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Original Research

Monitoring and Comprehensive Environmental Safety Assessment of Campus Noise Pollution: A Case Study

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Abstract

Campus noise pollution affects the study, work efficiency, and physical and mental health of teachers and students, which urgently requires scientific monitoring and precise governance. Therefore, this paper takes a university as an example to carry out noise pollution monitoring on the university campus and constructs a fuzzy comprehensive model integrating subjective and objective factors to evaluate environmental safety. Grid-based noise pollution monitoring was conducted at 38 time periods through 19 pre-set monitoring points to obtain continuous equivalent sound level (*Leq*) data; meanwhile, 380 questionnaires were used to explore the perception characteristics of noise among teachers and students. The heat map method was adopted to visualize the spatiotemporal distribution, and the noise pollution index method was used to quantify the pollution degree. On this basis, a fuzzy comprehensive evaluation model was introduced to judge the acoustic environment quality of the university campus from multiple dimensions. The results show that the average daytime sound level of the campus is 58.2 dB(A) and the nighttime average is 48.4 dB(A), which generally meets the Class 1 standard, but local areas such as roads at the school gate and sports areas exceed the standard. The dormitory area is listed as a priority governance object by 81.6% of the respondents, and the subjective annoyance is highly correlated with the measured sound level (r = 0.64). This method is superior to the single mode of traditional limit comparison, realizing a closed loop of “perception-monitoring-evaluation”, and providing technical support for experimental methods and data analysis for the optimal governance of campus acoustic environment.

Keywords: environmental safety assessment, campus acoustic environment, noise monitoring, questionnaire survey, fuzzy comprehensive evaluation

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Introduction

Campus noise pollution has emerged as a significant issue affecting both the quality of higher education and the well-being of students and staff. Research indicates that prolonged exposure to high-intensity environmental noise not only disrupts auditory perception but also impairs students' cognitive functions. These include diminished attention, memory, and information processing efficiency, which directly undermine learning outcomes and teaching effectiveness [1, 2]. Furthermore, chronic noise exposure is significantly associated with increased psychological stress, reduced sleep quality, and elevated long-term health risks among campus residents [3]. Therefore, systematic monitoring and assessment of the campus acoustic environment constitute a critical foundation for optimizing educational environments and safeguarding community health.

Research on noise pollution monitoring and environmental safety assessment in university campuses has advanced considerably in recent years. In terms of monitoring technologies, data acquisition methods have become increasingly diversified. Classical approaches, such as grid-based point sampling and functional zone classification, remain essential for establishing baseline acoustic data [4, 5]. Meanwhile, advanced techniques such as long-term wireless acoustic sensor networks have been increasingly adopted. Such systems can collect psychoacoustic parameters, including sound pressure level, loudness, and sharpness, over several months, providing long-term, high-resolution data support for analyzing spatiotemporal patterns and dynamic evolution of campus noise [6].

Regarding evaluation methodologies, research focus has shifted from single physical indicators toward more systematic and multidimensional assessment frameworks. Traditional objective methods, such as the equivalent continuous A-weighted sound pressure level and the noise pollution index, still serve as core metrics [5]. The introduction of the fuzzy comprehensive evaluation method has enhanced the systematicity and decision-support value of environmental assessments. This approach effectively addresses the fuzziness and uncertainty inherent in evaluation processes, enabling the scientific integration of multiple factors such as the differentiated weights of various functional zones [4].

In the field of data analysis and visualization, the integration of intelligent algorithms and advanced visualization techniques has significantly deepened research insights and practical applications. Three-dimensional heat maps constructed via open-source platforms such as Cesium allow stereoscopic and dynamic visualization of noise data, overcoming the spatial representation limitations of traditional two-dimensional contour maps [7]. In addition, the combination of Geographic Information Systems (GIS) and machine learning models has become a prominent trend. For example, ensemble learning algorithms such as Random Forest can integrate multi-source data, including traffic volume, land-use type, and topography, to achieve high-precision prediction and dynamic mapping of the spatial distribution of campus noise [8]. This provides an innovative technical tool for accurate noise source identification and effective pollution control.

