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Original Research

Ambient Air Quality Evaluation: A Comparative Study in China and Pakistan

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Abstract

Vehicle and industrial emissions are responsible for a considerable share of urban air pollution concentrations. We conducted a comparative study in Dalian, China and Faisalabad, Pakistan to reevaluate NO_2, SO_2, and CO concentrations. Our study was conducted over the course of one year at different stations in both cities, and measured values were compared with ambient air quality standards such as NEQS-Pakistan, NAAQS-USEPA, CNAAQS-China, and global standard WHO. The NO_2 concentrations in Faisalabad varied from 185-262 μg/m^3, whereas it was in the range of 44-133 μg/m^3 in Dalian. The SO_2 concentration was found in the range of 66-190 μg/m^3 and 56-128 μg/m^3, while CO varied from 5.4-22.3 mg/m^3 and 0.3-2.8 mg/m^3, respectively, in Faisalabad and Dalian. The annual average NO_2, SO_2, and CO concentrations were below the permissible limits in Dalian; however, the measured values were considerably higher in Faisalabad. Our results are the first to compare air quality of two countries at different stations and highlight the possibility of reducing air pollution by comparing conditions.

Keywords: NO_2, SO_2, CO, NEQS-Pakistan, CNAAQS-China

Introduction

The adverse impacts of air pollution on environment and human health has been a major problem due to the rapid growth of population, industrialization, and urbanization in recent decades. Many countries have established ambient air quality standards around the world together with air quality guidelines by the World Health Organization (WHO) for the protection of the global atmosphere [1].

In recent decades research has found that outdoor air pollution is harmful to health, and traffic emission is an important contributor to air pollution [2]. The mechanisms of the harmful effects of air pollution also have changed, with health effects connected rather to the lung deposited surface area and reactivity [3, 4]. Vehicular emissions are the major source of air pollution in urban environments. Combustion engine-produced air pollution includes carbon monoxide (CO), nitrogen oxides (NO_x), and sulphur dioxide (SO_2). Pollution from heavy vehicles one of the major anthropogenic source of the gaseous pollutants CO, NO_x, and NMHCs, as well as fine particles [5-7].

During the last decade Pakistan has seen an extensive escalation in population growth, urbanization, and industrialization, together with a great increase in motorization and energy use. As a result, a substantial rise has taken place in the types and number of emission sources of various air pollutants: PM, SO_2, O_3, CO, NO_2, and Pb. However, due to the lack of air quality management capabilities, the country is suffering from deterioration of air quality. Evidence

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from various governmental organizations and international bodies has indicated that air pollution is a significant risk to the environment, quality of life, and health of the resident [8]. The rapid growth of urbanization and industrial development in the past two decades also greatly deteriorated air quality in China. Air pollution now has become one of the top environmental concerns in China. The primary air pollutants, namely NO_2 and SO_2 in Chinese cities, are mainly emitted from industrial and domestic energy production, burning, and transportation [9-17].

This study compared the ambient air quality of two cities of two separate countries (Faisalabad-, Pakistan and Dalian, China). The principle objectives were:

1) to measure the concentrations of NO_2, SO_2, and CO in the urban areas of Dalian and Faisalabad,
2) to compare the ambient air quality of Faisalabad and Dalian date-wise as well as station-wise.

The NO_2, SO_2, and CO were assessed at different stations within both cities for a period of one year (January-December, 2013). Finally, the measured air quality parameters such as NO_2, SO_2, and CO were compared with air pollution indexes such as NEQS-Pakistan, NAAQS-USEPA, CNAAQS-China, and WHO.

Table 1. Monitoring stations with location.

No.	Monitoring Station	Locations	
		Latitude	Longitude
1	Clock Tower Chowk	31°25'07"N	73°04'44"E
2	Station Chowk	31°25'07"N	73°05'43"E
3	Chenab Chowk	31°24'47"N	73°04'02"E
4	D-Type Chowk	31°22'47"N	73°04'19"E
5	National Hospital Chowk	31°25'15"N	73°03'46"E
6	Millat Chowk	31°26'49"N	73°05'48"E
7	Ganjingzi	38°57'10.65"N	121°31'31.68"E
8	Zhoushuizi	38°57'57"N	121°32'18"E
9	Xinghai three stations	38°54'31.81"N	121°36'39.92"E
10	Qingniwaqiao	38°55'04.82"N	121°38'09.16"E
11	Fujiazhuang	38°52'05.35"N	121°37'29.90"E
12	Qixianling	38°51'02.74"N	121°31'21.78"E

Materials and Methodology

Study Area

With a population of 6 million, Faisalabad is one of the third largest cities of Pakistan after Karachi and Lahore (formerly known as Lyallpur), and is situated at 31º25'4.8" N, 73º4'44.4" E. At present, the city has a very dense transport system with high energy consumption. According to a report by the Pakistan Statistical Year Book 2012-13, the number of registered vehicles in Faisalabad is 767,453 – out of the total 9,893,373 vehicles of Punjab Province [18]. The city has elevation of 184 m above sea level and covers an area of 1,230 km^2. Faisalabad stands in the rolling flat plains of northeastern Punjab and features hot desert-like climate because of high transpiration rates across the year. Thus the city experiences extreme climates, with summer temperatures as high as 50ºC and winter as low as -2ºC; mean maximum and minimum temperatures in summer are 39 and 27ºC, respectively. On the other hand, winter temperature peaks around 17 and 6ºC. Summer season usually starts from April and lasts until October, out of which May, June, and July are the hottest months. Winter lasts from November to March, during which December, January, and February are the coldest months. The average humidity in the city is 40% and pressure recorded is 1020 hPa [19].

Dalian, with a population of 6.6 million, is one of the major cities in China, located in southern Liaoning Province. It is the southernmost city of northeastern China situated at 38º55′15″N, 121º38′21″E. Dalian has heavily developed industrial areas with an elevation of 33 m above sea level, and the city covers 13,237 km^2. Dalian has sloppy featured land and has a monsoon-influenced humid continental climate, characterized by humid summers due to the East Asian monsoon, and cold, windy, dry winters. Though it is heavily concentrated in the summer months and can greatly vary from year to year, the annual precipitation averages 602 mm. With 2,740 hours of bright sunshine annually, the monthly percent possible sunshine ranges from 49% in July to 68% in September and October. The average humidity in the city is 56% and average pressure is recorded at 1024 hPa. The annual mean temperature is 10.90ºC. The city is witnessing a double-digit percentage increase in GDP annually since 1992. The city's GDP registered an increase of 15%, reaching RMB 441.77 billion, while per capita GDP hit RMB 71,833 in 2009 [20].

