Online ISSN: 2588-3526

Journal of Wildlife and Biodiversity

Volume 9(1): 314-331 (2025) (http://www.wildlife-biodiversity.com/) **Research Article**

Comparative assessment of ambient air quality in large and small ruminant farms: Insights from Lahore and Pattoki

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Received: 29 October 2024 / Revised: 01 January 2025 / Accepted: 08 January 2025/ Published online: 12 January 2025.

How to cite: Mushtaq, K., Arooj, F., Iftikhar, A., Luqman, M., Ur-Rehman, S.A., Naseer, R., Safdar, S. (2025). Comparative assessment of ambient air quality in large and small ruminant farms: Insights from Lahore and Pattoki, Journal of Wildlife and Biodiversity, 9(1), 314-320 . DOI: https://doi.org/10.5281/zenodo.14635192

Abstract

Livestock farming systems deteriorate the air quality as 7.1 Giga tons of CO_2-equivalents are emitted by livestock globally per year, which amounts to 14.5 % of all human-caused GHGs emanations. This study was designed to investigate the ambient air quality of livestock farms (10 large ruminants, 7 small ruminants) at Pattoki and Peri-urban areas of Lahore. Particulate matter ($PM_{2.5}$, PM_{10}), methane (CH_4), carbon dioxide (CO_2), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), hydrogen sulfide (H_2S), ozone (O_3), and carbon monoxide (CO) were measured at each livestock farm thrice during six months of the study. The measurements were taken using HazScanner (HIM-6000) and Series 500 Portable Air Quality Monitor (AeroQual). Results revealed that, on average, $PM_{2.5}$ concentrations exceeded the standard values by 6 times at large ruminant farms and 5.5 times at small ruminant farms. In contrast, PM_{10} concentrations exceeded the standard values by 4 times at large ruminant farms and 3 times at small ruminant farms. Similarly, high concentrations of SO_2 were observed at both types of farms where mean concentrations far exceeded the standard values. Moreover, higher CH_4 concentrations were also recorded at both types of farms. Hence, particulate matter, methane, and sulfur dioxide were identified to be air pollutants of concern at livestock farms in comparison to other air pollutants (CO_2, O_3, CO, NO_2, H_2S) assessed in this study. A significant difference in air pollutant concentrations between the large and small ruminant farms was only found for H_2S. The poor air quality at the livestock farms also affects the animal health as indicated by the increased prevalence of diseases during the study period. Further research should encompass larger geographic regions to generate comprehensive data and establish causative relationships between pollutants and livestock health. Moreover, considering the escalating impacts of climate change, it is important to integrate its influence on air quality and its subsequent effects on animal welfare into future studies.

Keywords: Livestock, Ruminants, Enteric fermentation, Ambient air quality

Introduction

Air pollution has become a major challenge in recent years due to rapid urbanization, industrialization, land use changes, growth of road traffic, and agricultural practices (Irfan et al., 2015; Sabir et al., 2024; Zheng et al., 2019). Consequently, the increased emissions of gaseous air pollutants like CH_4, NO_2, SO_2, CO_2, H_2S, O_3, CO, etc along with particulate matter ($PM_{2.5,10}$) result in a threat to the quality of life, environment, and health of the general population (Colbeck et al., 2010; Habib et al., 2022). Moreover, some of these pollutant gases act as major greenhouse gases (GHG) responsible for higher global temperatures and climate change (Springmann et al., 2017). The direct and indirect effects of these pollutants include climatic changes such as sea level rise, disrupted precipitation patterns, increased flooding, extreme droughts, smog episodes, and heat waves, as well as epidemiological impacts on humans and animals (Bolan et al., 2024; Borlée et al., 2017). These outcomes affect not only human or animal health but also agricultural yields (Bernabucci, 2019; Lacetera, 2019; Zervas & Tsiplakou, 2012). As a result, food security is emerging as another challenge. The increased demand for fresh meat, milk, and eggs within urban communities and the lack of efficient infrastructure in rural areas have resulted in a large concentration of livestock production near cities leading to air pollution as approximately 18% of human-induced greenhouse gases come from livestock production systems (Gerber et al., 2013; Grossi et al., 2019; Hur et al., 2024).

