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Noise pollution mitigation and control in urban areas near international borders through 2D noise mapping

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Noise pollution is defined as any disturbing or unwanted sound that disrupts or harms human health or wildlife. Noise pollution can have profound effects on both human health and the environment. For humans, exposure to excessive noise levels has been linked to a range of health issues, including hearing damage, stress, and sleep disturbances. Noise monitoring and mapping play a crucial role in understanding, managing, and mitigating the impacts of noise pollution on communities and the environment. Urban areas near borders are generally less studied due to restrictions. Therefore, a study has been conducted aiming the monitoring of noise level and looking into its propagation through 2D noise maps in the urban areas of Jammu and Kashmir lying near the Indian border. The monitoring results revealed that even boarder areas are exposed to high noise levels. Bhatindi in Jammu city recorded highest equivalent noise level, Leq of 91.2 dB(A) during evening. Nowshera is calmest among other study area with noise level, Leq of 80.1 dB(A). Further, 2D noise mapping showed some critical locations in study areas of Jammu and Kashmir that the noise propagates to the nearby residential and commercial areas which require immediate remedial measures. The findings not only contribute to the scientific understanding of noise patterns in border regions but also hold practical implications for urban planning, public health, and environmental conservation.

Keywords Noise Pollution, Border areas, Noise monitoring, Noise mapping, Traffic volume, Noise mitigation

Noise is defined as any unwanted or excessive sound that disrupts the normal acoustic environment[1]. It can be generated by various sources, including transportation (e.g., traffic and aircraft), industrial processes, construction activities, and even daily human activities[2]. Road traffic is considered as the main source of noise pollution in the urban areas, and the current trends indicate that it will only become worse as traffic grows into weekends and evenings, as well as into rural and recreational sites[3]. Therefore, noise pollution has become a significant concern in urban areas that is causing adverse effects on human health, well-being, and the environment[4,5]. Thus, it is important to monitor noise levels as noise monitoring offers several advantages, both for individuals and organizations, in assessing and managing noise levels such as identification of sources, compliance with regulations, assessment of noise exposure, data for noise control planning, public awareness etc. However, only noise monitoring does not provide a clear picture of noise propagation in the X, Y, and Z directions. The actual propagation of noise can be clearly understood by noise mapping[6]. Noise mapping is a tool used to assess, visualize, and manage noise levels in a given area[7]. It highlights areas with high noise exposure, aiding in environmental assessments, urban planning, and noise management efforts to mitigate adverse effects on public health and well-being[8]. It involves the collection of noise data from various sources and the creation of detailed maps or models that represent noise levels at different locations. Noise mapping can be of 2D or 3D in nature[9]. Two-dimensional (2D) noise mapping is a technique that represents noise levels in a flat, planar format, typically on a map or diagram[10]. It provides a visual representation of noise levels at specific

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locations in a given area. The process of two-dimensional noise mapping is similar to that of one-dimensional noise distribution[11]. The distinction is that, in 2D noise mapping, we are seeking for values that are sitting on a grid rather than along a linear path[12]. Noise maps developed by Pinto and Mardones[13] have been effectively applied to Copacabana's heavily populated districts in Rio de Janeiro, Brazil. They depict the distribution and spread of noise in the surrounding environments using noise maps[13]. In order to compare the effects of urban morphology on traffic noise dispersion between the UK and China, Wang and Kang[14] employed noise mapping. For accurate estimation of noise levels in urban environments, noise mapping has been utilized extensively and successfully[15]. Dynamic modelling has also been used for the development of noise maps by Tang et al.,[16]. Numerous researchers have utilized 2D noise mapping to demonstrate the distribution of road traffic noise with success[17–21]. One of the studies conducted by Benocci et al.,[22] investigated noise pollution in urban areas by developing a high-resolution road traffic noise map using in-situ measurements combined with noise prediction software. Their work highlighted how road traffic patterns, density, and speed influence noise levels and used for precise mapping of noise in high-exposure zones. In another study conducted by Guillaume et al.,[23] focused on road traffic noise mapping in major Asian cities and examined the link between noise pollution and public health. They collected data on traffic noise intensity and assessed its impact on health outcomes, particularly hypertension and sleep disturbances among urban residents. Stansfeld et al.[24] through their study found that exposure to the environmental noise has been linked to various physical and psychological health effects. While noise sensitivity may also play a role in influencing these health outcomes, similar to its impact on annoyance, this aspect has not been thoroughly investigated. Further, Lokhande et al.[25] suggests a total ban on honking within the tunnel. From a safety standpoint, road tunnels longer than 500 m should include dedicated pedestrian walkways separated by barriers. In addition, international borders often exhibit distinct noise pollution characteristics due to their unique socioeconomic and geopolitical factors. Carrillo et al.[26] noted that the noise levels at US-Mexican border often exceed permissible limits, impacting both border personnel and nearby residents. The study recommended implementing stricter noise regulations and monitoring systems at border points. However, due to various challenges, there have been only a limited number of studies focused on noise pollution and related issues in border areas.

While significant strides have been made in the study of noise pollution and its impact on urban environments, current research predominantly focuses on noise monitoring and two-dimensional (2D) noise mapping. Despite the successful application of 2D noise maps in various contexts, such as the work of Pinto and Mardones[13] in Rio de Janeiro and Wang and Kang's[14] comparative study between the UK and China, there remains a notable gap in integrating three-dimensional (3D) noise mapping techniques. Moreover, studies and researchers have mainly focused on the urban areas the mainland of a country for noise monitoring as well as mapping and ignored the bordering areas due to various reasons/restrictions. However, the local population and communities living in the bordering areas of a country also suffer from the similar trauma of noise pollution. Therefore, an exhaustive study has been conducted to monitor the noise levels at 20 locations in Jammu and Kashmir, a bordering territory of India and 2D noise maps are prepared to show the effect and propagation of road traffic noise. In addition, mapping results have been validated through t-test and comparison of monitored and predicted noise levels. The study would help federal agencies in managing and implementing necessary measures to curb the noise pollution.

Methodology

Study area, instrument and software used and procedure for noise monitoring and mapping have been discussed in the subsequent sections of methodology.

Study area

Jammu and Kashmir, an union territory of India shares the border with Pakistan and China. Jammu division is located in the northernmost part of the Indian union territory of Jammu and Kashmir. It covers an area of approximately 26,293 square kilometres and includes nine districts[27]. Based on the survey, high traffic areas of Jammu city, Poonch, Rajouri, Nowshera laying in Jammu division have been selected for noise monitoring and 2D mapping to know the propagation of noise levels on either side of the roads. The Jammu city serve as a commercial, cultural, and administrative hubs, whereas Poonch is located near the Line of Control – the de facto border with Pakistan administered Jammu and Kashmir and the Poonch town is located at an elevation of 1,021 m (3,349 ft), on the bank of the Poonch river. Further, the Rajouri is located about 150 km (93 mi) from the Jammu city on the Poonch highway[28], whereas Nowshera is a town and the headquarters of an eponymous tehsil of Rajouri district in the Jammu division. Based on the physical survey the five most traffic congested/ volume locations have been selected in all the four-study area. Therefore, total 20 locations have been selected for monitoring and mapping of the noise levels in Jammu division. The details of monitoring locations along with latitude and longitude of the selected study are presented in Fig. 1; Table 1.

Instruments and software used

Two Class-1 Larson and Davis Sound level meter (SLM) Model 831 along with wind shield have been used for the monitoring of noise level at different selected locations of J & K. Simpex tripod has been used to keep SLM at desired height as per the noise monitoring protocol. The SLM has been calibrated for each time for new monitoring station using sound level calibrator CAL200. Further, for the development of 2D noise map, NoiseTools software has been used. NoiseTools is commonly used for managing noise monitoring data from the SLM. It allows to create detailed sound level models and noise maps and supports adding sources, barriers, buildings, and decibel receiver points, making it easy to visualize and adjust sound paths and levels. It helps in understand how calculations from ISO 9613 parts 1 and 2[29,30] are implemented and their effects on predicted noise levels.

