

Environmental Determinants of Transformer Noise and Particulate Emissions: Implications for Community Health in Ughelli North, Delta State, Nigeria

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ABSTRACT

This study evaluates environmental noise and air quality conditions surrounding electrical transformer installations in Ughelli North Local Government Area (LGA), Delta State, Nigeria. Using a structured questionnaire and in situ environmental monitoring, data were gathered to assess community awareness, subjective experience, and ambient environmental parameters. Respondents exhibited a balanced demographic spread across gender, age, and occupation, with 97.1% acknowledging awareness of nearby transformers. Although 70.5% reported rarely hearing noise from these installations, 24.5% experienced disturbances in daily activities, indicating localised acoustic impacts. A substantial majority (over 70%) agreed that environmental factors influence transformer noise propagation, particularly wind speed, followed by humidity and geography. However, 85% of respondents were unaware of existing mitigation measures, highlighting a gap in infrastructural communication and policy outreach. Environmental measurements revealed mean ambient temperatures of $30.42 \pm 0.59^\circ\text{C}$ (morning), $30.28 \pm 0.55^\circ\text{C}$ (afternoon), and $29.93 \pm 0.41^\circ\text{C}$ (evening), with no statistically significant variation. Relative humidity showed significant diurnal differences ($p < 0.05$), peaking in the morning at $72.52 \pm 1.93\%$. Noise levels across the day remained consistently high (63–65 dB), exceeding WHO thresholds for residential zones. Particulate matter concentrations varied across particle sizes ($\text{PM}_{0.3}$ to $\text{PM}_{10.0}$), with notable peaks in the morning and evening due to anthropogenic and meteorological influences. $\text{PM}_{0.3}$ and $\text{PM}_{5.0}$ displayed significant diurnal differences ($p < 0.05$), while $\text{PM}_{1.0}$ and $\text{PM}_{10.0}$ did not. Findings underscore the need for environmental management strategies including the implementation of noise barriers, adoption of noise-absorbing materials, and regulatory enforcement. Furthermore, the persistent elevation in fine particulate matter across several time points necessitates public health interventions such as air quality monitoring, public sensitisation, and transformer siting policies. Overall, the study reveals both perceptual and empirical evidence of environmental stressors linked to transformer installations, with implications for energy planning and public health in rural and semi-urban Nigerian settings.

Keywords: Transformer Noise; Particulate Matter; Environmental Stressors; Ambient Air Quality; Diurnal Variation; Noise Pollution; Community Health; Meteorological Influences; Public Awareness; Mitigation Strategies; Niger Delta; Nigeria.

1. Introduction

The rapid expansion of electrical power infrastructure across developing nations has been indispensable in meeting the rising demand for energy and sustaining socioeconomic development. In Nigeria, as in many other low- and middle-income countries, the proliferation of power distribution transformers and related installations in residential and commercial zones underscores the urgent need for reliable electricity access. However, this infrastructural necessity is increasingly accompanied by environmental challenges, particularly in relation to noise emissions and air quality concerns. Despite the widespread presence of transformers within urban and peri-urban communities, relatively little empirical research has been directed toward understanding their environmental impacts, especially with regard to human health and well-being.

Noise pollution has long been recognised as one of the most pervasive yet underappreciated environmental hazards worldwide. Defined as unwanted or harmful sound, noise constitutes a form of pollution capable of exerting both auditory and non-auditory health effects. The World Health Organization [1] highlights that chronic exposure to noise levels above recommended thresholds (55 dB during the day and 40 dB at night in residential areas) can contribute to a range of health conditions including sleep disturbance, cardiovascular diseases, cognitive impairment, and psychological stress. Recent studies in Nigerian urban settings reveal that ambient community noise frequently exceeds permissible limits, often reaching 60–70 dB, thereby exposing populations to long-term

health risks [2,3]. In communities where transformers are sited close to dwellings, schools, or markets, the persistent humming and vibrations from these installations may represent a chronic acoustic stressor. Yet, unlike traffic or industrial noise, transformer noise is often overlooked in environmental assessments, leading to a gap in mitigation policies and protective regulations [4].

The sources of transformer noise are diverse and often inherent to the operation of the equipment. Magnetostrictive vibrations within the transformer core laminations, electromagnetic forces in the windings, and vibrations transmitted to the tank surface contribute to the characteristic low-frequency hum. External components such as cooling fans and pumps can exacerbate the acoustic output, while environmental factors—including humidity, wind speed, and temperature—further influence the propagation and perception of this noise in surrounding areas [5]. Studies conducted in high-voltage substations in Asia and Europe have demonstrated that local microclimatic conditions significantly modulate the amplitude and spread of transformer noise [6,7]. However, such nuanced analyses remain scarce in African contexts, where climatic conditions, infrastructural design, and settlement patterns differ markedly from those of industrialised nations.

Parallel to noise emissions, the air quality implications of transformer installations demand closer attention. Electrical transformers are typically co-located with other anthropogenic pollution sources, including generators, vehicular traffic, roadside commercial activities, and open burning of biomass. This clustering of emission sources creates micro-environments in which particulate matter (PM)—a key indicator of air pollution—is likely to accumulate. Fine and ultrafine particulate fractions ($PM_{0.3}$ to $PM_{2.5}$), in particular, are of concern due to their ability to penetrate deeply into the respiratory tract and translocate into systemic circulation, initiating oxidative stress, inflammation, and adverse cardiovascular outcomes [8,9]. While transformers themselves are not direct emitters of particulate matter, the electrostatic fields surrounding high-voltage components can influence particle behaviour by attracting charged aerosols, thereby contributing indirectly to localised PM enrichment [10]. In tropical regions such as the Niger Delta, meteorological factors including diurnal humidity cycles, boundary-layer dynamics, and rainfall patterns further mediate particulate dispersion, with implications for exposure risk [11,12].

Noise and air pollution around transformers remain underexplored in environmental toxicology. Globally, most environmental impact studies on electricity infrastructure have focused on high-voltage transmission lines and their corona discharges, which generate broadband and tonal audible noise [13]. Less emphasis has been placed on the distribution-level transformers that dot residential neighbourhoods, despite their ubiquity and proximity to human populations. Moreover, existing research in Africa has largely centred on traffic-related or industrial noise and ambient particulate pollution [14,15], with little integration of these phenomena within the context of power distribution infrastructure. As a result, there is limited evidence to inform policies on transformer siting, zoning, or mitigation measures in Nigeria and similar developing contexts.