Livestock production system pollutes the air by emitting dust, particulate matter (PM) along with a mixture of gases like carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), and hydrogen sulphide (H_2S) through various processes like exhalation, enteric fermentation, feeding practices and poor manure management (Springmann et al., 2017; Zervas & Tsiplakou, 2012). In Pakistan, GHG emissions from enteric fermentation and manure management for the year 2014-2015 were 78.8 and 11.4 Mt of CO_2-equivalent respectively (Ijaz & Goheer, 2021). However, the livestock sector not only badly affects the air quality but is also being affected by the poor air quality which is evident by the increased prevalence of various disease outbreaks (mastitis, lumpy skin disease, foot rot, etc.) during the recent years (Bernabucci, 2019). Moreover, the decline in milk yield, increase in the rate of abortion, decrease in fertility, and higher livestock mortality rates were also reported (Orru et al., 2017; Rojas-Downing et al., 2017).

Livestock has been known to be a significant contributor of methane, carbon dioxide, and particulate matter which leads to massive air pollution due to poor livestock management practices (Sohil & Kichloo, 2023). The livestock sector occupies a unique position in the socioeconomic development of Pakistan. It has a share of 61.9 % in agriculture and 14 % in GDP achieving a growth of 3.76 % (Jamil et al., 2023). In less developed countries like Pakistan, millions of rural population are engaged in livestock raising, which helps them to derive a part of their income from livestock (Rehman et al., 2017). However, livestock production systems contribute to greenhouse gas emissions including carbon dioxide (CO_2), methane (CH_4), and nitrogen dioxide (N_2O) as well as particulate emissions along with sulfur dioxide that contribute to climate change and major air pollution episodes like smog respectively (Borhan et al., 2012; Raza et al., 2021). The major cities of Pakistan, particularly, the Central Punjab region, have the worst air quality with severe smog episodes since 2016, becoming a serious public health concern (Khan et al., 2023).

Moreover, the air quality of livestock farms is not monitored in Pakistan and no baseline data is present about ambient air quality parameters from livestock farms. Therefore, this study is the first of its kind that compares the ambient air quality of large and small ruminant farms in terms of particulate matter ($PM_{2.5,10}$) and gaseous pollutants (CO_2, CO, CH_4, NO_2, SO_2, H_2S, and O_3). Moreover, the health impacts of poor air quality on livestock health were also assessed during the six months of the study.

Material and Methods

Study Site

The study was conducted in peri-urban areas of Lahore and Pattoki livestock farms (large and small ruminants). Lahore is the second largest city in Pakistan having a total land area of 404 square kilometers (156 sq mi) with more than 13 million population and it is the capital of the Punjab province (31°32′59″N 74°20′37″E). According to livestock census, Punjab is the largest province of Pakistan; having cattle and buffalo populations of 14.41 million and 17.74 million, respectively, while sheep and goats are 6.3 million and 19.8 million, respectively. Pattoki lies on the N-5 National Highway about 70 kilometers (43 mi) from Lahore.

The farms were first visited and then selected by the consent of the administration of these farms to investigate ambient air quality at selected locations. A total of 17 farms were selected including 7 small ruminants and 10 large ruminants (Fig 1). The air quality was monitored from 5 sampling points (entry, exit, manure, storage, and operation) at each farm thrice during six months. The selected farms were divided into two groups:

Group I: Large ruminant farms having a median herd size (26-30) of cows and buffalos

Group II: Small ruminant farms having a median herd size (18-26) of goats and sheep

Figure 1. Map showing the study sites in Punjab province of Pakistan

Data Collection

Data on basic information about the livestock farms, livestock production parameters, herd size, occurrence of diseases and mortality, ventilation, and hygiene practices were collected through a questionnaire from large ruminants (n=10) and small ruminants (n=7) farms.

A real-time portable air quality monitoring station Haz-Scanner HIM-6000 equipped with electromagnetic sensors (Environmental Devices Corporation, Plaistow, Hew Hampshire) was used to monitor the air quality parameters including particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and ozone (O_3). Methane (CH_4) and hydrogen sulphide (H_2S) were determined using Series 500 Portable Air Quality Monitor (AeroQual, Auckland, New Zealand). The detection ranges of the instruments for the studied pollutants are given in Table 1. The data was acquired at purposefully selected locations. A GPS device was used to record the coordinates of the sampling points. The Haz-Scanner was raised at a height of 1.5 metres above the ground and a warm-up time of 15 minutes was given before data recording. It was placed in the direction of the prevailing wind away from obstructions like near doors or walkways at each sampling point. The equipment was run for eight hours at each site from 8:00 am to 4:00 pm and the data observed were automatically transferred and saved in the database of the device.

