this study. The Grand Trunk (GT) road for heavy and light vehicles is bustling. This area usually has traffic congestion due to vehicular emissions polluting the air. These vehicular emissions are responsible for high PM, Pb, Cd, and SO_4^{-2} concentrations in the study area. Heavy construction works due to the Orange Line Metro Train project caused a high amount of particulate matter to be suspended in the surrounding air. As no proper mitigation was provided during the construction activities, the pollutants remained suspended at lower heights, resulting in poor dispersion and significantly damaging the area's air quality. Industrial units located mainly near GT road and at Quaid-E-Azam Industrial Estate constitute a significant source of toxic metals and anions determined in air samples. Many steel and iron industries, refractory industries, metallurgical and electroplating units, battery manufacturing industries, and paint industries surround the sampling site and Quaid e Azam Industrial Estate (Jalees et al., 2021). During sampling, wind direction sometimes remained northeast and sometimes northwest, which caused a significant increase in toxic metals, anions, and PM concentrations at the sampling location because of these industries. Most of these industries have power generation plants that are significant sources of SO_4^{-2} and PM in the study area.

The enrichment factor is used to calculate the increase in the concentration of metals due to anthropogenic activities (Rattigan et al., 2002). It is calculated based on metal concentration in Earth's crust. The following formula is used for the calculation of enrichment factor (Shah et al., 2012):

$$\text{Enrichment Factor}(\text{EF.}) = \frac{\left(\frac{C_{Me}}{C_{Fe}}\right)\text{Sample}}{\left(\frac{C_{Me}}{C_{Fe}}\right)\text{Crust}} \tag{7}$$

Where;

C_{Me}= Concentration of metal

C_{Fe} = concentration of iron

The value of EF gives the extent of enrichment. For EF values ≤ 5, it is not enriched. For EF values between 10–100, it is moderately enriched. For EF≥ 100, it is highly enriched. Figure-4 shows the enrichment factor. The EF value of Fe was used as a reference metal to calculate the enrichment factor because iron abundance is highest among other metals in Earth's crust. Figure-4 shows the order of metal enrichment as Cd > Pb > Cu > Cr > Mn > Ni. It shows that Cd, Pb, and Cu are extensively produced due to different anthropogenic sources as they are highly enriched (EF > 100) in the air of the study area.

In the present study, considerably higher concentrations were observed for toxic metals, anions, and particulate matter than in previous studies. A comparison of literature values is presented in Table-7. It clearly showed the highly damaged air quality of the study area.

The toxic metals are present in the air at concentrations seriously lethal to human health. The air quality of Lahore is being continuously damaged at a breakneck pace because of increased industrialization and transportation. It has reached a very harmful extent. No consistent and appropriate interventions are being adopted at governmental and industrial levels for air quality management in major city urban centres. A cancer risk assessment was determined to check the health effects of this poor air quality on humans.

For risk assessment, the 1st step was calculating the lifetime average daily dose (LADD) using Equation 1. At sites where localized atmospheric fallout of contaminants has been observed or is expected, the potential for the uptake of contaminants may exist. It may result in exposure among local populations via inhalation in the contaminated area. Exposure via inhalation of polluted air considers not only the concentrations of contaminants in the air but also the rate at which the pollutant is inhaled and the frequency and duration of exposure. For this purpose, LADD is calculated. Table-8 shows the values of LADD for various pollutants under study. The average noncancer LADD values of pollutants showed the following trend: PM>Cl^{-1}>Cu>Fe>Pb>SO_4^{-2} ≈ Cd>Cr ≈ Mn>Ni. The trend for cancer LADD was PM>Cl^{-1}>SO_4^{-2}>Cu ≈ Cr ≈ Mn>Fe ≈ Ni>Pb ≈ Cd. The higher the LADD values, the higher the chances for cancer

and noncancer health risk. The LADD values showed that PM has the highest risk associated