Measuring NO_2, SO_2, and CO

This study is based on 6 monitoring sites for sampling (Fig. 1 and Table 1). Data-wise and station-wise, samples were collected and analyzed from the months of January to December 2013. A total of 144 samples of each pollutant (NO_2, SO_2, and CO) were collected. A high-volume sampler was used. The samples were collected for a period of 24-hr at an average flow rate of 40 cfm (1.13 m^3/min) and two times per week. The concentrations of NO_2, CO, and SO_2 were analyzed by standard methods such as carbon monoxide analyzer, non-dispersive infrared detection, 6500-smoke meter, and gas phase chemiluminescence methods. All the collected samples were analyzed in the laboratory of the Environment Protection Department (EPD) in Faisalabad, Pakistan. The results of NO_2, SO_2, and CO were compared with four different regional standards like NEQS-Pakistan, USEPA-NAAQS, CNAAQS-China, and WHO (Table 2).

The data of Dalian city's NO_2, SO_2, and CO pollutants was collected from the official website of the Dalian Environmental Protection Bureau (Dalian EPB) [20], which covers the period from January to December 2013 at different stations (Fig. 2 and Table 1). The gravimetric method is used to determine the concentrations of NO_2, SO_2, and CO at these monitoring stations [20]. NO_2, SO_2, and CO measured values were compared with the four different regional standards like NEQS-Pakistan, USEPA-NAAQS, CNAAQS-China, and WHO (Table 2).

Statistical Analysis

One-way ANOVA and t-test were performed using Microsoft Excel 2007. The concentrations were initially reported by descriptive statistics (mean and standard deviation).

Table 2. Ambient air quality standards.

Standards	Time-Weighted Annual Avg.	NO_2 ($\mu g/m^3$)	SO_2 ($\mu g/m^3$)	CO (mg/m^3)
NEQS-PAK	24-hr*	80	120	10
NAAQS-USEPA	24-hr**	100	200	10
CNAAQS-CHINA	24-hr***	80	150	10
WHO	24-hr	40	20	10

*24 hourly/8 hourly values should be met 98% of the in a year; 2% of the time it may exceed, but not on two consecutive days.
**Not to be exceeded more than once per year on average over three years, 98% average over three years.
***Grade II is for residential, commercial, industrial and rural areas.

Results and Discussion

Comparison of NO_2 at Dalian and Faisalabad Cities

The concentration of NO_2 was calculated from January to December 2013. NO_2 date-wise concentration distribution in Faisalabad and Dalian is shown in Fig. 3. NO_2 concentrations in Faisalabad varied from 185 to 262 $\mu g/m^3$, with an average of 219 $\mu g/m^3$. These concentrations are relatively higher than the other cities in the regions like Lahore-Pak (76 $\mu g/m^3$), Karachi-Pak (76 $\mu g/m^3$), Islamabad-Pak (30 $\mu g/m^3$), Beijing-China (122 $\mu g/m^3$), Shanghai-China (53 $\mu g/m^3$), Tokyo-Japan (55 $\mu g/m^3$), Mumbai-India (43 $\mu g/m^3$), and Kolkata-India (37 $\mu g/m^3$) [21, 22]. The minimum value of NO_2 concentration was found to be 185 $\mu g/m^3$ in April 2013, whereas the maximum was recorded at 262 $\mu g/m^3$ in August 2013. The average NO_2 concentration in Faisalabad through the year was higher than the standards of NEQS, USEPA, WHO, and CNAAQS. The average NO_2 concentration during the cold period (10 November to 25 March) was found to be 200

