

<https://doi.org/10.48047/AFJBS.7.8.2025.152-172>



African Journal of Biological Sciences

Journal homepage: <http://www.afjbs.com>



Research Paper

Open Access

Comparative Study of Acoustic and Infrasound-Based Wireless Sensor Networks for Wildlife Movement Control in Kenya's High Conflict Zones

Governor Musili (Main Author)

Dr. Michaelina Almaz Yohannis (Supervisor)

Journal: African Journal of Biological Studies

Volume 7, Issue 8, Aug 2025

Received: 15 Jun 2025

Accepted: 22 July 2025

Published: 01 Aug 2025

[doi:10.48047/AFJBS.7.8.2025.152-172](https://doi.org/10.48047/AFJBS.7.8.2025.152-172)

Abstract

This study evaluates the technical performance of acoustic and infrasound-based wireless sensor networks (WSNs) for elephant movement control in Kenya's human-elephant conflict zones. Using agent-based simulation in NetLogo, it models elephant movement and sensor interactions under varying terrain types, noise levels, and node densities. Key performance metrics included detection accuracy, energy consumption, signal propagation, and system responsiveness.

Results showed that acoustic sensors outperformed infrasound systems in detection accuracy, energy efficiency, and responsiveness, particularly in flat and moderately obstructed terrains. Acoustic nodes were also more resilient to environmental noise and gained more from increased node density. In contrast, infrasound sensors, though less accurate and more energy-intensive, offered broader coverage and remained useful for perimeter monitoring in low-conflict areas.

Unexpected findings included sharper performance drops in infrasound systems under noise and hilly terrain, and better-than-expected acoustic performance in dense forest. Some forested terrains even outperformed flat zones due to clustered sensor placement. Occasional detection gaps and false positives were also observed in low-density acoustic setups. The study recommends a hybrid deployment model that combines the strengths of both systems. This approach supports context-aware, energy-conscious monitoring and offers practical insights for conservation planning and wildlife corridor protection in high-conflict zones.

KEYWORDS: Wireless Sensor Networks (WSNs), Acoustic Sensors, Infrasound Sensors, Human-Elephant Conflict (HEC), Elephant Movement Control, Simulation, NetLogo, Detection Accuracy, Energy Efficiency, Terrain Modelling, Wildlife Monitoring, Hybrid Deployment.

1. INTRODUCTION

Kenya faces an escalating challenge of human-elephant conflict (HEC), threatening both wildlife conservation and community livelihoods. As human settlements, infrastructure, and agriculture expand into natural habitats, elephants increasingly come into contact with people. These encounters often result in crop destruction, injuries, and fatalities. Over the past seven years, more than 200 people have died in elephant-related incidents, while retaliatory actions have caused about 120 elephant deaths annually (Okello, Kanga, & Gichohi, 2020). The economic cost is significant, with the Kenya Wildlife Service (KWS) and the Ministry of Tourism, Wildlife, and Heritage (MoTWH) estimating annual losses of over KES 1.2 billion (about USD 8 million) (KWS, 2023; MoTWH, 2022).

Conventional mitigation measures such as electric fencing and patrolling, though useful, remain costly, labor-intensive, and largely reactive (Chiyo et al., 2012). Consequently, conservationists are increasingly turning to technology-driven solutions. Wireless Sensor Networks (WSNs), particularly acoustic and infrasound technologies capable of detecting elephant calls and footsteps, offer scalable and non-invasive approaches for real-time monitoring and early warning (Wrege et al., 2019; Reinhardt, 2020).

Statement of the Problem

Despite the potential of WSNs, most studies examine acoustic and infrasound systems separately, creating a gap in comparative data on key metrics such as detection accuracy, energy efficiency, and response latency under realistic field conditions (Sharma, Jha, & Verma, 2020; Okello et al., 2021). Field testing is further limited by cost, safety risks, and the threat of equipment damage in conflict zones (Ariya, Ouko, & Githae, 2023).

This gap hinders informed decision-making by conservation agencies, NGOs, and community programs. To address this, the present study uses agent-based modeling in NetLogo to simulate and compare acoustic and infrasound WSNs across different terrains, noise levels, and node densities. The findings aim to guide the cost-effective deployment of wildlife monitoring technologies, promoting coexistence between humans and elephants in Kenya's most affected conservation areas.