The health and social implications of ignoring these environmental stressors are significant. Chronic exposure to transformer noise may exacerbate sleep deprivation, learning difficulties in children, and long-term cardiovascular risk, while persistent particulate exposure elevates the burden of respiratory and systemic diseases [16,17]. Furthermore, the absence of adequate community engagement or sensitisation has created a perceptual gap, where

residents are often unaware of mitigation measures or of the potential health risks posed by their proximity to transformers. This lack of awareness not only limits protective behaviours but also perpetuates environmental inequities, disproportionately burdening lower-income communities that are more likely to live close to poorly regulated infrastructure [18,19].

Addressing these challenges requires a comprehensive approach that integrates empirical environmental monitoring with community-based perception analysis. Measuring ambient parameters such as temperature, humidity, noise levels, and particulate matter concentrations around transformers can provide objective data on environmental exposures, while structured surveys can capture residents' subjective experiences and coping strategies. Together, these methods offer a holistic understanding of both measurable impacts and lived realities, thereby generating evidence relevant for policy, planning, and public health interventions [20,21].

The present study was conducted in Ughelli North Local Government Area (LGA) of Delta State, a rapidly urbanising region within Nigeria's Niger Delta. This area exemplifies the convergence of rural and semi-urban settlement patterns, with residential, commercial, and industrial activities often situated in close proximity to power installations. Against this backdrop, the study investigated the influence of environmental factors on transformer noise propagation, quantified ambient noise and particulate levels, and explored community awareness and perceptions of environmental impacts. Specifically, the research aimed to (i) evaluate diurnal variations in temperature, humidity, noise, and particulate matter concentrations in transformer vicinities; (ii) assess residents' awareness of and experiences with transformer-related noise; and (iii) identify gaps in knowledge and policy regarding mitigation strategies.

By combining quantitative environmental monitoring with qualitative survey methods, this research provides one of the first comprehensive evaluations of transformer-related environmental stressors in Nigeria. Its findings hold important implications for energy planning, environmental management, and public health protection. In highlighting both perceptual and empirical dimensions of the issue, the study underscores the urgent need for regulatory agencies such as the Nigerian Environmental Standards and Regulations Enforcement Agency (NESREA) and the Nigerian Electricity Regulatory Commission (NERC) to incorporate noise and air quality considerations into infrastructure policies. Moreover, the research contributes to the broader discourse on environmental justice, emphasising the importance of protecting vulnerable communities from disproportionate exposure to infrastructural externalities [22].

The novelty of this study lies in its integrated focus on transformer noise, particulate pollution, and human well-being within a developing country context. Unlike high-voltage line studies conducted in Europe or Asia, this work situates the environmental impacts of transformers within the tropical climatology, settlement dynamics, and infrastructural realities of Nigeria. The research also advances the discourse by linking diurnal environmental dynamics—such as morning humidity peaks and evening particulate accumulation—to transformer-related stressors, thereby providing actionable insights for both technical and policy interventions [23]. Finally, by documenting community perceptions and awareness gaps, the study highlights the critical role of public engagement in achieving sustainable energy infrastructure that balances reliability with environmental health.

In summary, the introduction of this research frames transformer installations not merely as technical assets for electricity distribution but as environmental entities with complex interactions that shape human health and well-being. The challenge for Nigeria, and by extension other rapidly urbanising nations, is to integrate environmental monitoring, technological innovation, and regulatory enforcement in order to ensure that the benefits of electrification do not come at the cost of public health. Through its multidimensional approach, this study provides the foundation for such integration, offering a model that can inform both local interventions and broader regional strategies in environmental management and toxicology.

1.1. Study Objectives

The specific objectives of this study are to:

- 1) Evaluate diurnal variations in environmental parameters (temperature, humidity, noise levels, and particulate matter concentrations) around transformer installations.
- 2) Assess residents' awareness, perceptions, and experiences of transformer-related noise and particulate emissions in Ughelli North LGA.
- 3) Identify environmental factors (e.g., atmospheric temperature and humidity) influencing the propagation and intensity of transformer noise.
- 4) Determine community knowledge gaps regarding existing mitigation measures for noise and particulate emissions.
- 5) Recommend context-specific strategies and policy interventions for reducing the environmental and health impacts of transformer installations.
- 6) Contribute empirical evidence to support sustainable energy infrastructure planning in semi-urban Nigerian communities.

2. Materials and Methods

2.1. Study Area and Design

The study was conducted in Ughelli North Local Government Area (LGA), Delta State, Nigeria (5.5000° N, 6.0000° E), a rapidly urbanising region characterised by residential, commercial, and industrial activities. The area experiences tropical climatic conditions with high temperatures, humidity, and seasonal rainfall, which can influence environmental parameters around transformer installations.

A cross-sectional design was employed, integrating environmental monitoring with community-based surveys. This approach allowed for a comprehensive assessment of both objective environmental conditions and residents' perceptions regarding transformer-related noise and air quality.

2.2. Population and Sampling Technique

The target population comprised adult residents (≥ 18 years) living within 100 metres of electrical transformer installations in selected communities of Ughelli North LGA. Stratified random sampling was used to ensure

inclusion across demographic groups. A total of 260 respondents participated, based on proximity to transformers and willingness to participate.

2.3. Data Collection Instruments and Procedures

- **Questionnaire Administration:** A pre-tested structured questionnaire was administered to collect demographic information, awareness of transformer installations, perceived noise exposure, and opinions on mitigation measures (Appendix I).
- **Environmental Monitoring:** Ambient temperature and relative humidity were measured using a digital thermo-hygrometer (HTC-1 model). Noise levels were recorded with a digital sound level meter (SL-5868P) positioned 5 m from transformers. Particulate matter (PM_{0.3}, PM_{0.5}, PM_{1.0}, PM_{3.0}, PM_{5.0}, and PM_{10.0}) concentrations were measured using a calibrated Temtop M2000C handheld air quality monitor. All instruments were checked for calibration prior to field deployment, and measurements followed manufacturer specifications. The devices had stated accuracies of ± 0.5 °C for temperature, $\pm 3\%$ for relative humidity, ± 1.5 dB for sound level, and $\pm 10\%$ for particulate matter. Measurements were conducted at 20 transformer sites during morning (7:00–9:00 AM), afternoon (12:00–2:00 PM), and evening (5:00–7:00 PM).

Note: The full geographic coordinates of the 20 sampling sites are provided in Supplementary Table S1, as they are not critical for interpreting the main results but may be relevant for replication purposes.

2.4. Data Analysis

Descriptive statistics were computed using Microsoft Excel 365 and SPSS (Version 26.0). Results were expressed as percentages, means, and standard errors, with charts used for clarity. For environmental data, one-way ANOVA tested for differences across time periods, followed by Tukey's HSD post hoc test where appropriate. Statistical significance was set at $p < 0.05$.

