Research Article

Ambient air monitoring and health risk assessment of traffic wardens at selected roads of Lahore, Pakistan

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Abstract

Air pollution is a significant environmental and public health concern worldwide. This study investigated the day and night-time concentrations of seven air pollutants: carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), particulate matter (PM_{10} and $PM_{2.5}$), and total suspended particulate matter (TSP) along five urban roads in Lahore, Pakistan. A human health risk assessment was also conducted for traffic police personnel regulating traffic at busy road intersections, by using the parameters of Chronic Daily Intake (CDI), Hazard Quotient (HQ), and Hazard Index (HI) to evaluate potential health risks associated with individual and cumulative exposure to the air pollutants. Day-time concentrations of all the contaminants were significantly higher than the night-time concentrations, reflecting the impact of vehicular emissions on ambient air quality. The highest CDI was detected for CO (8.46 mg/kg/day) for the most traffic-dense road (R5) with the lowest vegetation cover and an equally high day and night-time average HI (21.06) and pronounced health effects were observed for the traffic wardens stationed at this road. The findings underscore the role of vehicular emissions as a significant source of air pollution and health hazards for the exposed individuals. The study also highlights the need for extensive urban air quality management and stricter vehicular regulations, especially in developing countries, to protect the health of exposed individuals.

Keywords: Air Quality, Chronic Daily Intake, Hazard Quotient, Hazard Index, Lifetime Average Daily Dose, Traffic Personnel.

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Introduction

Air pollution is the release of toxic chemicals from anthropogenic activities in concentrations sufficient to modify the atmosphere's natural composition and cause harmful impacts on the environment and its components [1]. For a substance to act as an air pollutant, it must be released into the air, undergo chemical transformation, and subsequently affect the biotic and abiotic components of the environment [2]. Polluted air is a mixture of numerous gaseous and particulate materials [3], such as ozone, oxides of nitrogen and sulfur, carbon monoxide, volatile organic compounds, lead, and particulate matter, which are also called criteria air pollutants [2]. The presence and concentration of these pollutants vary for each location, depending on the geography and emission sources [4]. Certain air pollutants are emitted naturally from volcanic eruptions, cattle, radiation, plants such as pine trees, etc. [5, 6]. Anthropogenic sources comprise industrial activities, fossil fuel combustion for energy generation, vehicular emissions, and agricultural activities [7]. These anthropogenic sources add to the existing background, natural sources of emissions [8], thus making air pollution one of the ongoing environmental problems with significant ramifications on a global scale [9]. Several studies have linked exposure to air pollutants ozone, NO2, SO2, CO, and PM, with lung cancer, respiratory and cardiovascular diseases [10 -14]. There are reports on human exposure to air pollutants and associated decline in productivity in adults and cognitive performance of children, and excessive production of stress hormones and associated behavioral changes [4, 15, 16]. Air pollution also negatively impacts biodiversity and the ecosystem [17, 18] by mechanisms such as eutrophication caused by atmospheric nutrient depositions, ozone-induced phytotoxicity in plants, impacts on lichens and plants from acid rain caused by high concentrations of SOx and NOx [19], and blackening of birds' feathers from soot deposition, etc. [20]. Since the early 1990s, air emissions from anthropogenic activities have declined in some parts of the world, but Asia and the Middle East have seen a rise in these emissions [21 - 23]. Despite the decline in these emissions, billions of individuals are still exposed to various air pollutants all over the world [24, 25] since the problem of air pollution is more pronounced in growing cities in developing countries [26]. For instance, about 92% of the global population breathes dirty air, contributing to 11.6% of global deaths [27]. In 2019 alone, 4.2 million premature deaths occurred worldwide due to ambient air pollution, with 89% of these fatalities being in low- and middle-income nations [28, 29].

This aggravating air pollution problem has been frequently linked to an ever-increasing rise in industrial emissions, poor waste management systems, and rapid urban sprawl [30]. Likewise, air quality is worsening in South Asia due to increased population, unchecked urbanization, deforestation, and industrial activities [31, 32]. Among these Asian countries, Pakistan is one rapidly populating and developing country with a population of more than 231 million [33]. It ranks third on the list of countries facing adverse air quality issues [34], given rapid urbanization, industrialization, transportation, and other anthropogenic activities [35]. The World Health Organization (WHO) has marked Pakistan's air quality as "unsafe," given the constantly elevated concentrations of air pollutants, which exceed the safe levels established by the WHO [36].

Lahore, a city known for its rich culture and historical context, has seen a surge in its population over the last few years [37]. Lahore has undergone rapid urbanization, with an annual population growth rate of 3% over the last two decades [38]. This urban expansion is accompanied by an equal increase in the number of automobiles; according to a recent estimate, about 10.4 million vehicles are present in Lahore [38]. Vehicular exhaust is a known source of air pollutants [39], and the ambient air quality of urban regions like Lahore city is deteriorating at an alarming level due to increasing traffic density [40, 41]. Elevated concentrations of air pollutants, especially particulate matter at the roadside, can affect the health of daily commuters and those who live in vicinities [42]. Each year, approximately 1250 individuals die in Lahore because of air pollution [43]; given this increase in the number of vehicles, associated emissions, and air pollution-related morbidities and mortalities are likely to rise. Traffic police personnel are one such group of workers who are frequently exposed to stressors such as air pollution, noise, musculoskeletal disorders, and work-related stress, which can affect their physiological and psychological well-being [44 - 47]. The traffic police officers in major urban cities are even more exposed to outdoor air pollution due to the markedly higher traffic density [48].