Figure 2. Large ruminant farms at Pattoki (a) and Peri-urban areas of Lahore (b), Small ruminant farms at Pattoki (c) and Peri-urban areas of Lahore (d)

Table 1. Detection ranges of electromagnetic sensors for Ambient air quality assessment by Haz-scanner

Sr. No	Sensors	Measurement/Concentration ranges
1	Particulates (PM_{10} and $PM_{2.5}$)	0-5000 µg/m^3
2	Carbon dioxide (CO_2)	0-5000 ppm
3	Carbon monoxide (CO)	0-10 ppm
4	Sulphur dioxide (SO_2)	0-5000 ppb
5	Nitrogen dioxide (NO_2)	0-5000 ppb
6	Methane (CH_4)	0-5000 ppm
7	Ozone (O_3)	0-150 ppb
8	Hydrogen sulfide (H_2S)	0-5000 ppb

Statistical Analysis

Descriptive statistics were used to calculate the mean and standard deviation values of the studied parameters. The two-sample t-test was applied to check the difference in air quality parameters between large and small ruminant farms.

Results

The ambient air quality of 17 livestock farms in Lahore's peri-urban areas and Pattoki having median herd size (26) was monitored thrice during six months (June to November) in 2022. The average concentrations of particulate matter ($PM_{2.5,10}$) and gaseous pollutants (CH_4, CO_2, CO, O_3, SO_2, NO_2, H_2S) were measured and compared with Punjab Environmental Quality Standards (PEQS).

Particulate matter concentrations

The average concentration of $PM_{2.5}$ in large (group I) and small (group II) ruminants' farms is shown in Fig. 3. The mean concentration of $PM_{2.5}$ (8-hour average) in group I farms ranged between 19.80 to 479.74 µg/m^3. The $PM_{2.5}$ values at Lahore's large ruminant farms (Farms 1, 2, 3, and 4) greatly exceeded the PEQS while at Pattoki's farms, the concentration was below the PEQS limit in all farms except for one farm (Farm 10). In group-II farms, the $PM_{2.5}$ values ranged between 23.37 to 436.58 µg/m^3, out of which four farms greatly exceeded the recommended value of 35 µg/m^3 while three farms were below the limit (Fig. 3). While ammonia is inherently emitted from manure in animal farms, it can serve as a precursor to forming fine particulate matter when it interacts with air pollutants like sulfur dioxide and nitrogen oxides (Hristov, 2011; Lunghi et al., 2024). Generally, both large and small ruminant farms in Lahore's peri-urban areas exhibited higher values of $PM_{2.5}$ primarily due to inadequate infrastructure, movement of vehicles inside and outside the farm, poor manure, and farm management practices (Roman et al., 2021). Shang et al., (2020) also reported higher levels of $PM_{2.5}$ (60-200 µg/m^3) in a study conducted on pig farms in China. Statistically significant differences were not observed in the $PM_{2.5}$ concentration between large- and small-scale ruminant farms ($p>0.05$).

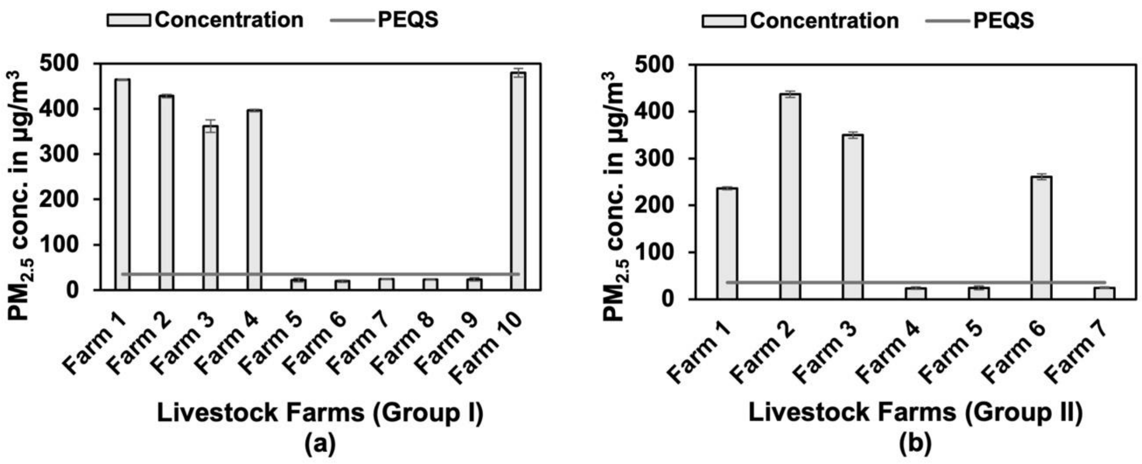

Figure 3. Concentration of $PM_{2.5}$ in large (a) and small (b) ruminant farms. Error bar = Standard deviation of triplicates

