Comparative Analysis of Noise Pollution in Urban Zones of Peshawar Through Noise Descriptors

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Abstract

In recent years, noise pollution in urban zones has reached critical levels, primarily driven by increased road traffic and poor urban planning. This research is crucial as it quantifies noise pollution in different urban settings of Peshawar, Pakistan, providing valuable insights into the severity of the issue. By using noise descriptors such as Leq-24h, L1, L10, L50, L90, L99, Lmax, Lmin, LNP, and NC. A comparison with the Pak-NEQS 2010 standards revealed that during the daytime, 100% of silence zones, 91% of commercial areas, and 90% of residential areas exceeded the permissible noise limits. Similarly, nighttime measurements showed that 83% of silence zones, 87% of commercial areas, and 90% of residential areas were also above the acceptable limits. Strong correlations between Leq and other noise descriptors were observed, and land use characteristics significantly impacted noise levels during the day. This data highlights the urgent need for regulatory measures to mitigate the growing issue of noise pollution in urban environments.

Keywords: Noise Pollution, Urban Zones, Noise Descriptors.

Introduction

Environmental noise has been well recognized as one of the major global problems (de Souza, et al., 2020), affecting quality of life in urban areas (Frei, et al., 2014; Ozkurt, et al., 2015; Sahu, et al., 2020). Increased urbanization can be linked to noise pollution and its adverse effects on human health (Basner, et al., 2014; Halonen, et al., 2015; Hohmann, et al., 2013; Yinhua, et al., 2020). The reason why noise pollution has gained attention from scientific community is because of its relationship with health problems (Murphy & King 2010). Continued exposure to noise has been linked to many health problems (Halonen, et al., 2015) such as sleep disturbance, cognitive impairment in children (Evans & Hygge, 2007), tinnitus (WHO, 2011), cardiovascular diseases (Babisch, 2014; Hemmingsen, et al., 2015; Lee, et al., 2015) physical and psychological discomfort (Jagniatinskis, et al., 2016), annoyance (Babisch 2014; Clark et al., 2012; Lee et al., 2015) and hearing impairment (Rana, et al., 2015). Noise can be benign, steady, unpredictable, anonymous and intermittent (Baker, 2015).