Materials and Methods

Perception of the Campus Acoustic Environment

In the subjective perception survey of the acoustic environment carried out in a university, the research team conducted non-suggestive interviews with 380 teachers and students by means of random questionnaires on campus, including 230 males and 150 females, mainly sophomores and juniors, which can comprehensively reflect the current situation of noise pollution on the campus and the subjective feelings of teachers and students.

Field Monitoring of Campus Noise

The distribution of monitoring points is shown in Fig. 1. The grid point method was adopted to divide the campus into 19 measurement points, and none of the measurement points were set in the lake area: 1, 2, 5, 12, and 13 are the staff areas; 3, 4, 8, 9, 10, and 11 are the teaching areas; 6 and 7 are the sports areas; and 14-19 are the living areas.

Measurements were performed using a TA652B digital sound level meter, as shown in Fig. 2 under weather conditions with no rain or snow and wind

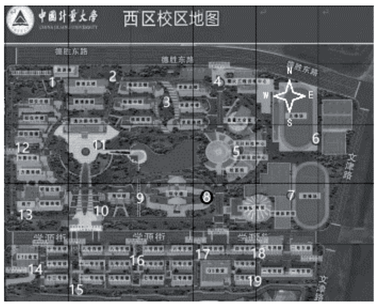


Fig. 1. Distribution of monitoring points.

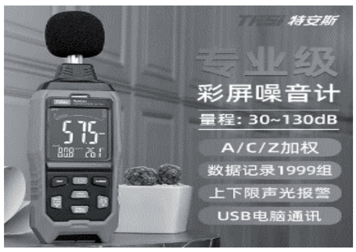


Fig. 2. TA652B digital noise meter.

speed less than 5 m/s. Monitoring points were located at least 3.5 m away from other reflective surfaces and more than 1.2 m above the ground. Monitoring and evaluation of the campus were conducted in accordance with the monitoring methods specified in Appendix B of China's Environmental Quality Standard for Acoustic Environment (GB 3096-2008). The monitoring period was April 18-25, 2025. All measurements were carried out during daytime hours (06:00-22:00 Beijing Time), specifically divided into two intervals: 08:00-18:00 and 18:00-22:00. Each measurement at every point lasted 20 minutes within the corresponding time interval, and monitoring results were expressed in terms of the equivalent continuous A-weighted sound pressure level.

Results

Analysis of Perception of the Acoustic Environment

Statistical analysis based on SPSS shows that the questionnaire presents favorable reliability and validity. In the reliability test, the Cronbach's α coefficient reached 0.87, exceeding the standard threshold of 0.7, confirming good internal consistency of the questionnaire. The validity test indicated that the KMO measure of sampling adequacy was 0.82 (>0.6), combined with a significant Bartlett's test of sphericity ($p<0.001$), jointly verifying the excellent structural validity of the questionnaire. These quantitative results sufficiently support that the questionnaire possesses scientific measurement properties, and its structural design can effectively reflect the real characteristics of the research objects, ensuring the validity and reliability of the research data.

Among the 380 students surveyed, 40% of respondents reported that the overall acoustic environment of the campus was noisy or rather noisy, which indirectly reflects that the subjective perception of the overall acoustic environment of the university is unsatisfactory, with a certain degree of noise disturbance. In particular, 15.79% of students considered their sleep quality to be greatly or severely disturbed, suggesting that the nighttime noise problem is relatively prominent. Meanwhile, 13.15% of students stated that they were greatly or severely disturbed during classes, indicating insufficient quietness in the teaching environment. In addition, 47.36% of students explicitly expressed the hope that the quality of the campus acoustic environment could be improved, demonstrating the urgent demand of teachers and students for a quiet and comfortable learning and living environment.

More notably, as many as 89.47% of students believed that the campus lacks noise management measures or that the existing management is ineffective. This not only reflects the weaknesses of the university in the construction and implementation of the noise control system, but also indicates that subsequent efforts should be strengthened in the campus environmental management system, including enhancing noise monitoring, formulating control standards, and implementing relevant governance measures.