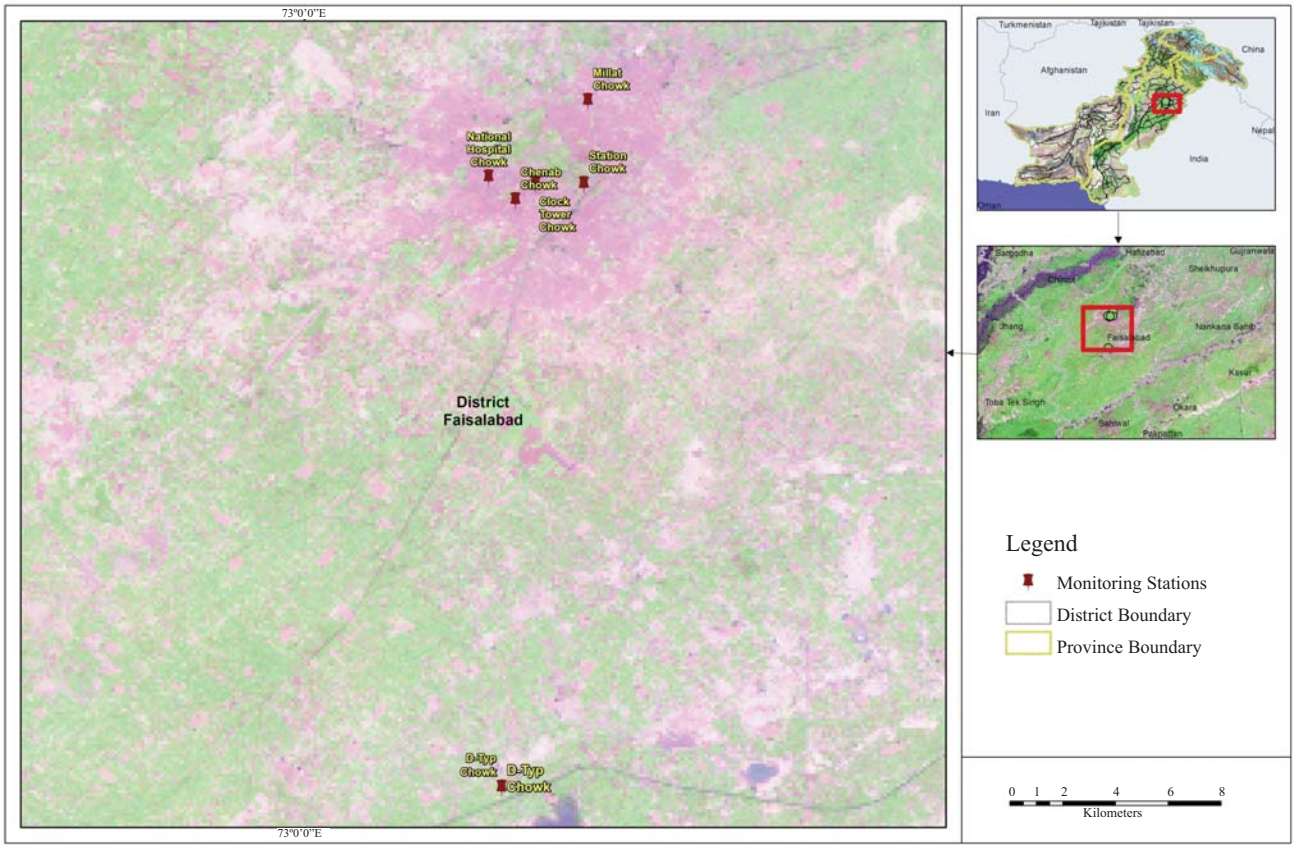

Fig. 1. Map of selected stations in Faisalabad, Pakistan.

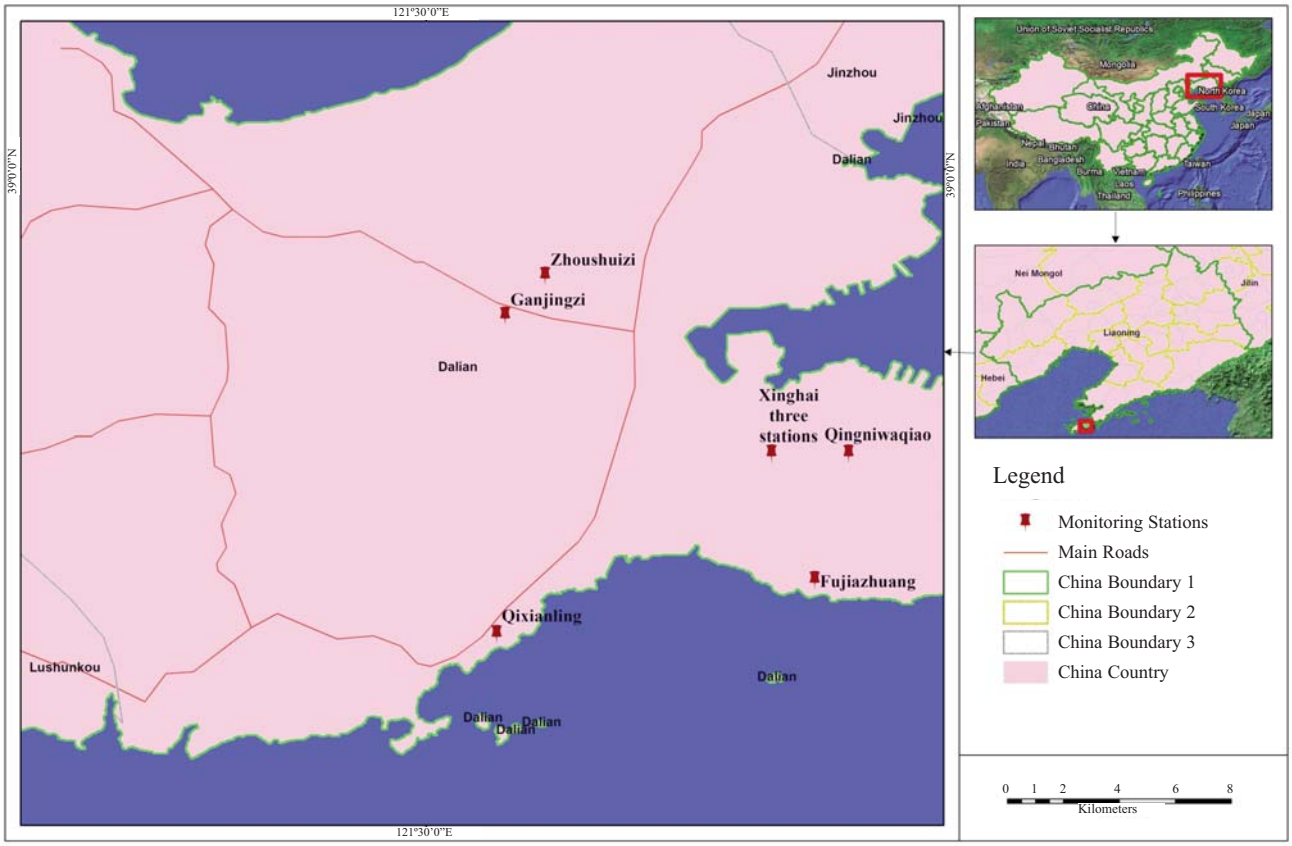

Fig. 2. Map of selected stations in Dalian P.R. China.

μg/m³ and in the warm period (10 April to 25 October) it was found to be 232 μg/m³. Overall, 100% values were beyond the permissible limit of NEQS, USEPA, WHO, and CNAAQS standards 80, 100, 40, and 80 μg/m³, respectively (Table 2).

NO_2 concentrations in Dalian varied from 44 to 133 μg/m³, with an average of 74 μg/m³. These concentrations are relatively higher than the other cities in the regions, like Islamabad-Pak (30 μg/m³), Shanghai-China (53 μg/m³), Tokyo-Japan (55 μg/m³), Mumbai-India (43 μg/m³), and