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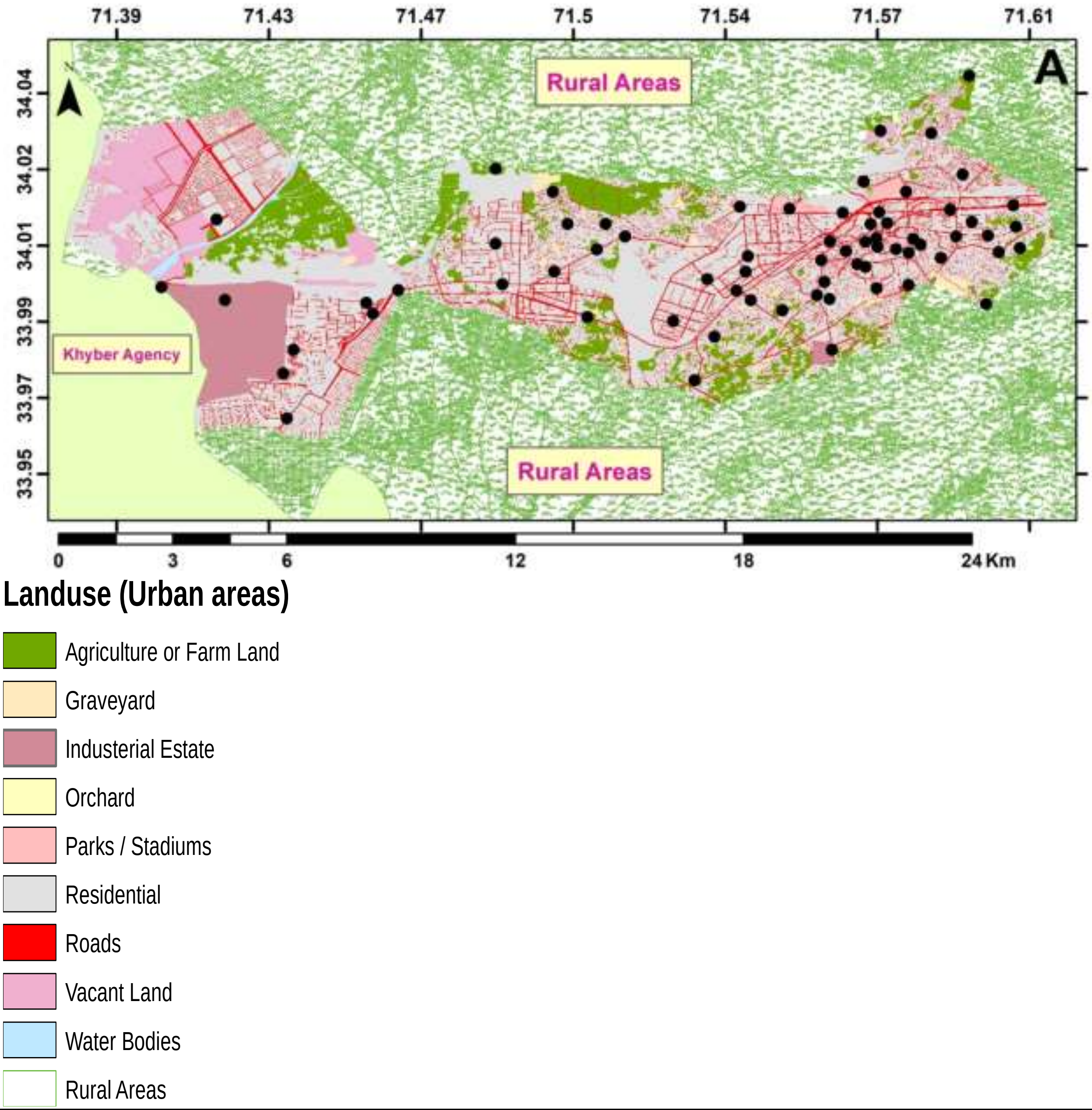
Important sources of noise pollution are urban traffic and industrial activities (Malakootian et al., 2012; Salvato et al., 2003). Among all sources, road traffic is the most dominant source of noise in many cities (Hammer, et al., 2014; Tobías, et al., 2015) and is proven by several previous studies (EEA 2014; Golmohammadi, et al., 2009; Lam, et al., 2009; Li, et al. 2002; Mansouri, et al., 2006; Méline, et al., 2013; Morillas, et al., 2002; Phan, et al., 2010; Sánchez-Sánchez, et al., 2015; Swain & Goswami, 2013) . Beside road traffic noise in urban areas, spatial distribution of noise pollution is also related to open spaces, the type of passages, construction density, physical position of buildings, population distribution (Ariza-Villaverde et al., 2014) , expansion of roads network, construction of flyovers (Mishra, et al., 2010) ubiquitous uses of machineries (Moudon , 2009) and unbalanced urban development (Gholami et al., 2012) . One of the effective scientific tools that can be used to measure noise is noise mapping that not only evaluates the current noise situation but also assess future scenario for the noisy environment (Cai et al., 2015; Suárez & Barros 2014; Yang et al., 2020) . It considers complex acoustic environment and provides concrete knowledge to policy makers, decision makers and related experts (Klæboe et al., 2006; Tsai et al., 2009) to visualize, identify and solve the condensed status of existing and changing trends in noise problems (Cho et al., 2007; Karipidis et al., 2014) , severity of noise pollution levels in urbanized cities (Mehdi, et al. 2011) , the invisible contaminants and hotspots of noise (Suárez & Barros 2014) . These maps are easy to understand as they help the users to easily identify the noise levels assigned to each location (Asensio et al., 2011) , help to visualize noise levels in colors and to raise exposed population awareness regarding noise levels (Rana et al., 2015) . Similarly, noise can be assessed through different parameters such as Equivalent Continuous Level (Leq) and different statistical centile levels such as L10, L90, L50, Noise climate, Level of Noise pollution as described in the methodology section.

Noise pollution varies significantly across different urban zones due to diverse noise sources and varying levels of human activity. In residential areas, noise is typically generated from household activities and moderate traffic, while commercial zones experience higher levels of noise from intense vehicular movement, businesses, and public interactions. Silence zones, such as hospitals or schools, are generally expected to have lower noise levels but are still impacted by external noise sources. Given these variations, this study was designed to comprehensively analyze and quantify noise levels in different urban zones—residential, commercial, and silence—in Peshawar, one of Pakistan is densely populated and congested cities. By utilizing noise descriptors such as Leq, L10, L50, L90, NC, and LNP, the study aims to assess both the intensity and fluctuation of noise in these zones. The results were further visualized through noise maps and other visual techniques to provide a clearer understanding of spatial noise distribution, making the data more accessible for stakeholders and policymakers to devise targeted noise management strategies.

Study Area

Peshawar, a capital city of one of the provinces of Pakistan is selected as a study area. It lies between 33° 44’ and 34° 15’ north latitude and 71° 22’ and 71° 42’ east longitude with a total area of 1,257 km 2 . It is divided into 92 union councils out of which 36 are urban union councils. The urban land use map of the study area is given in figure 1.

Figure 1: Land use of urban zones of Peshawar; Data points are represented as black dots