This study centers on determining the ambient air quality along selected busy roads of Lahore (Pakistan) and assessing the health risks faced by the traffic police officers working on these roads. To date, there have been numerous studies on the evaluation of the physical health of traffic wardens, with a special focus on musculoskeletal disorders, noise-induced hearing loss, and exposure to air pollutants [49 - 53]. However, to our knowledge, this study is the first attempt in Pakistan to conduct a human health risk assessment of traffic wardens in response to their exposure to air pollutants, focusing on their smoking and non-smoking status.

Materials and Methods

Study area

Pakistan is a developing South Asian country with a population of 241.49 million, out of which 38.8% is urban [54]. Lahore is Pakistan's second-largest city. It

is situated in the province of Punjab at the geographical coordinates 31° 13’0 N, 74° 0’0 E, between the longitudes 74° 0’ and 74° 39” and latitudes 31° 13’ and 31° 43’[55]. Over time, Lahore, one of Pakistan’s largest cities, has experienced extensive industrialization, urbanization, and population expansion, which, in one way or another, has created several environmental issues, including air pollution [56]. Globally, Pakistan ranks third in terms of worst air quality [57], and Lahore ranks as the second most polluted city in the world with an annual average of 136 µg/m³ of particulate matter in the air, six times the levels permissible by the World Health Organization [58].

Therefore, for this study, the five most traffic-bearing locations were selected in Lahore, a study area map is given in Figure 1. These sites included Canal Road (R1) 31°30'12.4"N 74°18'43.7"E, Maulana Shaukat Ali Road (R2) 31°29'03.4"N 74°17'45.9"E, Bhekewal Road (R3), 31°30'35.8"N 74°18'09.3"E, Ferozepur Road at Kalma Roundabout (R4) 31°30'17.0"N 74°19'53.5"E, Ferozepur Road at Ichra (R5) 31°31'57.0"N 74°19'07.6"E. A description of site codes, traffic density, and site characteristics is given in Table 1.

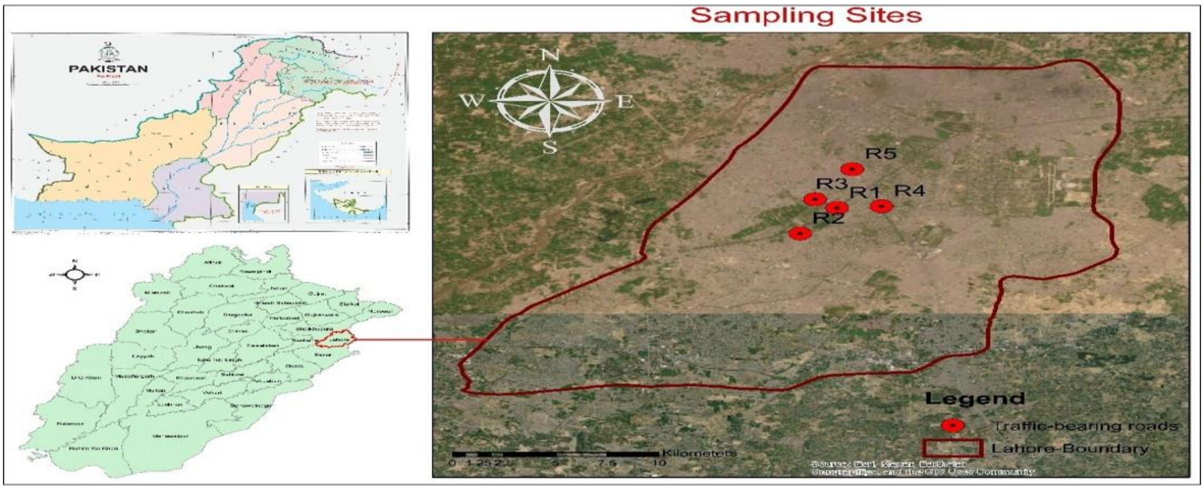

Figure 1: Study area map for selected sampling sites in Lahore, Pakistan.

Table 1: Description of study site codes and surrounding characteristics.

Road Name	Road Code	Traffic Density			Site Features		
		Low	Medium	High	Commercial Area	Residential Area	Green Belt
Canal Road (Campus Bridge)	R1			✓			✓
Maulana Shaukat Ali Road	R2		✓			✓	✓
Bhekewal Mor	R3			✓	✓		
Ferozepur Road (Kalma Roundabout)	R4			✓	✓	✓	✓
Ferozepur Road (Ichra)	R5			✓	✓	✓	

Data collection

Ambient air monitoring

Instant air monitoring was conducted, and the concentration of pollutants was measured for the day at 12 pm and at 8 pm at night. A certified mobile air monitoring van comprising an air sampling station (EPA, 1989) was used for the sampling. CO, SO_2, PM_{10}, and $PM_{2.5}$ were measured with the Zetian Model AM-5 series. NO_x, ozone, and TSP were measured with a Kimoto NA-72, Thermo Scientific Model 49i ozone analyzer, and High-Volume Air Sampler HVS3000, respectively. The equation for the measurement of TSP after dust collection on the filter paper was adapted from [59].

$$TSP = \frac{(Final\ weight - Initial\ weight) \times 1000{,}000}{Corrected\ volume\ (65.8m/hr)}$$

Human health risk assessment

A structured questionnaire was utilized to gather information from traffic police officers to assess the health impacts of exposure to air pollutants, in addition to ambient air monitoring. The questionnaire focused on the exposure assessment of the traffic wardens, as well as health impacts that were segregated based on the smoking and non-smoking status of the participants. Face validity of the questionnaire was assessed to assess its clarity, comprehensibility, and appropriateness for the target group, and three experts reviewed it. After pilot testing, the questionnaire was subjected to minor corrections. The questionnaire was filled out by 40 traffic police personnel, who performed their duties at different times and at different points along the selected five roads in Lahore. The questionnaire was distributed in a controlled setting while upholding moral standards and ensuring anonymity. The participants were made aware of the study objectives, their legal rights, and the voluntary nature of their participation. Prior consent was taken from the participants, and permission for the study was obtained from "City Traffic Police, Government of the Punjab." The study wholly adhered to data protection laws.