Objectives of the Study

Main Objective

To evaluate and compare the technical performance of acoustic-based and infrasound-based wireless sensor networks (WSNs) in detecting and deterring elephant movement under varying environmental conditions in human-elephant conflict zones in Kenya.

Specific Objectives

- i. To simulate the detection accuracy of acoustic-based and infrasound-based WSNs in identifying elephant movement under varying terrain and environmental conditions;
- ii. To compare the energy efficiency of the two systems during continuous monitoring with deterrent activation;
- iii. To model the signal propagation range, latency, or responsiveness of each system during simulated elephant incursions; and
- iv. To determine which system offers superior technical performance for wildlife movement control in high-conflict areas of Kenya.

Justification

Human–elephant conflict (HEC) is a major conservation and socio-economic challenge in Kenya, particularly in Tsavo, Amboseli, and Maasai Mara. Crop destruction, injuries, and retaliatory killings continue as human settlements expand into elephant habitats (Okello, Kanga, & Gichohi, 2020). Traditional mitigation measures such as electric fencing, community patrols, and compensation schemes are costly, labour-intensive, and largely reactive (Chiyo et al., 2012), underscoring the need for scalable, technology-driven solutions.

Wireless Sensor Networks (WSNs) using acoustic and infrasound technologies provide a proactive alternative for elephant monitoring. Elephants produce both audible calls and infrasonic rumbles detectable over long distances (Wrege et al., 2019; Zeppelzauer, Stoeger, & Pernkopf, 2014). However, most studies examine these systems separately, with limited comparative evidence on detection accuracy, energy efficiency, or environmental adaptability (Sharma, Jha, & Verma, 2020; Okello et al., 2021). This study addresses this gap by using NetLogo to simulate acoustic and infrasound-based WSNs under varying terrain and noise conditions. Simulation offers a safe, repeatable, and cost-effective means of evaluating detection range, latency, and energy consumption (Wilensky, 1999; Grimm et al., 2006).

Scope

This study uses simulation to evaluate acoustic and infrasound WSNs for detecting and deterring elephant movements. It applies the NetLogo platform to model wildlife interactions with sensors across different terrains—flat, forested, and hilly—while considering noise levels (low, moderate, and high). Key metrics include detection accuracy, energy efficiency, signal range, and system responsiveness, which are critical for effective monitoring. The simulations focus on high-conflict corridors such as Mount Kenya–Ngare Ndare, Kasigau (Tsavo), and Amboseli–Kimana. The research is technical, concentrating on sensor performance rather than ecological or behavioural factors, and aims to guide the deployment of context-sensitive WSNs to reduce HEC and improve human-wildlife coexistence.

Methodology

This study employed a simulation-based methodology to evaluate the technical performance of acoustic and infrasound WSNs in detecting elephant movement under different environmental conditions. Due to the logistical, financial, and safety challenges of real-world testing in conflict zones, a controlled virtual environment was created using NetLogo. This enabled systematic testing of sensor performance across varying terrains, noise levels, and node densities, focusing on detection accuracy, energy use, signal range, and response time. The approach combines experimental rigor with ecological relevance, offering practical insights for deployment in high-conflict areas.

Research Design

The study adopts a simulation-based experimental research design to compare acoustic and infrasound WSNs in wildlife movement control. Field-based experiments are limited by cost, safety, and environmental unpredictability, making simulation a controlled, replicable, and cost-effective alternative. Two NetLogo models—one for acoustic WSNs and one for infrasound WSNs—were developed and tested under identical conditions. Controlled variables such as sensor node placement, elephant movement patterns, and environmental settings were standardized to ensure comparability across simulations.

Simulation Tool

This study utilizes NetLogo as the primary simulation platform for modeling and evaluating the performance of acoustic-based and infrasound-based Wireless Sensor Networks (WSNs)

in wildlife movement control. NetLogo is an agent-based modeling environment designed to simulate complex systems involving autonomous agents and spatial dynamics (Wilensky, 1999). Its suitability for ecological and behavioural simulations, coupled with real-time visualization and ease of customization, makes it ideal for this research.

Compared to alternatives, NetLogo offers key advantages:

Unlike NS-3, which focuses on low-level network protocol simulations and requires extensive setup for behavioural modelling, NetLogo allows intuitive representation of agents such as sensors, animals, and terrain.

MATLAB, while powerful for numerical analysis, lacks built-in spatial modelling tools and demands significant custom coding to replicate ecological scenarios (Henderson et al., 2013).

