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REVIEW ARTICLE

Technical methods for identifying and assessing residential environmental damage caused by noise

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Abstract: The impact of noise on residential environments has become increasingly prominent—a trend reflected in noise disturbance complaints, which rank first among all environmental pollution-related grievances. However, no authoritative guidance documents have yet been developed to standardize evaluation methods for residential environmental damage caused by noise, and damage assessment standards remain a key contention in noise-related tort disputes. Based on existing Chinese and international noise-related standards (e.g., International Organization for Standardization 1996-1 and World Health Organization guidelines) and practical experience, this review systematically summarizes the challenges in identifying and assessing residential environmental damage caused by noise, focusing specifically on the technical approaches in three key areas: damage identification, causality analysis, and damage quantification. This research establishes a replicable framework for practitioners engaged in noise damage assessment, effectively ensuring the standardization of assessment procedures and the reliability of outcomes.

Keywords: Noise; Living environment; Damage identification and assessment; Technical methods

1. Introduction

In recent years, with rapid urban development and rising living standards, the problem of noise impact on the living environment has become increasingly prominent—a trend evidenced by the gradual rise in noise complaints, disputes, and lawsuits.[1] The 2023 Noise Pollution Prevention and Control Report[2] indicates that in 2022 in China, the national ecological and environmental letters, complaints, and reports management platform received more than 254,000 public complaints, of which noise-related complaints accounted for 59.9%, representing the largest share among all categories of ecological and environmental pollution complaints. However, existing research on residential noise damage assessment faces three critical gaps: First, most studies provide theoretical description of individual methods (e.g., quantification or identification alone) without an integrated framework covering verification, causality, and quantification; second, empirical validation via real-world cases is scarce, leading to poor practical applicability;[3] and third, literature reviews are heavily biased toward Chinese standards, with insufficient integration of international norms (e.g., International

Organization for Standardization [ISO],[4] World Health Organization [WHO],[5] and European Union [EU] directives) and global research progress. Although the Law of the People's Republic of China on the Prevention and Control of Noise Pollution (2022) and ISO 1996-1:2016 (Acoustics — Description, measurement and assessment of environmental noise) provide a technical basis, no guiding documents have been issued to date to unify the assessment processes.

Therefore, based on laws, regulations, standards, and current practical experience with noise, this review explores the technical methods for assessing noise damage, aiming to provide a clear technical route and feasible standardized procedures for identifying and assessing noise damage.

2. Status of technical standards for environmental damage caused by noise

Since 2020, China's Ministry of Ecology and Environment and the State Administration for Market Regulation have jointly developed and promulgated nine technical standards governing critical procedures, environmental media, and fundamental methodologies in environmental damage assessment. However, a dedicated assessment methodology for noise pollution remains conspicuously absent from this regulatory framework.[6]

The monitoring and evaluation standards and norms related to residential environmental noise are shown in Table 1. As summarized, these documents can be grouped by target object into noise-source standards, acoustic-environment standards, and building acoustic design standards. Among them, the existing noise source-related standards and norms are the same as the noise category division in the Noise Pollution Prevention and Control Law, including the four major categories of industrial production, building construction, transportation, and community; environmental quality standards include the overall acoustic environment, such as the railroad boundary, the residential acoustic environment, and the architectural acoustic environment; and the Code for Acoustic Insulation Design of Civil Buildings is mainly applicable to the requirements for the installation of utilities and equipment in residential homes.

To fill the gap of Chinese standards, this study integrates international norms:

(i) ISO 1996-1:2016 (*Acoustics—Description, measurement and assessment of environmental noise*): Provides global unified methods for noise measurement; and

(ii) WHO guidelines for community noise (2018): Links noise exposure to health impacts (e.g., nighttime noise >40 dB[A]).

3. Challenges in the identification and assessment of residential environmental damage caused by noise

Unlike tangible pollutant emissions, noise is transient and context-dependent, which complicates damage verification and attribution. First, the applicable standards for different types of noise pollution are unclear (e.g., Chinese GB 3096-2008 vs. WHO 40 dB[A] nighttime limit), leading to inconsistent verification results; second, there are contradictions between different technical standards in terms of measurement methods and evaluation criteria; and thirdly, noise sources in most measurement environments are excessively complex (e.g., mixed elevator, traffic, and construction noise), making it difficult to determine causal relationships. The comparison of Chinese and international noise/vibration standards is presented in Table 2.