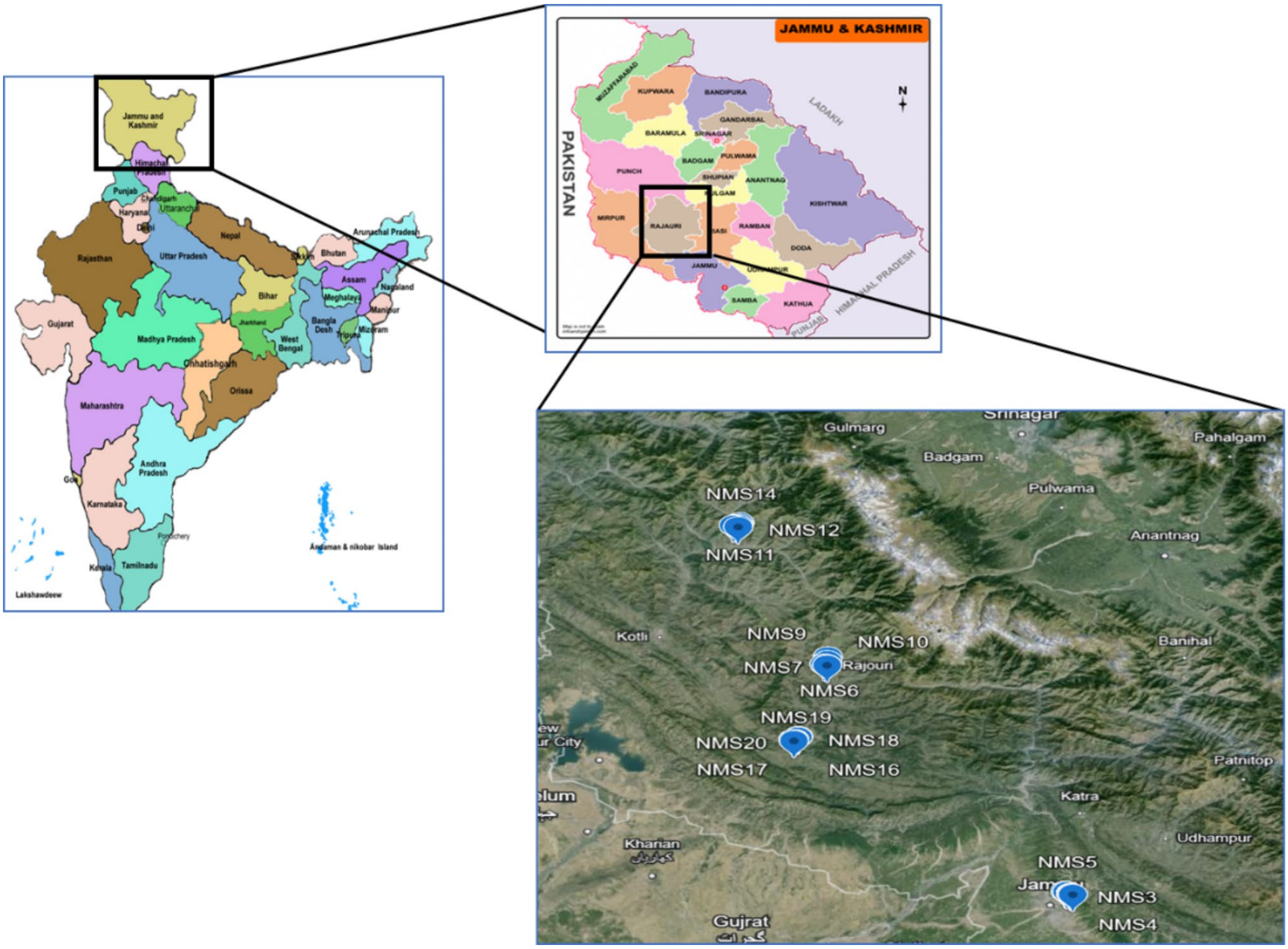

Fig. 1. Geographic location of study area.

S. No	Study Area	Noise Monitoring Location	Latitude	Longitude
1.		Khana Chorgol Bhatindi (*NMS-1)	32.711	74.910
2.		Jalalabad chowk sunjawan (NMS-2)	32.701	74.918
3.	Jammu	Sunjwan matador stand (NMS-3)	32.696	74.921
4.		Makkah masjid, Bathindi (NMS-4)	32.711	74.907
5.		Bathindi morh (NMS-5)	32.709	74.899
6.		Martyrs Memorial Rajouri (NMS-6)	33.377	74.313
7.		Dudhadhari Temple (NMS-7)	33.3677	74.307
8.	Rajouri	New bus stand Rajouri (NMS-8)	33.365	74.3130
9.		District hospital Rajouri (NMS-9)	33.387	74.315
10.		Salani bridge (NMS-10)	33.3646	74.313
11.		Poonch bus stand (NMS-11)	33.766	74.092
12.		Shere-Kashmir bridge (NMS-12)	33.757	74.095
13.	Poonch	Eidgah chowk (NMS-13)	33.766	74.096
14.		District hospital (NMS-14)	33.772	74.098
15.		Gurdwara bhai rocha singh ji purani (NMS-15)	33.765	74.0844
16.		Government hospital (NMS-16)	33.159	74.241
17.		Nowshera radio station (NMS-17)	33.151	74.232
18.	Nowshera	Gujral chowk (NMS-18)	33.158	74.241
19.		Lal Dwara (NMS-19)	33.1478	74.232
20.		Government Degree College (NMS-20)	33.151	74.230

Table 1. Noise monitoring locations. * NMS- Noise Monitoring Station.

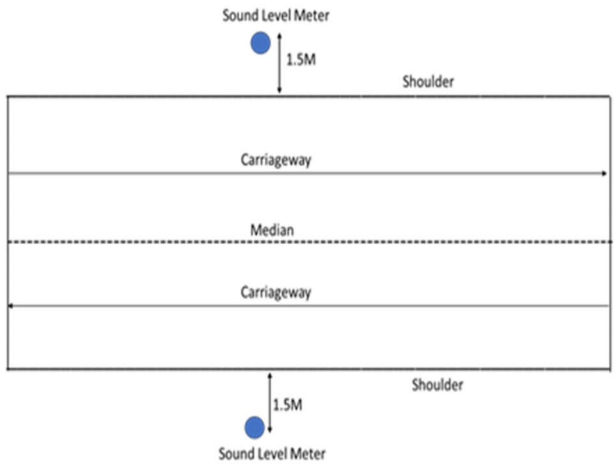

Fig. 2. Location of sound level meter along with road geometry.

Parameters	Jammu	Rajouri	Poonch	Nowshera
Width of Road	6.5 m	5.1 m	11.0 m	6.7 m
Type of Pavement	Flexible	Flexible	Flexible	Flexible
Wind Velocity	4.8 km/hr	9.4 km/hr	8.8 km/hr	7.4 km/hr
Road Condition	One side building other side open	One side building other side wall with a round about	One side building other side open	One side building other side open
Type of Vehicles	Mixed	Mixed	Mixed	Mixed
Type of Road	Double lane without divider	Double lane without divider	Double lane with divider	Single lane with footpath
Source of Noise	Road Traffic	Road Traffic	Road Traffic	Road Traffic
Leq Noise level	91.2 dB(A)	90.1 dB(A)	90.5 dB(A)	80.1 dB(A)
Zone/Category	Residential	Residential	Residential	Residential

Table 2. Features of the selected mapping sites in different study areas.

Procedure of noise monitoring

Monitoring road traffic noise is crucial for managing its impact on the environment and the quality of life for nearby residents. Effective noise monitoring can lead to improved road design and noise mitigation measures, making roadways more sustainable and less disruptive to communities[31]. As shown in Fig. 2 hourly average noise monitoring for 24 h has been done on the working days using two SLM to take care of both side traffic. At each site, noise levels are recorded using calibrated SLM, typically for 1 h intervals, with data averaged over this period to account for fluctuations. In addition, the monitoring has not been done on weekends or rainy day. To take care of traffic noise SLM has been kept at the height of 1.2 m from the ground level and wind shield is used to reduce the effect of wind. Further, the monitored noise levels have been compared with the prescribed standard set by Central Pollution Control Board (CPCB) for residential area i.e., 55 dB(A) and 45 dB(A) for day and night time respectively.

Noise mapping and validation procedure

Noise mapping is a visual representation of the spatial distribution of sound levels across a specific area[32]. It is an essential tool in environmental noise assessment and urban planning, allowing stakeholders to understand noise exposure and identify hotspots where noise pollution may be problematic[33]. It involves collection of information such as noise sources, topography, traffic patterns, and meteorological conditions of the area under investigation. The noise monitoring location having the maximum recorded noise level in each study area is selected for noise mapping. Features of the selected mapping locations in different monitoring areas are given in Table 2. This information is used as input parameter in the noise modelling software developed by MAS Environmental LTD (NoiseTools.net, version 1.7)[46], which calculates noise levels at various points within the area and generates a 2D map. The generated noise maps (Figs. 9, 10, 11 and 12), visualize noise levels typically through contour lines or colour-coded areas[34]. These maps help in identifying noise hotspots, areas of non-compliance with the regulations, and potential sources of noise pollution. For the development of 2D noise maps, an Equivalent Noise Level, Leq has been calculated using Eq. 1.

$$Leq = 10\log_{10}\{\sum{}_{i=1}^{i=n} 10^{\frac{Li}{10}} . t_i \tag{1}$$

Where,

Leq : Equivalent Noise Level, dB(A).