Methodology

A 24-h noise measurement was conducted with Extech's Datalogging Sound Level Meter. The Extech's data logger complies with application standard IEC 651 and ANSI 1.4 sound level meter. The instrument was calibrated by the internal sound level calibrator every time before taking noise sampling and was set at 'A' weighted network to record noise sample after every minute for 24 h exposure time. A total of 1440 readings were recorded for every location. The instrument was placed at a height of 1.5 meters above the ground and at a minimum distance of 2-3 meters from the building façade in accordance with the World Health Organization (WHO) Guidelines for Community Noise'2000. The protective foam on its sensor system was used to minimize the effect of airflow. Before conducting noise measurement, primary and secondary streets were surveyed and the study points were identified. A total of 59 points from commercial [n=23], residential [n=30] and silence zone [n=6] were selected and noise measurement was carried out on days without rain or strong wind. Noise indices are used to assess different noise levels. The noise indices that are helpful to assess noise are; Leq (Equivalent Continuous Level) which is used to determine noise level for specific period of time, Ld for noise disturbance during daytime, Ln for noise disturbance during the nighttime (Hadzi-Nikolova et al., 2012) . For daytime the values were taken from 06:00 am to 10:00 pm and for daytime 10:00 pm to 06:00 am as given in the Pakistan-National Environmental Quality Standards'2010. For every measured location Leq-24h, L1, L10, L50, L90, L99, LNP and NC were computed. Leq, Ld and Ln were determined by the following formula (Tripathy, 1999). Similarly, statistical centile levels are used for the percentage of time that the noise level exceeds" (Tripathy 1999) , Important statistical centile levels are L1 (maximum or the loudest noise events), L10 or peak sound levels (spatial, intrusive or intermittent), L50 or Mean Sound Levels (spatial median noise levels), L90 or background or residual noise levels (noise climate index) and L99 (lowest noise level during the measurement period), Noise Climate and Level of Noise Pollution were determined for each location using the formula. LNP represents short term variation of Leq (Phukan & Kalita, 2013) . It incorporates both Leq and NC and is the best indicator of noise pollution (Pathak et al., 2008) in the environment for psychological and physiological disturbance of the human system (Swain & Goswami, 2013) .

The limit set out by Pakistan National Environmental Quality Standards (Pak-NEQS'2010) for commercial areas for daytime is 65 dB (A) and nighttime is 55 dB (A), for residential areas, 55 dB (A) for daytime and 45 dB (A) for nighttime and for silence zone it is 50 dB (A) for daytime and 45 dB (A) for nighttime. According to Pak-NEQS'2010, the silence zone shall be declared by the competent authority and it is an area not less than 100 meters around hospitals, educational institutes and courts. United States Department of Housing and Urban Development (US HUD' 1971 and 1985) criteria was used for different zones to categorize them as clearly acceptable, normally acceptable, normally unacceptable and clearly unacceptable for the parameters of L1, L99 and LNP. Noise maps were created for urban zones of Peshawar using the sampled location measurement with the help of ArcGIS 10.4.1 also used by (Murphy et al., 2009; Nejadkoorki et al., 2010) using IDW interpolation method to predict noise levels at intermediate points. The interpolation techniques are used by many researchers in many fields including noise pollution (Mehdi et al., 2011; Nejadkoorki et al., 2010) . Road density map was also created for the urban zones. Different noise indicators Ld, Ln L10, L50, L90, NC and LNP both for day and nighttime were used to gauge noise emissions in the study area. Before selecting a data point extensive survey was carried out and characteristics of the road network such as slope, number of lanes, number of vehicles, settlements, traffic flow beside meteorological and topographic data was considered. Areas with the different characteristics were categorized and noise was recorded only in such areas which were different from one another in above mentioned aspects.

Statistical evaluation was done on the results of the noise measurements using SPSS v. 23 and figures were prepared on sigma plot v. 11.0. Noise pollution maps were created in ArcGIS v. 4.2.

Results and Discussion

Leq dB (A) At Different Zones during Day and Nighttime

The Leq dB (A) recorded for commercial areas (daytime) ranged between 61.3 - 87.2 dB (A) (mean=72.3 dB (A)), for residential areas, 48.8 - 77.9 dB (A) (mean=65.5 dB (A)) and for silence zone, 57.2 - 72.3 dB (A) (mean= 66.2 dB (A)). Comparing the noise levels with Pak-NEQS'2010 showed that during daytime, 100% silence zone, 91% commercial and 90 % residential areas were beyond the permissible limit. Leq dB (A) for nighttime recorded at commercial areas ranged between 24.6 - 70.7 dB(A) (mean=61.2 dB (A)), residential areas 38.3 - 70.9 dB(A) (mean=55.9 dB (A)) and silence zones 42.4 - 64.1 dB (A) (mean=57.6 dB (A)). Almost similar to the results of daytime, the noise levels recorded for nighttime showed that 83 silence zones, 87% commercial and 90 % residential areas were beyond the permissible limit set by Pak-NEQS'2010. It is pertinent that minimum, maximum and mean Leq dropped during the nighttime. Several studies conducted not only in developed but also developing countries have shown high noise levels in all the three zones (Al-Shobaki & Jamrah 2008; Alam, et al. 2001; Olayinka 2012; Pathak, et al. 2008; Phukan and Kalita 2013; Swain and Goswami 2013) .