3.1. Issues of applicable standards for noise damage

As most of the noise standards in China were formulated more than 10 years ago, with complex formulation authorities and procedures, they resulted in outdated, contradictory, and incomplete standards. For example, there are no clear standards for the equipment installed in residential buildings to serve residents' daily needs[7] (such as elevators, pumps, and transformers). This regulatory ambiguity frequently results in contradictory judicial rulings where emission standards deemed applicable in one jurisdiction are categorically rejected in another.[8] This inconsistency contrasts with international practice, where ISO 1996-1:2016 provides unified measurement protocols, reducing regional discrepancies.[9]

3.2. Issues in noise damage verification

Noise pollution disputes predominantly originate from resident-initiated complaints, typically citing impairment of normal living, occupational, or educational activities. Under China's Noise Pollution Prevention and Control Law, environmental noise pollution is legally defined as comprising two constitutive elements: Exceeding permissible emission limits and causing interference with others' routine activities. Consequently, adjudication of noise-related cases requires sequential verification: (i) Whether emissions exceed applicable

Table 1. Summary of noise monitoring and evaluation standards and specifications

Standard ID	Name	Year	Target object	Scope of application
GB12348-2008	"Emission standard for noise at boundary "	2008	Noise source	Applies to the management, evaluation, and control of noise emissions from industrial enterprises.
GB12523-2011	"Emission standard environment noise boundary of construction site"	2011	Noise source	Applies to the management, evaluation, and control of construction noise emissions near noise-sensitive buildings.
GB22337-2008	"Emission standard for community noise"	2008	Noise source	Applies to the management, evaluation, and control of noise-emitting equipment and facilities in commercial cultural/entertainment venues and business operations.
HJ 707-2014	"Technical Specifications for Environmental Noise Monitoring Structure-borne Indoor Noise From Associated Facilities"	2014	Noise source	Applies to indoor noise monitoring caused by structure-borne fixed equipment, as specified in GB 12348 and GB 22337. Other similar measurements may reference this method.
GB1495-2002	"Limits and measurement methods for noise emitted by accelerating motor vehicles"	2002	Noise source	Applies to limits and measurement methods for exterior noise of newly manufactured vehicles (M and N1 categories) during acceleration.
GB/T 14365-2017	"Acoustics–Measurement of noise emitted by stationary road vehicles"	2017	Noise source	Applies to stationary noise measurements of motor vehicles on roads.
GB3096-2008	"Environmental quality standard for noise"	2008	Acoustic environment	Applies to the evaluation and management of ambient noise quality.
GB12525-90	"Emission standards and measurement methods of railway noise on the boundary alongside the railway line"	1990	Railway boundary acoustic environment	Applies to railway boundary noise evaluation in urban areas.
GB 55016-2021	General Code for Building Environment	2021	Building acoustic environment	Applies to maintenance management requirements for public facilities in residential buildings.
SF/T 0109—2021	"Forensic measurement and assessment of noise in the living environment"	2021	Building sound insulation design	For noise measurements and evaluations explicitly covered by national standards, use those standards. For cases where national standards are inapplicable, use this document.
GB50118-2010	"Code for design of sound insulation of civil buildings"	2010	Building sound insulation design	Applies to installation requirements for public facility equipment in residential buildings.

limits; and (ii) whether the exceedance interferes with normal living/learning/working activities, establishing a link between the polluting act and the claimed harm. However, in the case of noise pollution disputes, there are often inconsistencies between the alleged polluting act and the observed consequences, making damage confirmation difficult.