Table 7. Comparison of literature data with the present study on air pollutants

Location	PM	Fe	Cu	Cr	Pb	Ni	Cd	Mn	SO_4^{-2}	Cl^-	Ref.
	mg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	
Lahore, Pakistan	21.3	338	580.21	45.03	167.41	2.82	7.84	45.32	88.4	4.84	Present study
Lahore, Pakistan	26.65	19.02	ND	ND	4.59	ND	ND	ND	ND	ND	(Jalees & Asim, 2016a)
Lahore, Pakistan	1.68	11.12	ND	2.54	6.94	1.87	ND	ND	ND	ND	(Lodhi et al., 2009)
Lahore, Pakistan	ND	9.38	0.799	0.024	1.035	0.016	ND	0.211	0.038	ND	(Rattigan et al., 2002)
Lahore, Pakistan	0.34	ND	ND	ND	ND	ND	ND	ND	10.46	0.0056	(Stone et al., 2010)
Lahore, Pakistan	0.406	10.25	0.23	0.038	0.93	0.013	0.04	0.298	ND	ND	(Alam et al., 2014)
Islamabad, Pakistan	1.614	ND	ND	ND	0.005	ND	0.026	ND	ND	ND	(Awan et al., 2011)
Gujranwala, Pakistan	2.756	ND	ND	ND	0.092	ND	0.326	ND	ND	ND	(Awan et al., 2011)
Faisalabad, Pakistan	3.074	ND	ND	ND	0.089	ND	0.321	ND	ND	ND	(Awan et al., 2011)
Peshawar, Pakistan	0.48	8.63	1.75	0.55	2.2	0.54	ND	0.19	ND	ND	(Alam et al., 2015)
India	0.194	ND	ND	ND	0.24	0.0096	0.05	0.29	ND	ND	(Mishra et al., 2013)
India	0.546	16.43	3.69	0.35	0.44	ND	ND	0.74	ND	ND	(Shah et al., 2012)
Korea	0.057	0.806	0.082	0.058	0.136	0.114	0.013	0.033	6.36	0.0012	(Oh et al., 2011)

Table 8. Lifetime average daily dose for cancer and noncancer risk of various pollutants present in the air of the study area.