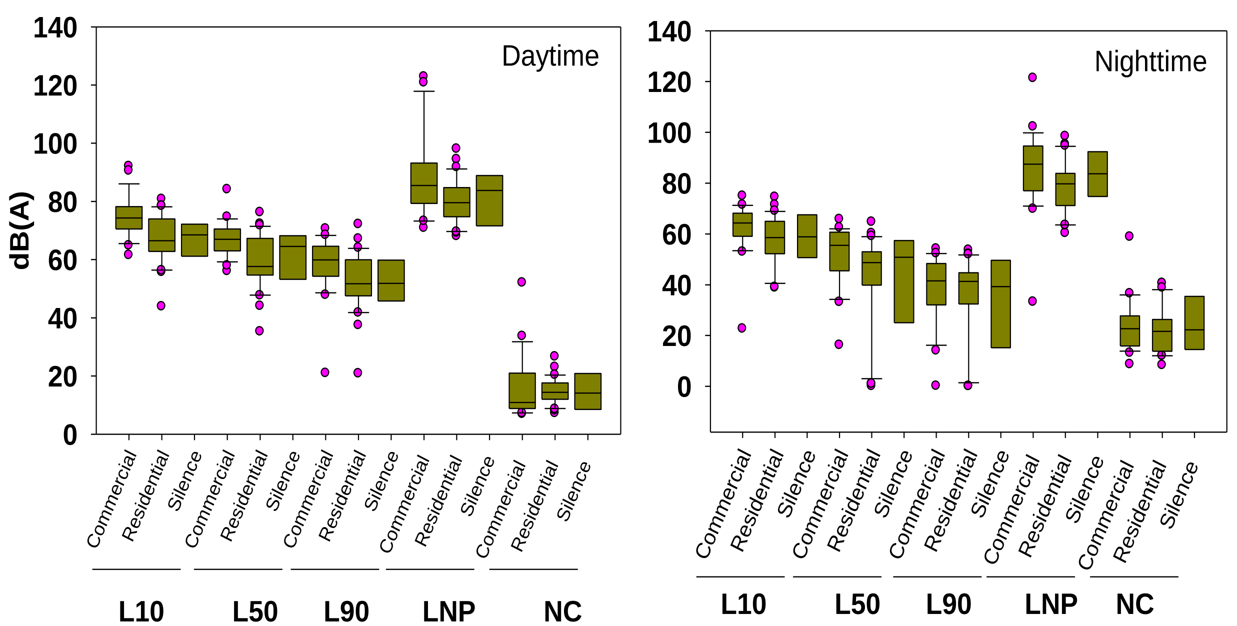
Khaiwal, et al. (2016) measured noise levels beyond the permissible limit in and around sensitive zone in north India, Hunashal & Patil (2012) revealed an alarming situation regarding noise pollution in Kolhapur, India and recorded highest Leq for industrial-cum-residential zone (72.25 dB (A)) followed by commercial-cum-residential zone (64.47 dB (A)), educational zone (63.71 dB (A)), and silence zone (42.84 dB (A)). Similarly, Chowdhury et al., (2010), Alam et al., (2001) in Dhaka, Bangladesh, Garoum et al., (2010) in Agdal district in (Rabat city, Morocco), Olayinka (2012) in Ilorin, Nigeria, Zeid et al., (2000) in Arrabba, Palestine, Zannin, et al., (2002) in Curitiba, Brazil, Li et al., (2002) in Beijing, Piccolo et al., (2005) in Messina, Italy and Yilmaz and Ozer (2005) in Erzurum, Turkey also recorded high noise levels in their study areas. In comparison to their daytime noise levels, the nighttime noise levels were low due to decrease in commercial activities. However, the noise levels recorded at the residential areas were not as high as recorded at the commercial areas but still beyond the permissible limits set for residential areas. The reason observed was that in these areas (residential), there was presence of all types of shops including audio/video CD shops, grocery shops, tailors and meat/poultry shops. This is one of the reasons that noise levels calculated were beyond the permissible limit both during day as well as nighttime. There were few residential areas which were far away from main roads but still showed high noise levels. The reason for these high noise levels were two wheeled vehicles (motor bikes) that can reach to narrow places and produces loud noise. Similarly, the noise levels recorded around hospitals and educational institutions showed high noise levels due to improper planning and mismanagement can be easily witnessed in these areas which had led to high noise levels both at day and nighttime. Standard deviation calculated at different locations both at night and daytime is indicative of the fact that high fluctuating noise is encountered in all areas that can lead to many health problems. It is well established fact that population exposed to high noise levels may suffer from ulcers, increase blood pressure, irregularity of heart rhythms, sleeplessness, stress, irritability, misunderstanding what is heard and reduction of productivity (Evans & Hygge 2007; WHO, 2011) , hearing loss (Joshi et al., 2003) , bad temper, headache, loss of concentration, aural communication disturbances, hearing problem (Agarwal & Swami, 2010; Lam, et al., 2009; Muzet ,2007) and annoyance (Khaiwal et al., 2016).

The high noise recorded in the study area in all the three zones made it evident that there is a violation of laws taking place in these areas; especially silence and residential zones and the people living in these areas may suffer from different psychological and physiological diseases related to noise pollution as evident from the literature.