Fig. 4 shows the average concentration of particulate matter (PM_{10}) recorded at large and small ruminant farms. The PM_{10} concentration ranged from 38.84 to 1371.81 µg/m^3 at group I farms and 35.71 to 1257.29 µg/m^3 at group II farms. The PM_{10} values at Lahore peri-urban area's farms were in a constant state of exceedance from the PEQS of 150 µg/m^3. However, in most Pattoki farms, its concentration is within the standard limit. The PM_{10} concentrations measured at small ruminant (group II) farms followed a similar pattern to the group I farms and no statistically significant differences were found between large and small ruminant's farms ($p>0.05$). The high PM_{10} concentrations could be attributed to poor farm maintenance and feeding practices, improper waste management, and frequent transportation activities (Habib et al., 2022). Vehicular movements in or around animal farms can also lead to excessive particulate matter in addition to the inherent particulate emissions of farm operations (Roman et al., 2021). Such was the case in Lahore's peri-urban areas where frequent traffic movements were also observed in and around the farms along with poor farm maintenance. The higher PM concentrations in ambient air affect animal health causing respiratory and cardiovascular problems (Borlée et al., 2017; Mannucci et al., 2019).

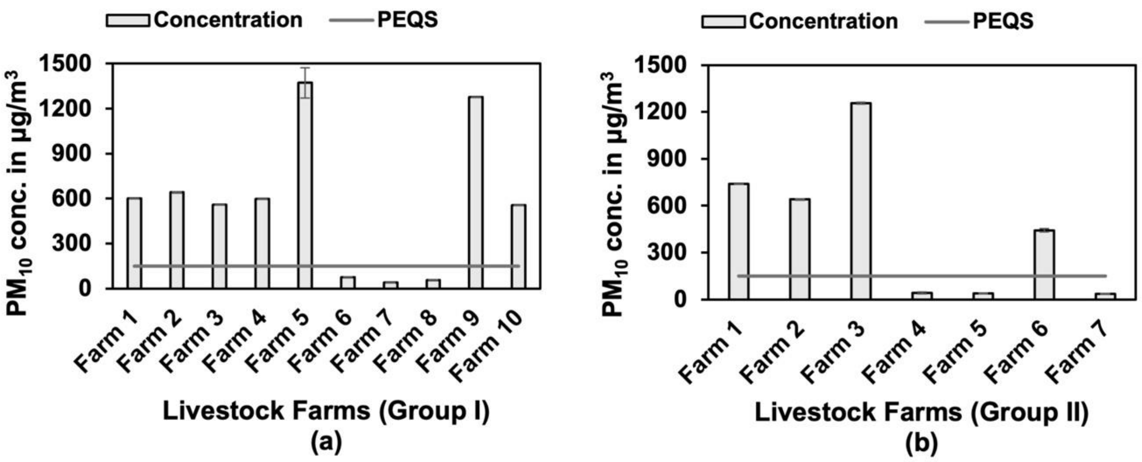

Figure 4. Concentration of PM_{10} in large (a) and small (b) ruminant farms. Error bar = Standard deviation of triplicates

Methane concentrations

Methane is the second largest potent greenhouse gas released from the livestock sector as a by-product of the enteric fermentation of ruminants (Knapp et al., 2014). In addition, the stockpiles of animal manure used as fertilizer and fuel also emit methane (Howard et al., 2019). As shown in Fig. 5, the ambient air CH_4 concentrations ranged from 14.36 to 58.11 ppm and 15.28 to 67.13 ppm at group I and II farms, respectively. However, the variation in CH_4 values was due to improper manure handling and management as its concentration was far high near-surface near animal manure. It was observed that farms with unmanaged manure piles and poor housekeeping practices showed higher CH_4 values of up to 58 ppm (farm 3). A similar trend was observed at group II farms. Likewise, statistical analysis showed no significant differences between large and small ruminant farms ($p>0.05$).