PM	Fe	Cu	Cr	Pb	Ni	Cd	Mn	SO_4^{-2}	Cl^-
LADD for Noncancer									
3.5E+00	7.9E-02	3.9E-01	5.0E-02	3.6E-02	1.4E-03	3.8E-04	9.5E-03	3.7E-02	9.2E-01
3.9E+00	7.2E-02	2.6E-01	3.0E-03	1.4E-02	0.0E+00	1.9E-04	8.5E-03	4.2E-02	7.0E-01
6.7E+00	5.4E-02	1.2E-01	1.7E-03	7.1E-03	5.8E-05	1.9E-04	7.7E-03	1.9E-02	3.7E-01
3.0E+00	8.2E-02	1.9E-01	6.8E-04	6.3E-02	9.2E-04	4.3E-03	1.1E-02	3.3E-02	1.3E+00
4.1E+00	6.1E-02	1.0E-01	0.0E+00	2.9E-02	7.3E-04	5.9E-04	1.0E-02	2.3E-03	9.2E-01
4.8E+00	6.8E-02	2.3E-01	5.3E-02	6.5E-02	3.0E-04	3.6E-03	1.1E-02	1.7E-02	6.1E-01
5.5E+00	6.9E-02	1.5E-01	1.1E-02	8.2E-03	0.0E+00	9.2E-05	1.1E-02	6.2E-03	4.8E-01
5.2E+00	5.8E-02	1.1E-01	6.4E-03	9.0E-03	2.2E-04	1.8E-05	8.1E-03	1.1E-02	6.5E-01
3.7E+00	5.9E-02	1.0E-01	4.6E-03	1.5E-02	5.0E-04	1.0E-04	8.0E-03	0.0E+00	8.3E-01
5.2E+00	8.4E-02	5.5E-02	2.2E-03	1.2E-01	4.4E-04	1.7E-02	9.5E-03	1.7E-02	7.7E-01
6.1E+00	5.1E-02	2.2E-01	3.1E-02	1.5E-02	7.6E-04	3.2E-04	6.2E-03	3.1E-02	5.6E-01
7.7E+00	4.1E-02	5.9E-02	5.4E-03	8.8E-03	3.6E-04	3.0E-04	4.7E-03	4.1E-02	7.6E-01
6.5E+00	5.4E-02	5.9E-02	3.1E-03	1.0E-02	3.4E-04	1.4E-04	6.2E-03	4.0E-02	7.6E-01
4.8E+00	7.2E-02	3.2E-02	3.8E-03	1.3E-02	0.0E+00	5.1E-04	8.0E-03	2.3E-02	7.2E-01
2.3E+00	8.6E-02	7.4E-02	5.7E-03	2.8E-02	0.0E+00	6.3E-04	1.1E-02	2.4E-03	2.0E+00
1.8E+00	6.8E-02	2.1E-01	1.4E-02	5.1E-02	6.5E-04	1.2E-03	8.6E-03	0.0E+00	1.1E+00
3.0E+00	7.0E-02	7.0E-02	3.9E-03	3.0E-02	0.0E+00	9.3E-04	8.1E-03	0.0E+00	1.3E+00
2.6E+00	6.2E-02	4.7E-02	2.2E-03	2.0E-02	4.1E-04	6.5E-04	7.5E-03	0.0E+00	1.1E+00
3.6E+00	8.0E-02	3.3E-02	4.7E-03	4.2E-02	1.9E-04	1.2E-03	8.6E-03	1.4E-02	9.3E-01
3.3E+00	8.6E-02	3.9E-02	5.3E-03	3.7E-02	0.0E+00	1.4E-03	8.4E-03	0.0E+00	9.2E-01
3.1E+00	5.8E-02	1.0E-01	4.7E-03	6.8E-02	0.0E+00	1.7E-03	7.0E-03	1.9E-02	1.1E+00
3.7E+00	7.1E-02	9.1E-02	9.3E-03	2.4E-02	1.3E-03	8.0E-04	1.2E-02	3.3E-02	1.1E+00
5.6E+00	5.5E-02	3.2E-02	3.0E-03	1.2E-02	0.0E+00	2.6E-04	6.2E-03	4.2E-02	8.4E-01
3.7E+00	7.2E-02	4.5E-02	3.5E-03	1.7E-02	0.0E+00	1.7E-04	6.4E-03	1.5E-02	1.7E+00
3.9E+00	7.5E-02	2.8E-01	7.0E-03	2.3E-02	1.8E-03	1.7E-03	1.7E-02	1.2E-02	1.2E+00
4.1E+00	6.2E-02	7.2E-02	4.2E-03	4.6E-02	0.0E+00	8.2E-04	1.0E-02	2.2E-02	1.1E+00
4.1E+00	7.0E-02	9.0E-02	6.7E-03	2.8E-02	2.4E-03	7.2E-04	1.5E-02	1.0E-02	1.1E+00
3.5E+00	7.6E-02	7.6E-02	8.1E-03	1.2E-01	3.1E-03	5.5E-03	1.0E-02	1.6E-02	1.3E+00
4.6E+00	6.8E-02	3.9E-02	4.1E-03	1.5E-02	5.4E-04	4.0E-04	7.3E-03	1.0E-02	8.9E-01