Noise Indices at Different Zones during Day and Nighttime

Fig. 2 summarizes the range of noise pollution indices (L10, L50, L90), NC and LNP calculated for commercial, residential and silence zones for daytime and nighttime. It is evident that L10 value as high as 92 dB (A) and 80.7 dB (A) for daytime was recorded for commercial and residential areas, respectively. However, for silence zones, highest values recorded for daytime was 74.1 dB (A). Similarly, values obtained for L50, L90, L1 and L99 were in the sequence of commercial & residential & silence. In terms of LNP high values were obtained for commercial areas for daytime and nighttime i.e. 122.8 and 121.3, respectively.

Figure 2: Range of L10, L50, L90, NC and LNP calculated for commercial, residential and silence zone of the study areas during day and nighttime



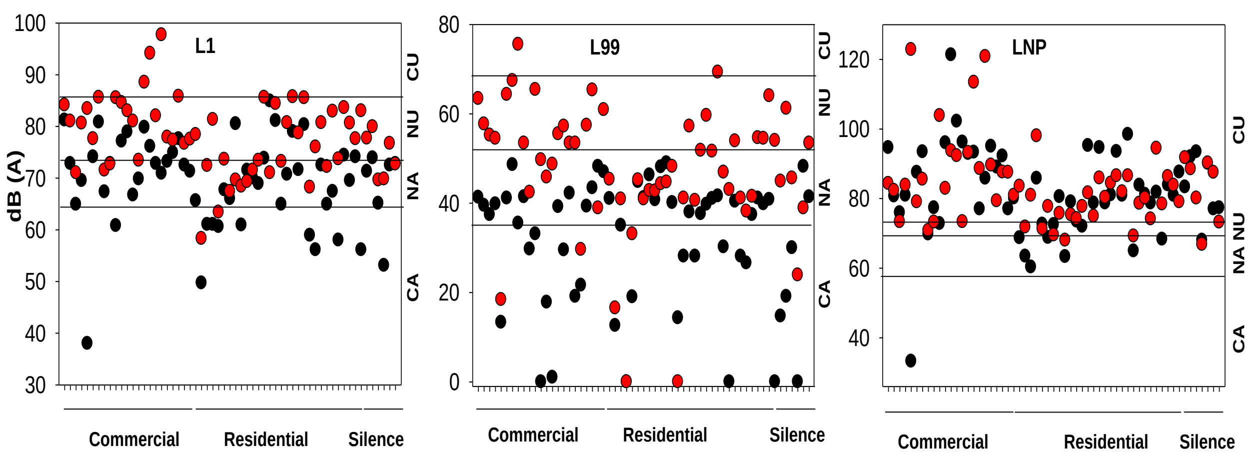
Similarly, values of NC as high as 52 was calculated for commercial areas. This is also pertinent to mention that nighttime values of NC calculated for all the 3 zones were high than the daytime values. This is because, the difference between L10 and L90 values were more at nighttime than at the daytime. The data show low values of Leq for night time but NC values are contradictory to Leq and as NC is an indicator of noise pollution which means that at nighttime high fluctuation is observed in all the three zones. Many studies take nighttime as a control due to less activities during nighttime; but noise descriptor such as NC in contrary to Leq were quite high which makes it evident that though Leq was low but fluctuation was high at nighttime.

Similarly, at few areas LNP values were high at nighttime than at daytime and mean difference between daytime and nighttime values were very low (S1). It is noteworthy that LNP is an important indicator of psychological and physiological impacts of noise (Hunashal & Patil, 2012). For healthy noise environment, LNP values shall not be greater than 88 dB (A) (Segaran et al., 2020) and in the current study 39% commercial areas at daytime and 49% of these areas at nighttime shows LNP values greater than 88 dB(A). Similarly, more residential areas shows LNP values greater than permissible limit at nighttime. As many people also work at nighttime, therefore it is deduced that these people may suffer from psychophysiological impacts of noise. Furthermore, many areas which showed Leq within permissible limit showed high values for NC and LNP for nighttime.

When analyzing noise indices through whisker plots (fig. 2), it is evident that median is lower than the mean values for residential areas for daytime and for silence zone it is higher than the mean, which means that high noise levels in residential areas and low noise levels in silence zone remained dominant throughout the day. However, no such skewedness was observed only for commercial areas and for nighttime for all the zones. For the daytime LNP, inner fence values extend more for commercial areas which is an indication that noise fluctuation is high for the commercial areas as compared to silence and residential areas. However, for nighttime fluctuations in the values of L50 and L90 are apparent for residential areas. Outliers are present as given in Fig. 2 for all the parameters which clearly show that extreme values were also recorded for all the areas. Therefore, whisker plots are an essential tool to analyze noise fluctuations, dominant values and extreme values.