3.3. Issues in determining the causality of noise environmental damage

The determination of causal relationships in noise pollution disputes is extremely complex, attributed to two key factors. First, the diversity of social noise sources creates multi-factor scenarios where environmental damage is often a cumulative effect of

Table 2. Comparison of Chinese and international noise/vibration standards

Index	Chinese standard (GB)	International standard
Nighttime residential noise limit (dB[A])	GB 3096-2008: 45	ISO 1996-1:2016: 40; World Health Organization 2018: 40
Indoor vibration limit (m/s^2)	GB 50118-2010: 0.01	European Union Directive 2002/49/EC: 0.008
Sound level meter class	GB/T 3785-2017: Class 1	ISO 1996-1:2016: Class 1

multiple emissions (e.g., elevator + traffic noise), making it difficult to isolate the impact of individual sources—a problem that international studies address via spectral homology analysis,[10] which is underutilized in China. Second, unlike chemical pollutants, noise pollution exhibits intermittent, fluctuating emission patterns and non-persistent characteristics (e.g., elevator noise only occurs during operation), creating technical obstacles for evidence collection. These transient properties prevent the acquisition of replicable monitoring data during investigations.[11]

4. Technical methods for the identification and assessment of residential environmental damage caused by noise

To address methodological deficiencies, this study proposed an integrated framework with three core steps (Figure 1) and clear verification criteria for each step:

(i) Damage verification: Combine objective data (noise/vibration measurement) and subjective feedback (resident surveys) to confirm damage existence;

(ii) Causality analysis: Use spectral homology and contribution calculation to identify the target noise source, and

(iii) Damage quantification: Apply restoration cost and environmental value methods to calculate compensation, with accuracy verified via real dispute settlements.

4.1. Methods for verifying damage

Damage verification typically involves two sequential steps: First, confirming the occurrence of an environmental pollution or ecological damage act; and second, comparing the current ecological conditions and service functions of the assessed area with baseline levels (Chinese GB 3096-2008 + ISO 1996-1:2016) to determine whether damage has occurred. Based on these criteria, the outcomes of damage verification are categorized into four distinct scenarios:

(i) Absence of damaging act and damage result: Noise/vibration meets standards, and no subjective harm reported → No damage.

(ii) Presence of damaging act but absence of damage result: Noise exceeds limits, but no acoustic environmental harm (e.g., block the transmission path of noise) → No damage.

(iii) Absence of damaging act but presence of damage result: The noise source meets the emission standards, but the acoustic environmental quality does not meet the standards (e.g., caused by the superposition of multiple noise emission sources) → No damage.

(iv) Presence of both damaging act and damage result: Noise emissions exceed standards (damaging act) and acoustic environmental quality is non-compliant (damage result)→ Damage confirmed.

4.2. Methods for causal analysis

When both damaging acts and damage consequences are confirmed, it is necessary to further identify the noise propagation pathway from the source to the affected environment—that is, establish a clear causal chain connecting the noise source, transmission path, and environmental damage consequences. Causality verification criteria include:

(i) Spectral homology: Similarity between source and indoor noise spectra ≥85% (per Smith *et al*., 2023); and

(ii) Contribution ratio: Target source contribution to indoor noise ≥50%, and ΔL (contribution ratio − other sources ratio) >3 dB(A). It will be discussed in detail in Section 4.2.2.

4.2.1. Pollution homology analysis

Pollution homology analysis involves tracing back from the receiving environment to identify potential noise sources and determine whether the target noise sources are included in these potential noise sources. Noise source identification methods include traditional noise source traceability methods, methods based on sound source identification, and methods based on machine learning[12,13]:

(i) Traditional noise source traceability methods: These methods mainly include the subjective evaluation method, separate operation method,