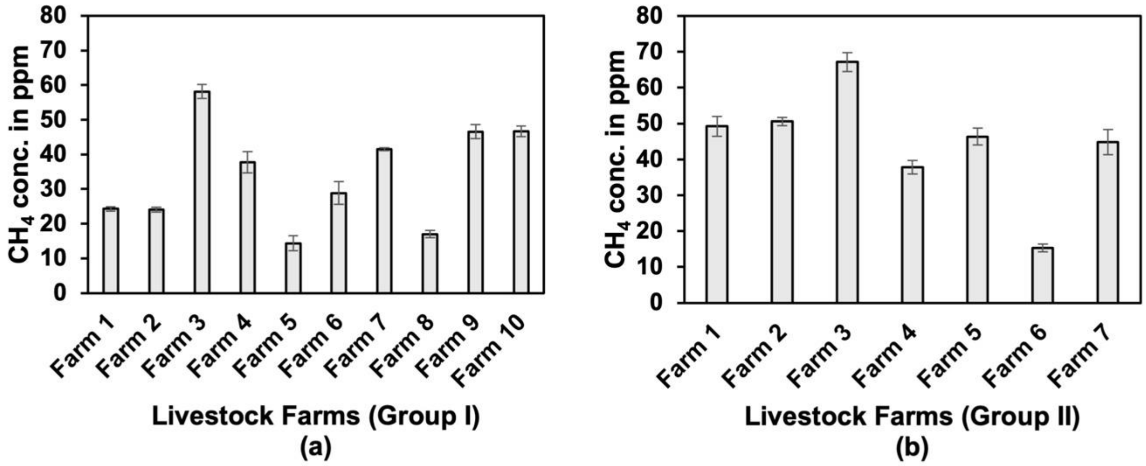

Figure 5. Concentration of CH_4 in large (a) and small (b) ruminant farms. Error bar = Standard deviation of triplicates

Concentrations of NO_2 and SO_2

Figs. 6 & 7 show the concentrations of nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) at large (a) and small ruminant farms (b) compared to the PEQS respectively. The concentrations of NO_2 measured at small ruminant farms were far below the Punjab Environmental Quality Standard of 80 µg/m^3. However, two large ruminant farms exceeded the standard value, and maximum concentrations of 121.32 and 145.90 µg/m^3 were recorded at farms 3 and 4, respectively. Much higher concentrations at both farms were due to the excessive vehicular movement inside and outside of these farms.

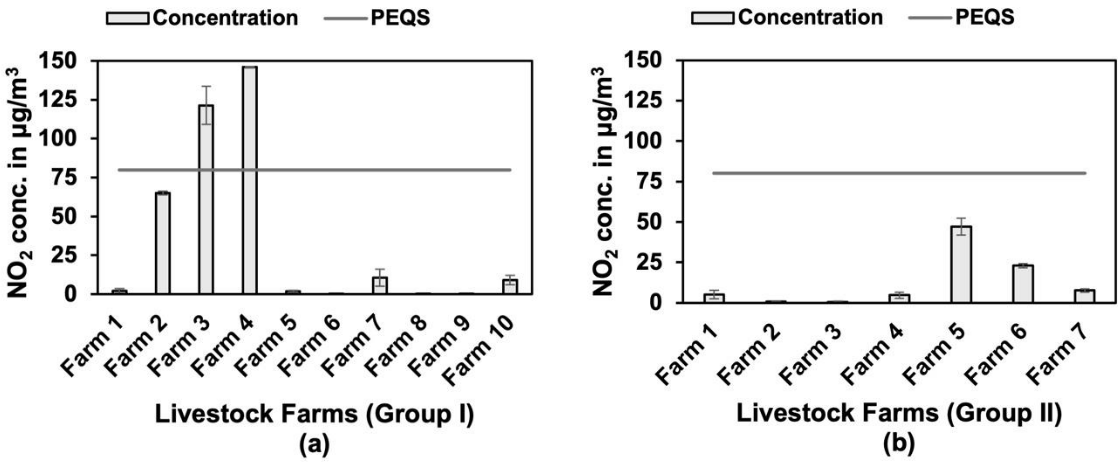

Figure 6. Concentration of NO_2 in large (a) and small (b) ruminant farms. Error bar = Standard deviation of triplicates

Like other pollutants, no significant difference in mean NO_2 and SO_2 concentrations was observed between the large and small ruminant farms (p>0.05). The concentration of SO_2 recorded at group II farms ranged from 222-4248 µg/m^3 while at group I farms, it ranged from 20-4327 µg/m^3. Most of these farms were located along the roadside, thus leading to higher SO_2 emissions. Moreover, farms having higher SO_2 concentrations had high animal density, poor ventilation, and waste removal systems. The average concentrations of SO_2 showed great fluctuations associated with the frequent vehicular movement and unmanaged manure as animal manure accounts for about half of the known sulfur emissions (Uyo et al., 2021).