2.5. Ethical Considerations

Ethical approval was obtained prior to fieldwork. Verbal and written informed consent was secured from all participants, with confidentiality assured. Environmental monitoring was conducted exclusively in public spaces, without intrusion into private property.

3. Results and Discussion

The pie chart in Figure 1 (A) illustrates the gender distribution of individuals who responded to the administered questionnaire. Out of the total respondents:

- **50.8% were Male**
- **49.2% were Female**

This near-equal representation suggests a balanced demographic response across genders, which is crucial for reducing gender-based bias in data interpretation and enhancing the generalisability of the study findings.

The bar chart in Figure 1 (B) represents the age distribution of respondents to the questionnaire:

- **18–25 years:** Highest representation, suggesting strong participation from younger individuals.
- **26–35 and 36–45 years:** Moderate representation, indicating fair involvement from early to mid-career adults.
- **46–55 years:** Slightly higher response rate than the middle age groups.
- **56 and above:** Second highest group, showing active engagement from older adults.

This distribution suggests a diverse respondent base across age categories, with a notable tilt towards both the youngest (18–25) and oldest (56+) groups. Such spread is valuable for analysing perceptions or behaviours across generational lines.

The bar chart in figure 1 (C) above illustrates the occupational distribution of questionnaire respondents. The findings are as follows:

- **Self-Employed (50 respondents):** The largest group, suggesting significant engagement from individuals running their own businesses or freelance work.
- **Employed (49 respondents):** Closely follows the self-employed, indicating strong participation from salaried or formally employed individuals.
- **Students (49 respondents):** Represent a substantial segment, reflecting youth and academic community involvement.
- **Unemployed (31 respondents):** A considerable proportion, potentially offering insight into economic vulnerability or job market issues.
- **Retired (21 respondents):** Smaller yet important group, providing perspectives from individuals no longer in active service.

This distribution highlights a diverse occupational profile, making the dataset suitable for assessing cross-cutting socio-economic perceptions and behaviours.

The pie chart in figure 2 (A) illustrates respondents' awareness of the presence of electrical power installations in their vicinity:

- **YES:** 97.1% of respondents are aware.
- **NO:** Only 2.9% indicated unawareness.

This overwhelming awareness suggests that the presence of electrical infrastructure is both visible and recognised in the community, forming a solid foundation for further inquiry into perceptions, risks, or experiences related to such installations.

The pie chart in figure 2 (B) illustrates respondents' personal experience of noise from electrical power installations:

- **Rarely (70.5%)** – The majority of respondents acknowledged that they have occasionally noticed noise, but not frequently.

- **Never (14.5%)** – A modest portion has never experienced such noise.
- **Occasionally (9.5%)** – A smaller group reported occasional disturbances.
- **Frequently (5.5%)** – A minor segment indicated recurrent noise exposure.

This distribution suggests that while most respondents are not heavily burdened by noise from power installations, it remains an observable concern in the environment for a noteworthy fraction.

The bar chart in figure 2 (C) presents responses to the question: “Have you noticed any disturbances in your daily activities due to noise from power installations?”

- **No ($\approx 75.5\%$)** – A majority of respondents reported no noticeable disturbance, implying that for most, power installation noise is not disruptive to daily life.
- **Yes ($\approx 24.5\%$)** – A considerable minority, however, acknowledged noticeable interference, highlighting a potential environmental or public health concern in affected zones.

This contrast underscores the importance of localised assessments when evaluating the broader impact of electrical infrastructure on community wellbeing.

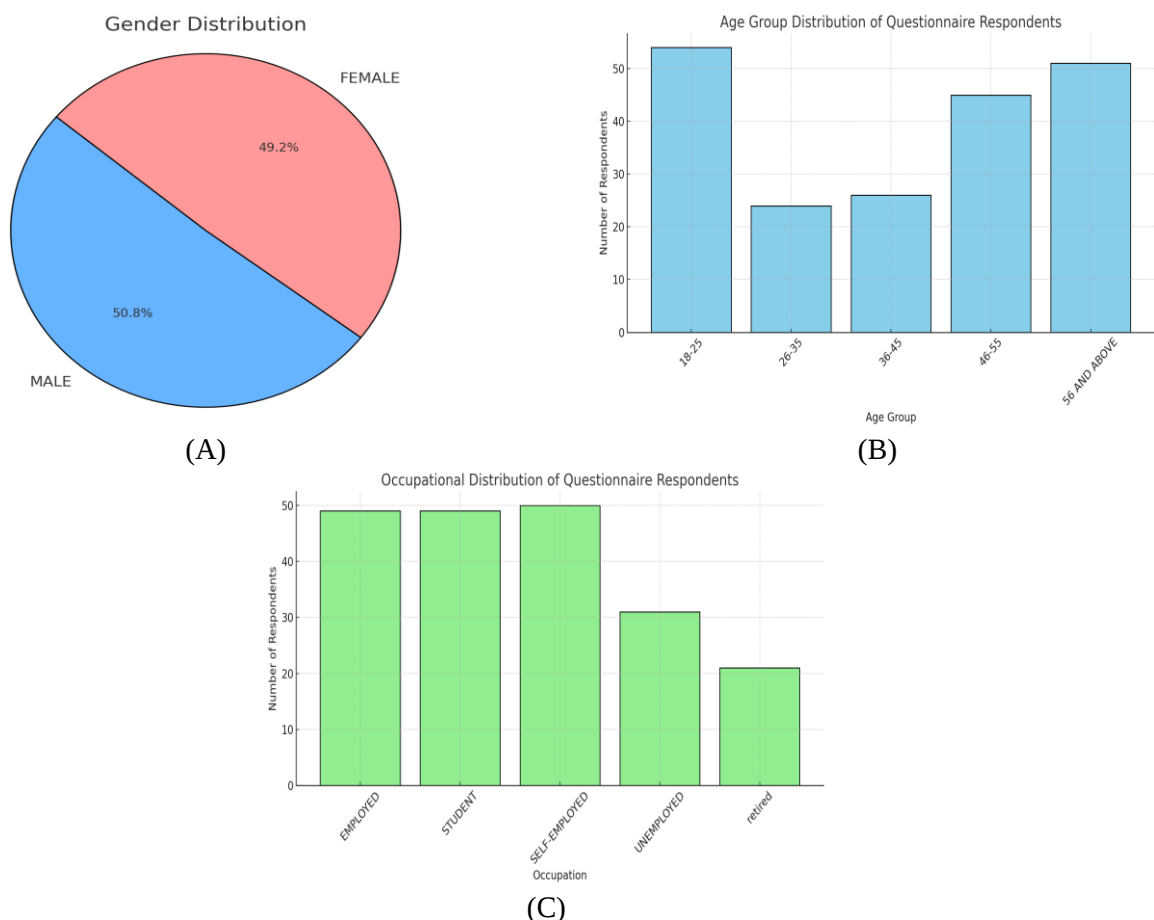


Figure 1. Gender (A), age group (B) and Occupational (C) distribution of respondents to the questionnaire