Based on the concentrations of ambient air pollutants and the questionnaire-based responses of the traffic police officers, a human health risk assessment comprising Chronic Daily Intake (CDI), Lifetime Average Daily Dose (LADD), Hazard quotient (HQ), and Hazard Index (HI) were calculated to assess the exposure of the wardens.

Chronic daily intake (CDI) and lifetime average daily dose (LADD)

Chronic daily intake represents the average daily quantity of a chemical that an individual consumes over an extended duration in milligrams per kilogram of body weight per day (mg/kg-day) [60]. Since inhalation is the primary route of exposure to ambient air pollutants, only inhalation

CDI (CDI_{inh}) was calculated. The equation used for calculating chronic daily air intake and the assumptions for each of these variables used for the CDI_{inh} calculation were adapted from [61] and is as follows:

$$CDI_{Inh} = \frac{CA \times ET \times IR \times EF \times CF}{AT \times BW}$$

Where CA is the concentration of contaminants in the air (µg/m^3), ET is the exposure time (hours), IR is the inhalation rate (30m^3/day), EF is the exposure frequency (days/year), and CF is the conversion factor of 10^{-6} for converting concentration from µg to mg, AT is the averaging time in days (ED x 365).

In the case of carcinogens, a lifetime average daily dose (LADD) was also calculated similarly by taking averaging time as AT= 70 ×365.

Reference concentrations (R_fC) and "no observable adverse effect level" NOAEL values are not available for air pollutants measured in our study; therefore, the reference concentrations were derived from the permissible exposure limits (PEL) established by the Occupational Health and Safety Administration (OSHA) [62].

Cancer risk

Cancer risk refers to the likelihood of developing cancer in response to exposure to a carcinogen. The cancer risk was calculated for the carcinogenic pollutants by adapting the equation given by [63] as follows:

$$CR = LADD \times SF \text{ or } IUR$$

CR refers to cancer risk, LADD is the lifetime average daily dose, SF is the slope factor specific to a carcinogen, and IUR is the unit inhalation risk. The US EPA [64] considers a cancer risk between 10^{-4} and 10^{-6} acceptable.

Hazard quotient

A hazard quotient is measured for non-carcinogenic effects and refers to the ratio of the measured/exposure concentration of a contaminant to the concentration at which it poses no adverse effects [65]. This no adverse effect concentration can either be a reference concentration (R_fC), or any toxicity reference value (TRV), as established by any regulatory agency [66], and is used to calculate the hazard quotient as follows:

$$HQ = \frac{CDI}{R_f C \text{ or } TRV}$$

According to the US Environmental Protection Agency [67], an HQ value <1 means no adverse health effects, while an HQ > 1 indicates that adverse health effects are possible.

Hazard index

The hazard index was calculated by summing up individual hazard quotients for each of the air pollutants [68] as follows:

$$HI = \sum_{i=1}^{n} \text{HQ}$$

Like HQ, an HI value less than 1 is considered safe, while a value greater than 1 indicates adverse health effects from exposure.

Data analysis

Descriptive statistics were applied to the concentration of pollutants. A two-way analysis of variance (ANOVA) was applied to determine the impact of location and sampling time on pollutant concentrations. *The post-hoc Tukey test* was used for pairwise comparisons of pollutant concentrations according to time and location. All of these analysis were performed on RStudio (version 4.2.0) [69], by using the package *"dplyr"* (version

1.1.4) [70]. All results were considered significant at $p<0.05$. Data was visualized with the help of Microsoft Excel (version 2405) [71].

Results

Air pollutant concentration profile

Air monitoring data was collected for the selected high-traffic roads in Lahore (Pakistan) to obtain a representative city profile. Except for $PM_{2.5}$, PM_{10}, and TSP, all pollutants were within the permissible range of Punjab Environmental Quality Standards (PEQS) established by the Environment Protection Department, Government of the Punjab (Pakistan) [72]. Day and nighttime concentrations of ambient air pollutants for the road sites studied are summarized in Table 2.

The mean concentration of carbon monoxide was found to be 3385± 57 μg/m^3 for all roads, with a range of 3650 to 3180 μg/m^3, and an average mean concentration for day and night as 3486 and 3284 μg/m^3, respectively. The highest concentration (3650 μg/m^3) was observed for R5 during the daytime, and the lowest (3180 μg/m^3), was observed at R2 during nighttime. While at R1, R3, and R4, the concentrations varied from 3570 to 3210 μg/m^3. The concentration of carbon monoxide at each sampling site was within the limits established by PEQS.

Similarly, the sulfur dioxide concentration was found within the range of 52.7 and 71.13 to μg/m^3 with an average mean concentration for day and night at 67.8μg/m^3 and 54.6 μg/m^3, respectively. The highest concentrations were observed during the daytime at R5 (71.13 μg/m^3) and R4 (69.28 μg/m^3), while the lowest concentration (52.69 μg/m^3) was measured at location R2 at nighttime. At R1 and R3, the average concentrations were 67.34 to 53.23 μg/m^3. Overall, all the concentrations were within PEQS. The collective mean value of SO2 was 61.19 ±7.24 μg/m^3.