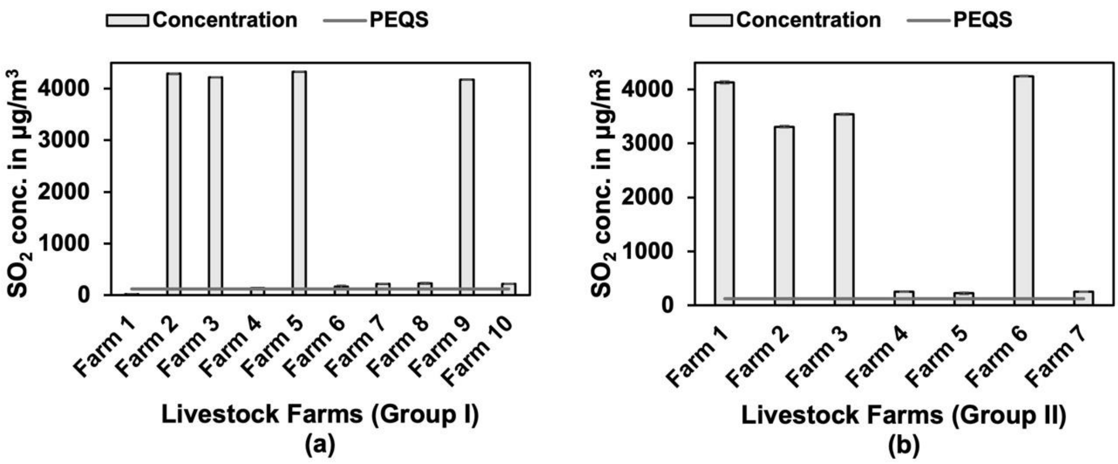

Figure 7. Concentration of SO_2 in large (a) and small (b) ruminant farms. Error bar = Standard deviation of triplicates

Carbon dioxide concentrations

Carbon dioxide (CO_2) is one of the leading gases released from fossil fuel burning and livestock production systems (Matenda et al., 2024). The increase in atmospheric carbon dioxide concentration results in higher temperatures and precipitation fluctuations having potentially adverse effects on livestock including changes in quality and quantity of feed crop and forage, water availability, animal growth and milk production, reproduction, and disease outbreaks (Bernabucci, 2019). The daily average CO_2 concentration at livestock farms is a function of the ventilation rate, the number of animals, and the quality of the waste removal system (Souza et al., 2024). Our results indicated that the CO_2 concentrations were relatively consistent and ranged from 304 - 437 ppm and 296 - 402 ppm at group I and II farms, respectively over the monitoring period (Fig. 8). The mean concentrations of CO_2 at both types of farms were not statistically different based on t-test ($p>0.05$). These results are in agreement with previous study of Ugbogu et al., (2019).

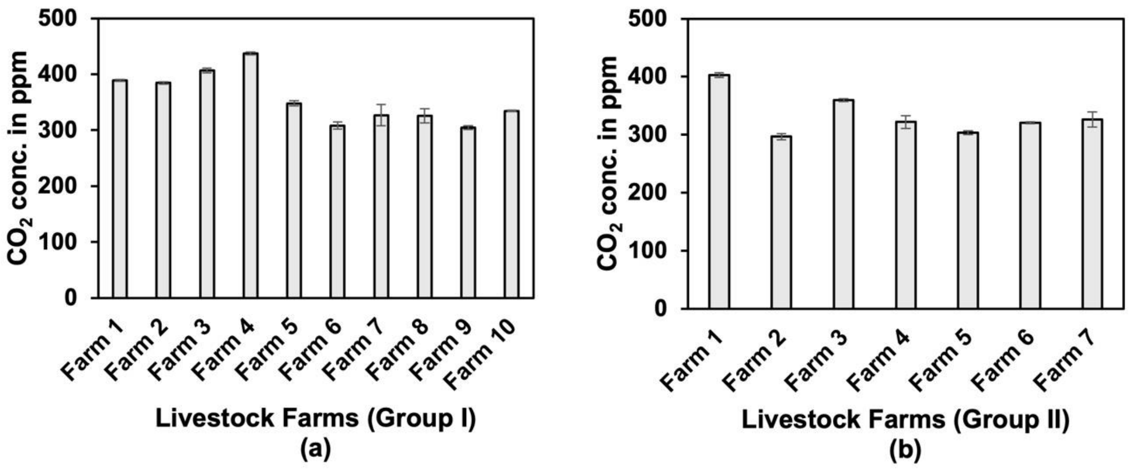

Figure 8. Concentration of CO_2 in large (a) and small (b) ruminant farms. Error bar = Standard deviation of triplicates

Other gaseous pollutants

The concentration of ozone was far below its recommended value (70 ppb) with concentrations ranging from 8.29-43.81 and 9.54-16.38 ppb in large and small ruminant farms respectively. The concentrations of carbon monoxide (CO) and hydrogen sulfide (H_2S) were negligible in the study area. However, H_2S is the only pollutant whose mean concentrations varied significantly between small and large ruminant farms (Table 2).