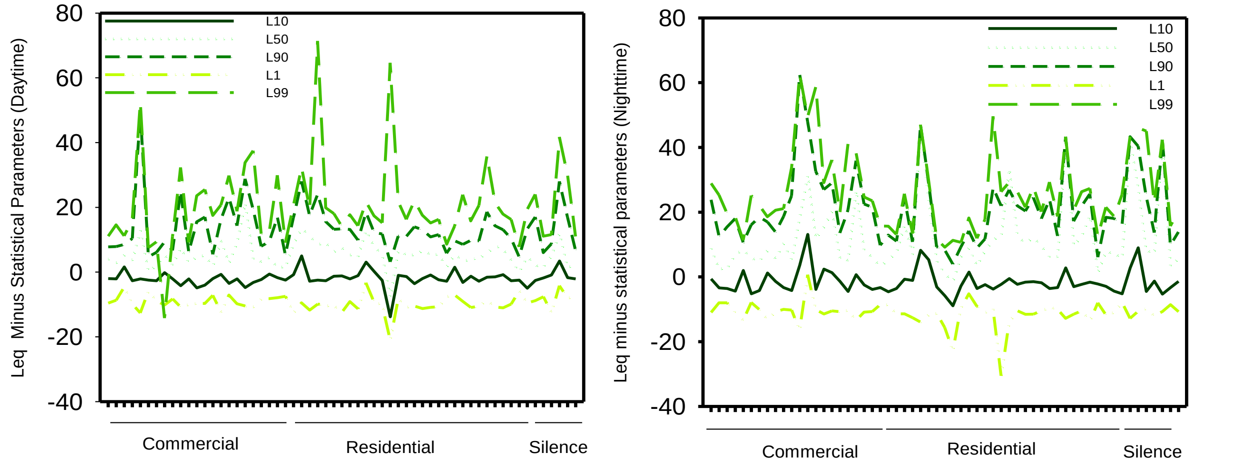
Analyzing the noise parameters through US HUD criteria (fig. 3) showed that the half of the values of noise descriptor L1 [daytime] for all the areas (commercial, residential and silence) are falling under normally acceptable and 50% are falling under normally unacceptable values; for nighttime most of the values were falling under normally acceptable and clearly acceptable values. But still few values fall in the zone of clearly unacceptable values. As L1 is the loudest noise recorded during a time period therefore, L1 shall be taken into account while conducting noise surveys. The values of L99 [daytime] for majority of the commercial areas were falling in the range of normally unacceptable, while residential areas were within normally acceptable range. However, for nighttime majority of the areas were in the range of clearly acceptable and normally acceptable values. LNP values for almost all the zones were in the range of clearly unacceptable values both for daytime and nighttime.

Figure 3: Commercial, residential and silence zone categorization according to US HUD criteria for L1, L99 and LNP where red dots represent daytime and black dots represent nighttime; CA is clearly acceptable, NA is normally acceptable, NU is normally unacceptable and CU is clearly unacceptable



Another technique used to identify the fluctuations in the noise was to compare Leq values with other noise descriptors through line graph. Values of L10, L1, L50, L90 and L99 in comparison with Leq are summarized in fig. 4. It is clear from the data that Leq values are close to L10 values at commercial, residential and silence zone and not to L50, which means noise fluctuates broadly and extreme fluctuations were also encountered at locations where Leq values exceeded L90 by 10 dB(A), same results were also witnessed for nighttime and for residential zone. Extreme fluctuations were also recorded at silence zones.

Figure 4: Difference between Leq and statistical parameters values



Relationship between Leq and Different noise indices at different zones. According to Evans (1996) the absolute value of r can be very weak (0.00-0.19), weak (0.20-0.39), moderate (0.40-0.59), strong (0.60-0.79) and very strong (0.80-1.0). A strong significant (+ve) correlation between Leq and L10, L50, L90, L1, Lmax was found for commercial and residential areas. However, for L99 and Lmin strong linear correlation was determined with Leq values for the commercial zones but not for the residential areas. On the contrary, Pearson's correlation between Leq and LNP was found for 83% residential areas but mixed results were obtained for commercial areas. For NC, –ve and no linear correlation was encountered (table 1). These results are in line with Garoum, et al. (2010) who observed linear
correlations between Leq and statistical noise levels and concluded that higher correlation of R^2=0.97 was observed between L10 and Leq and lower correlation of R^2=0.74 between L90 and Leq; Nassiri, et al. (2016) determine Leq has a positive strong correlation with L50 (R 2 of 0.76).
Table 1 Pearson test to find relationship between Leq and different noise indices at commercial, residential (in percentage).

Pearson's Test	**Commercial**								
	L10	**L50**	**L90**	**L1**	**L99**	**Lmax**	**Lmin**	**LNP**	**NC**
Very strong +ve	82	83	70	91	52	61	48	35	0
Strong +ve	14	17	22	4	35	35	39	22	0
Moderate +ve	4	0	4	4	4	4	4	4	0
No Relationship	0	0	4	0	9	0	9	39	54
Very strong –ve	0	0	0	0	0	0	0	0	4

Strong -ve	0	0	0	0	0	0	0	0	18
Moderate -ve	0	0	0	0	0	0	0	0	22
	Residential								
Very strong +ve	87	67	57	90	40	83	33	57	3
Strong +ve	13	23	27	7	23	14	20	23	20
Moderate +ve	0	7	3	0	14	3	13	3	13
No Relationship	0	3	13	3	23	0	34	17	51
Strong -ve	0	0	0	0	0	0	0	0	3
Moderate-ve	0	0	0	0	0	0	0	0	10

