RESEARCH ARTICLE

Temporal and seasonal variations of noise pollution in urban zones: a case study in Pakistan

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Abstract

Noise pollution is widely recognized as an important problem and can negatively affect quality of life. This study aimed to examine the temporal and seasonal variations of noise pollution in urban zones of Peshawar, Pakistan. This city is increasingly becoming congested and traffic-related problems are common. Noise levels were assessed in four different seasons at 20 points around the city, including three different zones: commercial, residential, and silent. All the noise indices including equivalent noise level, day and night time noise level, noise climate, and noise pollution level were calculated for all zones. In winter, the Leq values ranged between 52.5 and 73.3 dBA; while in spring, summer, and autumn, it ranged between 56.2 and 88.3 dBA; 46.9 and 88.6 dBA; and 49.2 and 76.6 dBA, respectively. The level of the noise was observed highest in commercial followed by residential and the silent zones. The levels of the noise were beyond the permissible limits in some zones mentioned in the Pakistan National Environmental Quality Standards (Pak-NEQS' 2010). The seasonal variation in Leq revealed that the noise level in 70% of areas increased from winter to spring, 45% from spring to summer, 35% summer to autumn, 30% autumn to winter, 70% winter to summer, and 40% spring to autumn. Temperature, humidity, and wind speed were the main seasonal factors causing the seasonal variations and traffic was the main source of noise pollution identified in the area.

Keywords Noise pollution · Temporal trends · Seasonal variations · Temperature · Humidity

Introduction

With rapid urbanization and industrialization, the developing countries are facing the problems associated with increasingly

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Research highlights
- Noise indices including Leq, NC, and LNP were calculated for urban zones.
- The Leq values observed in the sequence of summer > spring > winter > autumn.
- Noise level was highest in commercial zone followed by residential and silent zones.
- Humidity, temperature, and wind are the seasonal factors affecting the noise levels.
- Majority of the areas showed noise levels crossed Pak-NEQS (2010).

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crucial matters of multiple sources of pollutants in the environment (Tao et al. 2020). There are many different types of pollutions including air, water, soil, and noise (Brundle 2018). Noise is an eminent issue in urban areas (Fecht et al. 2016) and of complex nature. It is measured as the most persistent lethal pollution (Salhab and Amro 2012). In the scientific community, the focus on noise pollution research is due to its potential for human health damages (Murphy et al. 2009). It affects the exposed population across the sphere and become more severe with the passage of time (Halonen et al. 2017). It works as an environmental stressor whether it is formed by machines or humans (Sharma and Atri 2010). It is uninterruptedly mounting in scale and severity and this is likely to continue in future. Regarding human health, noise pollution effects measured by WHO (World Health Organization) to be the third utmost lethal sort of pollution (Berglund et al. 1999).

The scientific literature shows that the noise pollution has adverse effects on metabolic, nervous, respiratory, and cardiovascular systems (Gozalo et al. 2020). Beside non-auditory indications, damages to auditory system (Tripathy 2008) such as tinnitus or ringing in the ears are also adverse effects of noise on health (Nazneen et al. 2020). People living in noisy

areas suffer from considerable adverse effects on their physiological and psychological health effects due to traffic. Annoyance and disturbance of sleep are the most negative psychosocial traffic effects of noise. Negative emotions such as anger, anxiety, depression, and disappointment are also due to the result of annoyance (Kim et al. 2011). Loud noises can increase blood pressure and heart rate and exacerbate sleep disorders (Pepper et al. 2006). Psychological health issues as a result of noise exposure are more common than physiological issues (Rana 2009). To the same type of noise, different people react differently (Nazneen et al. 2017). The noise levels of 55-65 dB and 50 dB can persuade severe and moderate irritation, while the probable hearing impairment is due to highest noise level of 110 dB (Kim et al. 2011). A normal ear can perceive sounds with frequency of 20 to 20,000 Hz. Decibel (dB) is the unit of noise level and is the ratio of two sound pressures. It is 10 times the logarithmic fraction of two concentrations. It can be expressed as given below:

$$dB = 1/10 \ dB = \ 10_{log}10 \ Q/Q_0$$

where Q is the quantity measured, and Q_o is the reference quantity, whereas A-weighted decibels (dB(A)) is the comparative loudness of sound in air as perceived by the human ear (Tripathy 2008).