Table 2. Mean values and t-test analysis of air quality parameters at both large (Group I) and small (Group II) ruminant farms.

Parameters	Mean Value		t-statistic	p-value
	Group I	Group II		
$PM_{2.5}$ µg/m^3	224.37	193.66	0.31	0.76
PM_{10} µg/m^3	577.39	456.67	0.53	0.60
CH_4 ppm	33.92	44.45	1.43	0.17
CO_2 ppm	356.34	332.92	1.13	0.28
SO_2 µg/m^3	1798.69	2279.93	0.48	0.64
NO_2 µg/m^3	35.70	12.73	1.23	0.24
H_2S ppb	0.056	0.25	4.78	0.0003
O_3 ppb	14.6	12.87	0.54	0.60

CO ppb	2.98	7.3	0.85	0.41

*$p<0.05$ indicates significant differences between two groups

*$p>0.05$ indicates no significant differences between two variables

Impacts of climate change on livestock production system

Livestock farming system badly affects the ambient air quality by emitting higher concentrations of particulate matter, methane, carbon dioxide, and sulfur dioxide which directly or indirectly affect animal health (Borhan et al., 2012) by any change in their surrounding environment or climate particularly any rise in the temperatures. Direct effects are related to the increasing environmental temperature and heat stress which disturb the livestock thermoregulation, metabolism, immune system function, and reproduction (Bernabucci, 2019). The feed shortage, water scarcity, and increased prevalence of pest/pathogen populations are indirect effects of climate change as animal welfare and productivity are a function of the ambient environment, ad-libitum food and water supply, heat, and stress management (Lacetera, 2019).

The livestock farms survey's data (Table 3) showed that the energy consumption on the farms increased during the last three years due to a rise in temperature and humidity. This is because animals require extra energy to maintain thermoregulation at elevated temperatures above their thermal comfort zone (Bernabucci, 2019). This negatively affects the animals' health by causing metabolic alterations, oxidative stress, immune suppression, and death (Lacetera, 2019). Therefore, farmers need to use more energy to provide a comfort zone to the animals. The mortality rate also increased significantly during the last three years with the highest in 2022 (330 animals died) followed by 2021 (66) and 2020 (29). This high rise in mortality was caused by floods and lumpy skin disease (LSD) during the year 2022. The indirect impacts of climate change resulted in increased prevalence of vector-borne diseases, food-borne diseases, and feed and water scarcity (Borhan et al., 2012; Sejian et al., 2016). It was also observed that in 2022, livestock farms faced major disease outbreaks including lumpy skin disease (LSD) and bovine ephemeral fever (BEF) compared to previous years, i.e. 2021 and 2020. Both LSD and BEF are vector-borne diseases. The outbreak of both diseases is due to early summers that result in an increased population of vectors because high temperature provides a conducive environment for the growth of microbial populations.

Table 3. Survey results of Livestock farms of Pattoki and Lahore

Sr. No.	Variables	Responses	No. of Responses (%)
1	Knowledge about climate change	Yes	55 (90)
		No	6 (10)
2	Animal weight loss	Yes	46 (75)
		No	15 (24)
3	Extreme weather events	Drought	15 (24)
		Flood	19 (31)
		Heavy rain	27 (44)
4.	Disease outbreaks	2020	4(6)
		2021	7(11)
		2022	50 (81)
5.	Livestock loss due to flood	Yes	27(44)
		No	34 (56)
6.	Increase in energy consumption	Yes	53 (87)
		No	8 (13)
7	Change in milk production	Increase	11 (18)
		Decrease	42 (69)
		No Change	8 (13)
8	Fodder availability	Increase	10 (16)
		Decrease	38 (62)
		No Change	13 (21)

The fodder shortage (38 %) was also recorded in the year 2022 because heavy rainfalls and floods destroyed the crops and agricultural lands and in peak summer (July and August 2022) majority of the farms faced fodder shortage which might be due to the unexpected early summer followed by heavy rains and floods. Most of the farmers correlated it with adverse climate change. The increase in temperature and atmospheric carbon dioxide (CO_2) concentration and precipitation fluctuations have potentially adverse effects on livestock including changes in production and quality of feed crop and forage, water availability, animal growth and milk production, reproduction, and diseases (Bernabucci, 2019; Sejian et al., 2016).