Table 2: Temporal variations in ambient air pollutant concentrations at the road sampling sites

Pollutant Name	PEQS (μg/m3)	Air pollutant concentrations at sampling sites (μg/m^3)										Mean ± Standard deviation
		R1		R2		R3		R4		R5		
		Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	
CO (8hours)	5000	3460	3280	3360	3180	3390	3210	3570	3340	3650	3410	3388 ± 157
CO (1 hour)	10,000											
SO_2 (24 hours)	120	67.3	54.4	65.3	52.7	66	53.2	69.3	55.4	71.1	57.2	61 ± 7
NO_2 (24 hours)	80	4	8.4	3.9	8.1	3.9	8.2	4.1	8.6	4.3	9	–
NO (24 hours)	40	5	2.3	5	2.2	5.1	2.3	5.2	2.4	5.3	2.5	–
NO_x*	-	9.1	10.7	8.7	10.4	8.8	10.5	9.3	11	9.6	11.6	10 ± 1
O_3 (01 hour)	130	37.6	34	32.1	28.5	35.8	29.3	39.7	37.1	41.5	38.5	35 ± 4
PM_{10} (24 hours)	150	152	151.4	145	142.3	148	143.2	163	162.5	180	175.1	156 ± 13
$PM_{2.5}$ (24 hours)	35	37.3	36	34	32.2	36.3	34.1	40.4	40	43.8	43	38 ± 4
TSP (24 hours)	500	509	501.6	421	408.2	487	466	518	505.4	522	515.7	485 ± 41

*NOx concentrations obtained by summing up NO and NO_2.

The concentrations of Nitric Oxide (NO) and Nitrogen dioxide (NO_2) were taken separately, as mentioned in the table, and subsequently summed up as Nitrogen Oxides (NO_X). As Table 2 indicates, the concentration of NO_X was also within permissible levels, ranging between 8.73µg/m^3 ¬¬(at daytime for R2) and 11.6 µg/m^3(at nighttime for R5), with the average mean concentration for day and night being 9.1 and 10.82 µg/m^3, respectively. The average concentrations at all other sites (R1, R3, R4) ranged between 11 to 8.73 µg/m^3. The collective mean concentration of NOx was 9.97± 0.99 µg/m^3.

Likewise, in the case of ozone (O_3), the mean concentration was 35.42 ± 4.35 µg/m^3, with concentrations for roads falling within permissible levels. In the case of ozone as well, the highest concentration was detected for R4 and R5 during the day at (39.73 µg/m^3 and 41.53 µg/m^3) respectively, while the lowest concentrations were found for the road R2 at nighttime (28.49 µg/m^3). On the contrary, particulate matter PM10 and $PM_{2.5}$ concentrations exceeded the PEQS, albeit slightly. The average mean concentration of PM10 was 156.28 ± 13.27 µg/m^3 with a range of 142.32 µg/m^3 to179.521 µg/m^3. Road R5 had the highest PM10 concentration, slightly varying between day (179.521 µg/m^3) and nighttime (175.119 µg/m^3). For $PM_{2.5}$, the mean concentration was 38 ± 3.96 µg/m^3, with a range of 43.821 to 32.154 µg/m^3. A similar trend was observed for road R5, having the highest concentration of $PM_{2.5}$ for day and nighttime at 43.821 µg/m^3 and 42.991 µg/m^3, respectively.

Similarly, total suspended particulate matter measurement also revealed that the concentrations exceeded the PEQS at many roads; however, the average concentration (485.39 ±40.89 µg/m^3) was within the PEQS. Overall, R5 had the highest TSP concentration among all sites, with a higher prevalence during the daytime (521.881 µg/m^3).

A two-way ANOVA was conducted to determine the impact of "location" and "time (day/night)" on the respective concentrations of all pollutants (CO, SO_x, NO_x, $PM_{2.5}$, PM10, TSP, and O_3). It was found that both variables had a significant effect ($p<0.05$) on the pollutant concentrations, which varied with the location and time (Table 3).

Table 3: Results of analysis of variance (ANOVA) for air pollutants across sampled locations and times.

Pollutant	Factor	D_f	Sum Sq	Mean Sq	F value	Pr(>F)
CO	Location	4	93200	23300	50.65	0.001
	Time	1	102010	102010	221.76	1.80E-04
SO_2	Location	4	35.7	8.9	44.76	0.001
	Time	1	435.6	435.6	2183.18	1.26E-06
NO_x	Location	4	1.401	0.35	53.35	0.001
	Time	1	7.43	7.43	1131.83	4.66E-06
Ozone	Location	4	129.38	32.35	29.31	0.003
	Time	1	37.29	37.29	37.29	0.0043
PM_{10}	Location	4	1557.8	389.4	189.419	8.24E-05
	Time	1	18.5	18.5	8.996	0.04
$PM_{2.5}$	Location	4	135.15	33.79	144.7	1.41E-05
	Time	1	4.36	4.36	18.66	0.012456
TSP	Location	4	14618	3654	205.95	6.98E-05
	Time	1	364	364	20.49	0.0106

Likewise, a Tukey post hoc test also revealed significant spatial variations, as the concentrations of TSP, CO, SO_x, $PM_{2.5}$, PM_{10}, and ozone were significantly different (higher) for R1, R5, and R4, as compared to R2 and R3. Temporal differences were also observed as the concentrations of CO, SO_x, PM_{10}, $PM_{2.5}$, and ozone were significantly different (higher) at daytime as compared to nighttime ($p<0.05$). These results highlight the significant yet intricate interactions between spatial and temporal factors affecting the concentrations of air pollutants.