Different types of noise sources include urbanization, changes in life style, human activities, road traffic, jet planes, railways, generators, industries, and other machines but the transportation noise is the chief source of the escalation in pollution of noise in urban zones (Kim et al. 2011), which has become a major problem in recent years (Bouzir and Zemmouri 2017). In urban environment, the noise pollution is due to the traffic and transportation activities. According to the European Environment Agency, the largest source of noise pollution is the road traffic (EEA. 2017). According to Wu et al. (2019), traffic noise is the major cause of pollution in the environment and its effects are increasing day by day.

The main factors that need to be considered when measuring noise pollution are the sound intensity, period, interval, and place at which it is received (USITC 2005). The noise level heard by the receiver from the source is influenced by a range of different factors. Humidity, temperature, and wind speed have an infinite effect on the level of noise because of the velocity of sound increases as temperature increases. By relative humidity, the reduction of the sound is also affected. The ratio of the humidity is mainly high when the temperature is high. High wind speed also disturbs the circulation of the sound over long spaces (Riki and Morris 1995). Noise levels rise and fall depending on the activity taking place in the area or as a result of seasonal variation. Higher frequency noise is more easily attenuated over distance than lower frequencies (Riki and Morris 1995).

The noise pollution assessment level in different sites of Dehradun city, Uttarakhand, revealed that the maximum reading of noise pollution was recorded in afternoon during summer season. The reason is the arrival of the most of the tourists during this season and the wide range of automobiles (Pallavi 2019). There is a high degree of contradiction between months at all locations selected by Dublin City Council. At most of the sites when the level of noise between weeks was compared, some sites were significantly dissimilar but some sites would seem to show similarities within winter and summer season imitating seasonal deviations in the pattern of human activity (Geraghty and Mahony 2016). According to Bjork (1994) that the noise level is highest and transportation is the main source of community noise in spring and autumn season in Kuopio, Finland. Shakya et al. (2019) reported that the useful approach for measuring intra-urban distinction of noise pollution is mobile monitoring and study the spatial temporal variability in urban neighborhoods of Philadelphia. At three different times, morning and afternoon rush hours, and midafternoon, a total of 62 sets of measurements were made. There was a temporal inconsistency of contaminants liable on the neighborhood. Noise of the environment showed the maximum temporal variations of the monitored component.

Numerous studies have focused on noise pollution and its health effects (Nazneen et al. 2020), but very few have conducted study on the temporal trends and seasonal variations of noise pollution. Therefore, this study was designed to study the temporal and seasonal trends in developing country like Pakistan. This is a novel and unique study of its kind as the research was conducted in in the urban zones of Peshawar, Pakistan, and this will be helpful to fill the gaps in the existing literature.

Material and methods

Area of study and measurement of noise

Peshawar is the largest city in Khyber Pakhtunkhwa Province, Pakistan, and is positioned at 33° 44′–34° 15′ N, 71° 22′–71° 42′ E (Fig. 1). The total population of Peshawar is 1.97 million and 1257 km^2 is the total area (GOP 2017). The three categories of areas (commercial, residential, and silent zones) were selected as mentioned in Pak-NEQS' 2010 (Table S1).