Figure 3A presents respondents’ opinions on whether *environmental factors affect noise levels from power installations*. The majority of respondents (145) agreed, expressing a strong belief in environmental influence. An

additional 14 respondents strongly agreed, reinforcing this view. Conversely, 100 respondents remained neutral, indicating uncertainty or lack of knowledge, while a minority (11) disagreed. This distribution suggests that over 70% of the population support the assertion that environmental factors significantly impact noise propagation, highlighting widespread perceptual awareness within the community. Figure 3B illustrates the *specific environmental factors perceived to have the greatest impact on noise propagation*. A dominant majority (184 respondents) identified wind speed as the most influential factor, followed by humidity (33) and geographic features such as hills and valleys (23). In contrast, temperature (14) and rainfall (6) were less frequently identified. The pattern indicates a prevalent understanding of wind as the primary vector for acoustic dispersion around power installations. Figure 3C summarises responses to the question: *Are you aware of any existing noise mitigation measures implemented for electrical power installations in your area?* A significant majority (221 respondents) indicated no awareness, with only 39 claiming to be informed. This suggests a critical information gap between regulatory or utility actions and community engagement, underscoring the need for improved visibility and stakeholder communication regarding environmental management. Figure 3D outlines respondents' preferences regarding *effective measures for reducing noise emissions*. Among the suggested options, noise-absorbing materials (200 responses) and sound barriers (199) were the most favoured, indicating a strong inclination toward engineered, structural solutions. Vegetative buffers received moderate support (122 responses), while restricted operational hours (108) were the least preferred. These findings reflect a community preference for permanent, physical interventions over behavioural or temporal restrictions.

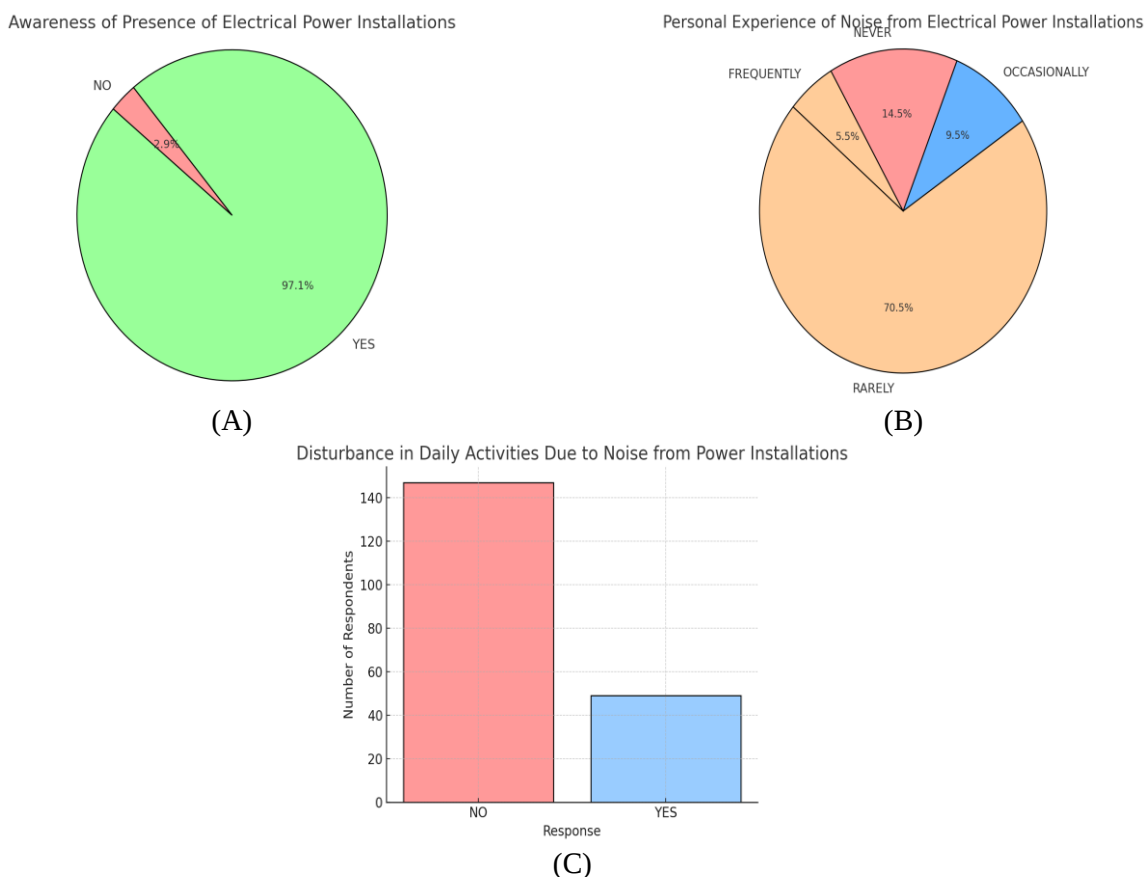


Figure 2. Respondents' (A) awareness of the presence of, (B) personal experience of noise from and (C) disturbance in daily activities due to noise from electrical power installations in their vicinity