The results of the present study showed that significant correlation between characteristics of the land use and noise indices was only observed for Ld, L10, L50 and LNP for the 3 different zones i.e. commercial, residential and silence for daytime but no significant difference was observed for the nighttime and for L90 and NC values in all the three zones both for daytime and nighttime (table 2). However, Oyedepo and Saadu (2009) statistically analyzed the correlations between different areas and concluded that there was no significant difference in noise pollution levels between commercial, high density areas and industrial areas. Post hoc comparisons for Ld, L10, L50 and NC using the Tukey HSD test indicated that the mean score for the commercial areas during daytime for the said parameters was significantly different than the residential areas respectively. However, rest of the parameters did not significantly differ from one another for day and for nighttime and no significant difference was observed for all noise indices for any zone. Ozer, et al. (2009) analyzed significant differences in noise levels among the streets but Anari and Movafagh (2014) found no significant difference between amount of traffic and road widths. Portela and Zannin (2010) used one-way ANOVA and Tukey statistical test to compare Leq means with different bus models, Palamuleni (2015) used the same tests to evaluate the effects of land-use types on noise and found significant difference between mean noise levels and study areas. Similarly, To, et al. (2002) revealed that most significant factors of urban traffic noise are number of heavy vehicles and the total traffic flow and Geraghty and O'Mahony (2016) by using same technique found significant differences in the mean of Leq between months. Table-2 ANOVA test to compare the effects of commercial areas, residential areas and silence zone on noise indices (Ld, L10, L50, L90, LNP and NC).

Table 2: ANOVA test

		Sum of Squares	df	Mean Square	F	Sig.
Ld	Between Groups	636.935	2	318.468	7.593	0.001
	Within Groups	2348.692	56	41.941		
	Total	2985.627	58			
L10	Between Groups	751.375	2	375.687	6.637	0.003
	Within Groups	3169.859	56	56.605		
	Total	3921.234	58			
L50	Between Groups	750.715	2	375.357	6.113	0.004
	Within Groups	3438.343	56	61.399		
	Total	4189.058	58			

L90	Between Groups	469.028	2	234.514	2.357	0.104
	Within Groups	5571.547	56	99.492		
	Total	6040.575	58			
LNP	Between Groups	1035.801	2	517.901	4.468	0.016
	Within Groups	6491.046	56	115.912		
	Total	7526.847	58			
NC	Between Groups	39.509	2	19.755	.328	0.721
	Within Groups	3368.727	56	60.156		
	Total	3408.236	58			

Noise maps were created for all the parameters to analyze the study area for noise pollution. Fig. 5 and 6 show the daytime maps for different noise indices; it clearly shows that noise pollution map for Leq, L10, L50 and L90 highlights more or less the same areas for high values but when looking at the LNP and NC the high noise levels shifts to other areas and same results are shown by nighttime maps. These maps are clearly indicative of the fact that while calculating noise levels in terms of Leq other noise descriptors shall also be considered to highlight for hot spots of noisy areas and the locations where there is high fluctuation.

Figure 5: Noise Pollution map for the urban zones of Peshawar; A (Leq); B (L10), C (L50); D (L90); E (LNP); F (NC) map for daytime i.e. from 06:00am to 10:00pm