Li : Noise Level of any i^{th} sample,

t_i : time duration of i^{th} sample expressed as fraction of total sample time.

Before developing the 2D noise maps of different study areas, firstly the noise modelling and mapping technique is validated through real time noise monitoring and comparing with predicted noise values and further analysing statistically by t-test. A t-test calculates a t-statistic, which is compared against a t-critical value to decide if the difference is statistically significant, assuming the data is normally distributed, and variances are similar. If the p-values are higher than the 0.05 significance level, it indicates that there is no statistically significant difference between the observed and predicted noise levels, suggesting that the noise prediction tool accurately estimates the noise levels. For validation noise levels are measured at distance of 3.5 m, 7.0 m, 10.5 m from the centre line of the road and compared with the predicted noise levels. After getting satisfactory prediction of noise levels through NoiseTools software, 2D maps of selected location in all the study areas are prepared to see the propagation of noise levels in X and Y directions. Mitigation measures have been recommended based on the findings, and stakeholders are engaged for feedback and input.

Flow chart for noise mapping

As shown in Fig. 3 the flowchart provides a detailed process for creating a noise map, starting with defining the study area, which involves selecting and outlining the region on a high-resolution map. Afterward, data collection includes gathering necessary inputs such as noise level measurements, meteorological data (e.g., wind speed, temperature), road layout, and traffic information. The data processing stage involves cleaning the collected data and analysing patterns over time. The processed data is then fed into a noise prediction model, chosen based on the study's requirements, to simulate noise levels. The outputs are used in the development of noise maps, where noise contours are created using GIS software to represent different noise levels. Finally, the generated map is subjected to a validation step, comparing predictions against actual measurements to ensure accuracy before any recommendations or actions are made.

Results and discussion

Noise monitoring, 2D noise mapping, validation of noise prediction model and mitigations measures have been discussed in the subsequent sections of results and discussion.

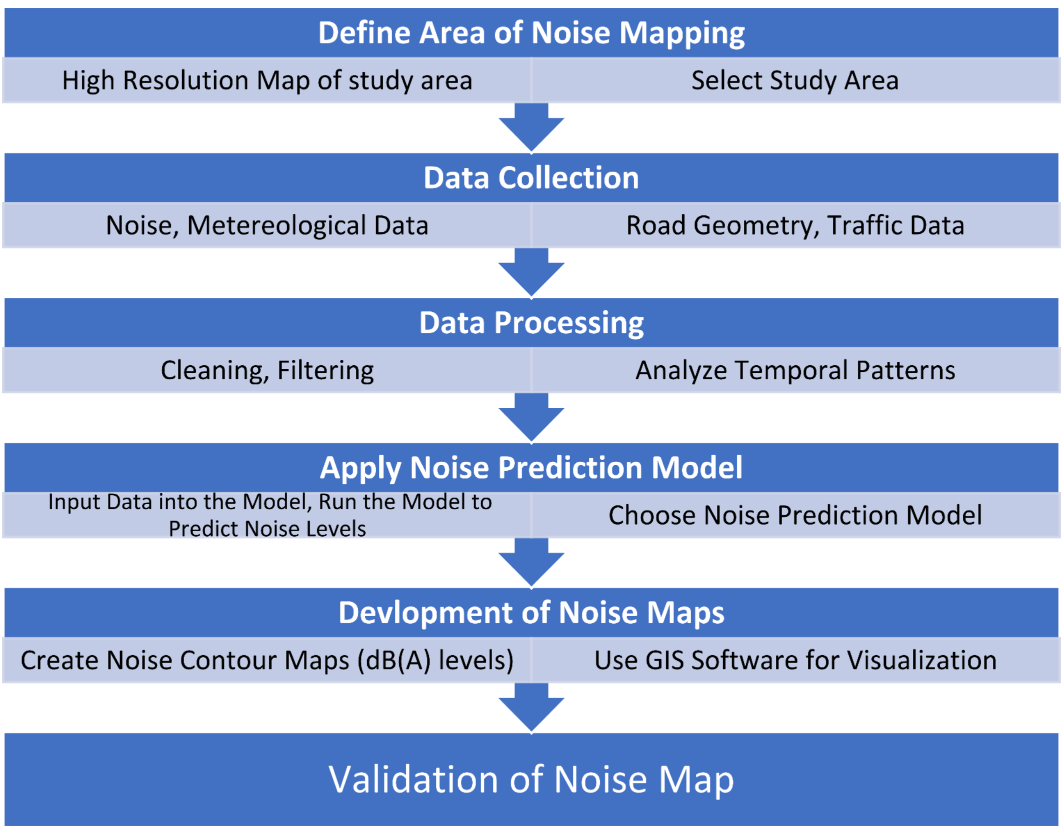

Fig. 3. Flow Chart of Noise Mapping.

Noise monitoring

Twenty locations selected on the basis of traffic volume in the study area of Jammu, Rajouri, Poonch and Nowshera have been monitored for noise levels and the observed results are as follows:

Jammu

Five locations in the city of Jammu have been monitored for the day and night noise levels as the Central Pollution Control Board (CPCB) standards for day and night noise level are 55 dB(A) and 45 dB(A) respectively. Figure 4 shows the variation of noise level at the five selected locations of Jammu city during day and night. The highest noise level is recorded during the day at Bhatindi, around 91.4 dB(A) at 4 p.m., followed by Jalalabad Chowk Sunjawan where noise level was recorded to be 83.6 dB(A) at 4 p.m. Except between 6 and 9 a.m., the noise level is observed to be always higher than the CPCB regulation of 55 dB(A). During the night, between 1 a.m. to 5

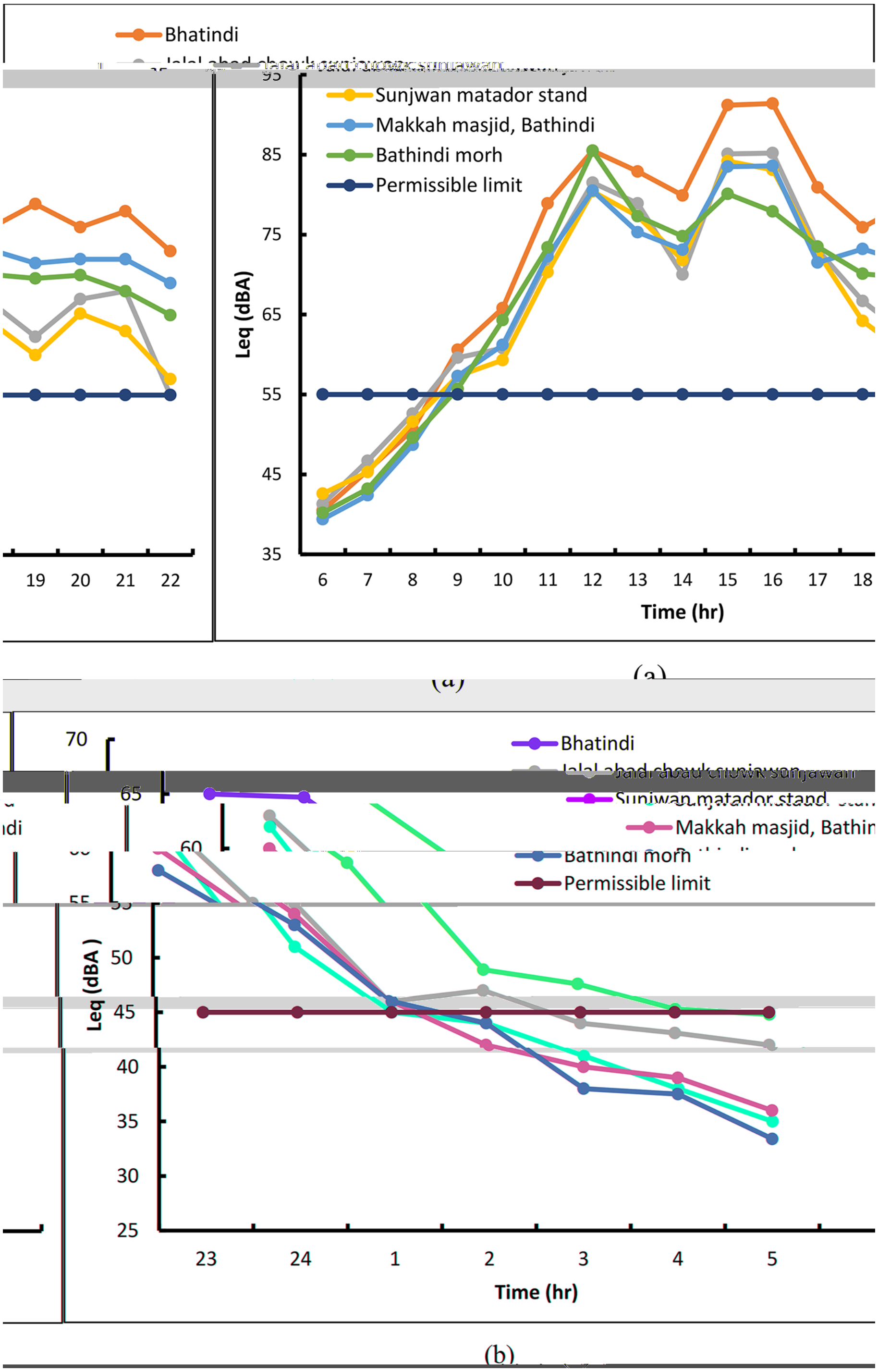

Fig. 4. Variation in noise level at five selected locations of Jammu city during (**a**) day and (**b**) night.