Analysis of Noise Monitoring

According to the Environmental Quality Standard for Acoustic Environment (GB 3096-2008), the campus belongs to a Class 1 standard area, where the daytime noise level is required to be lower than 55 dB. The average value of measured data at each monitoring point represents the overall noise level of that point and is used as the final result. The daytime noise monitoring values of the campus are presented in Table 1.

The sound pressure levels at the 19 monitoring points during working days ranged from 44.17 dB to 67.40 dB. As shown in Table 1, the difference between daytime and nighttime noise was small in most areas, and noise

Table 1. Daytime campus noise monitoring levels / dB(A).

No.	Point	Day	Night	No.	Point	Day	Night	No.	Point	Day	Night
1	Energy Building	60.87	60.10	8	Huanyu Building (East)	53.45	53.45	14	Canteen F16	56.63	52.03
2	Saibo North Building (East)	60.47	59.73	9	Xiangyu Building (East)	67.40	59.33	15	Building 11 (South)	44.87	44.17
3	Gezhi Middle Building (East)	56.00	52.53	10	Xiangyu Building (West)	44.90	49.67	16	Building 7 (North, West)	62.22	66.81
4	Engineering Training Center	61.05	60.07	11	Library (South)	45.63	45.00	17	Canteen G3	57.64	58.44
5	Qiming Square	62.70	67.40	12	Fangyuan North Building (North)	62.17	59.27	18	Building 3 (North, North)	54.18	52.50
6	North Sports Ground	58.38	57.36	13	Wen Hall	47.90	48.47	19	Building 3 (South, South)	53.27	51.47
7	South Sports Ground	58.54	59.40								

levels were generally higher during the daytime. Noise levels were significantly lower at night in staff residential areas and teaching areas. However, monitoring point 10 exhibited lower daytime noise, which was attributed to its proximity to the school gate with higher pedestrian volume. In general, areas near roads showed higher noise levels; a regression equation will be established in the following section to verify this trend.

Quieter locations, such as the lecture hall (monitoring point 13) with fewer people, exhibited lower noise levels. In contrast, the library (monitoring point 11) was noticeably quieter than its surrounding areas.

Heat Map Analysis

The heat map method is a visualization method that intuitively displays data density, intensity, or numerical distribution through color gradients [9]. The spatial or temporal distribution of noise levels can be clearly presented using heat maps. The standards adopted in this study are listed in Table 2. The noise distribution characteristics during typical daytime and nighttime periods were analyzed, and the results are shown in Fig. 3 and Fig. 4.

From observations of heat maps 3 (Fig. 3) and 4 (Fig. 4), the following can be visually identified:

Areas near the urban expressway, namely monitoring points 1, 2, 3, and 4, represent the regions with the highest noise levels. Dark blue coverage is mainly distributed over the library, teaching areas, and most living areas, which can ensure students' learning and living quality. Living areas are significantly quieter at night, and more low-noise regions are represented by dark blue at night.

Analysis of the sports areas (north and south playgrounds) reveals that there are more people during the daytime. The south playground is more popular due to its quieter environment, and the gymnasium can effectively reduce noise. As the metalworking practice center of the university, the Engineering Training Center generates relatively high noise from operating equipment, while this area is less affected by road traffic noise.

Analysis by the Noise Pollution Index Method

The noise pollution at each monitoring point on campus was analyzed using the Noise Pollution Index (NPI) method, following the approach described by Xu et al. (2021) [9]. The calculation formula is as follows in Formula (1).

$$P_N = L_{eq} / L_b \tag{1}$$

Where P_N is the Noise Pollution Index, L_{eq} is the average equivalent A-weighted sound pressure level (dB), and L_b is the benchmark value for the equivalent sound level, set at 75 dB in this study. Applying Formula (1) in conjunction with the noise pollution classification criteria presented in Table 3, the Noise Pollution Index for each of the 19 monitoring points was calculated. The results are summarized in Table 4.