Human health risk assessment

A human health risk assessment was carried out for the traffic police officers based on their exposure to various air pollutants on each of the five roads. The results of human health risk assessment are as follows:

Lifetime average daily dose (LADD)

The lifetime average daily dose (LADD) is calculated for known or suspected carcinogens. Particulate matter, especially $PM_{2.5}$, is a Group I carcinogen [73]; therefore, this study only calculated LADD for particulate matter ($PM_{2.5}$ and PM_{10}). As shown in Figure 2, the highest LADD was observed for PM_{10}, specifically during the daytime and at R5. The LADD values for $PM_{2.5}$ were considerably lower than those for PM10.

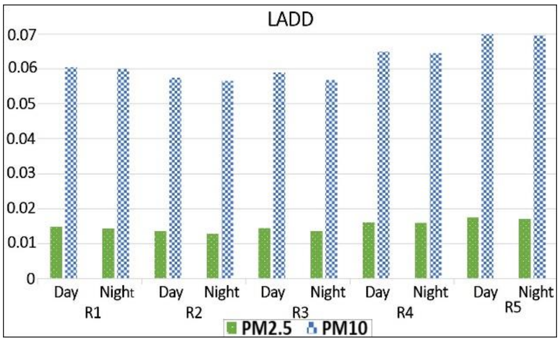

Figure 2: Lifetime average daily dose (LADD) for $PM_{2.5}$, and PM_{10} for each of the five roads.

The average cancer risk for $PM_{2.5}$ and PM_{10} was calculated as 1.2 x 10^{-4} and 1.24 x 10^{-7}, respectively. For $PM_{2.5}$, this cancer risk value means a low but existing chance (1.2 in 10,000) of developing cancer from $PM_{2.5}$ exposures. Cancer risk for PM_{10} is considerably low compared to the acceptable cancer risk of 1 x 10^{-6}, suggesting that the existing exposure level of PM_{10} is unlikely to pose a cancer risk for the exposed traffic police personnel. Cancer risk for both pollutants for each road and sampling time is given in Table 4.

Table 4: Cancer risk for $PM_{2.5}$ and PM_{10} corresponding to each road and exposure time.

Road	Time	Cancer Risk	
		$PM_{2.5}$	PM_{10}
R1	Day	1.18 x10^{-4}	1.21 x10^{-07}
	Night	1.14 x10^{-4}	1.20 x 10^{-07}
R2	Day	1.08 x 10^{-4}	1.15 x 10^{-07}
	Night	1.02 x 10^{-4}	1.13 x 10^{-07}
R3	Day	1.15x 10^{-4}	1.18 x10^{-07}
	Night	1.08 x 10^{-4}	1.14 x 10^{-07}
R4	Day	1.28 x 10^{-4}	1.30 x 10^{-07}
	Night	1.27 x 10^{-4}	1.29 x 10^{-07}
R5	Day	1.39 x 10^{-4}	1.43 x 10^{-07}
	Night	1.37 x10^{-4}	1.39 x 10^{-07}
	Average	1.20 x 10^{-4}	1.24 x 10^{-07}

Chronic daily intake (CDI)

The inhalation exposure of traffic police workers to the air contaminants was quantified through the chronic daily intake (CDI); the results are presented in Figure 3. The CDI was found to be in the following decreasing order: CO > TSP > SO_2 > O_3> NO_x. The average CDI_{inh} for CO on all roads was the highest among all pollutants (7.81 mg/kg/day). The daytime carbon monoxide CDI_{inh} values ranged between 7.7 mg/kg/day and 8.46 mg/kg/day. A slightly lower CDI_{inh} (7.3 mg/kg/day-7.7415 mg/kg/day) was observed for nighttime. Compared with the derived R_fC for CO (1.83 mg/kg/day), the CDI_{inh} of traffic police officers in this study is significantly higher, indicating a high inhalation exposure. The chronic daily intake of TSP demonstrated a mixed trend as the intake value is higher for daytime on some roads and nighttime on others. The average CDI_{inh} value for TSP was determined to be 1.12 mg/kg/day. A slightly higher CDI_{inh} was observed for daytime (average CDI_{inh}: 1.139 mg/kg/day) than nighttime CDI_{inh} (average CDI_{inh}: 1.105 mg/kg/day). The highest average CDI_{inh} for TSP was measured for R4 and R5 (1.86 mg/kg/day for each road). Compared with the derived R_fC (0.5 mg/kg/day), the average CDI_{inh} for TSP is slightly higher, indicating possible long-term health effects. Likewise, for SO_2, the nighttime levels decreased slightly, thus leading to a lower chronic intake of 0.122 mg/kg/day, 0.123 mg/kg/day, 0.126 mg/kg/day, 0.126 mg/kg/day, and 0.128 mg/kg/day, for R2, R3, R1, R5, and R4, respectively.

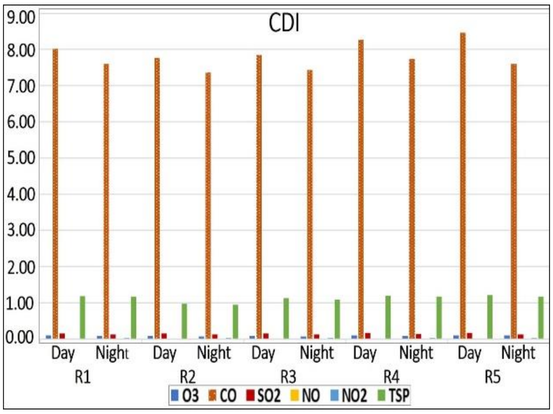

Figure 3: Chronic aily intake (CDI) for Ozone, $PM_{2.5}$, and PM_{10} corresponding to each of the five roads.