a.m., however, the noise level remains under the CPCB limit of 45 dB(A), with only exception during the period of 11 p.m. to 12 a.m. at the midnight. This variation in the noise level can be attributed to the variation in the traffic flow. Noise level around 12 p.m. may be high due to lunch break, ending of school hours etc. Noise level is high at all the locations around 4 p.m. because of high traffic due to ending of office hours, shopping/marketing by residents and others. Generally closing time of shops and market is around 10 p.m. and after that noise levels starts decreasing and reaches to below 50 dB(A). Bhatindi has the highest noise level and recorded always above the permissible limit most of the time during the day and night. Hence, it need attention from federal agencies as the noise levels even above 40 dB(A) during night should be mitigated as the continuous exposure leads to adverse health effects[4,35].

Rajouri
In Rajouri also the noise levels have been monitored at 5 important locations with significant traffic flow. Variation of the noise levels in Rajouri during day and night can been seen in Fig. 5. The highest noise level has been recorded during the daytime at the Bus stand Rajouri, reaching to 90.1 dB(A) at 5 p.m., followed by 89.3 dB(A) at 4 p.m. at the same location. Notably, Doodhadhari temple is an exception, as it consistently maintains noise levels lower than the CPCB regulations during most parts of the day. Apart from Doodhadhari temple, the noise levels in the region typically exceed the CPCB regulation of 55 dB(A) throughout the day. However, during the midnight and early morning hours, i.e. around 1 a.m. to 6 a.m., the noise levels remain within the CPCB limits across the different monitored locations with exceptions of minor peaks recorded between 11 p.m. to 12 a.m. The variation in the noise levels follows the trend of traffic volume and congestion in most of the cases. Rajouri bus stand has high traffic volume and congestion during the day but after 7 p.m. buses plying to and from the bus stand decreases and become empty at around 11 p.m. Therefore, highest, and lowest noise levels are recorded at this location. Salani bridge is a tourist spot and therefore higher noise level recorded even during midnight periods. However, if the average night noise level over a year is above 55 dB(A), it is considered dangerous to public health, causing annoyance, sleep disturbance and risk of cardiovascular disease[35].

Poonch
In Pooch, the variation of noise level recorded at five selected locations during day and night can be seen from Fig. 6. The maximum noise level during the day has been observed at Gurudwara Bhai Rocha Singh Ji, registering 90.5 dB(A) at 5 p.m. Following closely, Eidgah Chowk recorded a noise level of 90 dB(A) at 4 p.m. At these locations noise level is high for most of the day and exceed the permissible CPCB standard. These two locations are prominent place for markets and shops and experience congestion and large traffic volume even sometimes at night hours. After 12 a.m. midnight the noise level goes below 55 dB(A) and during the period of early morning after 3 a.m. the noise levels at most locations remain below 45 dB(A)and thus below the CPCB limit. High diurnal and nocturnal noise level is associated with various health problems[36]. Recio et al.[37] reviewed the health effects of traffic related noise pollution and reported that respiratory disease, cardiovascular disease, and type 2 diabetes can be significantly associated with such high noise levels. Hence Poonch region specially Gurdwara and Eidgah chowk need attention from residents, and municipal authorities to curb the noise pollution.

Nowshera
In Nowshera, Government hospital, Nowshera radio station, Gujral chowk, Lal Dwara, and Government degree college are selected for noise monitoring throughout the day and night. Figure 7 shows the variation of noise level during day and night at five selected locations of Nowshera. The highest noise level during the day is recorded at Nowshera radio station, recording 82.7 dB(A) at 10 a.m. An equally high noise level of 82.7 dB(A) was observed at Government degree college, registered at 9 a.m. whereas Lal Dwara recorded a noise level of 81.9 dB(A) at 9 a.m. Noise levels consistently surpass the prescribed CPCB limit of 55 dB(A) for most of the day in all the monitored locations. The trend of variation of noise level in Nowshera can be attributed to similar reasons as it is in case of Jammu. Between 8 a.m. to 10 a.m. traffic moving for schools, colleges, offices etc. leads to higher noise level. Again between 4 p.m. to 8 p.m. noise level is high due to high traffic volume and congestion arising from the commuters returning to home, going to markets, shops, and other recreational sites. After midnight the noise level reduces and at the early morning hours, the noise levels are below 45 dB(A), providing a quiet environment during early morning hours. However, near Gujral chowk and Government hospital noise level is not below the permissible limit neither during day nor during the night. Thus, it is a matter of concern and the noise levels around these locations need to be mitigated on priority basis for health and well beings of the public.

Noise mapping
Validation of noise prediction model and 2D noise mapping for selected areas have been discussed in the subsequent sections of noise mapping.

Noise map validation
Validation of the noise map has been done by real time monitoring of noise level and comparing with the predicted value of noise and further analysing the results by t-test. Figure 8 shows the positions of SLM from the centre line of road for measuring the real time noise levels and the map generated using NoiseTools to predict the noise level at different distance from the noise source. The monitored and predicted noise levels at three locations are shown in Table 3. It can be seen from Table 3 that predicted noise levels are close to monitored noise levels with maximum standard deviation of 1.76. Hence, it can be inferred that noise mapping through NoiseTools produces good results and can be used for prediction of noise level.

Furthermore, unpaired t-test is performed to statistically assess the fitness of monitored and predicted noise level. Table 4 displays the results of the unpaired t-tests for the Leq noise level at the 5% significance level using