Sound Source Analysis at Each Monitoring Point

Through observation of sound sources at monitoring points, it can be determined that the main sources of campus noise are vehicles, student activities, and equipment operation. Among them, motor vehicle noise mainly includes engine noise (including exhaust noise), wind noise, and tire noise, while electric scooter noise mainly consists of braking noise and tire noise.

Table 2. Heat map color classification standard.

Low Noise (≤55dB)	Medium-Low Noise (56~60 dB)	Medium Noise (61~65 dB)	Medium-High Noise (66~70 dB)	High Noise (≥71 dB)
Dark Blue	Light Blue	Green	Orange	Red

Fig. 3. Daytime campus noise heat map.

Fig. 4. Nighttime campus noise heat map.

Table 3. Noise pollution classification criteria.

Parameter	I	II	III	IV	V
NPI	<0.60	0.60~0.67	0.68~0.75	0.76~1.0	>1.0
Quality status	Excellent	Good	Moderate	Poor	Severe
L_{eq}/dB(A)	<45	45~50	51~56	57~75	>75

Table 4. Calculation results by zone.

Number	Daytime Noise		Nighttime Noise		Number	Daytime Noise		Nighttime Noise	
	P_N	NPI	P_N	NPI		P_N	NPI	P_N	NPI
1	0.8116	IV	0.8013	IV	11	0.6084	II	0.6000	II
2	0.8062	IV	0.7964	IV	12	0.8289	IV	0.7902	IV
3	0.7467	III	0.7004	III	13	0.6387	III	0.6462	III
4	0.8140	IV	0.8009	IV	14	0.7550	III	0.6937	III
5	0.8360	IV	0.8987	IV	15	0.5982	I	0.5889	I
6	0.7784	IV	0.7648	IV	16	0.8296	IV	0.8908	IV
7	0.7805	IV	0.7920	IV	17	0.7685	IV	0.7792	IV
8	0.7126	III	0.7126	III	18	0.7224	III	0.7000	III
9	0.8987	IV	0.7910	IV	19	0.7102	III	0.6862	III
10	0.5987	II	0.6622	II					

The university should regulate the driving of campus electric scooters and adopt a pavement wearing course overlay to reduce road noise. Student activity noise is mainly from playing and talking, which can be managed by strengthening education and posting warning signs. Mechanical equipment noise can be controlled through regular maintenance or equipment improvement.

Noise Prediction Using Nonlinear Regression

Noise prediction serves not only to analyze future trends in monitoring data but also to provide a scientific basis for long-term acoustic planning on campus [4, 5]. To achieve an objective and accurate fit for the measured data, this study employs univariate polynomial regression analysis. This method effectively captures potential nonlinear characteristics in the noise data through its curvilinear form. The fundamental equation is presented as Formula (2).

$$y = a_0x + a_1x^2 + a_2x^3 + \cdots a_nx^m \tag{2}$$

In the prediction model, time and distance from the road were used as the abscissa, and dB(A) as the ordinate, with data imported accordingly. The ordinate of each data point represents the average equivalent continuous A-weighted sound pressure level of the monitoring point during a certain monitoring period, and the abscissa represents the time of measurement or the distance from the road.

Fig. 5 shows the regression analysis of the influence of distance from the road on noise level, with a correlation coefficient of 0.3919. The absolute value of 0.3919 falls within the range of 0.3-0.5, indicating a weak correlation. It can be observed from Fig. 5 that