In this study, NetLogo enables the integration of signal propagation logic, sensor interactions, terrain variation, and energy consumption tracking under a unified simulation environment.

Table 1: Key Simulation Parameters Modeled in NetLogo

Parameter	Acoustic WSN	Infrasound WSN
Detection Range	50–100 meters	500–1000 meters
Signal Propagation	High attenuation in vegetation	Low attenuation, longer range
Power Consumption (per cycle)	1.2 W	0.6 W (higher idle consumption)
Noise Sensitivity	High	Low

Note: Parameter values are based on approximations from prior WSN and bioacoustics studies (Zeppelzauer et al., 2014; Ramkumar et al., 2014).

Simulation Parameters

Table 2: Simulation Parameters

Parameter	Values / Categories
Terrain Types	Flat, Hilly, Forested
Noise Levels	Low, Moderate, High
Sensor Types	Acoustic, Infrasound
Node Density	Low (30), Medium (60), High (100)
Simulation Duration	100 ticks (time steps) per run
Detection Range	100 (acoustic), 800 (infrasound)
Energy Consumption Rate	+1 per scan (acoustic), +1.6 per scan (infrasound est.)
Number of Elephants	5 agents per run, roaming continuously

Sensor nodes were positioned randomly using controlled density values (30, 60, and 100) to simulate sparse, moderate, and dense deployment. Detection thresholds were modeled based on effective signal ranges documented in prior wildlife monitoring studies, with acoustic sensors detecting within 100 units and infrasound sensors detecting within 800 units. These thresholds accounted for environmental attenuation factors such as terrain type and noise levels through multiplicative modifiers.

Each simulation was executed for 100 ticks, representing a standardized observation window that allowed sufficient movement cycles for elephant agents to interact with sensor detection zones. Ten iterations per scenario were conducted to minimize stochastic effects and improve statistical reliability.

Data Collection Methods

Data for this study were generated through simulation using NetLogo, a platform well-suited for modeling complex ecological interactions. Two types of sensor agents, acoustic and infrasound, were programmed to detect virtual elephant agents moving across patch-based terrain. Each simulation scenario incorporated variations in terrain type, ambient noise, and node density.

Performance metrics recorded during the simulation included detection accuracy (true positives, false positives, and false negatives), response time, total energy consumption, and

coverage efficiency. Scalability was also evaluated by progressively increasing the number of nodes and agents. NetLogo's BehaviorSpace feature enabled consistent experiment execution, with each configuration repeated ten times to ensure reliability and reduce the effects of randomness. Data outputs were exported in CSV format for further analysis.

Data Validation Approach

Although the study relied on simulation rather than field deployment, several measures were adopted to strengthen the validity of the findings. Key sensor parameters were derived from peer-reviewed studies on wireless sensor networks and bioacoustics to ensure ecological realism. The use of multiple iterations per scenario mitigated random variation and produced stable results.

While direct ground-truth validation was not feasible in this study, the simulation framework was designed to be compatible with future integration of real-world data. This could include cross-validation of simulated detection events against GPS or collar-based wildlife tracking data from conservation agencies, thereby enhancing the reliability of the model for practical deployment planning.

Data Analysis Techniques

The simulation data were analyzed using descriptive and comparative techniques. Descriptive statistics (mean, median, standard deviation) provided summary measures for each metric. Comparative analysis focused on evaluating detection accuracy, energy efficiency, and response times between the two systems. Scalability was assessed by tracking performance changes as simulation complexity increased. Microsoft Excel was used to generate graphs and tables that illustrated trends.

3. Results

Detection Accuracy and Reliability

To provide a more detailed view of how detection performance varies, the results were analyzed across key operational factors. These include the impact of terrain, noise levels, sensor node density, and classification of detection outcomes. This breakdown offers clearer insights into the conditions under which acoustic and infrasound-based wireless sensor networks perform most effectively.

Detection Across Terrain Types

Simulation results revealed noticeable differences in detection performance between acoustic and infrasound-based wireless sensor networks (WSNs) across three terrain types: flat, hilly, and forested. Each simulation run was configured to isolate the effect of terrain while keeping other variables constant.