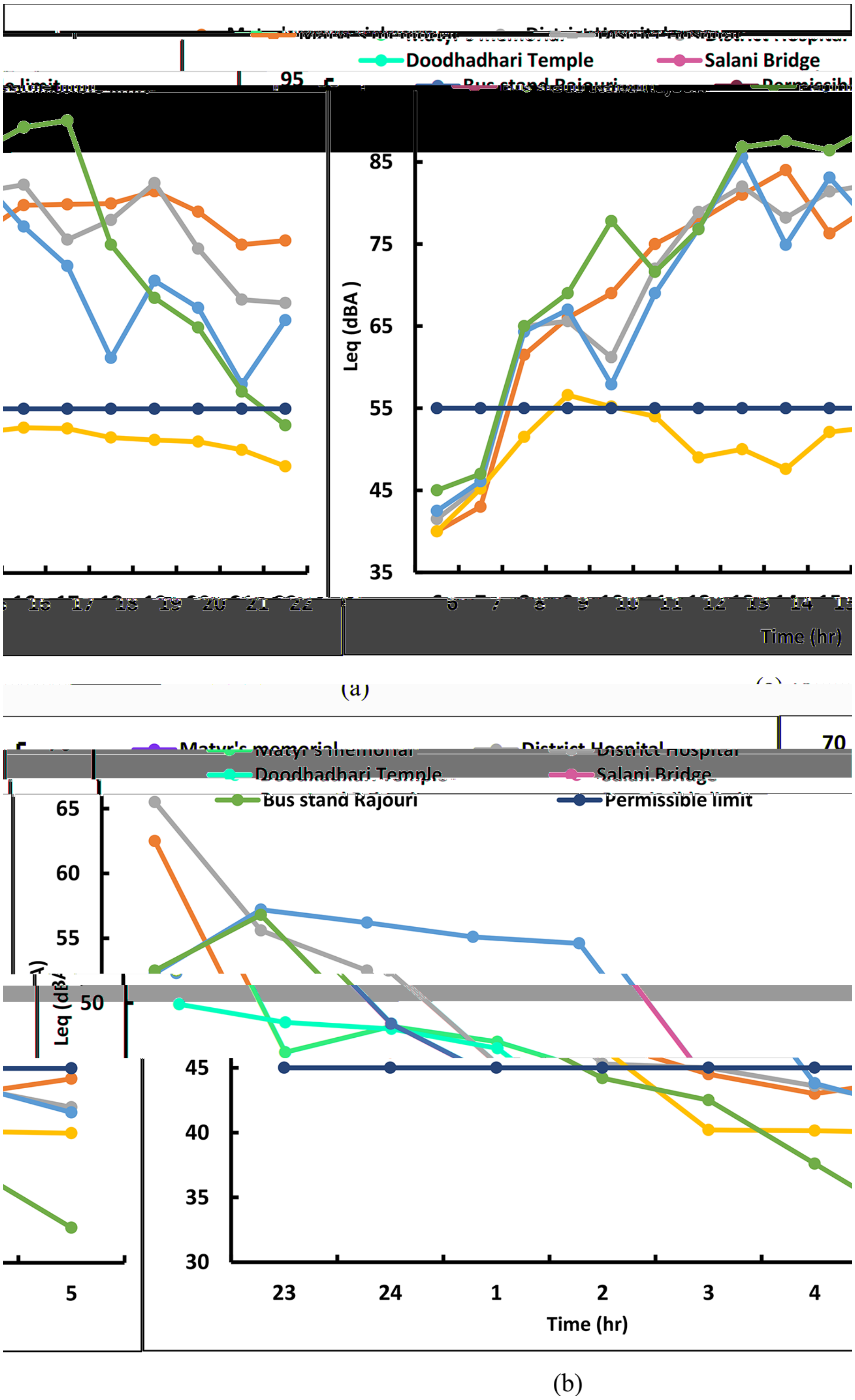

Fig. 5. Variation in noise level at five selected locations of Rajouri during (**a**) day and (**b**) night.

the observed data. The NoiseTools produced a t-statistical value less than t-critical for a degree of freedom of 4 at a 5% significance level. The table presents the validation of a noise prediction tool using a T-test at a 5% significance level. It compares observed (measured) noise levels with predicted noise levels. The mean observed noise level is 66.03 dB(A), while the mean predicted level is 64.33 dB(A), with variances of 24.22 and 37.33, respectively, based on three observations each. The hypothesized mean difference is zero, indicating no assumed difference between the observed and predicted means. With 4 degrees of freedom, the calculated t-statistic is 0.375, which is less than the critical t-value for both one-tail (2.13) and two-tail tests (2.78). The p-values (0.36 for one-tail and 0.73 for two-tail) are higher than the 0.05 significance level, suggesting that there is no

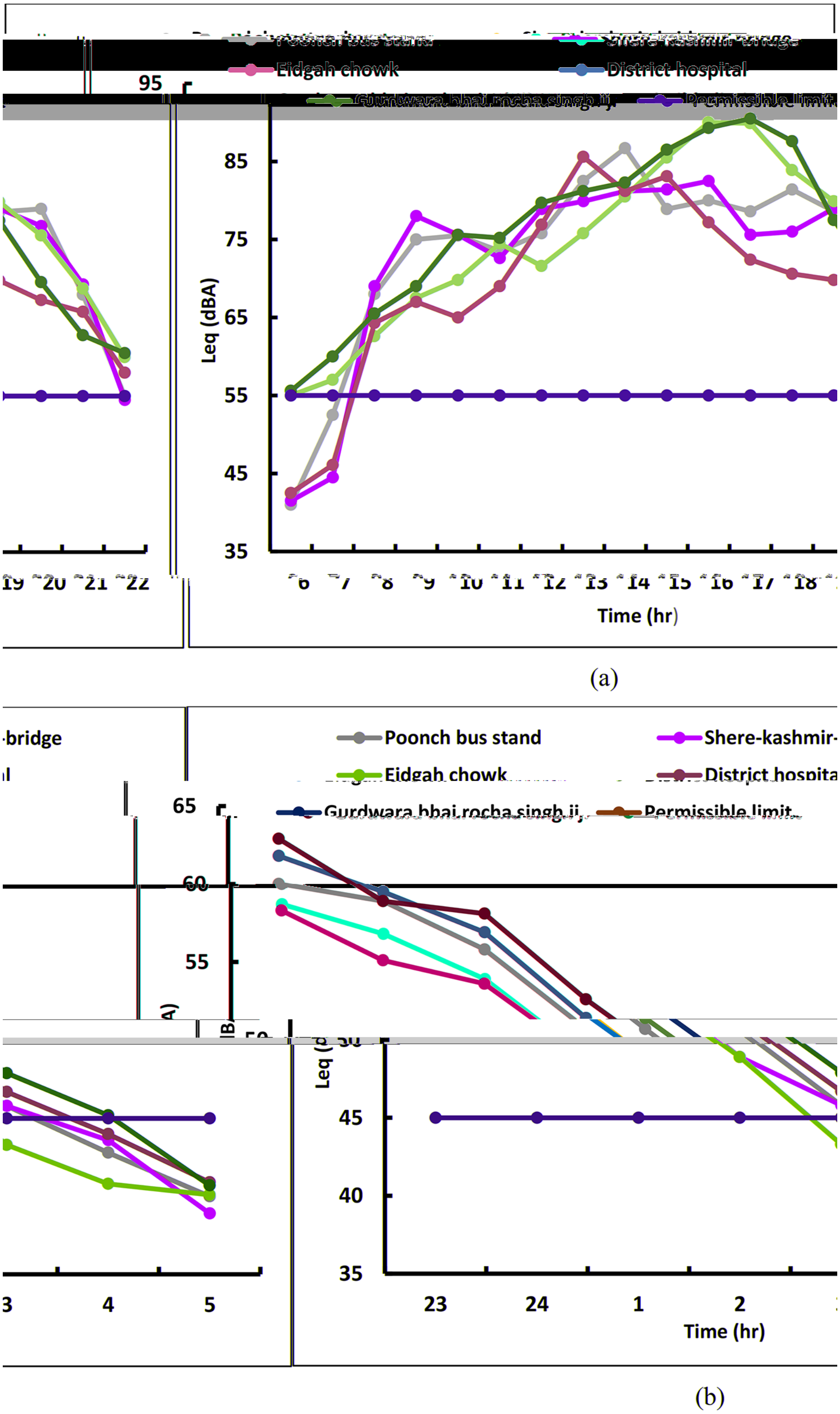

Fig. 6. Variation of noise level at five selected locations of Poonch during (**a**) day and (**b**) night.

statistically significant difference between the observed and predicted noise levels. This indicates that the noise prediction tool performs well in estimating noise levels accurately.

Noise maps of study area

Noise mapping gives better idea about the propagation of noise levels in the X and Y directions. Therefore, in the present study 2D noise maps are developed for the locations with maximum noise level using the noise