LADD for Cancer									
1.1E+00	2.5E-02	1.2E-01	1.6E-02	1.1E-02	4.3E-04	1.2E-04	3.0E-03	1.2E-02	2.9E-01
1.2E+00	2.3E-02	8.1E-02	9.5E-04	4.5E-03	0.0E+00	6.0E-05	2.7E-03	1.3E-02	2.2E-01
2.1E+00	1.7E-02	3.7E-02	5.3E-04	2.2E-03	1.8E-05	6.0E-05	2.4E-03	6.0E-03	1.2E-01
9.5E-01	2.6E-02	5.9E-02	2.2E-04	2.0E-02	2.9E-04	1.4E-03	3.6E-03	1.0E-02	4.2E-01
1.3E+00	1.9E-02	3.3E-02	0.0E+00	9.3E-03	2.3E-04	1.9E-04	3.3E-03	7.4E-04	2.9E-01
1.5E+00	2.2E-02	7.4E-02	1.7E-02	2.1E-02	9.6E-05	1.1E-03	3.4E-03	5.3E-03	1.9E-01
1.7E+00	2.2E-02	4.7E-02	3.5E-03	2.6E-03	0.0E+00	2.9E-05	3.6E-03	2.0E-03	1.5E-01
1.6E+00	1.8E-02	3.6E-02	2.0E-03	2.9E-03	7.0E-05	5.7E-06	2.6E-03	3.4E-03	2.0E-01
1.2E+00	1.9E-02	3.2E-02	1.5E-03	4.7E-03	1.6E-04	3.2E-05	2.5E-03	0.0E+00	2.6E-01
1.6E+00	2.7E-02	1.7E-02	6.8E-04	3.8E-02	1.4E-04	5.3E-03	3.0E-03	5.3E-03	2.4E-01
1.9E+00	1.6E-02	7.0E-02	9.8E-03	4.9E-03	2.4E-04	1.0E-04	2.0E-03	9.7E-03	1.8E-01
2.4E+00	1.3E-02	1.9E-02	1.7E-03	2.8E-03	1.1E-04	9.4E-05	1.5E-03	1.3E-02	2.4E-01
2.1E+00	1.7E-02	1.9E-02	9.8E-04	3.2E-03	1.1E-04	4.4E-05	2.0E-03	1.3E-02	2.4E-01
1.5E+00	2.3E-02	1.0E-02	1.2E-03	4.2E-03	0.0E+00	1.6E-04	2.5E-03	7.4E-03	2.3E-01
7.2E-01	2.7E-02	2.3E-02	1.8E-03	8.9E-03	0.0E+00	2.0E-04	3.4E-03	7.7E-04	6.3E-01
5.6E-01	2.2E-02	6.5E-02	4.4E-03	1.6E-02	2.1E-04	3.8E-04	2.7E-03	0.0E+00	3.4E-01
9.5E-01	2.2E-02	2.2E-02	1.2E-03	9.4E-03	0.0E+00	3.0E-04	2.6E-03	0.0E+00	4.2E-01
8.2E-01	2.0E-02	1.5E-02	7.0E-04	6.3E-03	1.3E-04	2.1E-04	2.4E-03	0.0E+00	3.6E-01
1.1E+00	2.6E-02	1.0E-02	1.5E-03	1.3E-02	5.9E-05	3.7E-04	2.7E-03	4.4E-03	2.9E-01
1.0E+00	2.7E-02	1.2E-02	1.7E-03	1.2E-02	0.0E+00	4.6E-04	2.7E-03	0.0E+00	2.9E-01
9.7E-01	1.8E-02	3.2E-02	1.5E-03	2.2E-02	0.0E+00	5.5E-04	2.2E-03	6.1E-03	3.4E-01
1.2E+00	2.3E-02	2.9E-02	3.0E-03	7.5E-03	4.2E-04	2.5E-04	3.8E-03	1.0E-02	3.5E-01
1.8E+00	1.7E-02	1.0E-02	9.6E-04	3.9E-03	0.0E+00	8.2E-05	2.0E-03	1.3E-02	2.7E-01
1.2E+00	2.3E-02	1.4E-02	1.1E-03	5.3E-03	0.0E+00	5.5E-05	2.0E-03	4.7E-03	5.4E-01
1.2E+00	2.4E-02	8.8E-02	2.2E-03	7.2E-03	5.7E-04	5.3E-04	5.4E-03	3.7E-03	3.8E-01
1.3E+00	2.0E-02	2.3E-02	1.3E-03	1.4E-02	0.0E+00	2.6E-04	3.2E-03	7.0E-03	3.6E-01
1.3E+00	2.2E-02	2.9E-02	2.1E-03	8.9E-03	7.6E-04	2.3E-04	4.7E-03	3.2E-03	3.4E-01
1.1E+00	2.4E-02	2.4E-02	2.6E-03	3.6E-02	9.7E-04	1.8E-03	3.2E-03	5.0E-03	4.1E-01
1.5E+00	2.2E-02	1.2E-02	1.3E-03	4.9E-03	1.7E-04	1.3E-04	2.3E-03	3.2E-03	2.8E-01