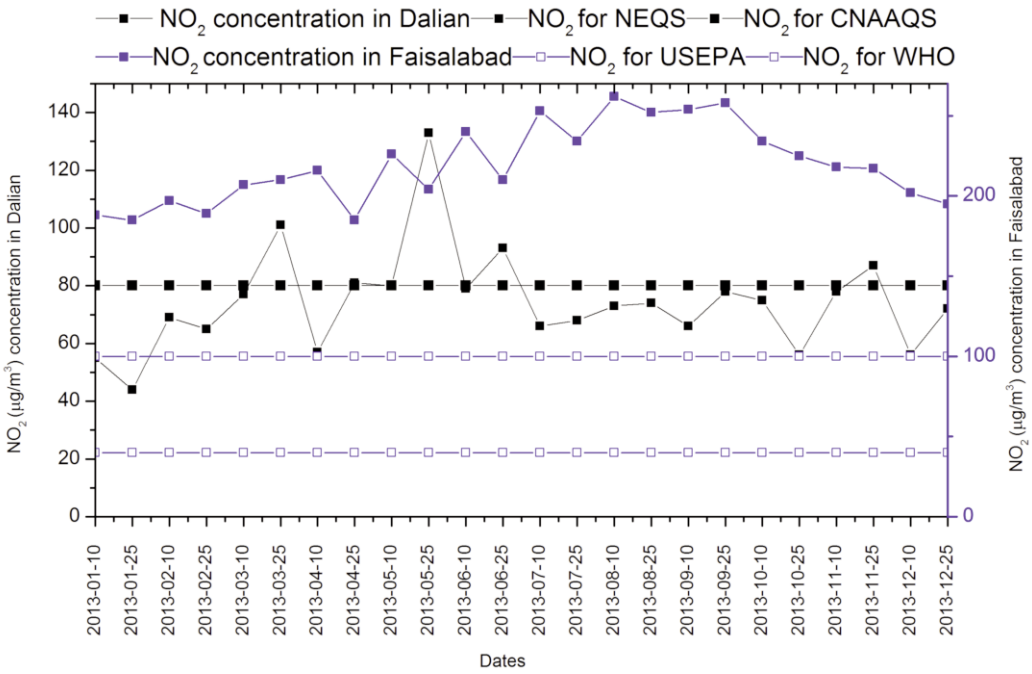

Fig. 3. Date-wise comparison of NO_2 concentrations between Dalian and Faisalabad.

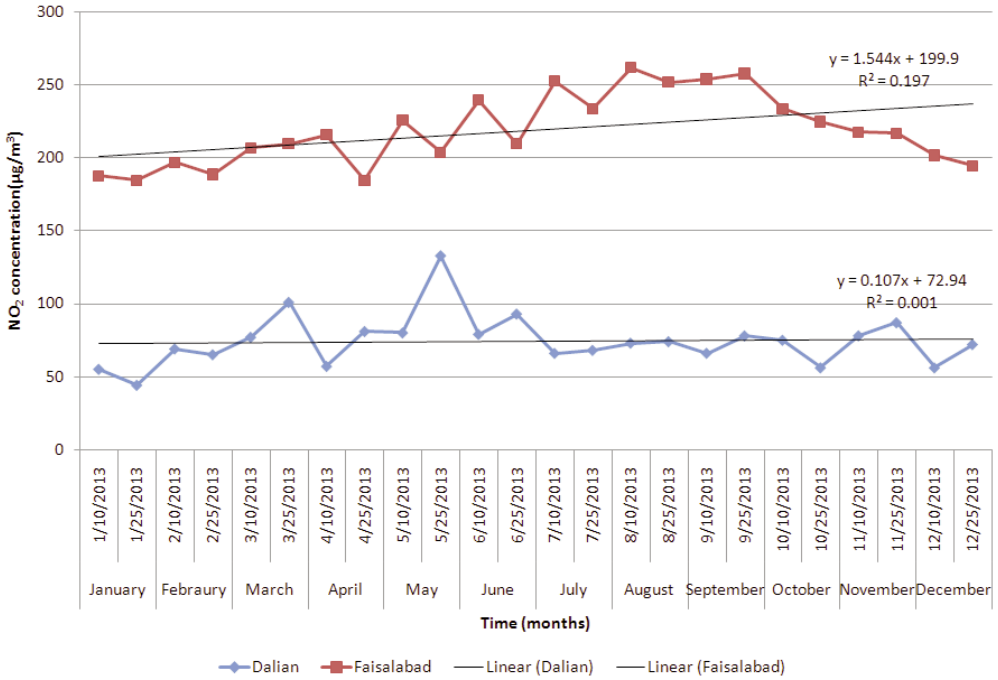

Fig. 4. Month-wise comparison of NO_2 concentrations between Dalian and Faisalabad.

Kolkata-India (37 µg/m³), but lower than Lahore-Pak (76 µg/m³), Karachi-Pak (76 µg/m³), and Beijing-China (122 µg/m³) [21, 22]. The minimum value of NO_2 concentration was 44 µg/m³ in January 2013, whereas the maximum (133 µg/m³) was in May 2013. The average NO_2 concentration during the cold period (10 October to 25 March) was 69µg/m³, and within the permissible limits of NEQS, USEPA, and CNAAQS, but higher than the WHO limit. The corresponding concentration for the warm period (10 April to 25 September) was 79 µg/m³, which was also higher than the WHO (40 µg/m³) limit. But within the permissible limits of USEPA, NEQS, and CNAAQS limits of 100, 80, 80 µg/m³, respectively (Table 2).

Overall, 80% of the values of NO_2 concentrations in Dalian city (date wise) were within the permissible limits of CNAAQS and NEQS, whereas 91% were within the USEPA standard and beyond WHO limits (Table 2). In comparison to standards, 100% of NO_2 values were beyond the permissible limits. Furthermore, the average NO_2 concentration in Faisalabad city in dry season was higher than the wet season, and the same was observed for Dalian city. The monthly comparison of NO_2 is shown in