The daytime intake was slightly higher, with maximum exposure occurring for the traffic police personnel at R5 (0.165 mg/kg/day) and R4 (0.161 mg/kg/day). Akin to the previously mentioned pollutants, the CDI_{inh} of SO_2 also exceeds the R_fC (0.3 mg/kg/day). Similarly, for ozone, the average CDI_{inh} was found to be 0.082 mg/kg/day, with higher values for daytime (0.07 mg/kg/day-0.09 mg/kg/day) relative to nighttime (0.06 mg/kg/day- 0.08 mg/kg/day). The highest CDI_{inh} was measured for R5 (average CDI_{inh}: 0.09 mg/kg/day). The NOAEL for ozone is 0.04 mg/kg/day for an exposure of 8 hours [74], while the derived R_fC is (0.006 mg/kg/day). The CDI_{inh} of the traffic wardens in this study exceeds both doses for all five roads. On the other hand, given the low concentration of NO and NO_2 in the ambient air, their corresponding CDI_{inh} values were the lowest among all pollutants. For NO, the highest intake was observed at R5 (0.0123 mg/kg/day) in the daytime, and the lowest CDI_{inh} was detected at nighttime at R3 and R4 (0.0052 mg/kg/day for each). On the other hand, NO_2 exhibited higher CDI_{inh} at nighttime (average: 0.019 mg/kg/day) than at daytime (average 0.0094 mg/kg/day). The CDI_{inh} derived from OSHA PEL yielded a CDI of 8.7 mg/kg/day and 2.6 mg/kg/day for NO and NO_2, respectively. Therefore, the inhalation exposure of our study participants is well below this limit. The R_fC for NO and NO_2 is 1 and 0.3 mg/kg/day, respectively. The CDI of NO and NO_2 for all roads is within R_fC, indicative of safe exposure of traffic police workers.

Hazard quotient and hazard index

Day and nighttime hazard quotients (HQ) and hazard indices (HI) were calculated for all ambient air pollutants at each of the five roads and are presented in Table 5. The HQ values reflect the possible health effects associated with exposure to individual air pollutants, whereas the HI reflects the cumulative risk from exposure to all these pollutants. A hazard quotient and hazard index value of more than one indicates substantial health risks. In this study, the day as well as nighttime HQ of SO_2, NO, and NO_2 were found to be below 1, with an average value of 0.32, 0.008, and 0.04, respectively, indicating a safe exposure. On the other hand, the HQ for O_3, CO, and TSP was significantly higher than 1, indicating potential non-carcinogenic health risks with continued exposure. Ozone exhibited the

Table 5: Day and nighttime hazard quotient (HQ) and hazard index (HI) for the five roads.

Road	Daytime Hazard Quotient (HQ)						Hazard Index	Nighttime Hazard Quotient (HQ)						Hazard Index	Hazard Index (HI) average (Day+ Night)
	O_3	CO	SO_2	NO	NO_2	TSP	(HI)	O_3	CO	SO_2	NO	NO_2	TSP	(HI)	
R1	13.1	4.373	0.36	0.01	0.03	2.36	20.2	11.8	4.15	0.29	0	0.07	2.33	18.7	19.43
R2	11.2	4.235	0.349	0.01	0.03	1.95	17.7	9.91	4.02	0.28	0	0.06	1.89	16.2	16.95
R3	12.4	4.286	0.353	0.01	0.03	2.26	19.4	10.2	4.06	0.29	0	0.06	2.16	16.8	18.07
R4	13.8	4.513	0.371	0.01	0.03	2.4	21.1	12.9	4.22	0.3	0	0.07	2.34	19.8	20.49
R5	14.4	4.615	0.38	0.01	0.03	2.42	21.9	13.4	4.15	0.29	0	0.07	2.33	20.2	21.06

highest HQ across all roads, especially at R5 (day and nighttime average: 12.3), followed by CO (day and nighttime average: 4.23) and TSP (day and nighttime average: 2.24). Overall, the daytime hazard quotients for all pollutants are higher than the nighttime, except for NO2, where the nighttime HQ (0.065) is slightly higher than the daytime values (0.031).

Likewise, the HI values substantially exceed the safe benchmark of one, ranging from 16.2 for R2 at night to 21.9 for R5 at daytime. On average, the daytime HI (average 20) was significantly higher than the nighttime HI (average 18.3). The HI for road R5 was found to be the highest (day and night average: 21). For daytime exposure, the HQ values for ozone (O_3) are significantly high across all roads, ranging from 11.164 on Road 2 to 14.439 on Road 5, indicating a substantial potential health risk due to ozone exposure. Similarly, carbon monoxide (CO) exhibits elevated HQ values ranging from 4.23 on Road 2 to 4.61 on Road 5, suggesting significant health risks. Total suspended particles (TSP) show HQ values from 1.951 on Road 2 to 2.419 on Road 5, indicating potential health concerns. Although the HQ values for sulfur dioxide (SO_2), nitric oxide (NO), and nitrogen dioxide (NO_2) are lower, some still exceed 1, suggesting potential health risks. The cumulative HI values for daytime exposure are notably high, ranging from 17.740 on Road 2 to 21.899 on Road 5, indicating significant cumulative health risks from multiple pollutants. On the other hand, R2 (average 16.9) and R3 (18) have slightly lower HI than R1, R4, and R5. Nevertheless, all these values exceed 1, suggesting potential long-term health consequences of exposure to these ambient air pollutants.