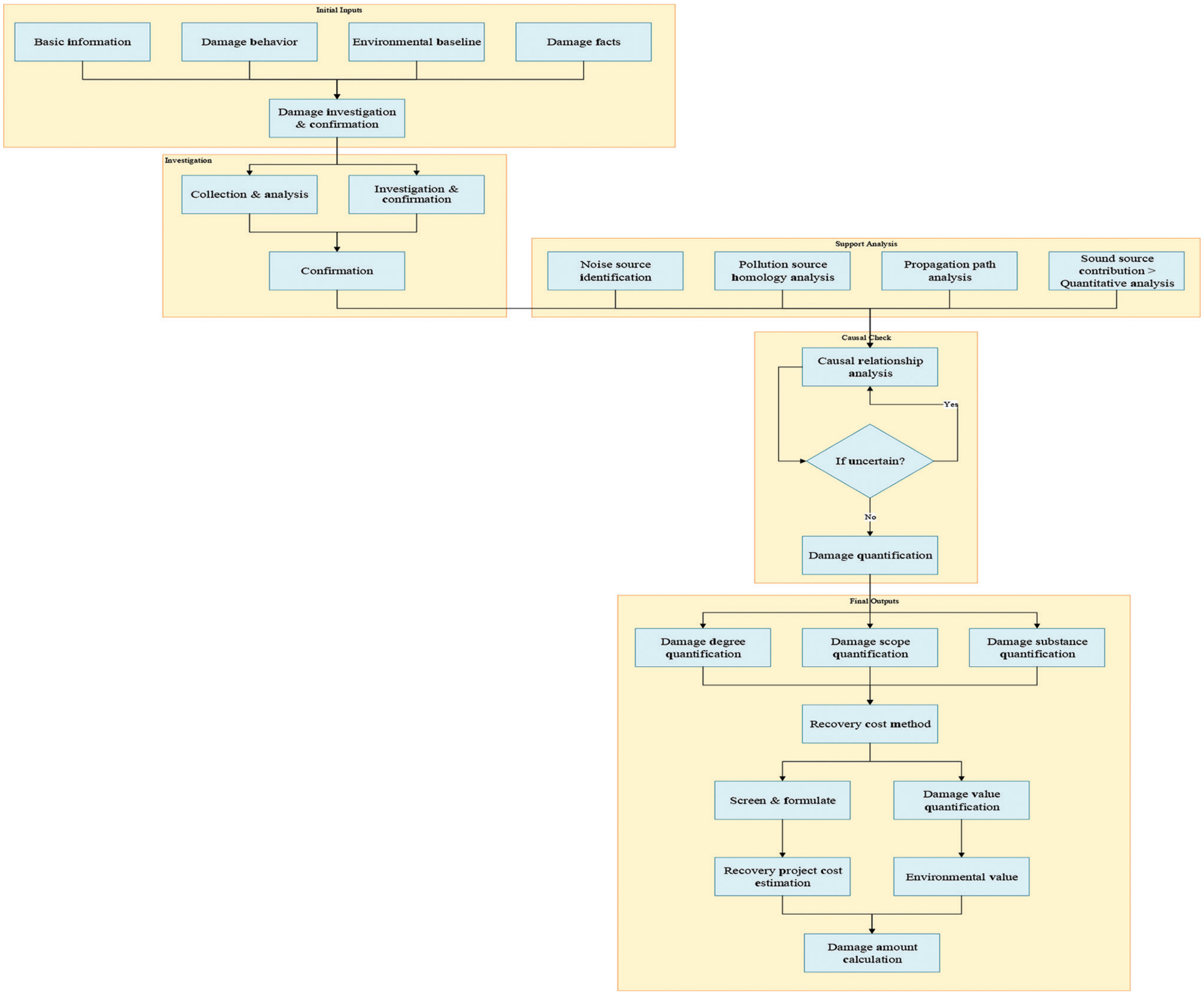

Figure 1. Technical methods for assessing residential environmental damage caused by noise

coverage method, and spectrum analysis method. Among them, the most commonly used methods for monitoring and evaluating the impact of noise on the environment are the separate operation method and the spectrum analysis method. The separate operation method identifies homology by controlling interfering sources and regulating the target source's start/stop, for example, in a pumped storage power station noise case, through restricting traffic, shutting down household noise, and controlling station modes.[14] The spectral analysis method converts time-domain signals to the frequency domain via the Fourier transform, extracting the frequency structure and amplitude/phase. Yu *et al*.[15] analyzed 12 high-noise sources, finding low-frequency dominance in elevators and air conditioners, while mid-frequency in air compressors.

(ii) Methods based on sound source identification: These methods combine acoustics and sensor technologies, including acoustic holography and sound intensity measurement. Developed in the 1970s–1980s, sound intensity measurement captures magnitude/direction unaffected by background noise.[16,17]. Acoustic holography utilizes both sound intensity and phase information, demonstrating stronger noise source identification capabilities than conventional sound intensity measurement methods.[18].