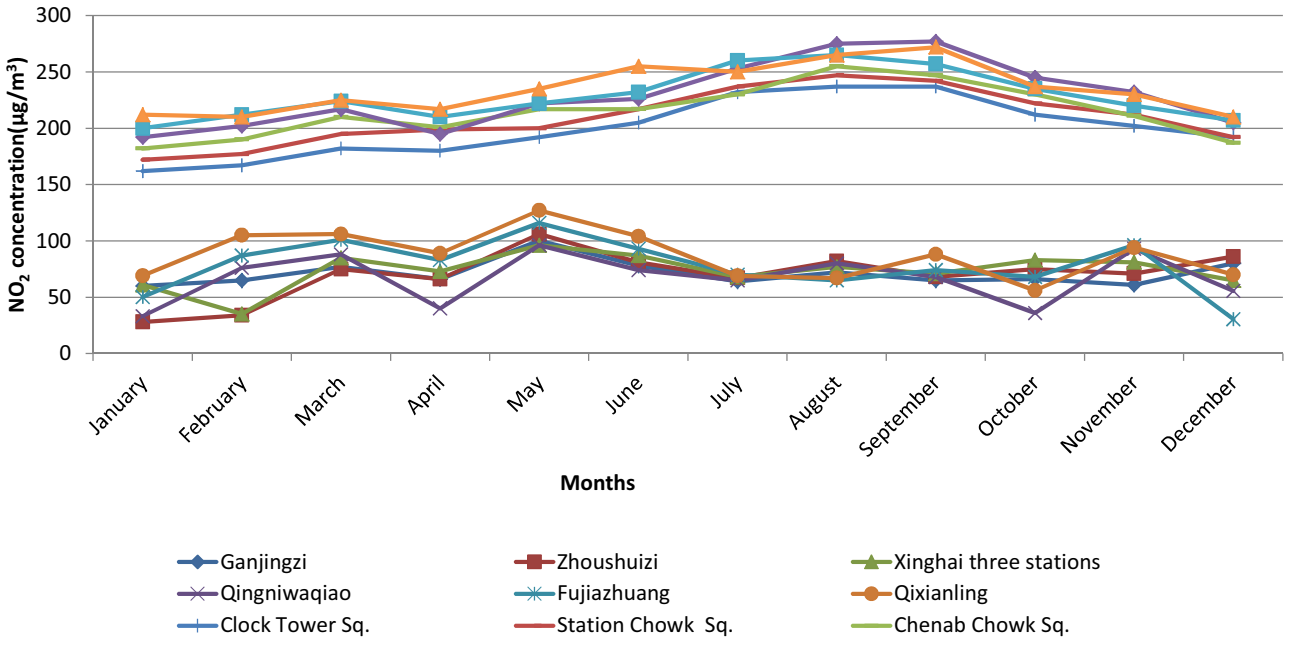

Fig. 5. Station-wise comparison of NO_2 concentrations in Dalian and Faisalabad.

Fig. 4. We observed that in Dalian in May there was a sudden increase in NO_2 concentration, although in the remaining period the trend was almost the same. The value of linear co-relation coefficient R^2 for Dalian is 0.001 and it was 0.197 for Faisalabad.

The NO_2 concentrations recorded at different stations throughout the year in Dalian and Faisalabad are shown in Fig. 5. These six monitoring sites in both cities selected randomly are residential, commercial, industrial, and vehicular areas. The minimum and maximum annual average values of NO_2 concentration in Faisalabad were recorded at Clock Tower Square and Millat Square at 200 μg/m³ and 234 μg/m³, respectively, and were beyond the permissible limits set by NEQS, USEPA, WHO, and CNAAQS. The minimum and maximum annual average values of NO_2 in Dalian were recorded at Qingniwa and at Qixianling as 67 μg/m³ and 87 μg/m³, respectively, and were within the limits of NEQS, USEPA, and CNAAQS, but higher than the WHO standards. Station-wise, NO_2 concentration results show that NO_2 was significantly higher in Faisalabad versus Dalian at all stations.

Comparison of SO_2 at Dalian and Faisalabad Cities

The concentrations of SO_2 were recorded from January to December 2013 and the trend thus observed at Faisalabad and Dalian stations is shown in Fig. 6. SO_2 concentrations in Faisalabad varied from 66 to 190 μg/m³ with average values of 134 μg/m³. These concentrations were relatively higher than the other cities in the region, such as Lahore-Pak (115 μg/m³), Karachi-Pak (30 μg/m³), Islamabad-Pak (73.4 μg/m³), Beijing-China (120 μg/m³), Shanghai-China (53 μg/m³), Tokyo-Japan (19 μg/m³), Mumbai-India (18 μg/m³), and Kolkata-India (19 μg/m³) [22-24]. The minimum value of SO_2 concentration was recorded 66 μg/m³ in February 2013, whereas the maximum (190 μg/m³) was detected in July 2013. The average SO_2 concentration during the cold period (10 November to 25 March) was 108 μg/m³ and was within the permissible limits of NEQS, USEPA, and CNAAQS, but higher than the limit set by WHO. The average concentration in warm period (10 April to 25 October) was recorded to be 152 μg/m³ and was beyond the permissible limits of NEQS, CNAAQS, and WHO, while within the USEPA range. Overall, 25% of recorded values were found within the permissible limit of NEQS, 100% within the limits of USEPA, and 66% within the standards of CNAAQS, but 100% of values were beyond the limit set by WHO (Table 2). The SO_2 concentrations in Dalian varied from 56 to 128 μg/m³, with an average of 103 μg/m³.

These concentrations are relatively higher than other cities in the regions, like Karachi-Pak (30 μg/m³), Islamabad-Pak (73.4 μg/m³), Shanghai-China (53 μg/m³), Tokyo-Japan (19 μg/m³), Mumbai-India (18 μg/m³), and Kolkata-India (19 μg/m³), but lower than Beijing-China (120 μg/m³) and Lahore-Pak (115 μg/m³) [22-24]. The minimum value of SO_2 concentration was 56 μg/m³ in January 2013, whereas the maximum (128 μg/m³) was recorded in June 2013. The average SO_2 concentration in Dalian was low year-round, but there was a sudden increase found in April to September 2013. The average NO_2 concentration during the cold period (10 October to 25 March) was found to be 95 μg/m³, whereas it was 111 μg/m³ in the warm period (10 April to 25 September) and was within the permissible limits of NEQS, USEPA, and CNAAQS, but higher versus the WHO standard.