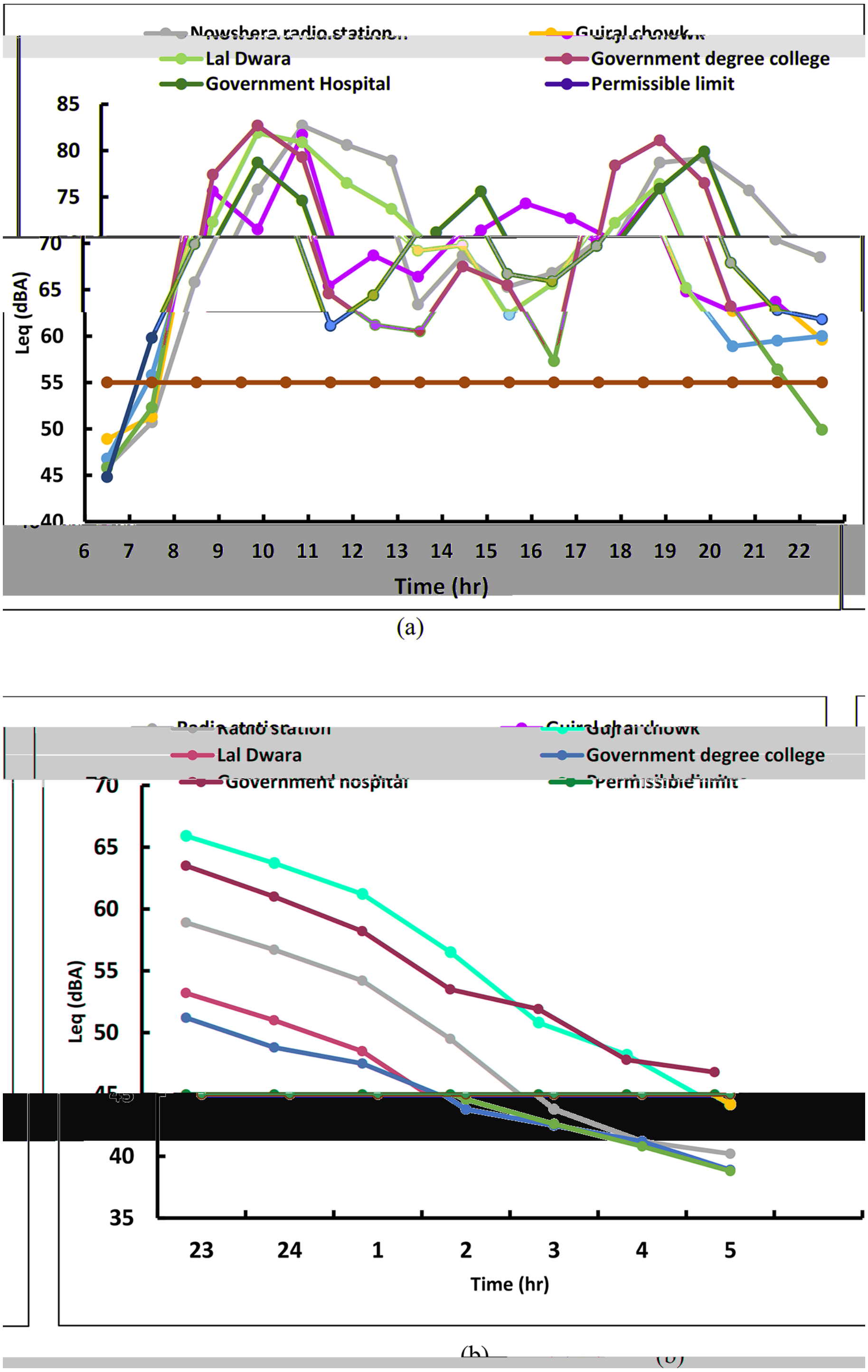

Fig. 7. Variation in noise level at five selected locations of Nowshera during (**a**) day and (**b**) night.

monitoring data. Additionally, it also provides the region and population exposed to loud noise. Noise maps of the selected locations are presented and discussed below.

Jammu

A comprehensive 2D noise map representing the noise level distribution in Bhatindi, Jammu city has been shown in Fig. 9. Notably, Bhatindi emerges as the area with a Leq noise level of more than 80–90 dB(A) as indicated by the colour **Blue** and **Purple**. This noise level can be attributed to various factors, such as the presence of multiple intersections and reflection of noise due to proximity of tall buildings in the vicinity, which collectively contribute to an increased acoustic disturbance during peak hours. According to hearing health foundation, New York, continuous exposure to noise level 55 dB(A) may lead to non-auditory negative health effects such

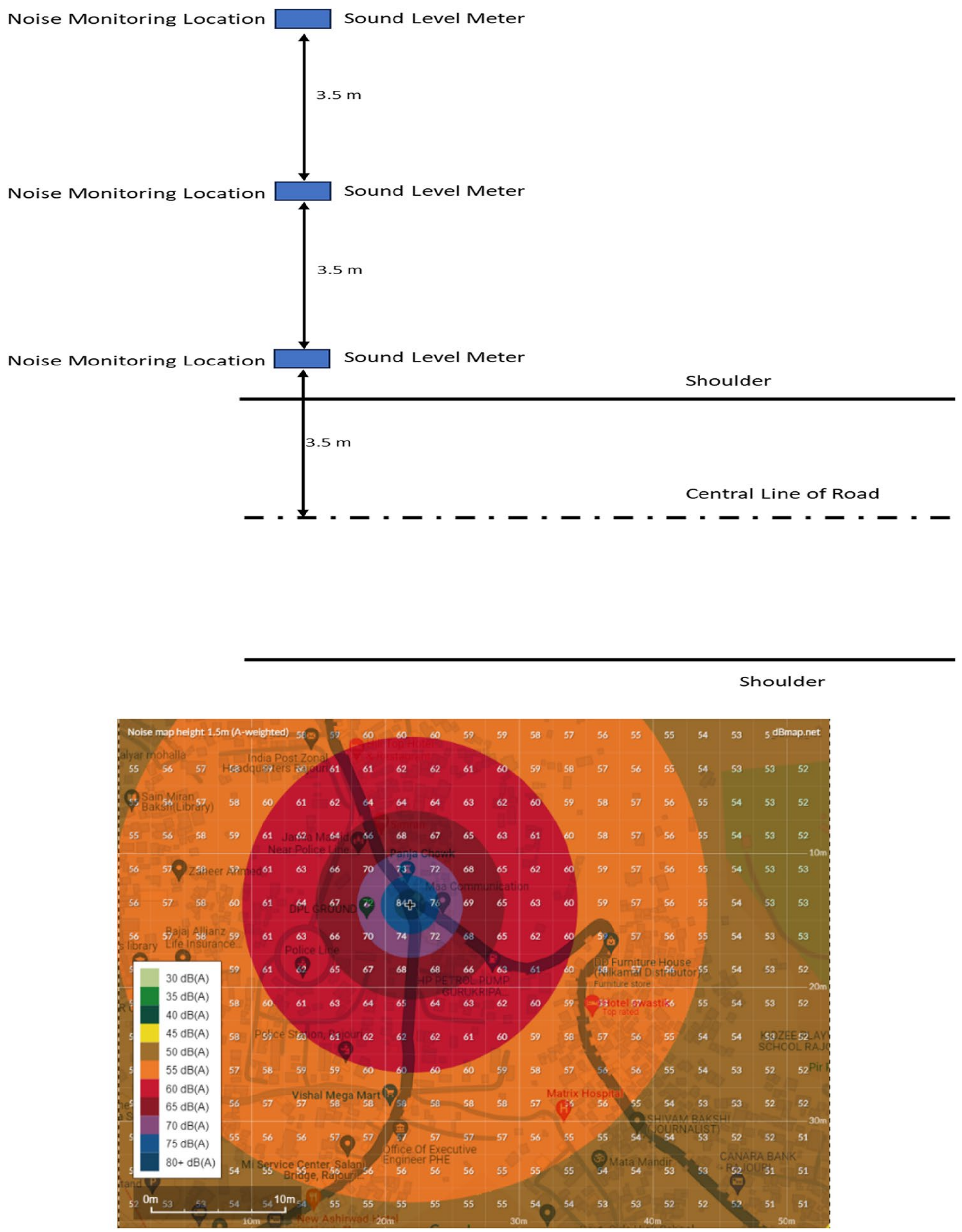

Fig. 8. Noise mapping for validation.

Location	Distance from central line of road	Monitored Noise Level (Leq), dB(A)	Predicted Noise level, dB(A)	Standard Deviation
NML-1	3.5	71.2	71.0	0.14
NML-2	7.0	65.5	63.0	1.76
NML-3	10.5	61.4	59.0	1.69

Table 3. Monitored and predicted noise level for validation. NML, Noise Monitoring Location.

as cardiovascular, respiratory, hypertension and metabolic disorder[36,37]. Conversely, there are regions within Bhatindi where the noise levels are comparatively lower, ranging from 55 –5 dB(A), denoted by **Orange**, **Brown** and **Green** colour on the map. These areas experience a relatively quieter environment due to fewer obstructions and lower concentration of bustling activities. The 2D noise map of Bhatindi serves as a valuable visual representation of the noise distribution across the area, highlighting the varying degrees of acoustic impact throughout the region.

	Monitoring Noise Level	Predicted Noise level
Mean	66.03333333	64.33333333
Variance	24.22333333	37.33333333
Observations	3	3
Hypothesized Mean Difference	0	
df	4	
t Stat	0.375294329	
P(T<=t) one-tail	0.36324708	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.72649416	
t Critical two-tail	2.776445105	

Table 4. Validation of noise Tool using T-Test at 5% significance level.

Fig. 9. 2D noise of selected location of Jammu city.

Rajouri

Figure 10 shows a comprehensive 2D noise map representing the noise distribution near the Bus stand, Panaja Chowk and Mandi in Rajouri. Notably, Rajouri emerges as the area with higher noise levels, reaching a noise level of 80 – 65 dB(A) as indicated by the colour **Blue** and **Red** at the centre of road that is more than the prescribed standard in daytime as well as during night. Prolonged exposure to such noise level to the street vendors, shop owners and workers at this area may negatively affect their health and may develop auditory and non-auditory problems[3,35,36,38–41]. However, after 2D mapping it is observed that buildings/structures distant from the road are within the prescribed standard of CPCB and not exposed to high noise level as they lie in the **Orange**, **Brown** and **Green** region and remain safe during the day and in the night as well. This is due to the neighbouring structures acting as a noise barrier for the distant establishment, reducing the noise level to the permitted CPCB standard.