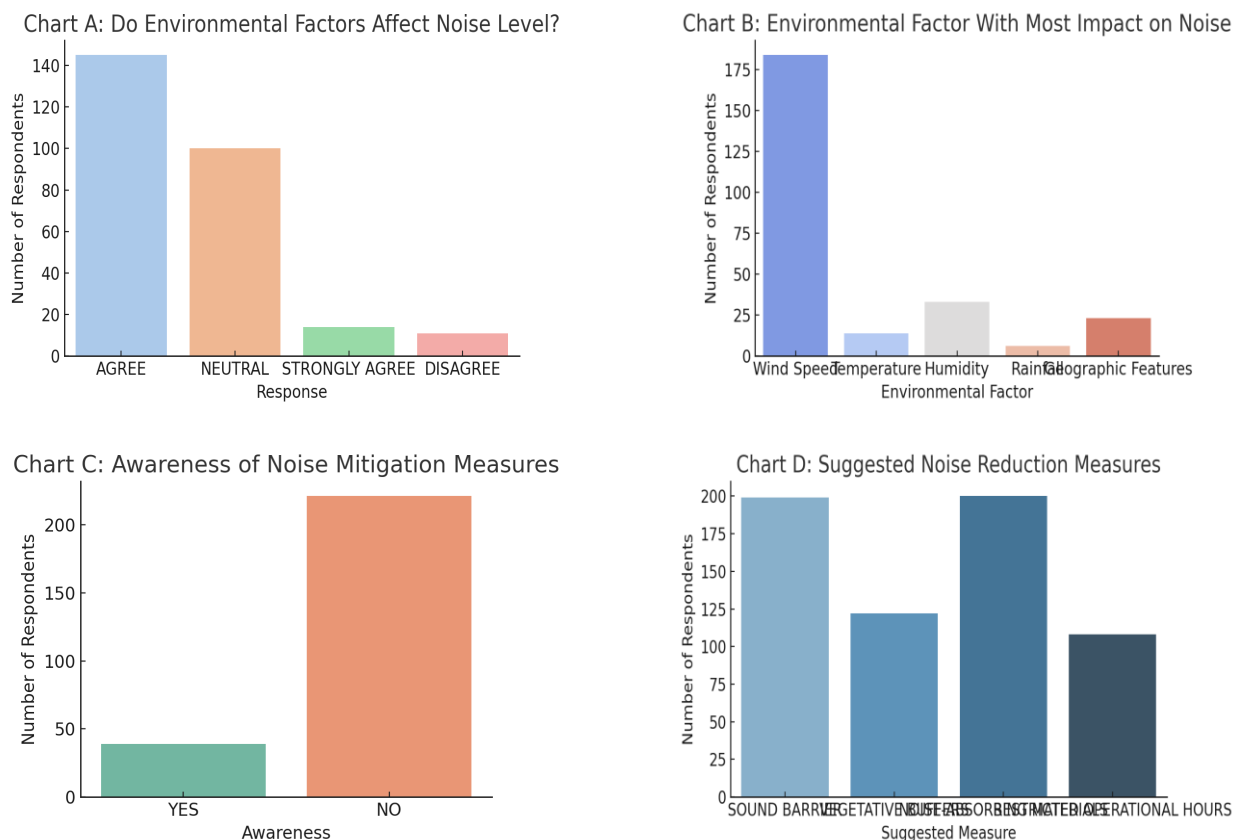


Figure 3. Respondents' suggestions on reduction of noise from electrical power installations

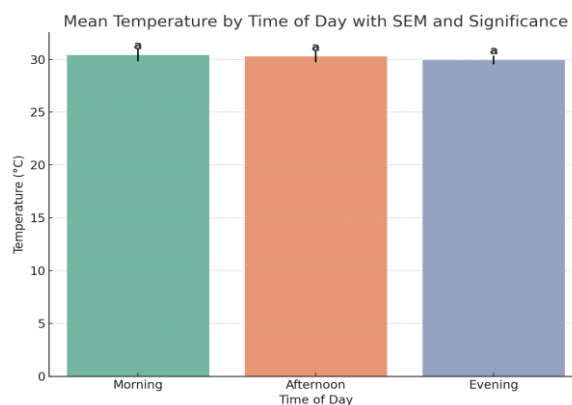


Figure 4. Ambient Temperature of Electrical Transformers in Ughelli North LGA of Delta State. Plotted values are means $\pm$ SEM. Bars carrying different alphabets are significantly different ($p < 0.05$)

The ambient temperature around electrical transformers in Ughelli North LGA, Delta State (Figure 4), exhibited diurnal variations, with mean values of $30.42 \pm 0.59^{\circ}\text{C}$, $30.28 \pm 0.55^{\circ}\text{C}$, and $29.93 \pm 0.41^{\circ}\text{C}$ for morning, afternoon, and evening, respectively. Statistical analysis using one-way ANOVA and Tukey's HSD post hoc test revealed no significant difference among the time periods ($p > 0.05$), suggesting thermal stability in the surrounding environment within a narrow thermal band.

This thermal profile falls within the optimal range for transformer operation, as transformers are generally designed to withstand ambient temperatures up to 40°C [24]. However, sustained operation near or above 30°C , particularly in tropical climates, may accelerate insulation aging and reduce transformer lifespan [25]. Although the differences

in daily temperature cycles are subtle, the cumulative thermal stress over time could still impact performance, particularly in distribution transformers without forced cooling mechanisms.

It is important to highlight that ambient temperature is a critical determinant of transformer loading capability. The ANSI/IEEE C57.91-2011 loading guide emphasises that even modest increases above 30°C can significantly impact the hottest-spot temperature and consequently reduce insulation life by up to 50% if not properly managed [26]. In rural Nigerian settings where transformers are frequently overloaded due to population growth and unregulated connections, these ambient conditions exacerbate the risks of premature failure.

Moreover, localised heating due to proximity to buildings, vegetation, or metallic enclosures could create microclimatic zones of elevated temperature, not fully captured in ambient readings. Similar studies conducted in other sub-Saharan regions have reported evening cooling trends with similar magnitudes, which align with the evening drop observed in this study [20,27].

The lack of significant thermal variation between dayparts could also suggest that the transformer environments are located in shaded or semi-enclosed settings, reducing the amplitude of thermal swings. Alternatively, the dominance of convective heat transfer under high humidity conditions, typical of Delta State, may dampen temperature differentials across the day [23].

In conclusion, while ambient temperatures measured remain within acceptable operational thresholds, the consistently high values underscore the need for preventive maintenance schedules and thermal condition monitoring to mitigate long-term degradation. The findings also point to the importance of integrating climatic resilience into rural power infrastructure planning, especially under projected climate change scenarios.

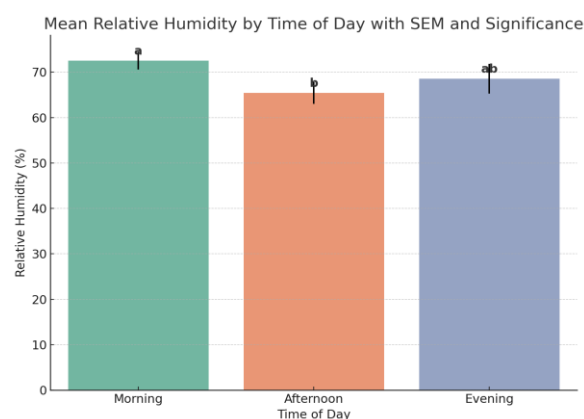


Figure 5. Relative Humidity around Electrical Transformers in Ughelli North LGA of Delta State. Plotted values are means $\pm$ SEM. Bars carrying different alphabets are significantly different ($p < 0.05$)

The observed relative humidity (RH) patterns surrounding electrical transformers in Ughelli North LGA (Figure 5) reveal a diurnal variation, with mean values of $72.52 \pm 1.93\%$ (morning), $65.45 \pm 2.43\%$ (afternoon), and $68.56 \pm 3.26\%$ (evening). Statistical analysis via one-way ANOVA and Tukey's post hoc test indicated a significant difference between morning and afternoon values ($p < 0.05$), with the morning exhibiting the highest RH. The evening RH, however, did not significantly differ from either, suggesting transitional atmospheric behaviour during that period.