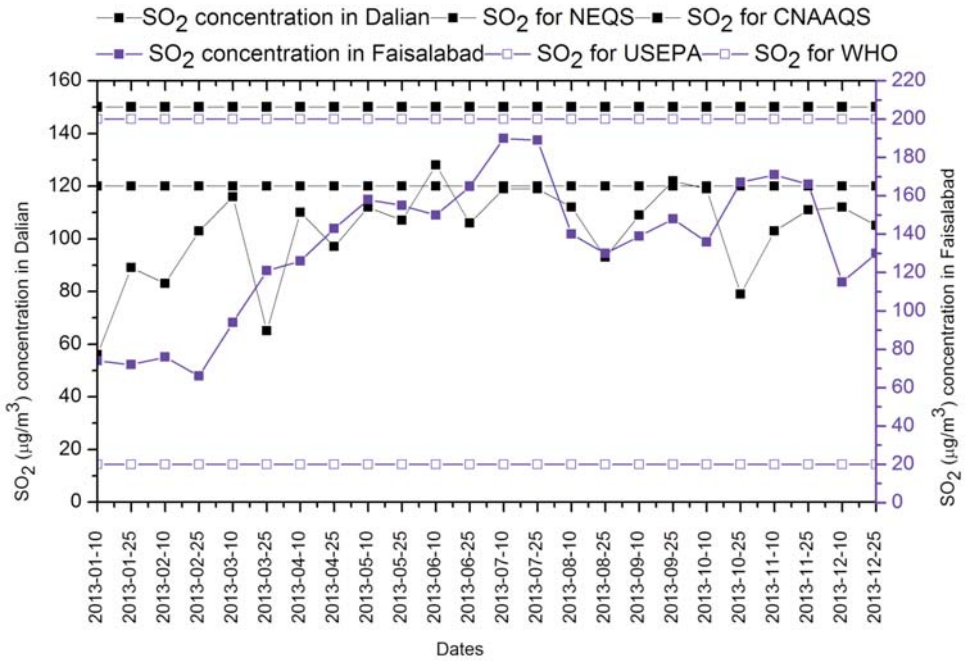

Fig. 6. Date-wise comparison of SO_2 concentrations between Dalian and Faisalabad.

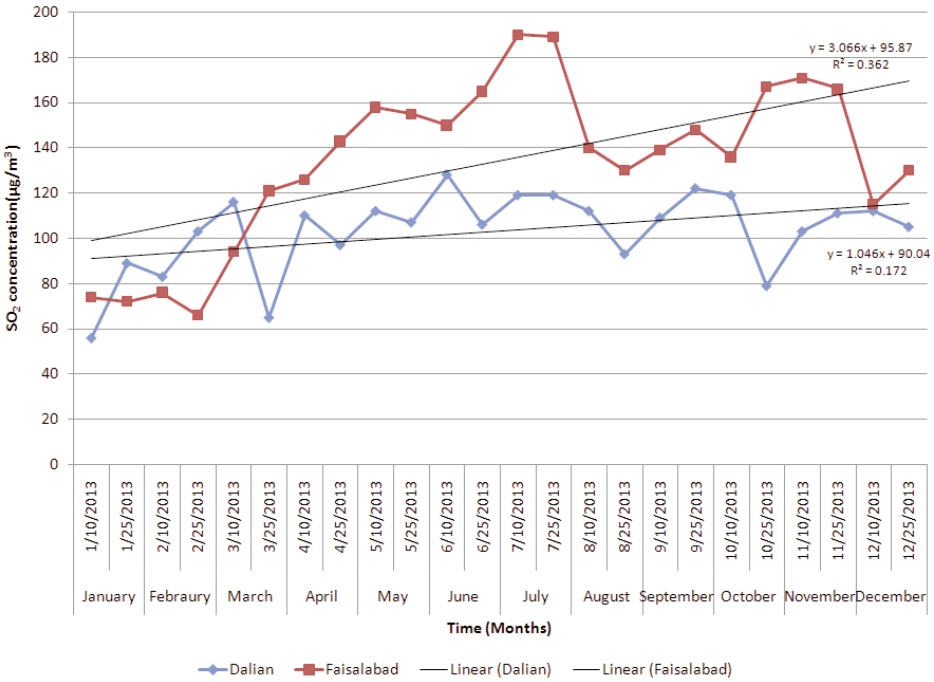

Fig. 7. Date-wise comparison of SO_2 concentrations between Dalian and Faisalabad.

Overall, 87% of values fall within the limit of NEQS, 100% of values within the USEPA limit, 100% of values within the CNAAQS standard, and 100% values were beyond the WHO limits (Table 2). Fig. 7 shows the SO_2 concentration month-wise in Faisalabad and Dalian. The SO_2 concentration in Faisalabad in June and July showed a sudden increase in concentration. The value of R^2 for Dalian was 0.172 and for Faisalabad it was 0.362, which indicates a significant variation in SO_2 concentration in Faisalabad versus Dalian. Fig. 8 shows the station-wise comparison of SO_2 concentrations in Dalian and Faisalabad. The minimum and maximum annual average values of SO_2 concentrations in Faisalabad was recorded at Chenab Chowk Square (130 µg/m³) and Millat Square (138 µg/m³), respectively, whereas the minimum and maximum annual average values of SO_2 concentration in Dalian were recorded at Zhoushuizi (88 µg/m³) and Xinghai (109 µg/m³), which are in the limits set by NEQS, USEPA, and CNAAQS, but higher than the WHO standard. Station-wise SO_2 concentration results shows that the level of SO_2 in Faisalabad was significantly higher than Dalian-China at all selected stations.