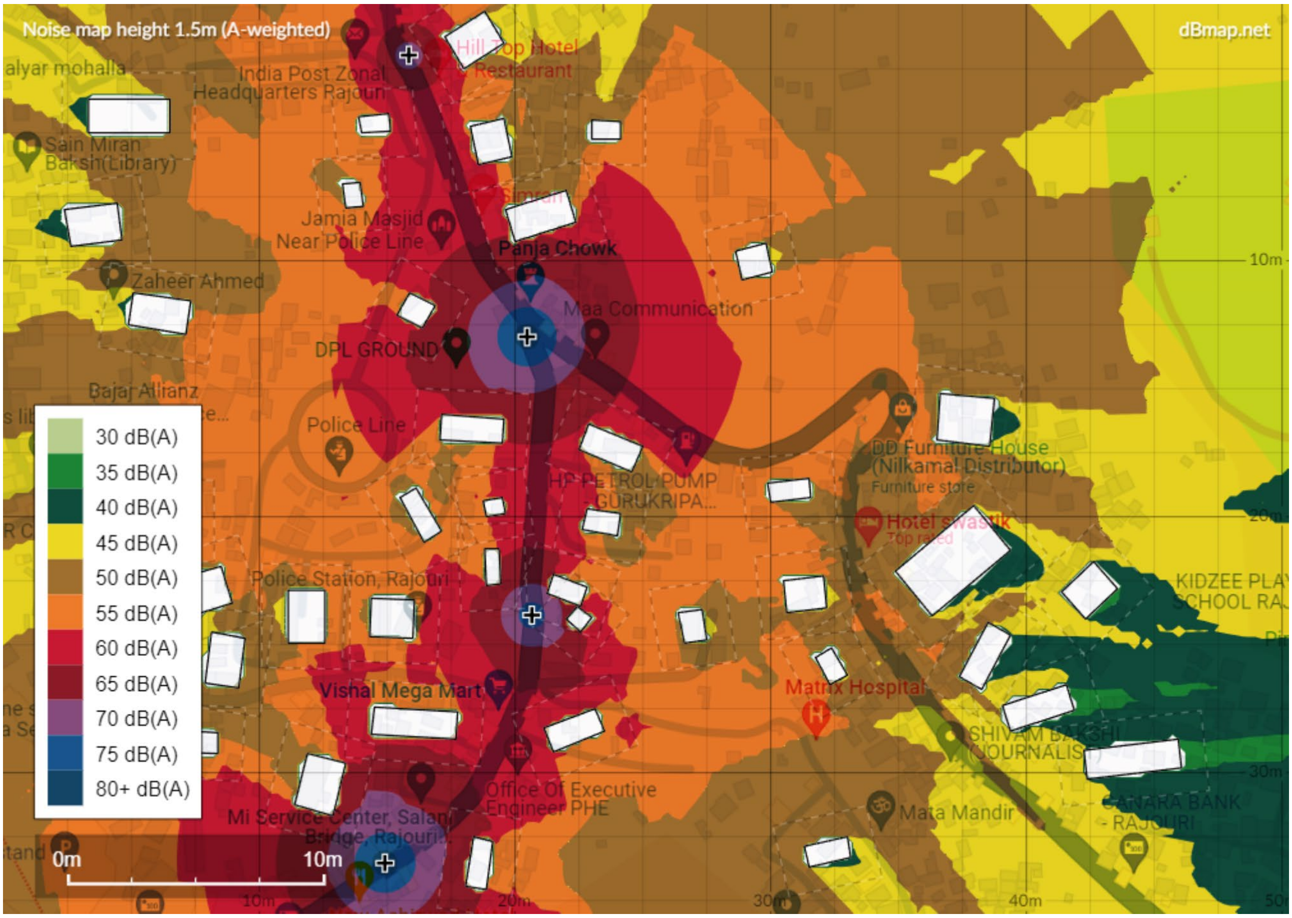

Fig. 10. 2D noise map of selected location of Rajouri.

Poonch

The developed 2D noise map for the location experiencing highest noise level in Poonch is shown in Fig. 11. Poonch experience a relatively quieter environment in comparison to Jammu and Rajouri due to fewer obstructions and lower concentration of bustling activities. The noise level reaches to 70–5 dB(A) as indicated by the colour at the centre of road that is more than the prescribed standard in daytime i.e., 55 dB(A). Suárez and Barros[42] carried out the noise monitoring of Santiago city and observed that the hourly average noise level was much greater during the day than during the evening hours because of the heavy traffic. However, it is discovered after 2D mapping that most of the buildings/structure lies in **Brown** and **Yellow** zone and people living near the selected location are safe due to a lower noise level in comparison to Jammu and Rajouri. This could be because roads in Poonch are wider than in other regions, resulting in reduced traffic volume and congestion.

Nowshera

Figure 12 presents a comprehensive 2D noise map showcasing the noise distribution in Gujral Chowk and other area of Nowshera. Notably, Nowshera stands out as the area with noticeable noise levels, reaching a maximum of 65–55 dB(A) as indicated by the colors **Dark red** and **Yellow** on the map. Nowshera has the calmest surroundings out of all the places that are chosen. Less people and a lower building/structural density could be the cause of this. The 2D noise map also showed that, for the most part of the Nowshera, the noise level stays under the CPCB's recommended standards. In a similar study conducted for Delhi, the regions with appropriate and well-controlled traffic movement had lower noise levels than places with poorly managed traffic, which leads to congestion and honking[43].

Mitigation and control of noise pollution

Noise pollution should be kept at the forefront of health policies and should be targeted by policy makers for avoiding adverse health impact on the public[4]. CPCB restricted the noise level to be less than 55 dB(A) during daytime and 45 dB(A) during night as above these noise levels may cause non-acoustic health hazard[36,38,39,41]. WHO[35] suggested the policy makers to mitigate the noise level above 40 dB(A) during night as the exposure to noise even above 30 dB(A) is linked to adverse health effects. However, the problem of noise pollution can be solved with the involvement of different stakeholders bearing collective and shared responsibilities. To alleviate noise pollution caused by traffic in the study area, several mitigation measures can be implemented. First and foremost, polycarbonate noise barriers[44] must be installed along busy roadways in Jammu, and Rajouri