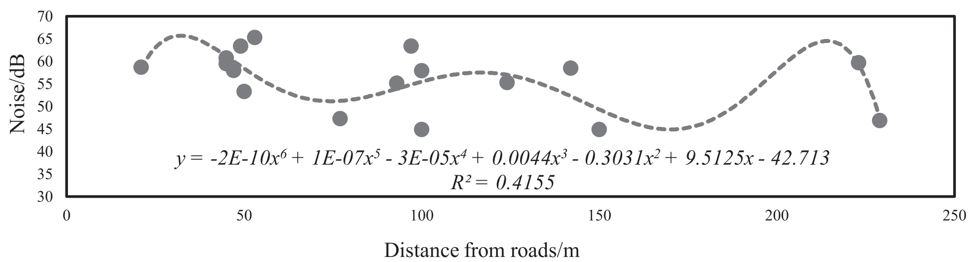
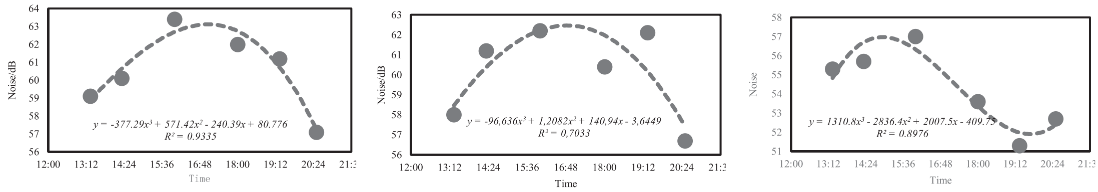
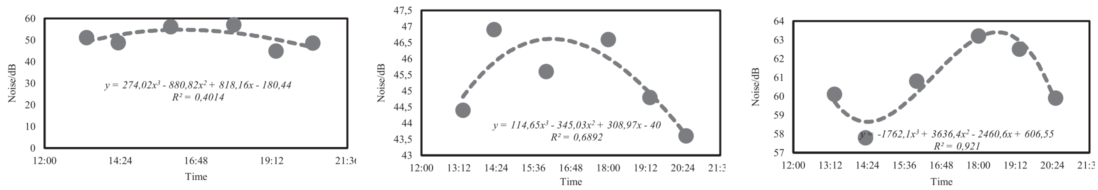


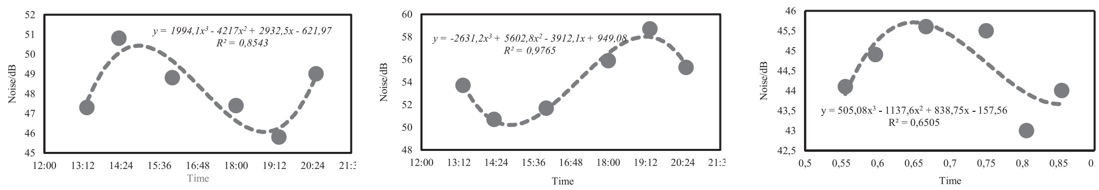
Fig. 5. Regression analysis of the effect of distance on noise.



a) Area 1: Energy Building   b) Area 2: Saibo North Building (East)   c) Area 3: Gezhi Middle Building (East)



d) Area 10: Xiangyu Building (West)   e) Area 11: Library (South)   f) Area 12: Fangyuan North Building (North)



g) Area 13: Wen Hall (South)   h) Area 14: Building 10 (South, West)   i) Area 15: Building 13 (South)

Fig. 6. Regression analysis of the effect of time on noise in selected zones.

there is a weak negative linear correlation between the two variables. Although their variations exhibit a certain inverse trend, this trend is unstable and may be significantly affected by other factors.

Fig. 6 presents the regression analysis of the influence of time on noise levels at selected monitoring points. The analysis reveals that the diurnal noise level fluctuates in a pattern highly consistent with the daily routine of students, as detailed below. During the midday period from 12:00 to 14:24, the noise level rose rapidly from 50 dB to 70 dB, forming the first peak, which was closely related to students returning to dormitories after classes and increased activities during lunch. Subsequently, from 14:24 to 16:48, the noise level dropped to 40-50 dB, presumably due to reduced student activities caused by classes or noon breaks. In the evening period from 16:48 to 19:12, the noise level increased again to 60-70 dB, coinciding with concentrated student activities such as dining, socializing, and sports. During the night period from 19:12 to 21:36, the noise level reached a peak of 70 dB and seriously exceeded the standard, which may result from intensive club activities, games, and gatherings. Late at night, from 21:36 to 00:00, as dormitory lights were turned off and students maintained a quiet schedule, the noise level decreased to a low level of 20-30 dB. Overall, the temporal variation in noise directly reflects differences in the intensity of student activities. The goodness-of-fit was calculated for each model to evaluate the accuracy of the prediction models. The coefficient of determination R^2 of each model was above 0.4 except for Zone 10, and values for Zones 1, 12, and 14 even exceeded 0.9, indicating satisfactory fitting performance.