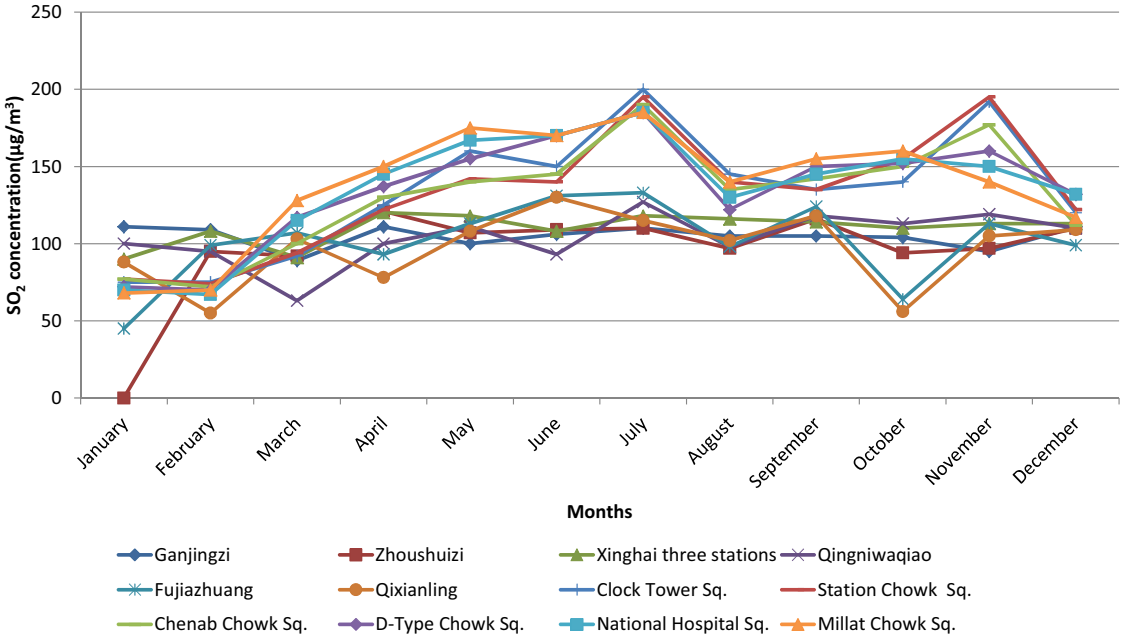

Fig. 8. Station-wise comparison of SO_2 concentrations between Dalian and Faisalabad.

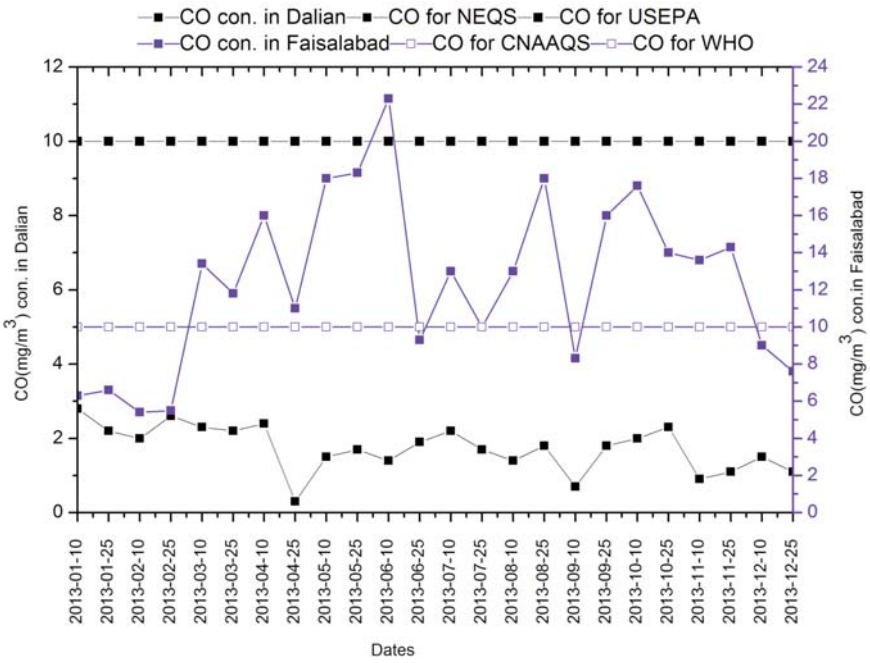

Fig. 9. Date-wise comparison of CO concentrations between Dalian and Faisalabad.

Comparison of CO in Dalian and Faisalabad

How CO concentrations in Faisalabad and Dalian differ year-round is shown in Fig. 9. In Faisalabad CO concentrations varied from 5.4 to 22.3 mg/m^3, with an average of 12.4 mg/m^3. These concentrations are relatively higher than for other cities in the regions, like Lahore-Pak (4.6 mg/m^3), Karachi-Pak (5.8 mg/m^3), Islamabad-Pak (3.5 mg/m^3), Beijing-China (2 mg/m^3), Shanghai-China (6.6 mg/m^3), Guangzhou-China (1.6 mg/m^3), Dhaka-Bangladesh (0.166 mg/m^3), and Kolkata-India (3.61 mg/m^3) [9, 25-28]. The minimum value of CO was 5.4 mg/m^3 in February 2013, whereas the maximum (22.3 mg/m^3) was recorded in July 2013. The average CO concentration during the cold period (10 November to 25 March) was 9.35 mg/m^3, and within the NEQS, USEPA, WHO, and CNAAQS limits, whereas in the warm period (10 April to 25 October) it was 14.6 mg/m^3 and beyond the permissible limits of NEQS,

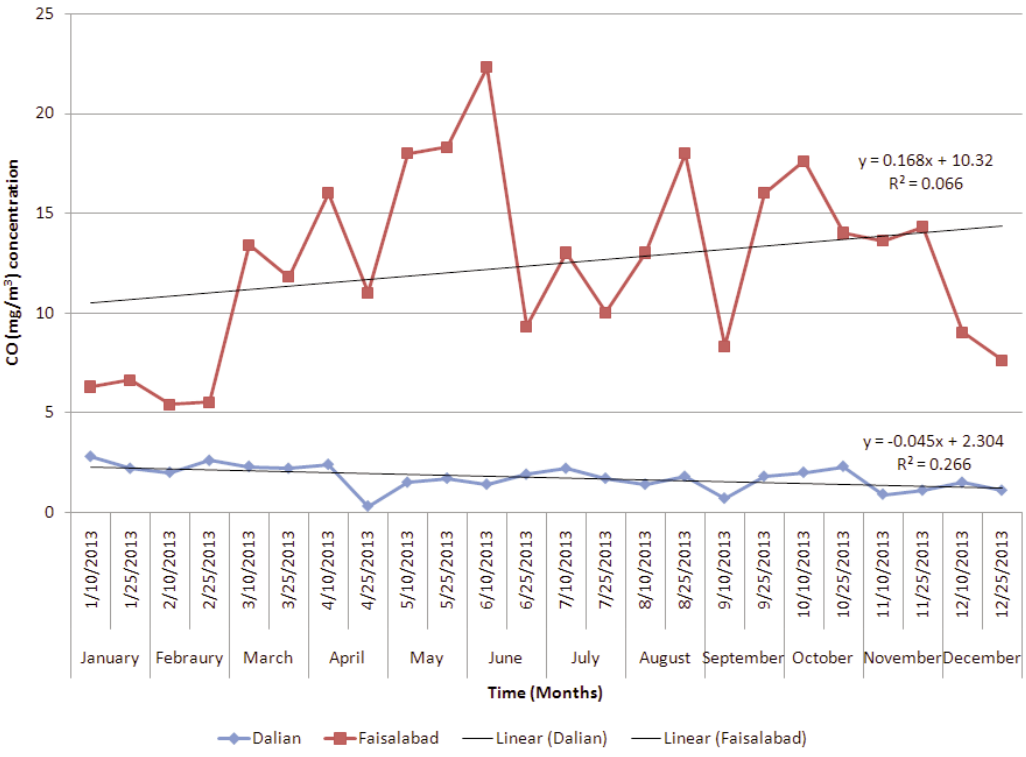

Fig. 10. Month-wise comparison of CO concentrations in Dalian and Faisalabad.