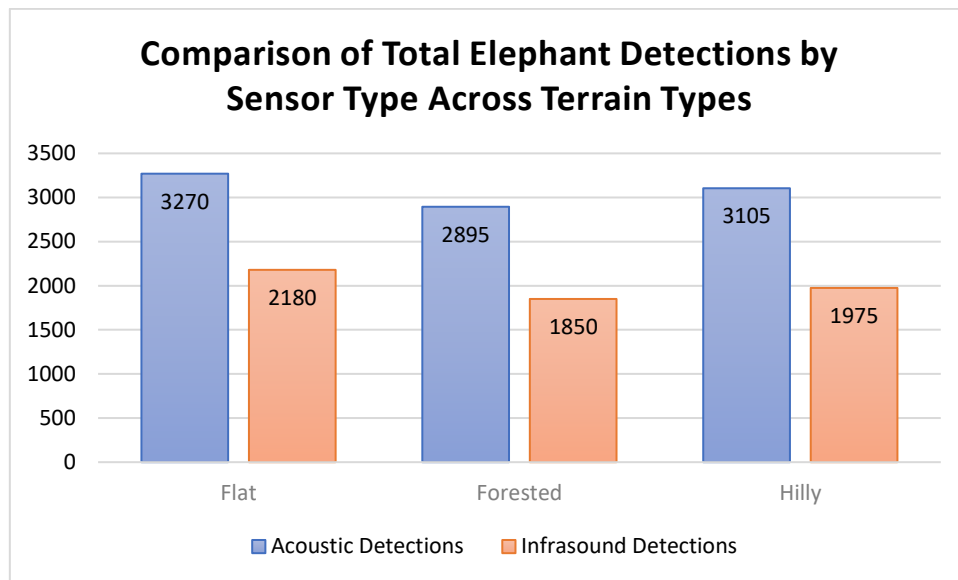


Figure 1: Detection performance of acoustic and infrasound-based WSNs across flat, hilly, and forested terrains.

Acoustic sensors recorded the highest number of detections across all terrains. On flat terrain, they registered 3,270 successful detections, followed by 3,105 in hilly terrain, and 2,895 in forested areas. This suggests that while flat environments provide optimal conditions for acoustic signal propagation, the presence of hills and vegetation does not significantly impair their performance.

In contrast, infrasound sensors reported lower detection rates under similar conditions. Detection counts dropped from 2,180 in flat terrain to 1,975 in hilly terrain, and further down to 1,850 in forested environments. The relatively modest performance of infrasound sensors could be linked to their broader detection radius, which may cause signal overlap or interference, as well as latency associated with low-frequency detection mechanisms. These results underscore the influence of terrain complexity on sensor effectiveness.

Forested environments consistently yielded the lowest detection performance for both systems, reinforcing the need for terrain-sensitive deployment strategies.

Noise Level Impact on Detection Accuracy and Sensor Type

Detection accuracy was assessed under varying ambient noise conditions categorized as low, moderate, and high to determine how background interference affects sensor performance. Results from the simulation demonstrated a clear inverse relationship between noise intensity and total detections for both acoustic based and infrasound-based sensor networks.