Fuzzy Comprehensive Assessment of Campus Acoustic Environment

A subjective-objective integrated method was adopted. Considering the continuous equivalent sound level (L_{eq}) at 19 grid monitoring points over 38 time intervals and 380 student questionnaires, a fuzzy comprehensive assessment model was constructed to conduct an overall judgment and classification of the campus acoustic environment [10]. Objective monitoring results show that the average daytime L_{eq} was 58.2 dB(A) and the nighttime L_{eq} was 48.4 dB(A), with significant differences in noise levels among different functional zones ($p<0.05$). For the subjective survey, the Cronbach's α coefficient of the questionnaire was 0.87, and the KMO value was 0.82, indicating good reliability and validity. The survey results reveal that 81.6% of respondents believed the dormitory area was most in need of improvement, and 73.7% identified construction noise as the primary source of disturbance. In the noise assessment, four types of functional zones – teaching area, living area, sports area, and staff area – were used as assessment units. A reciprocal matrix was established using the 1-9 scale method to determine the weight of each monitoring point.

$$A = \begin{bmatrix} 1 & 3 & 5 & 7 \\ 1/3 & 1 & 2 & 4 \\ 1/5 & 1/2 & 1 & 3 \\ 1/7 & 1/4 & 1/3 & 1 \end{bmatrix}$$

Following the calculation procedure described, the consistency test results for judgment matrix A are as follows: the maximum eigenvalue λ_max is approximately 4.117, the consistency index (CI) is 0.039, and the average random consistency index (RI) for a matrix of the same order is 0.90 (obtained from standard reference tables). The random consistency ratio (CR) is 0.043 (CR<0.10), which indicates that the judgment matrix passes the consistency test. Thus, matrix A is considered acceptable and well-constructed. Consequently, the normalized weight vector for the functional zones was determined to be Q = [0.602, 0.222, 0.123, 0.053].

Based on the daytime noise limits specified in the Environmental Quality Standard for Noise (GB 3096-2008), the sound level range from 0 dB to 75 dB was divided into five consecutive intervals, each corresponding to a standard acoustic environment category (Class 0 to Class 4). To ensure a smooth transition between adjacent categories and avoid abrupt changes at the boundaries, a hybrid membership function combining linear trapezoidal and triangular forms, as shown in Formula (3), was employed to calculate the degree of membership of each noise value to the different categories.

$$V_1(x)=\begin{cases}1, & x\le 50\\ -\frac{1}{5}(x-55), & 50<x<55\\ 0, & x\ge 55\end{cases}\quad V_2(x)=\begin{cases}0, & x\le 50\ ,\ x\ge 60\\ \frac{1}{5}(x-50), & 50<x<55\\ -\frac{1}{5}(x-60), & 55<x<60\end{cases}$$

$$V_3(x)=\begin{cases}0, & x\le 55\ ,\ x\ge 65\\ \frac{1}{5}(x-55), & 55<x\le 60\\ -\frac{1}{5}(x-65), & 60<x<65\end{cases}\quad V_4(x)=\begin{cases}0, & x\le 60\ ,\ x\ge 70\\ \frac{1}{5}(x-60), & 60<x\le 65\\ -\frac{1}{5}(x-65), & 65<x<70\end{cases}$$

$$V_5(x)=\begin{cases}0, & x\le 65\\ \frac{1}{5}(x-60), & 65<x<70\\ 1, & x\ge 70\end{cases} \tag{3}$$