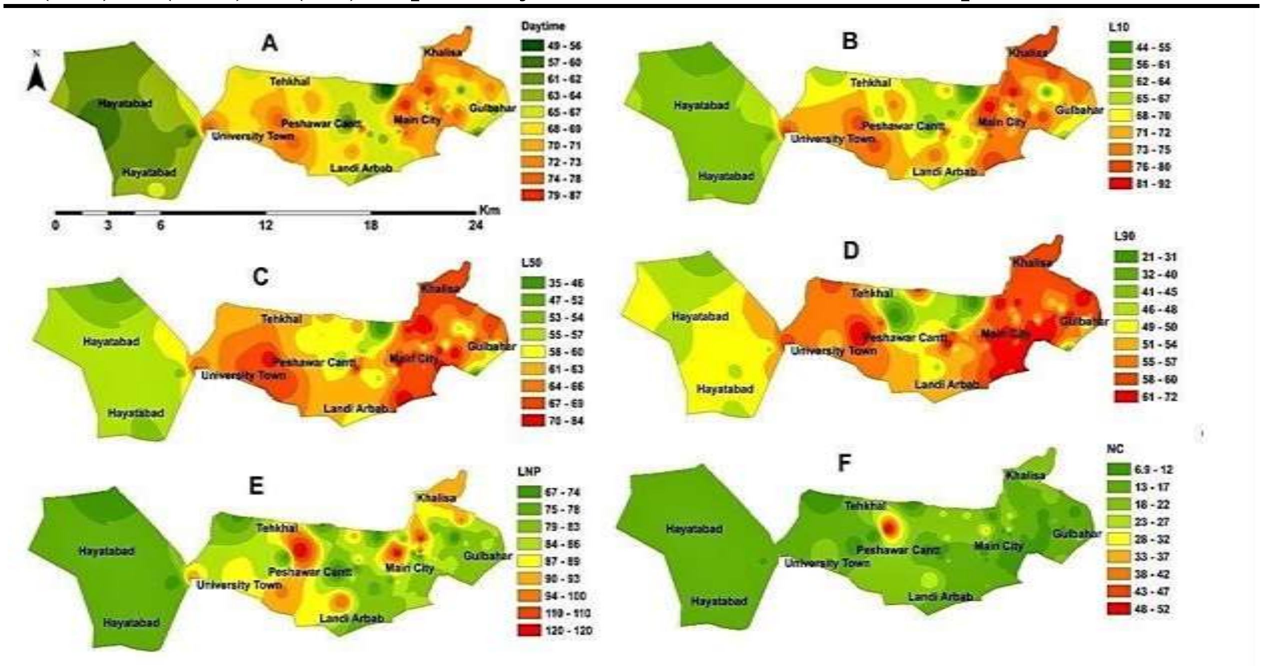
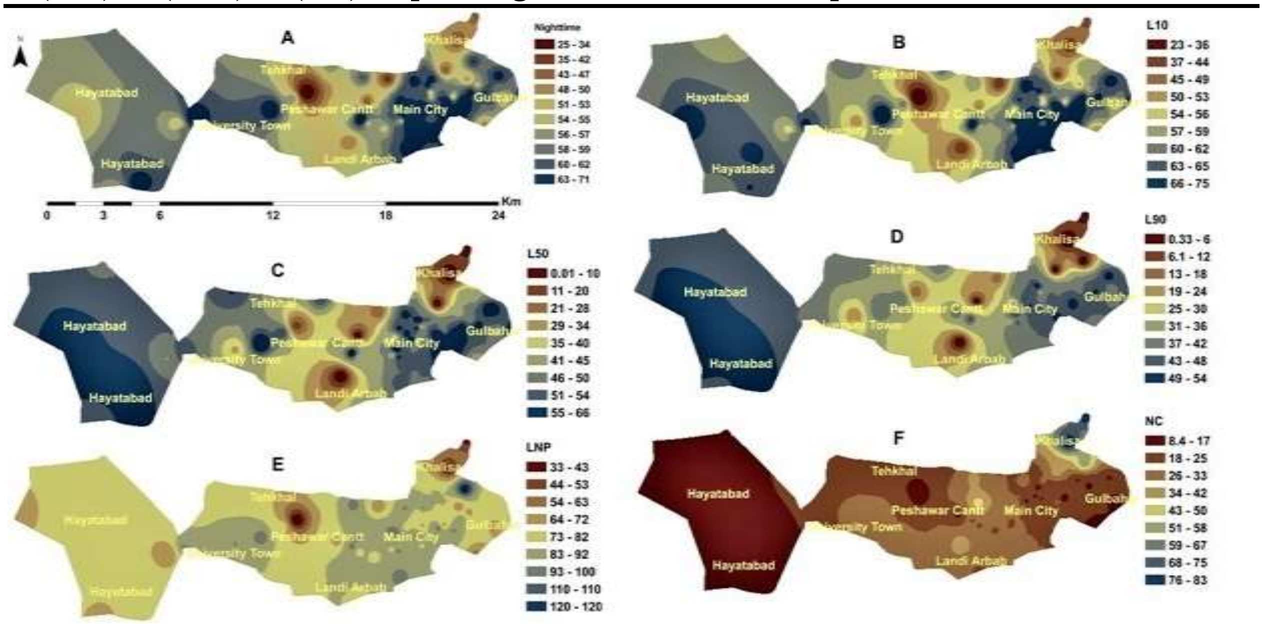


Figure 6: Noise Pollution map for the urban zones of Peshawar; A (Leq); B (L10), C (L50); D (L90); E (LNP); F (NC) map for nighttime i.e. from 10:00 pm to 06:00 am



The results of the study indicates that noise descriptor Leq, alone is not enough to understand the characteristic of noise, therefore, statistical noise levels are very useful for environmental noise monitoring as noise fluctuate over time in noise measurement. These statistical centiles help to understand the noise characteristic of the area and describes the magnitude of the problem.

Conclusion

The study concludes that noise levels measured across residential, commercial, and silence zones were consistently above the permissible limits set by Pak-NEQS and US HUD for various noise indices. Commercial areas exhibited the highest noise levels, followed by residential and silence zones. A strong correlation between Leq and other noise indices was observed across all zones, indicating that noise descriptors can effectively determine equivalent noise levels. However, relying solely on Leq is insufficient to fully assess the impact of noise on the exposed population. Therefore, additional noise indices should be included in noise surveys to capture the full spectrum of noise effects. Moreover, noise maps should not only represent Leq but also other noise indices to highlight fluctuations and their potential harm to residents health. These findings underscore the need for a comprehensive approach to noise monitoring and management.

The noise indices measured at the urban areas indicated broad fluctuations in the study area which may significantly affect the health of the exposed population. Due to these fluctuations the community is at risk of many psychophysiological diseases. It is recommended that detailed noise legislations and strict implementations of laws are required to protect the exposed population from high noise levels.

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