The high morning RH is consistent with typical coastal-tropical climatology where nocturnal radiative cooling results in air saturation, leading to higher humidity levels at dawn [28]. The afternoon drop reflects increased solar radiation and ambient temperature, which enhances the air's capacity to hold moisture, thereby reducing relative humidity even without actual moisture loss [29]. Evening levels, though slightly elevated compared to afternoon, remain lower than morning due to lagged thermal dissipation.

These findings have critical implications for the thermal performance and operational integrity of distribution transformers. Elevated RH can contribute to increased dielectric losses and insulation degradation, particularly in older transformers with compromised seals or insulation systems [31]. Moisture ingress facilitated by prolonged high humidity levels can lead to partial discharges, reduced breakdown voltage of oil-paper systems, and corrosion of metallic parts [26]. The marginally lower afternoon RH may provide temporary operational relief; however, daily reabsorption cycles during the evening and night exacerbate cumulative moisture stress over time [30].

In tropical environments like Delta State, where transformer housing is often poorly ventilated, these ambient moisture conditions may heighten internal humidity levels, especially in pole-mounted units exposed to direct rainfall and vegetation-induced microclimates [21]. The presence of such persistently high humidity reinforces the need for routine moisture analysis, adoption of sealed conservator systems, and the use of humidity-resistant materials in future transformer procurement and retrofitting.

Furthermore, high RH values exceeding 70%, such as those recorded in the morning, may have synergistic effects when combined with elevated temperatures, promoting accelerated ageing of polymeric insulation and promoting fungal growth on bushings and insulating boards, particularly in neglected rural installations [22].

In conclusion, the diurnal RH trends observed around transformers in Ughelli North LGA underscore the necessity for weather-adaptive maintenance protocols, especially in tropical climates where humidity remains elevated throughout much of the day. The results also point to the relevance of microclimatic monitoring as part of a predictive maintenance framework for ensuring transformer longevity and energy reliability in rural Nigerian communities.

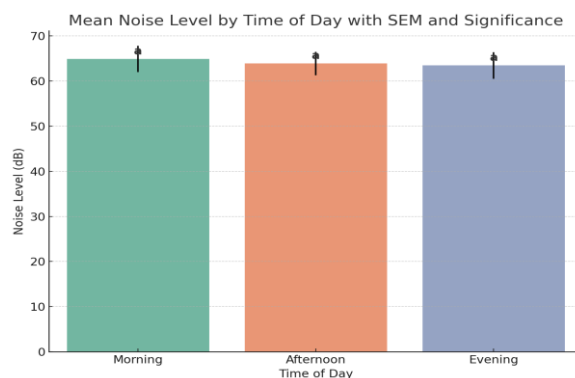


Figure 6. Noise Level around Electrical Transformers in Ughelli North LGA of Delta State. Plotted values are means $\pm$ SEM. Bars carrying different alphabets are significantly different ($p < 0.05$)

Figure 6 presents the diurnal noise distribution around electrical transformers in Ughelli North LGA indicates relatively high ambient sound levels across the day, with mean values of 64.90 ± 2.89 dB (morning), 63.90 ± 2.58

dB (afternoon), and 63.46 ± 2.92 dB (evening). Statistical testing using one-way ANOVA revealed no significant differences between the three time periods ($p > 0.05$), a result confirmed by Tukey's HSD test in which all groups were assigned the same significance notation.

These values reflect a consistently elevated noise environment exceeding the World Health Organization's recommended outdoor residential limit of 55 dB during the day and 40 dB at night [1]. The data suggests that transformers and associated activities constitute a chronic noise source, potentially attributable to core vibrations, cooling fans, radiated hum, and proximity to vehicular and human activity in mixed-use areas [4].

While noise emission from transformers is often considered minimal relative to industrial sources, field observations in Nigeria and other low- and middle-income countries (LMICs) suggest that transformers installed close to dwellings, especially in semi-urban communities, can generate sufficient acoustic output to contribute to cumulative environmental stressors [2]. The recorded levels in Ughelli North LGA indicate that transformers are either poorly shielded, inadequately distanced, or possibly oversized for the demand load, leading to elevated operational noise.

Chronic exposure to noise levels above 60 dB has been linked to adverse health outcomes including sleep disturbance, increased stress hormone secretion, cognitive impairment, and elevated cardiovascular risk [32]. For residents near transformer installations, particularly vulnerable populations such as children and the elderly, this exposure represents a significant public health concern [33].

The relatively uniform noise pattern across the day may be attributed to the continuous operation of transformers, which unlike vehicular or human-induced noise, do not follow peak-hour variability. This also suggests poor acoustic attenuation by surrounding materials or environments, indicating the need for architectural retrofitting or regulatory zoning [3]. Additionally, transformer sound may be amplified during periods of high relative humidity and stable atmospheric layering, which are typical of the area [28].

In conclusion, the persistently elevated noise levels observed in this study highlight the necessity of integrated noise mitigation strategies in transformer siting and operation. These may include installation of acoustic barriers, increased buffer distances from residential buildings, and adoption of low-noise transformer technologies. Moreover, regulatory authorities such as the Nigerian Environmental Standards and Regulations Enforcement Agency (NESREA) must enforce existing guidelines to protect public health in vulnerable communities.

Table 1 presents the comparative concentrations of particulate matter (PM) fractions measured around transformer installations during morning, afternoon, and evening periods. Values are expressed as mean $\pm$ SEM with significance indicators based on Tukey's HSD test ($p < 0.05$).

The diurnal variation in particulate matter (PM) across transformer environments in Ughelli North LGA shows clear temporal patterns. $PM_{0.3}$ concentrations increased progressively from morning ($6.78 \pm 0.65 \mu\text{g}/\text{m}^3$) through afternoon ($7.55 \pm 0.93 \mu\text{g}/\text{m}^3$) to evening ($9.47 \pm 1.02 \mu\text{g}/\text{m}^3$), with evening values significantly higher ($p < 0.05$) than earlier periods. This trend reflects tropical boundary-layer dynamics, where reduced dispersion in late afternoon and evening due to surface cooling and turbulence collapse allows fine particles to accumulate near

ground level [11]. Additional evening activities such as cooking with biomass, intensified traffic, and market operations likely contributed further [35]. Ultrafine particles like $PM_{0.3}$ are especially concerning given their ability to penetrate deep into alveolar regions, cross biological membranes, and initiate systemic inflammation [8]. Chronic exposure has been linked to cardiovascular morbidity, neuroinflammatory outcomes, and cognitive impairment [9]. Notably, the evening levels exceeded WHO interim targets for fine particulate matter, suggesting heightened health risks for residents living close to transformers.