The district Peshawar has four seasons prevail in a year. Summer season in Peshawar is from May to September, autumn from October to the mid of November whereas winter is from mid-November to the mid of February and spring season is from the mid of February to April. The mean maximum temperature in summer and winter exceeds 40°C and 18°C, respectively, while the mean minimum temperature is 25°C and 4°C, respectively. The area receives more rain during winter than in summer, ranging from about 20 to 76 mm
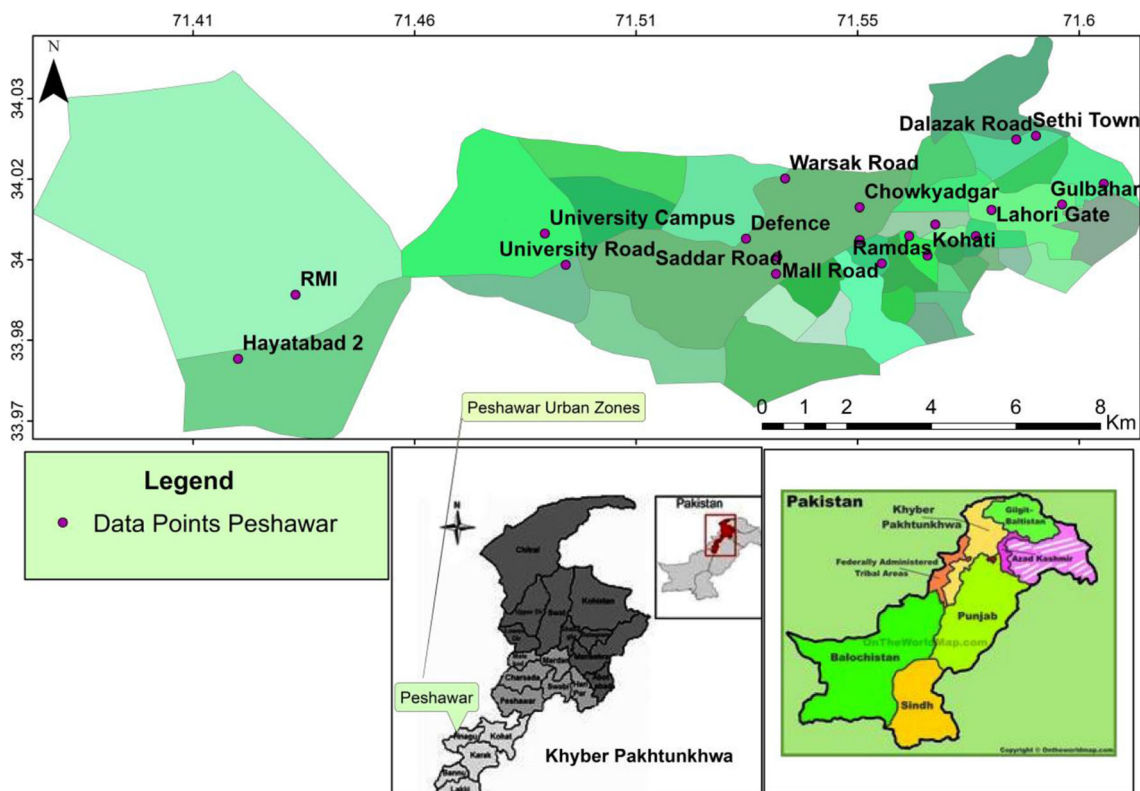
Fig. 1 Location map showing the study area and sampling sites. Different shades show different union councils of the study area

(DDMU 2017). The winter rainfall occurs under the influence of western disturbances, whereas considerable amounts of rainfall occur in summer because of monsoon.

In Peshawar, the main sources of noise pollution are traffic and the transportation sector. This includes noise from motorcycles, buses, and rickshaws. Loudspeakers and generators also contribute to noise pollution. Rapid population growth, changes in lifestyles, and increased human activities and industries are also contributing factors towards high noise aggravated by violation of laws and mismanagement (Hyder et al. 2006; Nazneen et al. 2017).

Methodology

The study area was divided into commercial, residential, and silent zones as previously done by Urban Policy and Planning Unit-Khyber Pakhtunkhwa. Noise measurement was carried out with type II Extech datalogging sound level meter (SDL600), USA. The instrument was positioned at 1.5 m above the ground (WHO 2000). Shielding foam was used to diminish the effect of airflow and to avoid turbulence or noise generated by the wind.

A total of 20 points from the commercial ($n = 10$), residential ($n = 6$), and silent ($n = 4$) zones were designated and noise measurements were carried out during clear sunny days for 24 h because rain and wind disturb the noise meter readings.

Noise was measured for 24 h. For day time from 06:00 am to 10:00 pm and for night time from 10:00 pm to 06:00am. To analyze the seasonal variations, noise was measured four times at each location (once in each of spring, autumn, summer, and winter). Day time limits for commercial and residential zones are 65 and 55 dBA, while night-time permissible limits are 55 and 45 dBA respectively. The perimeter set for the silent zone is 55 dB(A) at and 40 dB(A) at day and night time respectively (Pak-NEQS 2010).