The 19 monitoring points were grouped according to functional zones, and the daytime arithmetic mean values were calculated. Based on the calculated data, the average daytime L_{eq} values on working days for each campus functional zone are as follows: teaching area 55.3 dB, living area 56.8 dB, staff area 53.1 dB, and sports area 58.4 dB. Substituting these values into the function yields the single-factor evaluation matrix R.

$$R=\begin{bmatrix}0 & 0.94 & 0.06 & 0 & 0\\ 0 & 0.64 & 0.36 & 0 & 0\\ 0.38 & 0.62 & 0 & 0 & 0\\ 0 & 0.32 & 0.68 & 0 & 0\end{bmatrix}$$

According to the provisions on daytime noise limits in the Environmental Quality Standard for Acoustic Environment (GB 3096-2008), Class 1 standard applies to areas such as cultural education and medical and health care (limit 55 dB), and Class 2 standard applies to areas such as finance, commerce, and fairs (limit 60 dB). By constructing the weight vector Q = [0.602, 0.222, 0.123, 0.053] and using the M(·, ⊕) model for a fuzzy comprehensive assessment, the normalized result B = [0.04674, 0.80118, 0.15208, 0, 0] was obtained. The analysis shows that the maximum membership degree of 0.80118 corresponds to the "Class 1 compliant area", indicating that the overall acoustic environmental quality of the campus basically meets the requirements of the Class 1 functional area standard. However, the Class 2 membership degree of 0.15208 indicates that the sports area and part of the living area present slight noise exceedance, and these areas need to be regarded as key governance targets for attention and improvement.

Discussion

Analysis of Noise Measurement

This study conducted continuous noise monitoring at 19 grid points on the campus, combined with heat map visualization, noise pollution index (NPI) classification, and nonlinear regression analysis to systematically reveal the spatiotemporal distribution characteristics of the campus acoustic environment. The measured daytime equivalent sound pressure levels ranged from 44.17 dB(A) to 67.40 dB(A), and multiple monitoring points near urban expressways, teaching buildings, and sports fields exceeded the 55 dB(A) limit for Class 1 areas specified in GB 3096-2008, which is consistent with previous findings that key areas such as campus entrances, teaching areas, and residential quarters exhibit noise exceedance phenomena [11]. Heat map analysis intuitively demonstrated that noise levels were significantly higher in regions adjacent to traffic arteries, while quiet functional zones such as libraries and lecture halls maintained relatively low noise values, verifying the close correlation between the spatial distribution of noise and road distance as well as human activity intensity [12]. The NPI classification results indicated that most monitoring points were rated as moderate to poor pollution levels, and nighttime noise in residential areas remained prominent, which echoes the conclusion that long-term monitoring identifies acoustically saturated zones on campus requiring targeted governance [13].

In terms of testing methods, this study adopted fixed-point long-term monitoring and grid layout, which not only captured the diurnal fluctuation pattern of noise synchronized with students' daily routines but also enabled quantitative prediction of noise variation trends via nonlinear regression. Compared with short-term or single-point noise measurements at university campus entrances in previous research [12], the multidimensional testing scheme adopted in this study improved the accuracy and representativeness of data collection. Meanwhile, similar to noise assessments of high-speed railways affecting campus acoustic environments [14], this study confirmed that traffic and mechanical equipment were dominant noise sources, and noise generated by vehicle operation, equipment running, and student activities collectively determined the overall acoustic quality of the campus. In addition, the wireless acoustic sensor network used in the long-term psychoacoustic parameter analysis of campus acoustic environments [13] provided a reference for the continuous dynamic monitoring in this study, suggesting that the combination of fixed monitoring and visual analysis can effectively support refined identification of noise pollution sources. The distributed acoustic sensing (DAS) technology applied in campus mechanical noise monitoring [15] also indicates that advanced monitoring means can further improve the precision of noise source localization, which is instructive for the optimization of subsequent testing schemes. Furthermore, some educational environments meet local noise standards through reasonable environmental control [16], which provides a benchmark for evaluating the rationality of the test results in this study.