Regarding the farmers' knowledge and perception of climate change; the majority of the farmers (90 %) stated that they were aware of the term climate change and 69 % thought that it had a negative effect on milk production. Most respondents believed that climate change has increased the occurrence and spread of vector-borne diseases. However, the majority of the farmers stated that fodder availability would decrease with ongoing climatic variations including sudden and unexpected changes in weather conditions.

Discussion

This study is the first that compares the ambient air quality parameters between large and small ruminants farms in peri-urban areas of Lahore and Pattoki. Lahore is amongst the most polluted cities in the world and facing severe smog episodes since 2016. Although, industrialization, urbanization, transportation, and land use changes are major contributors to air pollution, the translocation of intensive livestock farming systems near cities is also aggravating the current scenario of high air quality index (AQI) and smog. Hence, the average concentrations of particulate matter ($PM_{10,\ 2.5}$) and gaseous pollutants (CH_4, CO_2, CO, O_3, SO_2, NO_2, and H_2S) emitted from livestock farming systems were measured and compared with Punjab Environmental Quality standards (PEQS).

Higher concentrations of particulate matter (PM_{10}, and $PM_{2.5}$) were recorded in the majority of the studied farms due to poor housekeeping, feeding, and waste management practices (Habib et al., 2022). Moreover, vehicular movements in or around the farms significantly contribute to high levels of particulate matter (Roman et al., 2021). The PM levels of this study were higher than the findings of other studies (Jamil et al., 2023; Khan et al., 2023). Elevated levels of particulate matter in rural and agricultural areas compared to urban areas originate from farming systems (Spencer & Van Heyst, 2018). Hence, livestock farms are significant contributors of PM emissions (Pue & Buysse, 2020).

Carbon dioxide (CO_2) and methane (CH_4) are the byproducts of respiration and enteric fermentation of ruminants and are continuously increasing due to increase in livestock production systems throughout the world (Gerber et al., 2013). Ruminant's gut system is the main source of enteric methane emissions into the atmosphere, while animal manure, and its storage and treatment also significantly contribute to CH_4 emissions (Crosson et al., 2011). Although, there is no standard value of methane, its concentration in ambient air was high and even higher near animal manure in this study as warm and wet conditions can further increase these emissions. A 30-50 % reduction of CH_4 emissions can be achieved by lowering the storage temperature of manure piles (Borhan et al., 2012).

Feed processing, agricultural operations, and manure management practices contribute to nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon dioxide emissions (Grossi et al., 2019). The concentrations of NO_2 and SO_2 in majority of the studied farms were higher than the previous studies (Uyo et al., 2021) and excessive transport of vehicles was the major source observed during this study.

Ruminants significantly contribute to the emissions of particulate matter ($PM_{10,}$ and $PM_{2.5}$), carbon dioxide (CO_2), methane (CH_4), and sulfur dioxide (SO_2) but at the same time are the most vulnerable too towards environmental pollution as indicated by higher disease incidence, increased mortality either due to pollution or natural disaster/s, decreased fodder availability and lowered animal production leading to huge economic losses to the livestock farmers. Therefore, methods and policies for climate-smart and resilient livestock production systems should be developed and implemented.

Conclusion

The ambient air quality of large and small ruminant farms was compared in terms of particulate matter $PM_{2.5,10}$ and gaseous emissions like CH_4, CO_2, NO_2, SO_2, CO, O_3, and H_2S at Pattoki and peri-urban areas of Lahore. The concentrations of PM_{10}, $PM_{2.5,}$ and SO_2 were much higher than the PEQS values. Although there is no generally accepted threshold limit for CH_4 and $CO_{2,}$ higher concentrations of methane (38.26 ppm) and carbon dioxide (347 ppm) were recorded at both farm types which are the by-products of respiration and enteric fermentation of ruminants. The concentrations of ozone, hydrogen sulfide, and carbon monoxide were lower than the Punjab Ambient Air Quality Standards (PEQS). However, the t-test showed that there were no significant differences in ambient air pollutants between small and large ruminant farms except H_2S whose mean concentrations varied significantly between small and large ruminant farms. Moreover, poor air quality is also affecting the animal's health as indicated by the recent disease outbreaks like lumpy skin diseases and bovine ephemeral fever during the study period. However, these emissions can be reduced by improving farm management (feed and manure) practices. Further research should be extended at a broader level including large geographic areas throughout the country and some interventions regarding manure management, feed changes should be introduced to reduce these emissions.

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