Noise indices were calculated for every measured position, e.g., Leq, Ld, Ln, L10, L50, L90, LNP, and NC (Tripathi et al. 2006). Leq is the equivalent constant linear weighted sound pressure level (20 µPa) and indicates noise pollution with variations in level of noise. Leq is calculated with following equation adopted by Jamir et al. (2014):

$$\text{Leq} = 10\log_{10}\left(\frac{1}{T_M}\int_{Q}^{T_M}\left(\frac{P(t)}{P_0}\right)^2 dt\right)$$

where T_M represents the time interval (s), $P(t)$ the instantaneous pressure of sound, while P_0 of 20 µPa is the reference pressure of sound. Day time noise level (Ld) is defined as a sign for noise disruption during the day, while night time noise level (Ln) is an indicator for disturbance of noise at night (Hadzi-Nikolova et al. 2012). L10 is the sound level exceeding for 10% of complete time of measurement, and L50 is the sound level above for 50% of total time of measurement. For

90% of total measuring time, the sound level exceeded is L90. Noise pollution level (LNP) represents short-term variation of Leq (Phukan and Kalita 2013). It incorporates both Leq and NC and considers as the best sign of the noise pollution (Pathak et al. 2008). The values of LNP are calculated as follows: LNP = Leq + (L10–L90). Noise climate (NC) shows the range over which the noise levels fluctuate in a given period of time in dBA (Phukan and Kalita 2013), while NC is calculated as follows: NC = L10 − L90.

Statistical analysis

Statistical analyses were performed using SPSS v.23.0 to calculate the mean and standard deviation. Sigma Plot v.10 was used to prepare the graphs and map was generated using ArcGIS v.10.4.

Results and discussion

Table 1 summarizes the different levels of noise pollution indices (Ld, Ln, Leq, L10, L50, L90, NC, and LNP). Noise descriptor (Leq) alone is not enough to understand the characteristics of noise; therefore, for measurement of environmental noise, other statistical noise levels were used. The highest Ld value was recorded for summer (90.3 dBA, commercial) followed by spring (87.2 dBA, residential), winter (72.8 dBA, residential), and autumn (70.7 dBA, silent). The highest Ln values were recorded for spring (93.0 dBA, residential) followed by summer (74.3 dBA, commercial), autumn (63.0 dBA, commercial), and winter (63.0 dBA, silent). The highest Leq values were recorded for summer (88.6 dBA, commercial) followed by spring (88.0 dBA, residential), winter (73.3 dBA, commercial), and autumn (70.5 dBA, commercial) (Fig. 2).

The highest L10 value was recorded for the winter season (73.7 dBA, commercial), followed by spring (73.5 dBA, commercial), autumn (73.4 dBA, commercial), and summer (72.3 dBA, commercial). The highest L50 value was recorded for winter season (64.6 dBA, commercial), followed by autumn (63.2 dBA, commercial), summer (63.1 dBA, commercial),

and spring (62.3 dBA, commercial). The highest L90 value was recorded for winter season (72.3 dBA, residential), followed by summer (63.1 dBA commercial), spring (52.7 dBA, residential), and autumn (52.5 dBA, residential). The highest LNP value was recorded for winter (125.7, commercial) (Fig. 3) and the highest NC value was recorded for winter season (54.0 dBA, commercial) (Table 1). Mostly the noise level was observed at commercial areas followed by residential and silent areas and fluctuation was observed in all values. Most of the values were above the permissible limits mentioned in Pak-NEQS 2010. The highest L10, L50, L90, NC, and LNP mostly showed higher values in winter because duration of the day is short and night time is long in winter as compared to summer. So, more people came out in the day time to finish their routine work to avoid the cold weather after sunset.

Olayinka (2012) studied noise measurements for roads, commercial zones, and residential areas in Nigeria and found that the level of noise in 47% of commercial centers, 28% high-density residential areas, and 1% of low-density residential areas had noise levels higher than had noise levels higher than 75 dB(A), 70 dB(A), and 55 dB(A) respectively. The LNP calculated was in the range of 90–105 dB(A). The highest Ln recorded was 74 dB(A), Ld was 68 dB(A), and LNP was 90–100 dB(A). Pathak et al. (2008) studied that in the silent zone of Varanasi, India, maximum Leq was 75.3, LNP was 99.6, and NC was 24.3 dB(A), while the minimum values of Leq were 37.0, LNP was 5.3, and NC was 46.8 dB(A), respectively. Hunashal and Patil (2012) revealed distressing level of noise pollution in Kolhapur, India, and for a combined industrial and residential zone intended the highest Leq of 72.2 dB(A) followed by 64.47 dB(A) in a mutual commercial and residential region, while in educational and silent zones, the measured values were 63.7 dB(A) and 42.8 dB(A), respectively. Salhab and Amro (2012) measured the noise pollution of traffic where there was constant vehicular flow, density of high population, residential, and commercial structures in Hebron, Palestine.