Health impacts

The questionnaire-based survey on traffic police officers helped assess the possible health impacts of continuous exposure to the pollutants present in the ambient air where these personnel work. The smoking status of the participants was also considered. This helped identify if the reported health effects were from exposure to air pollutants, smoking, or the combined influence. Out of 40 study participants, 15 were smokers, and 25 were non-smokers. Of all participants, 84% stated that performing traffic control duties became more difficult during summer than in winter. Likewise, 45% believed that health problems became most pronounced in the afternoon (between 1 pm and 3 pm), and 38% opined that they faced air pollution-related health problems more in the morning between 8 am and 10 am. The results of health effects reported by the traffic police officers from their exposure to air pollutants are given in Figure. 4.

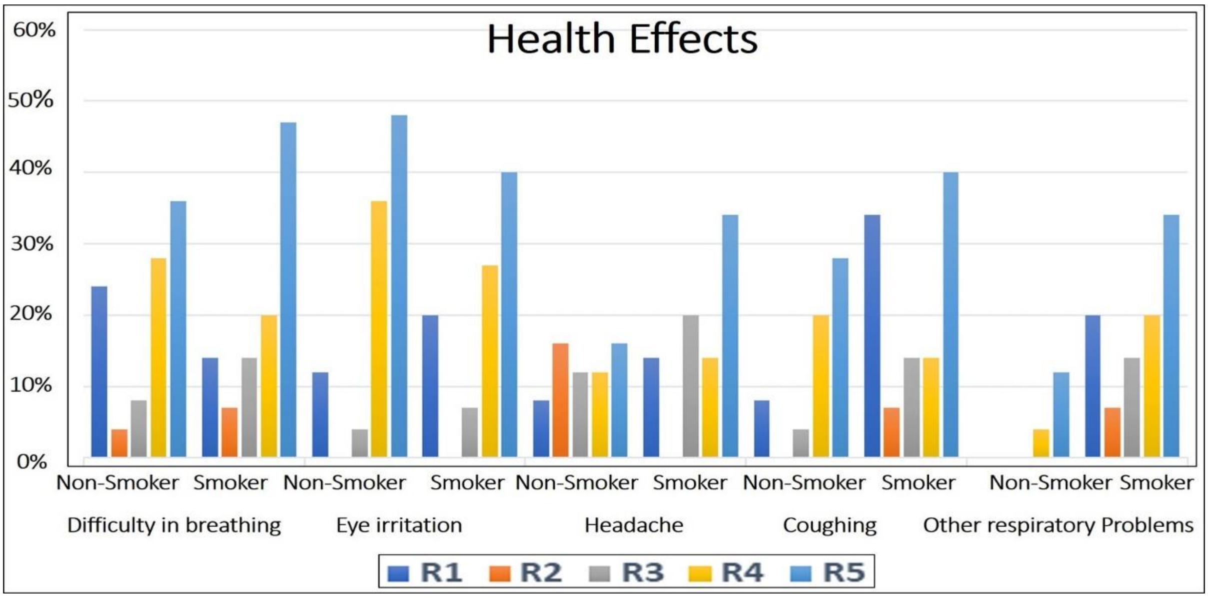

Figure 4: Health effects reported by the traffic police officers from their exposure to ambient air pollutants, categorized by smoking status.

Difficulty in breathing and eye irritation were the most frequently reported issues, with the highest prevalence at R5 for non-smokers (difficulty in breathing: 36%, eye irritation: 48%) as well as non-smokers (difficulty in breathing 47%, 40% eye irritation). Coughing was frequently reported by the traffic wardens who smoked (22%). Headaches were also more prevalent in smokers (0-34%) as compared to non-smokers (8-16%). Overall, concerning smoking status, traffic police personnel who smoked reported more health problems (average of 19%) than their non-smoking colleagues (average of 14%). Furthermore, most of the health problems were reported by the traffic police officers working at R5 (34%).

Discussion

In this study, a comprehensive assessment of ambient air quality parameters was carried out. Air pollutant concentrations viz. carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), nitrous oxide (N_2O), ozone (O_3), particulate matter (PM), and Total Suspended Particles (TSP) were determined to assess the implications for human health and the environment, particularly on traffic wardens. Carbon monoxide levels were relatively higher during the day, as observed by all locations. For instance, at R5, the level of CO during the daytime was 3650 µg/m³, while at night, it was 3410 µg/m³. This difference was mainly because most CO sources, such as vehicle emissions, industries, and home heating, were more in the day. Congestion during the daytime and the functional activities of industries contribute to the emission of CO. Sunlight is also instrumental in the deep mixing of the atmosphere, which further dilutes the pollutants and spreads them out. Carbon monoxide levels have also been higher during the day than in earlier studies conducted in urban areas [75].

In the case of nitrogen dioxide (NO_2), the values recorded were higher at night throughout all the sampling points, though within the permissible thresholds. For example, at R2, the concentration of NO_2 increased to 8.14 µg/m³ at night, while during the day it was 3.88 µg/m³. Primary sources of emission of NO_2 include vehicular and industrial emissions. Since at night, there is no sunlight, the NO_2 does not undergo photochemical reaction, resulting in elevated levels of the pollutant. This is consistent with previous research [76 - 78], which also observed a higher level of NO_2 at night than at any other time of the day due to low photochemical activity.