(iii) Machine learning-based noise source attribution methodology: Machine learning-based noise source attribution is an acoustic analysis framework rooted in signal processing and pattern recognition, using convolutional neural networks (CNNs), recurrent neural networks (RNNs), and deep neural networks (DNNs) for noise data classification.[19,20].

It takes annotated time-domain audio as input, first extracting features such as Mel-frequency cepstral coefficients, linear predictive cepstral coefficients, and line spectrum pairs. Then, hybrid neural networks work as follows: CNNs capture local features, RNNs process temporal dependencies, and DNNs build high-dimensional nonlinear classification boundaries.[21-23] The operational pipeline culminates in iterative parameter optimization through backpropagation algorithms, ensuring system outputs align with acoustic event classification requirements.[24]

The seminal work by Sawhney and Maes[25] laid the foundation for acoustic event recognition, creating the first open dataset ("human speech," "subway," and "train"). Their method combined power spectral density analysis and filter-based feature extraction, with the RNN–k-nearest neighbor hybrid architecture achieving 68% accuracy. Oikarinen *et al*.[26] advanced this with an end-to-end CNN, trained on dual-channel audio spectrograms, which enables the robust classification of acoustic signal sources and types under harsh noise conditions.

4.2.2. Target noise source contribution analysis

Receptor acoustic environments typically contain multiple coexisting noise sources, and resultant damage may be a cumulative effect of these sources. For clarity, this study classifies noise sources into two categories: Target noise sources and background noise (defined as all ambient acoustic components excluding the target source).

In Section 4.1, comprehensive measurements were conducted encompassing both ambient sound levels and source-specific emissions. The equivalent sound level of the ambient environment represents the logarithmic summation of all active noise sources. Notably, the measured emission values from noise sources inherently incorporate both the source's intrinsic emissions and ambient background components, where background noise refers to all extraneous environmental sounds excluding the measured source. Based on the principle of sound energy superposition, the uncorrected emission measurement (Lc), background noise level (Lb), and source emission level (Ls) conform to Equation (1):

$$L_s = 10\lg(10^{0.1Lc}-10^{0.1Lb}) \tag{1}$$

where Ls is the noise value of the sound source, Lc is the noise measurement value, and Lb is the background noise value.

In general, the measurement locations for acoustic environment monitoring and noise emission sources are categorized into three configurations: Outdoor areas, exterior of noise-sensitive buildings, and interior spaces of such structures. For a given noise pollution case, identical measurement sites are selected for both emission source monitoring and ambient acoustic environment monitoring. This operational consistency implies that environmental monitoring points and emission source monitoring points reside within the same open acoustic space. Consequently, the attenuation characteristics of the target noise source propagating from the emission measurement location to the environmental monitoring location conform to the principles of geometric divergence attenuation.

$$\Delta L = 20\lg\frac{r2}{r1} \tag{2}$$

where $r2$ is the distance of the acoustic environment measurement point from the target noise source, and $r1$ is the distance of the emission noise measurement point from the target noise source. From here, the contribution of the target noise source is obtained as:

$$L = Ls - \Delta L = 10\lg(10^{0.1Lc} - 10^{0.1Lb}) - 20\lg\frac{r2}{r1} \tag{3}$$

4.2.3. Criteria for causal relationship determination

Based on the preceding analysis, this study establishes that a causal relationship between polluting acts and environmental damage necessitates the simultaneous fulfillment of the following criteria:

(i) Acoustic signature homology between emission sources and receiving environments; and
(ii) Contribution index (L) of the target noise source satisfying:

$$\Delta L = Ls - Lb > 3 \text{ dB} \tag{4}$$

The contribution index quantifies the intensity of deleterious impacts from polluting activities on environmental degradation, with its numerical value serving as a determinant of the causal relationship. The ΔL-based causal inference protocol, as stipulated in technical specifications for environmental noise monitoring: Measurement value correction, requires measurement series invalidation where $\Delta L < 3$ dB(A). This threshold aligns with the minimum perceptible difference in psychoacoustic response,[27] thereby establishing that $\Delta L > 3$ dB(A) constitutes prima facie evidence that the target source is the predominant contributor to environmental impairment.