In the current study, the Leq percentage results (Table 2) indicate clear seasonal variation in the study area. From winter

Table 1 Noise indices measured in different seasons in the study area

Seasons	Parameters (dBA)															
	Ld		Ln		Leq		L10		L50		L90		LNP		NC	
	Max[a]	Min[b]	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Winter	75.1	53.6	63.6	30.7	73.3	52.5	73.7	26.5	64.6	32.4	72.3	13.6	125.4	83.0	54.0	19.9
Spring	87.2	57.6	93.0	37.4	88.3	56.2	73.5	50.4	62.3	37.6	52.7	36.3	112.9	63.3	33.7	6.7
Summer	90.3	48.6	74.3	34.3	88.6	46.9	72.3	41.0	63.1	34.5	63.1	29.6	111.5	53.5	34.0	6.0
Autumn	78.3	43.7	62.6	31.0	76.6	49.2	73.4	47.9	63.2	38.2	52.5	25.8	110.4	51.0	33.7	7.7

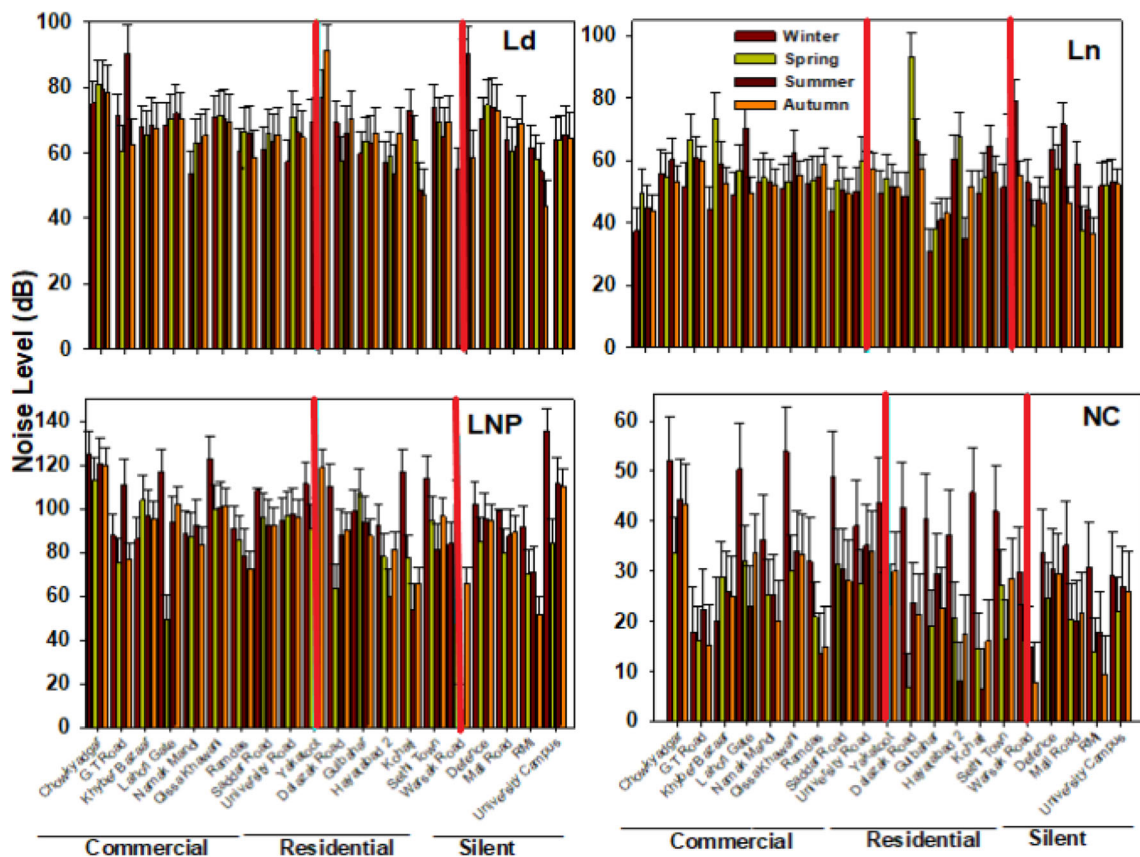"[a]" indicates maximum, while "[b]" represents minimum