with both cancer and noncancer health effects.

The hazard quotient (HQ) is calculated using Equation 2 for noncancer risk. The HQ values should be less than 1.0; otherwise, the noncancer risk is present. Table-9 shows the values of HQ for noncancer. The values range from 0.006 to 8.38. The maximum HQ was observed in

Table 9. Table showing the values of cancer and noncancer health risks for the selected pollutants of the study area.

Cu	Cr	Pb	Ni	Cd	Mn
H.Q. for Non-Cancer					
9.7E+00	3.3E-02	8.9E+00	6.8E-02	3.8E-01	1.9E+00
6.4E+00	2.0E-03	3.6E+00	0.0E+00	1.9E-01	1.7E+00
2.9E+00	1.1E-03	1.8E+00	2.9E-03	1.9E-01	1.5E+00
4.7E+00	4.6E-04	1.6E+01	4.6E-02	4.3E+00	2.3E+00
2.6E+00	0.0E+00	7.4E+00	3.7E-02	5.9E-01	2.1E+00
5.8E+00	3.5E-02	1.6E+01	1.5E-02	3.6E+00	2.1E+00
3.7E+00	7.3E-03	2.1E+00	0.0E+00	9.2E-02	2.3E+00
2.8E+00	4.3E-03	2.2E+00	1.1E-02	1.8E-02	1.6E+00
2.5E+00	3.1E-03	3.7E+00	2.5E-02	1.0E-01	1.6E+00
1.4E+00	1.4E-03	3.0E+01	2.2E-02	1.7E+01	1.9E+00
5.5E+00	2.0E-02	3.9E+00	3.8E-02	3.2E-01	1.2E+00
1.5E+00	3.6E-03	2.2E+00	1.8E-02	3.0E-01	9.4E-01
1.5E+00	2.1E-03	2.5E+00	1.7E-02	1.4E-01	1.2E+00
8.0E-01	2.5E-03	3.3E+00	0.0E+00	5.1E-01	1.6E+00
1.8E+00	3.8E-03	7.0E+00	0.0E+00	6.3E-01	2.1E+00
5.2E+00	9.3E-03	1.3E+01	3.3E-02	1.2E+00	1.7E+00
1.7E+00	2.6E-03	7.4E+00	0.0E+00	9.3E-01	1.6E+00
1.2E+00	1.5E-03	5.0E+00	2.0E-02	6.5E-01	1.5E+00
8.1E-01	3.1E-03	1.1E+01	9.3E-03	1.2E+00	1.7E+00
9.7E-01	3.5E-03	9.2E+00	0.0E+00	1.4E+00	1.7E+00
2.5E+00	3.1E-03	1.7E+01	0.0E+00	1.7E+00	1.4E+00
2.3E+00	6.2E-03	5.9E+00	6.7E-02	8.0E-01	2.4E+00
8.0E-01	2.0E-03	3.1E+00	0.0E+00	2.6E-01	1.2E+00
1.1E+00	2.3E-03	4.2E+00	0.0E+00	1.7E-01	1.3E+00
6.9E+00	4.7E-03	5.7E+00	9.1E-02	1.7E+00	3.4E+00
1.8E+00	2.8E-03	1.1E+01	0.0E+00	8.2E-01	2.0E+00
2.3E+00	4.5E-03	7.0E+00	1.2E-01	7.2E-01	3.0E+00
1.9E+00	5.4E-03	2.9E+01	1.5E-01	5.5E+00	2.0E+00
9.7E-01	2.7E-03	3.8E+00	2.7E-02	4.0E-01	1.5E+00
CR for Cancer					
---	7.9E-03	9.6E-05	3.9E-04	1.8E-04	---
---	4.8E-04	3.8E-05	0.0E+00	8.9E-05	---
---	2.7E-04	1.9E-05	1.7E-05	9.0E-05	---
---	1.1E-04	1.7E-04	2.7E-04	2.0E-03	---
---	0.0E+00	7.9E-05	2.1E-04	2.8E-04	---
---	8.3E-03	1.8E-04	8.8E-05	1.7E-03	---
---	1.7E-03	2.2E-05	0.0E+00	4.4E-05	---
---	1.0E-03	2.4E-05	6.4E-05	8.6E-06	---
---	7.4E-04	4.0E-05	1.4E-04	4.9E-05	---
---	3.4E-04	3.3E-04	1.3E-04	7.9E-03	---
---	4.9E-03	4.2E-05	2.2E-04	1.5E-04	---
---	8.5E-04	2.4E-05	1.0E-04	1.4E-04	---

Table 9. Table showing the values of cancer and noncancer health risks for the selected pollutants of the study area.

Cu	Cr	Pb	Ni	Cd	Mn
---	4.9E-04	2.7E-05	9.8E-05	6.6E-05	---
---	6.1E-04	3.6E-05	0.0E+00	2.4E-04	---
---	9.1E-04	7.6E-05	0.0E+00	3.0E-04	---
---	2.2E-03	1.4E-04	1.9E-04	5.8E-04	---
---	6.2E-04	8.0E-05	0.0E+00	4.4E-04	---
---	3.5E-04	5.4E-05	1.2E-04	3.1E-04	---
---	7.4E-04	1.1E-04	5.4E-05	5.5E-04	---
---	8.4E-04	9.9E-05	0.0E+00	6.9E-04	---
---	7.4E-04	1.8E-04	0.0E+00	8.3E-04	---
---	1.5E-03	6.3E-05	3.8E-04	3.8E-04	---
---	4.8E-04	3.3E-05	0.0E+00	1.2E-04	---
---	5.5E-04	4.5E-05	0.0E+00	8.3E-05	---
---	1.1E-03	6.2E-05	5.2E-04	7.9E-04	---
---	6.7E-04	1.2E-04	0.0E+00	3.9E-04	---
---	1.1E-03	7.6E-05	6.9E-04	3.4E-04	---
---	1.3E-03	3.1E-04	8.8E-04	2.6E-03	---
---	6.4E-04	4.1E-05	1.6E-04	1.9E-04	---