Additionally, the absence of dispersion during the day due to unstable atmospheric conditions and limited NO_2 diffusion at night due to low temperatures is not desirable for dispersion near the Earth's surface. In the daytime, oxidation of the nitrous oxides by organic chemicals in the presence of sunlight enables the formation of ground-level ozone. As depicted below, sulfur dioxide (SO_2) concentrations are higher during the day at all the sampling sites. For instance, at Ferozepur Road (Ichra), the SO_2 limit in the daytime is approximately 71.13 µg/m³ when it reduces to 57.23 µg/m³. The main anthropogenic emission sources of SO_2 are stack emissions from utility and industrial boilers, mobile sources, and residential heating. SO_2 reacts in the atmosphere during the day in various ways, including oxidation to form sulfuric acid, which can cause acid rain. These are photochemical reactions and are accelerated by sunlight. During the night, the rate of these processes is reduced due to the lack of sunlight available for photosynthesis. Furthermore, there are relatively fewer fluctuations in the weather, and there is less mixing of pollutants and, therefore, less presence of SO_2 at night compared to daytime.

On the other hand, TSP levels are generally higher during the day at all sampling sites. For example, at Ferozepur Road (Ichra), TSP concentrations are 521.881 µg/m³ during the day and 515.713 µg/m³ at night. TSP includes airborne particles from construction activities, road dust, industrial emissions, and vehicle exhaust. Natural sources include dust storms and sea spray. During the day, construction and traffic are at their peak, leading to higher emissions of suspended particles. Sunlight can also cause the resuspension of settled particles through thermal updrafts. At night, reduced human activities and lower wind speeds result in less resuspension of particles, leading to slightly lower concentrations of TSP. However, the difference between day and night levels might not be very pronounced due to the continuous emission of particles from various sources. PM_{10} and $PM_{2.5}$ levels were higher during the day at all sampling sites. For instance, PM_{10} levels at Ferozepur Road (Ichra) were 179.521 µg/m³ during the day and 175.119 µg/m³ at night. $PM_{2.5}$ levels at the same location were 43.821 µg/m³ during the day and 42.991 µg/m³ at night. PM_{10} primarily originates from mechanical processes such as construction, road dust, and agricultural activities, while PM_{25} originates from various sources such as, engine exhaust, combustion processes, industrial stack emissions, and domestic heating etc. During the day, increased human activities contribute to higher particulate matter emissions. Photochemical reactions in the atmosphere can also form secondary particles from gaseous components like SO_2, NO_x, and VOCs. At night, reduced traffic and industrial activities lead to lower emissions of PM_{10} and $PM_{2.5}$. However, temperature inversions can trap pollutants close to the ground, sometimes resulting in relatively high concentrations despite the reduced emissions. The accumulation of particles is less pronounced than gases like NO_2 due to the continuous settling and removal processes. In our study, we calculated the Chronic Daily Intake (CDI) using Permissible Exposure Limits (PELs) created by OSHA, as there are no established reference concentrations for each pollutant in Pakistan. This approach is supported by OSHA guidelines, which provide a basis for assessing occupational exposure to hazardous substances [61]. Our hazard index calculations, based on PELs, resulted in values exceeding 20, whereas a hazard index of more than 1 is generally considered harmful. However, some studies suggest a hazard index above 1 does not necessarily indicate a significant health risk [78]. The context and cumulative exposure to multiple pollutants must be considered when interpreting these values. Continuous exposure to vehicular exhaust puts traffic police personnel at an added risk of developing health problems. Furthermore, given the findings of this study, it is evident that these health effects are even more pronounced in the traffic wardens who smoked, potentially due to the exacerbation of pre-existing health conditions caused by smoking. This finding aligns with studies showing that smoking can worsen the effects of air pollution on respiratory health [79]. The observations made in this study highlight the significance of stricter vehicular maintenance policies in developing countries to control air pollution caused by automobiles. It also identifies the need for automated traffic control methods like those adopted by developed countries to minimize human exposure to traffic exhaust.

Conclusion

Our study reveals that while most pollutants were within permissible levels, particulate matter ($PM_{2.5}$, PM_{10}) and total suspended particles (TSP) exceeded permissible standards, especially at R5. Traffic police officers face significant health risks from long-term exposure, particularly to carbon monoxide, ozone, and TSP, with higher risks during daytime. The cumulative health impacts are concerning, highlighting the urgent need for targeted interventions to reduce exposure and safeguard the health of traffic police personnel. It also underscores the need for stricter regulations regarding vehicular health to minimize emissions, and frequent health assessment of traffic wardens to prevent long term health effects.

Study limitations

A limitation of our study is that a fewer air sampling sites and corresponding traffic wardens were included in this research. Including more locations and traffic wardens can provide a comprehensive representation of air quality and a detailed assessment of health impacts experienced by the traffic wardens in the region.

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Statements and Declarations

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contributions

All authors have contributed to the design and execution of this study. Fazeel Khalid Sandhu: Data visualization, formal analysis, writing original draft. Anum Tariq: Project administration, supervision. Noor Fatima: Conceptualization, writing, editing, and review. Muniba Akram: Investigation.

Ethics approval

A part of this research involved collection of data from human subjects through questionnaires. The study was carried out in accordance with the 1964 Declaration of Helsinki (clauses 24 and 25), and data confidentiality and privacy of each participant were maintained. Furthermore, an ethical approval was also obtained from the College of Earth and Environmental Sciences (University of the Punjab) Ethical Review Committee.

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