Fig. 2 The levels of Ld, Ln, LNP, and NC calculated for commercial, residential, and silent zones of the study area. The error bars show standard deviations

to spring, there was a 90% increase in noise level in commercial areas, 50% increase in residential areas, and 50% increase in the silent areas. From spring to summer, there was a 50% increase in noise level in commercial areas, 83% decrease in residential areas, and a 50% decrease in the silent areas. From summer to autumn, there was an 80% decrease in noise level in commercial areas, 83% increase in residential areas, and 100% decrease in the silent areas. From autumn to winter, the noise level increased by 20% in commercial areas, 90% in residential areas, and 30% in the silent areas. Between winter and summer, there was a 90% increase in noise level in commercial areas, 67% decrease in residential areas, and 75% increase in the silent zones. Noise level variation also occurred between spring and autumn season with a 70% decrease in commercial areas, 67% decrease in residential areas, and 50% decrease in the silent areas.

The percentage results of Ld in winter showed that 80% of residential, 60% of commercial, and 100% of silent zones showed noise levels beyond the permissible limits mentioned in the Pak-NEQS' 2010. The results of Ln showed that 80%, 0%, and 100% of residential, commercial, and silent zones have noise levels beyond the limits, respectively. In contrast, in spring, 100% of residential, 80% of commercial, and 100% of silent zones showed noise levels exceeding the permissible limits of Ld, while at the value of Ln showed 100%, 20%, and 75%

increases in noise level in residential, commercial, and silent zones, respectively. In summer, for Ld values, 60% of residential, 50% of commercial, and 75% of silent zones were beyond the permissible limits mentioned in Pak-NEQS 2010. Similarly, the Ln values showed 60%, 60%, and 75% increases in residential, commercial, and silent zones, respectively. In autumn, the value of Ld showed 80% of residential, 50% of commercial, and 75% of silent zones increased in noise level beyond the standards (Pak-NEQS 2010). For Ln, 80%, 20%, and 50% of residential, commercial, and silent zones, respectively, showed increases in noise level beyond the standards.

Temperature and humidity have a great influence on the noise level of all the selected points because the velocity of sound increases as temperature increases. As a result, we found higher noise levels in summer than in spring, autumn, and winter. On a sunny afternoon, near the ground, the air is warmest and at higher attitudes, the temperature decreases. This ascent of temperature causes waves of sound to refract upward, away from the ground; as a result, lower noise levels being perceived at the listener's position. In the evening, this gradient of temperature will reverse result in cooler temperature near the ground. Relative humidity and wind speed are the other seasonal factors. The attenuation of sound in air is affected by relative humidity. Humidity ratio is generally
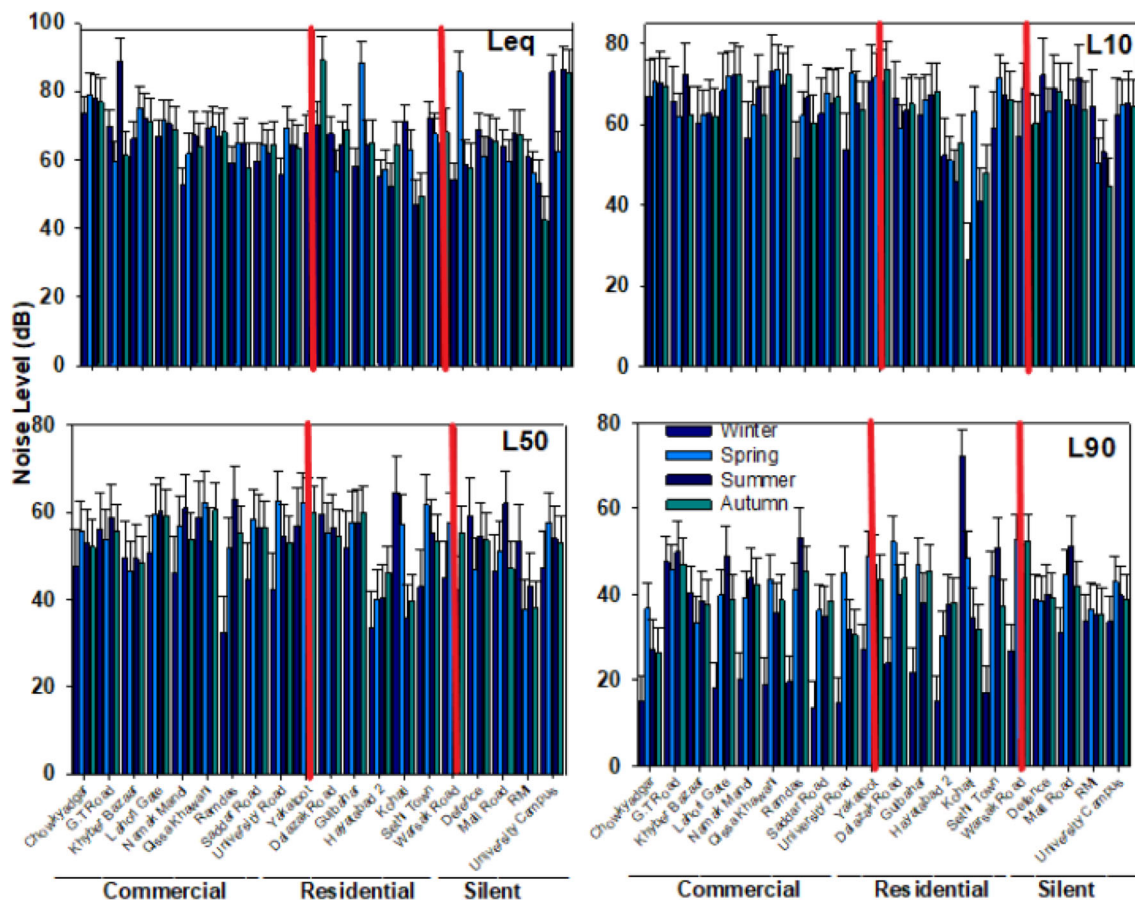
Fig. 3 Noise levels of Leq, L10, L50, and L90 calculated for commercial, residential, and silent zones of the study area. The error bars show standard deviations