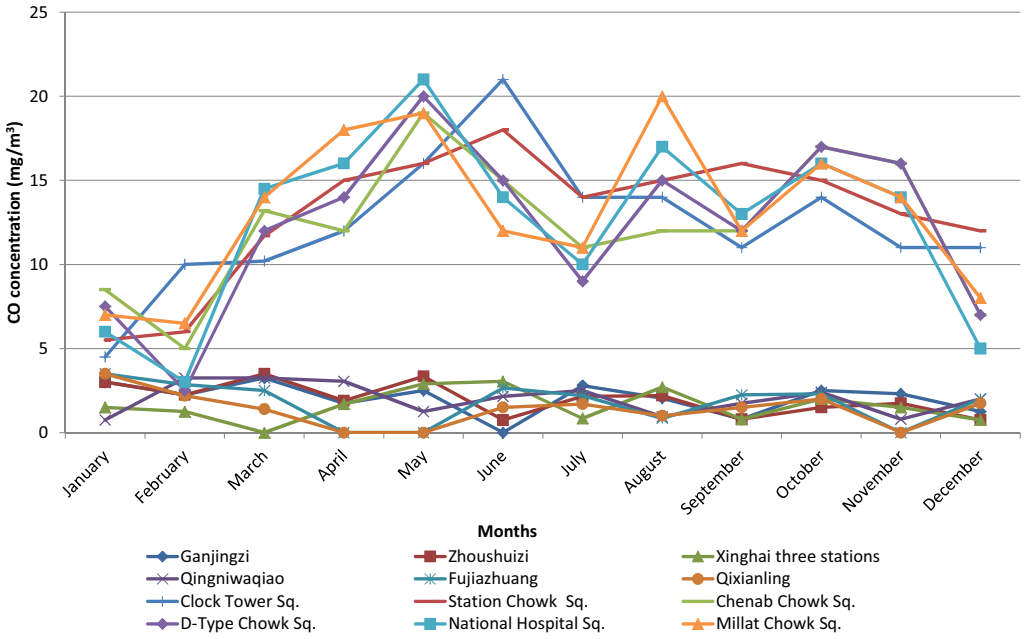

Fig. 11. Month-wise comparison of CO concentrations in Dalian and Faisalabad.

CNAAQS, WHO, and USEPA standards. Overall it was observed that 37% values were within the permissible limit of NEQS, USEPA, CNAAQS, and WHO (Table 2). Similarly, at Dalian CO concentration varied from 0.3 to 2.8 mg/m^3 with an average of 1.83 mg/m^3. These concentrations are relatively lower than Lahore-Pak (4.6 mg/m^3), Karachi-Pak (5.8 mg/m^3), Islamabad-Pak (3.5 mg/m^3), Beijing-China (2 mg/m^3), Shanghai-China (6.6 mg/m^3), and Kolkata-India (3.61 mg/m^3), but higher than Guangzhou-China (1.6 mg/m^3) and Dhaka-Bangladesh (0.166 mg/m^3) [9, 25-28].

The minimum CO concentration was recorded at 0.3 mg/m^3 in April 2013, whereas the maximum of 2.8 mg/m^3 in January, 2013. The average CO concentration during the cold period (10 October to 25 March) was 1.91 mg/m^3, within the permissible limits set by NEQS, USEPA,WHO, and CNAAQS, and during the warm period (10 April to 25 September) it was 1.56 mg/m^3 – also within permissible limits. Overall, 100% of annual CO values were lower than the limits set by NEQS, USEPA, CNAAQS, and WHO (Table 2). Fig. 10 shows analysis of CO concentrations by date and month in Faisalabad and Dalian. CO concentrations in Faisalabad from February to June 2013 increased and then decreased. The variation in CO concentration was not so pronounced in Dalian versus Faisalabad, and the R^2 for Dalian is 0.266 and 0.066 for Faisalabad. Fig. 11 shows the station comparison of CO concentrations in Dalian and Faisalabad. The minimum and maximum annual average values in Faisalabad were recorded at D-Type Chowk Square and Station Chowk Square of 12 mg/m^3 and 13.1 mg/m^3, respectively, and these both minimum and maximum values were beyond the limits set by NEQS, WHO, USEPA, and CNAAQS. The minimum and maximum annual average values of CO concentrations in Dalian were recorded at Qixianling (1.37 mg/m^3) and Ganjingzi (2.03 mg/m^3).

Conclusions

NO_2, SO_2, and CO concentrations were measured in the ambient air at various stations in Dalian, China and Faisalabad, Pakistan for one year from January to December 2013. The NO_2 concentrations in Faisalabad varied from 185-262 µg/m^3, whereas it was in the range of 44-133 µg/m^3 in Dalian. SO_2 concentrations were found in the range of 66-190 µg/m^3 and 56-128 µg/m^3, while CO varied from 5.4-22.3 mg/m^3 and 0.3-2.8 mg/m^3, respectively, in Faisalabad and Dalian. The annual average NO_2, SO_2, and CO concentrations were below the permissible limits in Dalian, although the measured values were considerably higher in Faisalabad. The NO_2, SO_2, and CO concentrations were found to be significantly different in both cities. Furthermore, different stations within cities also showed a significant variation in ambient air quality. On an average basis it was observed that the NO_2, SO_2, and CO remained within the permissible limits set by NEQS, USEPA, and CNAAQS in Dalian city, whereas above the WHO limits and in Faisalabad, it was higher than NEQS, USEPA, CNAAQS, and WHO. Therefore, the air quality should be controlled by taking serious measures to avoid negative health impacts, especially in Faisalabad in comparison to Dalian.

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