The elevated $PM_{0.3}$ values are not directly attributable to transformers themselves but rather to their microenvironments, which are often situated near generators, open burning sites, and dust-prone areas [36]. Electrostatic fields surrounding high-voltage components may also attract charged particles, indirectly concentrating pollutants [10]. The lower morning levels likely resulted from overnight settling and reduced early-day activity, while the modest afternoon rise points to increased vehicular emissions and photochemical secondary particle formation [34].

$PM_{0.5}$ displayed a contrasting profile, peaking in the morning ($10.40 \pm 1.15 \mu\text{g}/\text{m}^3$) and declining through the afternoon ($8.30 \pm 0.88 \mu\text{g}/\text{m}^3$) to evening ($7.29 \pm 0.53 \mu\text{g}/\text{m}^3$), with morning values significantly higher than evening ones ($p < 0.05$). This pattern underscores the role of early-day traffic, generator use, and market set-up activities [35], coupled with morning temperature inversions that trap pollutants near the surface [36]. The health relevance of $PM_{0.5}$ lies in its ability to evade mucociliary clearance and infiltrate the bronchial and alveolar regions [16], aggravating asthma, respiratory infections, and developmental impairments in children [37]. Indeed, morning concentrations exceeded WHO's 2021 guideline for $PM_{2.5}$ [38], raising concerns over chronic exposures, particularly for children and early risers. Evening reductions likely reflected improved mixing and deposition processes, though values still surpassed WHO limits, pointing to persistent background pollution.

For $PM_{1.0}$, mean values were highest in the morning ($8.51 \mu\text{g}/\text{m}^3$), slightly lower in the evening ($8.43 \mu\text{g}/\text{m}^3$), and lowest in the afternoon ($7.29 \mu\text{g}/\text{m}^3$). These differences were not statistically significant, reflecting fluctuations largely driven by daily activity cycles. Vehicular emissions and domestic combustion explain the morning peak [15], while stronger thermal uplift and boundary-layer mixing facilitated the afternoon decline [39]. Evening values rebounded with traffic and cooking activity combined with reduced dispersion. Although not significant statistically, $PM_{1.0}$ levels consistently exceeded WHO's 24-hour guideline for $PM_{2.5}$ ($15 \mu\text{g}/\text{m}^3$), suggesting potential risks of oxidative stress, cardiopulmonary dysfunction, and long-term health burdens [17].

Intermediate-sized $PM_{3.0}$ followed a similar non-significant trend, with evening levels ($9.45 \pm 1.23 \mu\text{g}/\text{m}^3$) exceeding morning ($8.45 \pm 0.80 \mu\text{g}/\text{m}^3$) and afternoon ($8.08 \pm 0.89 \mu\text{g}/\text{m}^3$). The evening increase may reflect reduced dispersion due to weaker winds and stable atmospheric layering, alongside increased human activity during post-work hours [12,42]. Emissions from vehicles, generators, biomass combustion, and dust resuspension likely provided consistent sources across all periods [14]. Though less investigated, $PM_{3.0}$ particles can still penetrate the respiratory tract and exert negative health effects [40].

The $PM_{5.0}$ fraction exhibited significant temporal differences, with afternoon concentrations ($5.85 \pm 0.42 \mu\text{g}/\text{m}^3$) notably lower than both morning ($7.45 \pm 0.75 \mu\text{g}/\text{m}^3$) and evening ($8.18 \pm 0.81 \mu\text{g}/\text{m}^3$). Peaks at the start and end of

the day are closely tied to vehicular emissions, domestic fuel use, and generator activity in semi-urban settings [43]. Conversely, the midday decline reflects enhanced atmospheric mixing and solar-driven dispersion [41]. Evening elevations may also be intensified by temperature inversions, which trap pollutants near ground level [44]. Elevated PM_{5.0} exposure has been linked to adverse respiratory and cardiovascular outcomes, especially in children and older populations [38].

By contrast, PM₁₀ showed no significant diurnal variation, with values of 6.90 µg/m³ (morning), 8.31 µg/m³ (afternoon), and 7.79 µg/m³ (evening). The modest afternoon elevation corresponds with peak vehicular flow, dust resuspension, and industrial activity, consistent with other Nigerian observations [41]. Such patterns have also been reported in semi-urban areas by Ibe et al. (2023). Encouragingly, all recorded PM₁₀ values were below the WHO 24-hour guideline of 45 µg/m³ [38]. Nonetheless, chronic exposure even to low concentrations has been associated with cardiovascular and respiratory complications [16], underlining the importance of continuous monitoring, particularly in rapidly urbanising settings.

Overall, the diurnal variability of PM fractions highlights complex interactions between human activities, meteorology, and local transformer environments. While fine and ultrafine particles (PM_{0.3} and PM_{0.5}) exhibited significant temporal variation and exceeded WHO thresholds, larger fractions (PM_{1.0}, PM_{3.0}, PM_{5.0}, and PM₁₀) displayed more modest or non-significant fluctuations. These findings emphasise the urgent need for regulatory measures, community sensitisation, and sustained monitoring to mitigate long-term exposure risks in vulnerable populations.

Table 1. Diurnal Variations in Particulate Matter (PM_{0.3}–PM₁₀) Concentrations around Transformer Installations in Ughelli North LGA, Delta State

PM Fraction (µm)	Morning (µg/m ³)	Afternoon (µg/m ³)	Evening (µg/m ³)	Significance
PM0.3	6.78 ± 0.65a	7.55 ± 0.93a	9.47 ± 1.02b	Evening > Morning & Afternoon (p<0.05)
PM0.5	10.40 ± 1.15a	8.30 ± 0.88ab	7.29 ± 0.53b	Morning > Evening (p<0.05)
PM1.0	8.51 ± 0.00a	7.29 ± 0.00a	8.43 ± 0.00a	NS (p>0.05)
PM3.0	8.45 ± 0.80a	8.08 ± 0.89a	9.45 ± 1.23a	NS (p>0.05)
PM5.0	7.45 ± 0.75a	5.85 ± 0.42b	8.18 ± 0.81a	Afternoon < Morning & Evening (p<0.05)
PM10.0	6.90 ± 0.00a	8.31 ± 0.00a	7.79 ± 0.00a	NS (p>0.05)

NS- Not significant.

Values are expressed as mean ± SEM with significance indicators based on Tukey's HSD test (p < 0.05).

4. Conclusion

The findings from this study underscore the multifaceted environmental implications of electrical power installations within Ughelli North LGA, Delta State. Both subjective assessments from community respondents and objective environmental measurements indicate that transformer installations contribute to elevated ambient noise and particulate matter levels, with potential adverse health and social effects.