higher in summer season or it is more appropriate to say that when the temperature is high. Dry air absorbs far more acoustic energy than moist air (Riki and Morris 1995). At the listener's position, a relative humidity decreases and the noise level also decreases, whereas a decrease of temperature increases the level of noise at the receiver. However, the observed noise level was substantially higher during day time than at night time. At higher altitude, the faster wind and at lower elevation, the slower wind causes waves of sound to twist downhill when they are drifting towards a location

upwind of the source. This occurrence can ominously disturb sound circulation over long spaces when speeds of wind speed are high (Riki and Morris 1995) in all the study area. By measuring the effects of different weather conditions such as air temperature, humidity, and surface temperature, a positive correlation has been observed between temperature and noise. However, a strong correlation has only been observed in spring. A negative weak correlation has been observed between humidity and noise. No significant correlation was found between surface temperature and noise (Table 3).

Table 2 Seasonal variation of noise levels (Leq 24 in %) in different zones of the study area

Seasonal comparison	Commercial zone		Residential zone		Silent zone	
	Increase (%)	Decrease (%)	Increase (%)	Decrease (%)	Increase (%)	Decrease (%)
Winter/spring	90	10	50	50	50	50
Spring/summer	50	50	17	83	50	50
Summer/autumn	20	80	83	161	0	100
Autumn/winter	20	80	90	10	30	70
Winter/summer	90	10	33	67	75	25
Spring/autumn	30	70	33	67	50	50

Table 3 Correlation of different weather conditions and noise levels in different seasons

Season		Temperature	Humidity	Surface temperature
Spring Leq	Pearson correlation	.544*	−0.277	0.386
	Sig. (2-tailed)	0.013	0.237	0.093
Spring Ld	Pearson correlation	.501*	−0.228	0.344
	Sig. (2-tailed)	0.024	0.333	0.138
Spring Ln	Pearson correlation	.546*	−0.199	.447*
	Sig. (2-tailed)	0.013	0.399	0.048
Winter Leq	Pearson correlation	0.036	−0.061	0.067
	Sig. (2-tailed)	0.881	0.799	0.778
Winter Ld	Pearson correlation	0.058	−0.076	0.049
	Sig. (2-tailed)	0.809	0.75	0.836
Winter Ln	Pearson correlation	0.234	.446*	0.174
	Sig. (2-tailed)	0.32	0.049	0.463
Autumn Leq	Pearson correlation	0.186	0.216	0.123
	Sig. (2-tailed)	0.431	0.361	0.606
Autumn Ld	Pearson correlation	0.202	0.193	0.145
	Sig. (2-tailed)	0.393	0.415	0.541
Autumn Ln	Pearson correlation	0.052	0.215	0.149
	Sig. (2-tailed)	0.828	0.362	0.531
Summer Leq	Pearson correlation	0.013	0.177	0.025
	Sig. (2-tailed)	0.957	0.456	0.917
Summer Ld	Pearson correlation	0.062	0.201	0.095
	Sig. (2-tailed)	0.797	0.395	0.692
Summer Ln	Pearson correlation	0.114	0.271	0.193
	Sig. (2-tailed)	0.631	0.248	0.414