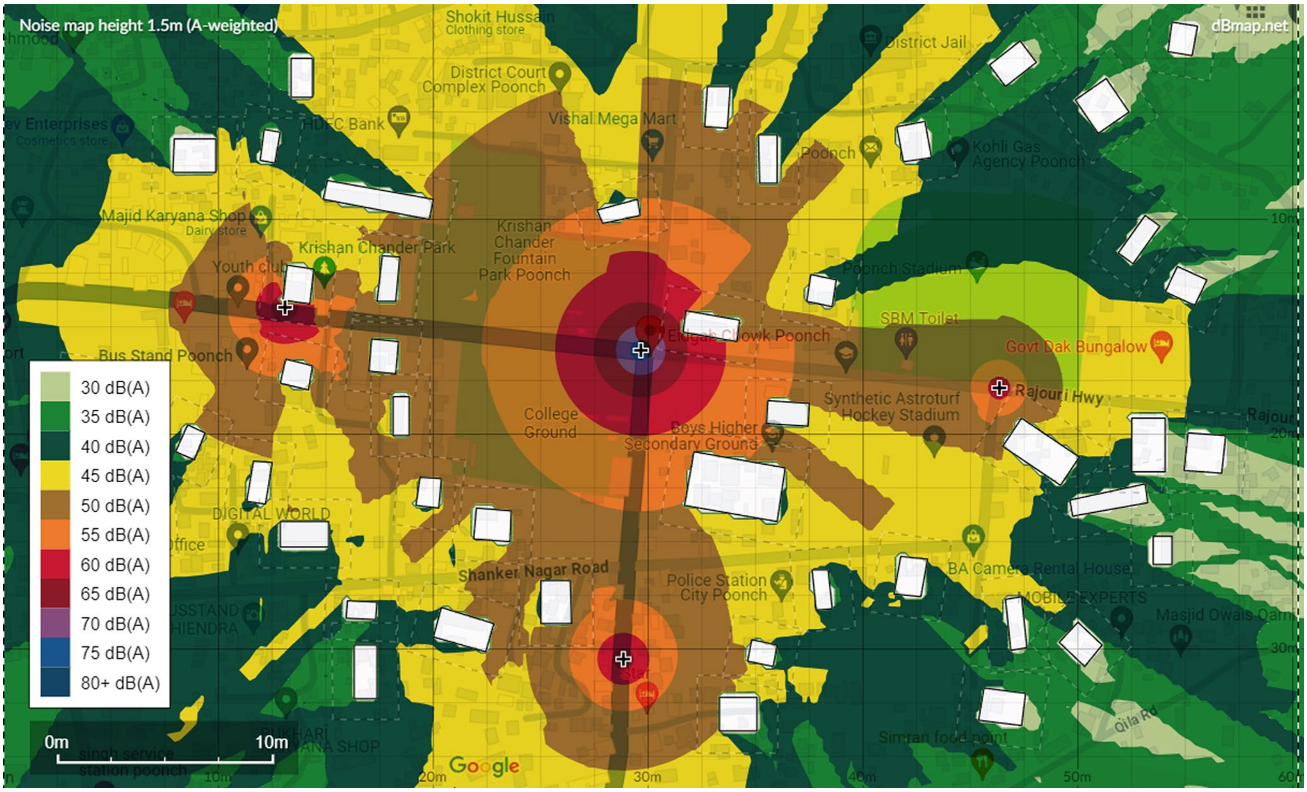

Fig. 11. 2D noise map of selected location of Poonch.

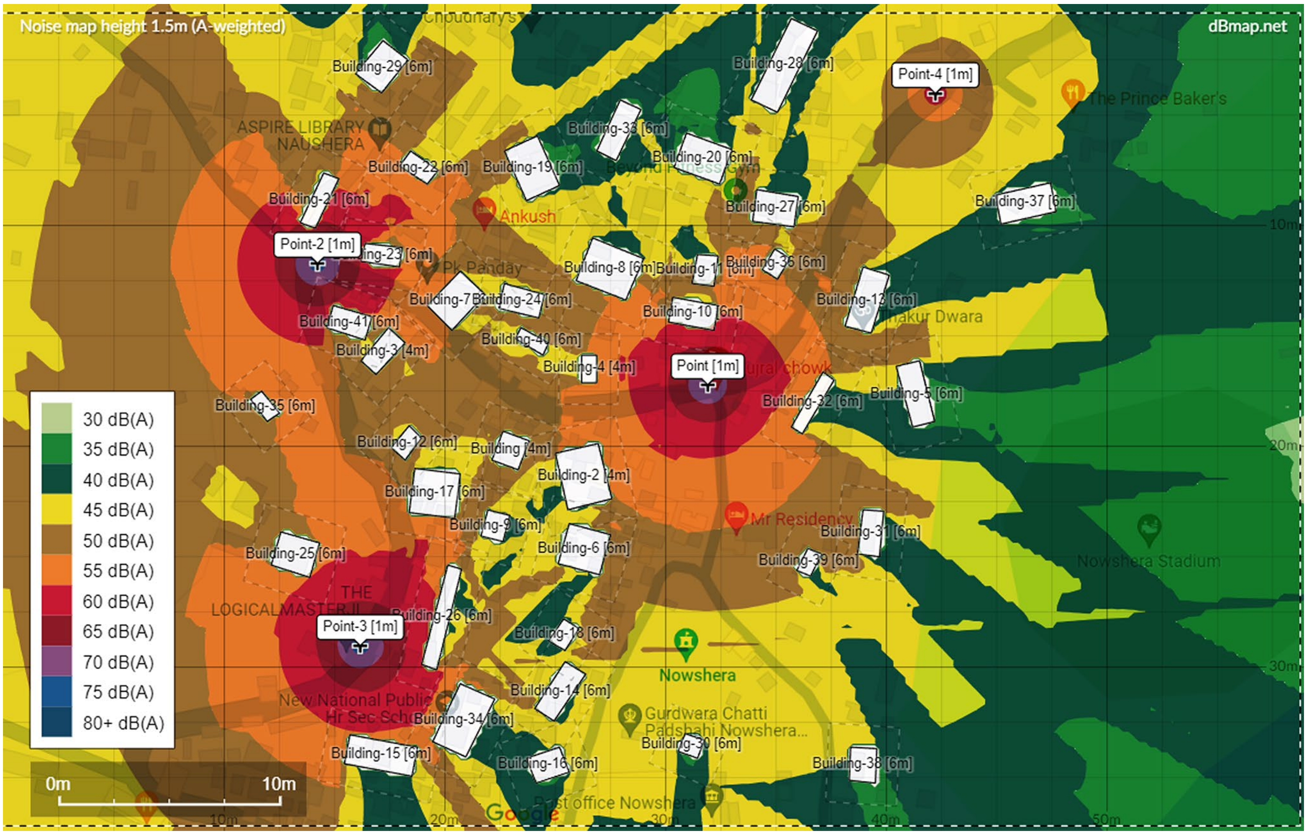

Fig. 12. 2D noise map of selected location of Nowshera.

which can effectively mitigate the transmission of sound waves into residential spaces. Because both of the studied locations have limited space, noise barrier would be an effective technique of reducing noise pollution. Furthermore, efficient traffic management, modified pavements and sustainable vehicles and tires can support the reduction in noise emission[45].

Hospitals are noise sensitive area but generally located within or close to urban population and exposed to high level of noise due to traffic. Thus, requiring mitigation and preserving sensitive area against the noise exposure. Montes-González, et al.[46] carried out the noise monitoring of a hospital in Spain and suggested mitigation measures like the reduction of speed limit to 30 km/h, no use of horn and use of porous asphalt pavement near hospital and predicted reduction in the noise level. Furthermore, establishing green spaces and planting dense vegetation belts of 10–15 m along highways in Poonch and Nowshera can reduce noise levels by up to 5–10 dB(A), serving as effective natural sound absorbers. The availability of open spaces in both study areas provides an opportunity to utilize these natural barriers to help mitigate noise pollution. Moreover, community awareness and education campaigns can educate residents about the detrimental effects of noise pollution and encourage responsible behaviour, such as avoiding unnecessary honking and maintaining vehicles properly to reduce noise emissions. A combination of these measures, tailored to the specific characteristics of the residential area, can contribute to a quieter and more peaceful living environment at the selected areas of Jammu province. Tobías et al.[40] reported that a study in Madrid (Spain) found that 1 dB(A) decrease in diurnal noise levels resulted in reduction of around 200 deaths per year due to cardiovascular and about 300 deaths per year due to respiratory diseases. Such, results can be realized in other parts of the world too, preparing a safer and sustainable environment.

Conclusion

This research paper underscores the significance of systematically assessing and understanding noise pollution in border regions of a country. Through comprehensive noise monitoring and 2D mapping, the study provided valuable insights into the variations of noise levels in four study areas of Jammu and Kashmir. Following conclusions are drawn from this study.

1. Jammu city has the highest day time noise level followed Rajouri and Poonch whereas Nowshera is the calmest area with highest hourly noise level of around 80 dB(A).
2. Commercial activities, heavy traffic, congestion, and narrow roads at some places in Jammu and Rajouri are causing noise pollution and nearby buildings, shops and commuters are exposed to higher noise levels.
3. Although Poonch is also having higher hourly noise level but from the 2D noise map it is clear that most of the buildings/structures are not much affected and lies in brown and yellow region due to distance from the road, wider road network and lesser commercial activities.
4. Nowshera has lesser noise pollution and except the roadside, most of the structures lie in yellow and green region. Nowshera is far from the main city with lesser traffic and closer to the international border.
5. Noise levels required to be mitigated for health and well-being of the public and could be done by installing noise barriers along busy roadways in Jammu, and Rajouri. Promoting green spaces and growing dense vegetation along highways in Poonch and Nowshera can act as natural sound absorbers.
6. As these border areas often present unique challenges, the study emphasizes the need for tailored approaches to address and manage noise pollution, ultimately contributing to the well-being of the communities in the Jammu and Kashmir and fostering sustainable development in the region.

Data availability

All data generated or analysed during this study are included in this manuscript.

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Author contributions

All authors have conceptualized the present study. Formal analysis and investigation are done by Pervez Alam and Tarique Ahmad. All authors have contributed in writing of the original draft of the manuscript. Reviewing and editing of the draft manuscript is carried out by Pervez Alam and Tarique Ahmad. All authors have contributed in preparing response to reviewer comments.

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Declarations

Competing interests
The authors declare no competing interests.

Ethical approval
Present research work does not involve human or animal and therefore approval from any ethics committee is not required. The work has been accomplished with research ethics.

Consent to participate
No human or animal participation therefore any statement of consent is not required.

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