Assessment of Noise Impact

The subjective–objective integrated evaluation results showed that 40% of respondents perceived the campus acoustic environment as noisy, 89.47% of students considered the existing noise management measures inadequate, and nighttime sleep disturbance and classroom interference were prominent, directly reflecting the negative impacts of noise on the daily life and learning of teachers and students. This subjective perception was highly consistent with the objective monitoring data of partial zone exceedance, jointly confirming that the current campus acoustic environment cannot fully meet the needs of quiet learning and living. The fuzzy comprehensive assessment based on monitoring data and questionnaire responses classified the campus as basically meeting the Class 1 functional area standard, but slight exceedance existed in sports areas and part of the living areas, marking these key zones as priorities for governance. This conclusion is similar to the evaluation results that noise pollution in hospital sensitive zones is severe with obvious non-auditory health effects [17], indicating that noise in education-sensitive areas poses potential public health risks similar to those in medical areas.

From the perspective of impact mechanisms, traffic noise, construction noise, and student activity noise were the main interference sources identified in this study, with traffic noise regarded as the primary factor by most respondents, consistent with findings that traffic is the main noise source in and around campus-sensitive zones [11, 17]. High-speed railway noise has been proven to exert significant maximum sound pressure level impacts on classroom learning environments [14], and this study further supplements that internal campus functional zone noise also presents substantial spatiotemporal differences in impact intensity, with evening activity noise peaks severely exceeding standards and exacerbating rest disturbances. In addition, long-term psychoacoustic parameter analysis of campus acoustic environments has shown that loudness is highly correlated with binaural annoyance [13], and this study further confirms that unreasonable spatial layout of noise sources and lack of effective control measures jointly reduce acoustic environment satisfaction. Compared with educational environments where noise complies with local legal standards [16], the study campus experiences partial exceedance due to the superposition of external traffic and internal activities, highlighting the necessity of formulating differentiated governance strategies for different functional zones. The unsatisfactory subjective perception of noise and prominent health-related disturbance effects in this study also align with the non-auditory health hazards (e.g., headache, sleep loss) caused by long-term noise exposure in sensitive areas reported in previous research [17], emphasizing the urgency of strengthening campus noise control and management.

Conclusions

In this study, an experimental investigation combined with a subjective-objective integrated fuzzy comprehensive method was adopted to systematically evaluate the acoustic environmental quality of a university campus. The main research findings are summarized as follows:

(1) In terms of noise monitoring, grid-based noise monitoring with continuous measurements at 19 monitoring points across 38 time intervals was integrated with a large-scale questionnaire survey involving 380 valid samples. Heat map analysis, noise pollution index method, and fuzzy comprehensive assessment model were employed to analyze the acoustic environment data.

(2) The experimental research focused on solving three key issues. First, the spatiotemporal distribution characteristics of campus noise were accurately identified. Under the overall levels of 58.2 dB(A) on average in the daytime and 48.4 dB(A) at night, local areas such as the road near the school gate (72.8 dB(A) in daytime) exceeded the standard limit. Second, the actual impact of noise on teachers and students was quantitatively evaluated; 81.6% of respondents believed that dormitory areas should be prioritized for treatment, and subjective annoyance was significantly correlated with measured values ($r = 0.64$). Third, a scientific evaluation system was established, and fuzzy comprehensive judgment confirmed that the campus generally meets Class 1 standards despite local risks.

(3) The results provide scientific and operable solutions for university noise control, including precise noise reduction measures and suggestions for optimizing management systems, which have important practical value for improving campus acoustic environmental quality. In the future, the application of Internet of Things monitoring technology can be further expanded, existing evaluation algorithms can be optimized, and a dynamic early warning system can be established to realize the intelligent upgrading of noise control.

AI Usage Disclosure Statement

The authors declare that they have not used Artificial Intelligence (AI) tools in the creation of this article. However, in the process of revising the manuscript, we used AI website (Doubao https://www.doubao.com/chat/) to translate some of the original Chinese content into English.

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Conflict of Interest

The authors declare no conflict of interest.

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