*Correlation is significant at the 0.05 level (2-tailed)

According to Chowdhury et al. (2016), correlation analysis between the average exceedance factor for temperature, wind, and humidity revealed that the temperature had a moderately negative and significant correlation in the post-monsoon season and for humidity and wind, the correlation was insignificant for post-monsoon season. Wang et al. (2016) investigated the temporal and spatial distinctions in traffic noise of roads for diverse rate constituents in metropolitan Taichung, Taiwan. This study revealed 24-h level of noise and association with entire traffic and the uppermost prediction in the multiple regression models examines their frequency modules to inspect relations between seasons, land use types, traffic, and meteorology. The average annual Leq24 was 66.4 dB(A). Noise levels had the highest correlation with total traffic and the highest prediction in the multiple regression models.

In the present study, the key source of noise is road traffic. Noise of the road traffic has been recorded recently high in developed as well as developing nations (Kim et al. 2011). Traffic noise might be one of an omnipresent environmental issue. Wu et al. (2019) showed that vehicular noise is the foremost cause of environmental contamination and its influences are increasing day by day and Pakistan is not exception to it, as urbanization is increasing day by day and a large number of people moving towards the cities for getting jobs and better facilities. Due to overpopulation, the commercial activities also increase and more people are sharing the same amount of space in the city. So the number of transportation also becomes dense. Traffic jams are a symptom of insufficient supply of transportation services and human activity pattern become change which is another cause of noise pollution, also known as community noise pollution (Moudon 2009). Sometimes many drivers wrongly park their cars which causes traffic jam (Arsalan and Mehdi 2005). The outdoor noises as produced by actions of mankind are high when residences are taken into deliberation. So, jamming of traffic and crowd are the chief issues in the high level of noise. Another vital factor responsible for the outdoor ambient noise pollution rises is the adjacent constructed corridors, constructional activities, and noise from industries (Rahmani et al. 2011) and has resulted in the dense environment creation (Moudon 2009). By creating awareness among local communities, by proper maintenance of road conditions and by banning the use of vehicle horns in silent as well as residential zones, and by proper following the rules and laws, noise pollution in the present study can be reduce.

Conclusion

Peshawar is a densely populated area. Noise pollution is increasing continually as a result of heavy traffic, urbanization, and commercialization, and now represents one of the main environmental issues in the city, with potential human health risks.

Seasonal variations (winter, spring, summer, and autumn) were observed, allowing us to identify the season with the highest noise levels. Noise levels were highest in summer followed by spring, autumn, and winter. The variation in seasons is mainly the result of temperature and humidity changes. Noise levels were high in Peshawar and exceeded permissible limits (Pak-NEQS 2010) in some study areas. The noise levels were highest in commercial areas followed by residential and silent zones. The highest average Leq was showed in summer than in spring, winter, and autumn. The highest Ld was showed in summer than in spring, winter, and autumn. The highest Ln was showed in spring than in summer, autumn, and winter. Noise pollution has considerable negative impacts and improper planning is evident in the study areas, leading to increases in noise pollution. The government of Pakistan should focus on measures to protect the human population and the environment from the negative effects of noise pollution in Peshawar. Government should also pay attention to the roads on the inner side of the city, which are in the worst condition (commercial and residential). Noise legislation and guidelines should be prepared by the Environmental Protection Agency (EPA) Peshawar and other relevant institutions.

Declarations

Ethical approval Not applicable

Consent to participate Not applicable

Consent to publish All the authors are willing to publish this paper in ESPR.

Competing interests The authors declare no competing interests.

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