Despite the general perception that noise from transformers is infrequent, a significant proportion of the population acknowledged disturbances in their daily activities, highlighting the need for context-specific noise mitigation strategies. The majority of respondents recognised the role of environmental factors—particularly wind speed—in modulating noise propagation. However, widespread unawareness of existing mitigation measures reveals a critical disconnect between infrastructure deployment and community engagement.

Environmental monitoring further revealed consistently high ambient temperatures and humidity levels, conditions that may exacerbate thermal stress and ageing of transformer components. Recorded noise levels across all diurnal periods exceeded WHO guidelines for residential exposure, signalling a chronic environmental noise burden. Additionally, concentrations of fine and ultrafine particulate matter, particularly $PM_{0.3}$ and $PM_{5.0}$, were elevated during morning and evening periods, likely influenced by anthropogenic activities and meteorological dynamics. Although not all PM fractions showed significant variation, their consistent exceedance of WHO thresholds suggests persistent background pollution and potential for long-term respiratory and cardiovascular health risks.

In conclusion, this study provides compelling evidence that transformer installations, while essential for power distribution, constitute localised environmental stressors. The interplay of noise, temperature, humidity, and particulate emissions demands urgent attention from policymakers, energy planners, and public health authorities. Future infrastructure siting must integrate environmental assessments, while existing systems require targeted retrofitting and maintenance. Community sensitisation, regulatory enforcement, and adoption of low-emission, noise-attenuated technologies are imperative for safeguarding public health and ensuring sustainable energy infrastructure in growing semi-urban Nigerian communities.

5. Future Suggestions

1. Conduct longitudinal studies across different seasons to capture the influence of climatic variability on transformer-related noise and particulate emissions.
2. Expand monitoring to include additional air pollutants (e.g., volatile organic compounds, CO, SO₂, NO₂) for a more comprehensive environmental risk assessment.
3. Evaluate the effectiveness of specific mitigation strategies, such as vegetative buffers, acoustic barriers, and low-noise transformer technologies, under Nigerian field conditions.
4. Incorporate geospatial mapping and modelling to identify high-risk zones and guide transformer siting policies.
5. Strengthen community engagement programmes to improve awareness of environmental and health risks and encourage local participation in mitigation practices.
6. Establish policy frameworks integrating energy infrastructure planning with environmental and public health safeguards, supported by regular monitoring and enforcement.

Declarations

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Competing Interests Statement

The authors declare that they have no competing interests related to this work.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

Both the authors took part in literature review, analysis, and manuscript writing equally.

Availability of data and materials

Supplementary information is available from the authors upon reasonable request.

Ethical Approval

Ethical approval was obtained prior to fieldwork.

Institutional Review Board Statement

Not applicable for this study.

Informed Consent

Informed consent was obtained from all participants, who were assured of confidentiality, anonymity, and the voluntary nature of their involvement.

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Appendix I

Questionnaire

Instructions

- Please tick the appropriate box for each question.
- If a question is not applicable, please indicate so.
- Your responses will remain confidential, and data will be used for research purposes only.

Section 1: Demographic Information

1.1. Gender:

- ☐ Male
- ☐ Female
- ☐ Other

1.2. Age Group:

- ☐ 18-25

- ☐ 26-35

- ☐ 36-45

- ☐ 46-55

- ☐ 56 and above

1.3. Occupation:

- ☐ Student

- ☐ Employed

- ☐ Self-employed

- ☐ Unemployed

- ☐ Other (Specify: _____)

Section 2: Awareness and Experience with Electrical Power Installations

2.1. Are you aware of the presence of electrical power installations in your vicinity?

- ☐ Yes

- ☐ No

2.2. Have you personally experienced noise from electrical power installations?

- ☐ Frequently

- ☐ Occasionally

- ☐ Rarely

- ☐ Never

Section 3: Noise Perception and Impact on Well-Being

3.1. How would you describe the noise level from electrical power installations in your area?

- ☐ Low

- ☐ Moderate

- ☐ High

- ☐ Very High

3.2. Have you noticed any disturbances in your daily activities due to noise from power installations?

- ☐ Yes

- ☐ No

3.3. If yes, please specify the nature of disturbances (e.g., sleep disturbances, stress, difficulty concentrating):

Section 4: Environmental Factors and Noise Emission

4.1. Do you think environmental factors (e.g., weather, geography) affect the noise level from power installations?

- ☐ Strongly Agree

- ☐ Agree

- ☐ Neutral

- ☐ Disagree

- ☐ Strongly Disagree

4.2. In your opinion, which environmental factor do you believe has the most significant impact on noise propagation?

- ☐ Wind Speed

- ☐ Temperature

- ☐ Humidity

- ☐ Geographic Features (e.g., hills, valleys)

- ☐ Other (Specify: _____)

Section 5: Mitigation Strategies and Policies

5.1. Are you aware of any existing noise mitigation measures implemented for electrical power installations in your area?

- ☐ Yes

- ☐ No

5.2. In your opinion, what measures could be effective in reducing noise emissions from power installations? (Tick all that apply)

- ☐ Sound barriers

- ☐ Vegetative buffers

- ☐ Noise-absorbing materials

- ☐ Restricted operational hours

- ☐ Other (Specify: _____)

Section 6: Suggestions and Comments

6.1. Do you have any additional comments or suggestions regarding noise emissions from electrical power installations? _____

Thank you for your participation! Your input is valuable for our research.

Supplementary Materials

Table S1. Geographic Coordinates of Transformer Sampling Locations

Location ID	Latitude (N)	Longitude (E)
L1	5°35'19.36"N	5°51'27.49"E
L2	5°35'25.23"N	5°51'44.44"E
L3	5°35'33.16"N	5°51'43.03"E
L4	5°35'37.44"N	5°52'2.56"E
L5	5°35'10.2"N	5°52'3.87"E
L6	5°35'23.6"N	5°51'35.67"E
L7	5°35'27.78"N	5°51'9.31"E
L8	5°35'13.9"N	5°51'36.68"E
L9	5°35'16.86"N	5°51'35.54"E
L10	5°35'46.15"N	5°51'31.13"E
L11	5°35'18.1"N	5°51'33.03"E
L12	5°35'26.47"N	5°52'1.59"E
L13	5°35'20.16"N	5°51'41.44"E
L14	5°34'59.51"N	5°51'37.22"E
L15	5°35'36.94"N	5°51'47.65"E
L16	5°35'36.42"N	5°51'45.49"E
L17	5°35'22.86"N	5°51'55.48"E
L18	5°34'55.39"N	5°51'49.66"E
L19	5°35'20.31"N	5°51'49.13"E
L20	5°35'24.83"N	5°51'21.76"E