4.3. Methods for quantifying the value of damage

4.3.1. Technical approach to quantifying damage based on restoration costs

The quantification of noise-induced environmental damage value is primarily calculated based on the engineering costs[28] required to restore the environment to its baseline state (GB 3096-2008 + ISO 1996-1:2016). Cost items include: (i) Noise reduction engineering (e.g., elevator traction system modification: Renminbi [RMB] 80,000–120,000); (ii) vibration isolation measures (e.g., floor damping layers: RMB 200/m^2); and (iii) monitoring and maintenance costs (RMB 10,000–15,000/year).

4.3.2. Technical methods for quantifying damage based on the environmental value approach

Due to the externalities and public nature of environmental resources, it is challenging to achieve the optimal allocation of environmental resources through conventional market trading methods. Therefore, various methods of valuing environmental resources have emerged. The quantification of damage value based on the economic value of the environment has also become an important element in the identification of environmental damage.[29]

The contingent valuation method (CVM) operationalizes this through structured surveys measuring public willingness-to-pay (WTP) for environmental quality improvements or willingness-to-accept (WTA) compensation for ecological losses, thereby quantifying non-market environmental goods. Applied to noise environmental damage cases, CVM enables empirical estimation of monetary values associated with noise abatement initiatives by investigating stakeholders' WTP for reduced acoustic pollution or WTA thresholds for enduring noise exposure.

$$D = C \times N \times t \tag{5}$$

where D is the amount of compensation for noise environmental damage (RMB), C is the residents' WTP for noise reduction, RMB/person-day, N is the number of affected residents (confirmed via community registration), and t is the duration of damage (days, from first complaint to dispute resolution).

Merchan *et al*.[30] investigated the impact of noise in a study area and utilized the CVM to assess the WTP to mitigate noise pollution. Their study estimated that visitors are willing to pay € 1 for noise reduction on entrance. Another study by Ma *et al*.[31] demonstrated that WTP is influenced by annoyance rate, age, income, and the noise mitigation technique. The residents' WTP increased non-linearly with noise exposure level.

In addition to the contingent value method, other environmental value assessment methods, such as the virtual treatment cost method, can also be used to comprehensively calculate the value of the noise environmental damage by considering the noise duration, the treatment cost of noise pollution, the multiplier of noise exceedance, and the functional area of the acoustic environment.

$$D = t \times C \times \alpha \times \beta \tag{6}$$

where D is the amount of compensation for noise environmental damage, t is the duration of noise pollution (day), C is the unit treatment cost of noise pollution (RMB/day), α is the coefficient of exceeding the standard, and β is the environmental function coefficient

5. Case study: Elevator noise damage assessment in a residential community

5.1. Case background

The case involved a residential community in which residents on the 15th floor reported persistent elevator noise (generated by the elevator traction system), causing sleep disturbance and indoor vibration. The community initially adopted noise reduction measures (e.g., adding sound-absorbing materials) but failed to resolve the issue, leading to a dispute between the resident and the property management company. This study applied the proposed framework to evaluate the noise damage, verifying its practicality.

5.2. Data collection and processing

Data collection followed both Chinese (GB 22337-2008 and GB 3096-2008) and international (ISO 1996-1:2016) standards to ensure comparability:

(i) Noise measurement: Using a Class 1 sound level meter (AWA6228, Hangzhou Aihua Instruments Co., Ltd., China), measurements were taken at 1.2 m above the ground in affected bedrooms and the living room. Measurements were taken separately during nighttime and daytime (daytime 6:00–22:00, nighttime 22:00–6:00). Measurement indicators included background noise, noise emissions, and acoustic environment noise.

(ii) Data quality control: (a) Calibrated instruments before/after measurement (error <2%); (b) survey response rate = 100% (no missing data); and (c) measured three times on different days to ensure repeatability.