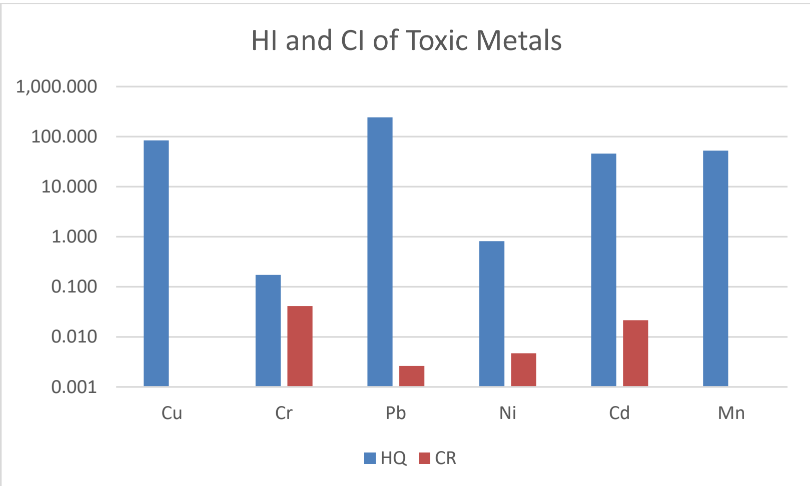

Fig. 5. Hazard Index (HI) and Cancer Index (CI) showing the cumulative effect of each toxic metal on the human population

Pb (8.38), as the minimum value was for Cr. The values of Pb, Cu, Cd, and Mn were above 1, which means noncancer risk was present. The trend of HQ was Pb>Cu>Mn>Cd>Ni>Cr. To calculate cancer risk (CR), Eq. 5 was used. The CR values reflect the cancer risk among the population. The acceptable value of CR is one person per 1 million population. Table-9 shows the values of CR. The maximum CR was observed for Cr (0.01) and the minimum was for Pb (0.0001). The CR trend for metals was Cr>Ni>Cd>Pb.

The individual values showed that for a population of 10,000, 100 persons would have cancer risk due to Cr, seven persons due to Ni, two persons due to Cd, and one person due to Pb. As the pollutant under study is present in the air, when a person inhales this air, all pollutants will also be inhaled. Hazard index (HI) and cancer index (CI) were calculated using Eq. 3 and 5, respectively, to check the effect of combined pollutants. Figure-5 shows the the values of HI and CI. The HI value for the air pollutant under study was 426, and the CR value was 0.07. It showed that in a population of 100, 7 people will have cancer.

CONCLUSIONS

This study analyzed the determination of air quality due to metropolitan pollution. The results showed that all parameters were beyond WHO's guideline values. The descriptive analysis showed that almost all parameters have positively skewed data, whereas the Box Whisker plot showed a symmetrical distribution for toxic metals and a non-symmetrical distribution for other parameters. The ANOVA and Pearson analysis showed a poor to moderate correlation among the PM (mainly from construction activities) and pollutants. The PCA and CA showed that the primary sources of pollutants are industries, construction (PM), roadside dust (PM), and wind-blown minerals. The enrichment factor showed high levels of anthropogenic activities with the following trend: Cd>Pb>Cu>Cr>Mn>Ni. The risk analysis showed that the highest daily intake was PM and the lowest was Ni. The cancer risk analysis showed that 1% of the population is at risk of cancer due to inhalation of poor-quality air. The noncancer risk indicated a very high value of HI, i.e., 426, which showed a severe threat of noncancer risk. The literature comparison of studied values indicated that the air quality of Lahore city is deteriorating rapidly and needs immediate attention from the Government.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the authors have completely observed the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy.

LIFE SCIENCE REPORTING

No life science threat was practised in this research.

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