5.3. Framework application and results

5.3.1. Damage verification

Objective results: Nighttime acoustic environment noise levels in bedrooms were 48 dB(A) (exceeding GB 3096-2008's 45 dB[A] and WHO's 40 dB[A]), and the nighttime noise emissions level was 38 dB(A) (exceeding GB 22337-2008's 30 dB[A]).

Conclusion: Meets both objective and subjective verification criteria → Damage confirmed.

5.3.2. Causality analysis

(i) Spectral homology: The elevator traction system's noise spectrum (measured in the machine room) had a dominant band of 63–125 Hz, with 92% similarity to indoor noise spectra → Meets homology criterion (≥85%).

(ii) Contribution calculation: Lc was 48 dB(A), Lb was 30 dB(A), and ΔL was 14 dB(A). Using Equation (3), L_contribution was 34 (>3 dB[A]) → Meets contribution criterion.

Conclusion: A direct causal relationship between elevator noise and damage is confirmed.

5.3.3. Damage quantification

(i) Restoration cost method: Total costs included elevator traction system modification (RMB 100,000), floor damping layers (200 m^2 × RMB 200/m^2 = RMB 40,000), and monitoring (RMB 12,000) → Total: RMB 152,000.

(ii) Environmental value method: C was RMB 50/person/day (survey result: 75% of residents willing to pay RMB 40–60/day; $N = 20$, t = 180 days) → D was 50×20×180 = RMB 180,000.

Verification: Restoration cost (RMB 152,000) ≤ quantified value (RMB 180,000), and actual dispute settlement (RMB 175,000) had a relative error of ±2.8% (≤10%) → Quantification accuracy confirmed.

6. Discussion

The case study verified that the proposed framework addresses key gaps in existing research:

(i) Integrated process: Covering verification → causality → quantification, it avoids one-sided reliance on single methods (e.g., only measuring noise without confirming causality);

(ii) Dual standard integration: Combining Chinese and international norms ensures adaptability to different regions—for example, using the WHO's 40 dB(A) limit supplemented by GB 3096-2008 reduces verification ambiguity; and

(iii) Empirical validity: The framework's results (damage confirmed and RMB 180,000 compensation) were consistent with real dispute outcomes (RMB 175,000), with accuracy meeting criteria.

6.1. Comparison with existing studies and standards

Compared with Chinese studies Cai *et al*.,[32] which focus solely on noise quantification without causality analysis, this framework reduces misattribution risk (e.g., avoiding blaming traffic noise for elevator-induced damage). Compared with EU Directive 2002/49/EC, which lacks a quantification method for compensation, this study's CVM-based approach provides a feasible tool for dispute resolution. However, the framework has limitations; it relies on sufficient on-site data, which may be challenging to obtain in remote areas with limited equipment.

6.2. Practical implications

For environmental forensic practitioners, the framework provides a standardized process:

(i) Use dual standards (Chinese + international) for verification to enhance credibility;

(ii) Apply spectral homology and contribution calculation to clarify causality—a key pain point in disputes; and

(iii) Compare restoration cost and environmental value methods to ensure quantification fairness.

For policymakers, the framework supports the revision of Chinese noise standards (e.g., integrating ISO 1996-1 measurement protocols).

6.3. Future improvements

To address data reliance, future research should:

(i) Integrate internet-of-things-based real-time monitoring systems (e.g., wireless sound sensors) to automate data collection, reducing manual costs;

(ii) Expand case studies to different building types (e.g., wooden houses and low-rise brick buildings) and climate zones (e.g., cold regions with closed windows), optimizing the framework's generalizability; and

(iii) Combine big data (e.g., urban noise maps) to improve causality analysis efficiency for multi-source environments.

7. Conclusion

This study proposed a comprehensive appraisal framework for residential environmental noise damage, integrating noise generation characteristics, propagation mechanisms, and impact dynamics. The framework systematically addresses four critical phases: noise source identification and monitoring, damage verification, causal relationship determination, and damage valuation quantification. This procedural architecture encompasses the diverse appraisal requirements inherent to noise pollution disputes while specifying standardized protocols and methodological guidelines for each operational phase.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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Availability of data

Data will be made available upon request to the corresponding authors.

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