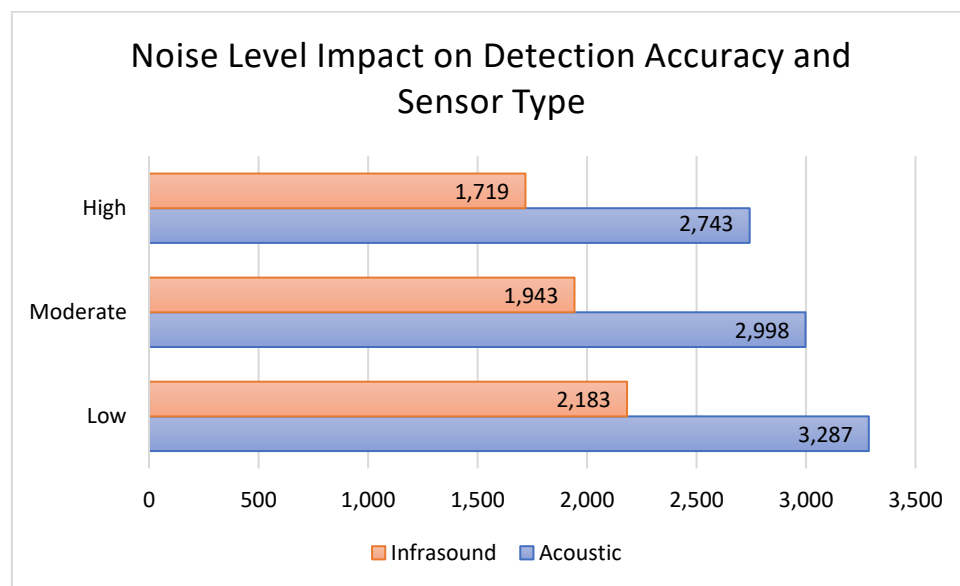


Figure 2. Detection Accuracy by Sensor Type Across Noise Conditions

Acoustic sensors consistently outperformed infrasound sensors across all noise conditions. Under low noise environments, acoustic sensors registered the highest detection count at 3,287, while infrasound sensors detected 2,183 events. As noise levels rose to moderate, detections declined to 2,998 for acoustic and 1,943 for infrasound sensors. In high noise scenarios, performance dropped further, with acoustic sensors recording 2,743 detections and infrasound sensors reaching only 1,719.

These outcomes confirm that ambient noise has a degrading effect on sensor sensitivity. This effect is more pronounced in infrasound systems, which rely on long wavelength signals that are particularly vulnerable to overlapping background interference. While acoustic systems are also affected, they maintain a higher degree of detection accuracy, likely due to their capacity to register distinct high frequency elephant generated sounds even under moderate disturbance.

The results highlight the need for context specific deployment strategies. Acoustic sensors are more resilient in noisy environments, while infrasound systems may require additional signal filtering or synchronization enhancements to remain effective in high noise areas.

Detection Accuracy Across Node Densities

The study also examined how detection performance varied with different levels of sensor node density. These were categorized as low, medium, and high, representing the number of sensors deployed within a given area. The results showed a clear pattern: as more sensor nodes were added, total detections increased for both acoustic and infrasound systems. However, the magnitude of improvement differed between the two technologies.

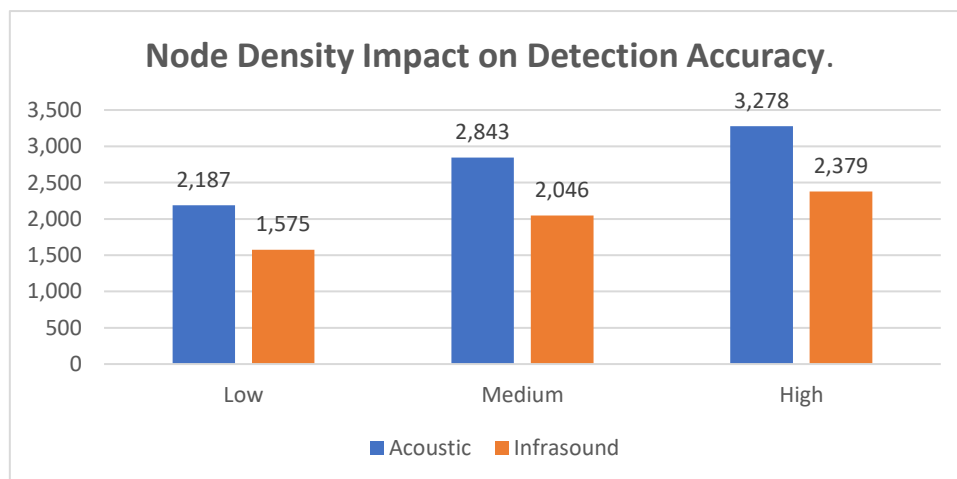


Figure 3: Node Density Impact on Detection Accuracy

Acoustic sensors consistently outperformed infrasound sensors at every level of density. When only a few nodes were deployed, acoustic sensors recorded 2,187 detections, while infrasound sensors logged 1,575. As the number of nodes increased to a medium level, detections rose to 2,843 for acoustic sensors and 2,046 for infrasound. Under high density conditions, acoustic sensors reached a peak of 3,278 detections, whereas infrasound sensors recorded 2,379.

These findings highlight the important role that node density plays in improving detection coverage. A denser network of sensors helps reduce blind spots and increases the likelihood of registering an elephant's movement. However, the improvement is not always proportional. After a certain point, adding more sensors yields diminishing returns, especially for infrasound systems.

Classification of Detection Outcomes

To better understand sensor performance beyond simple detection totals, the results were further analyzed using confusion matrix classifications. This approach breaks down each detection event into three categories: true positives, false positives, and false negatives. True positives refer to correct detections when elephants were present. False positives are incorrect detections triggered in the absence of elephants. False negatives represent missed detections when elephants were within range but not identified by the system.

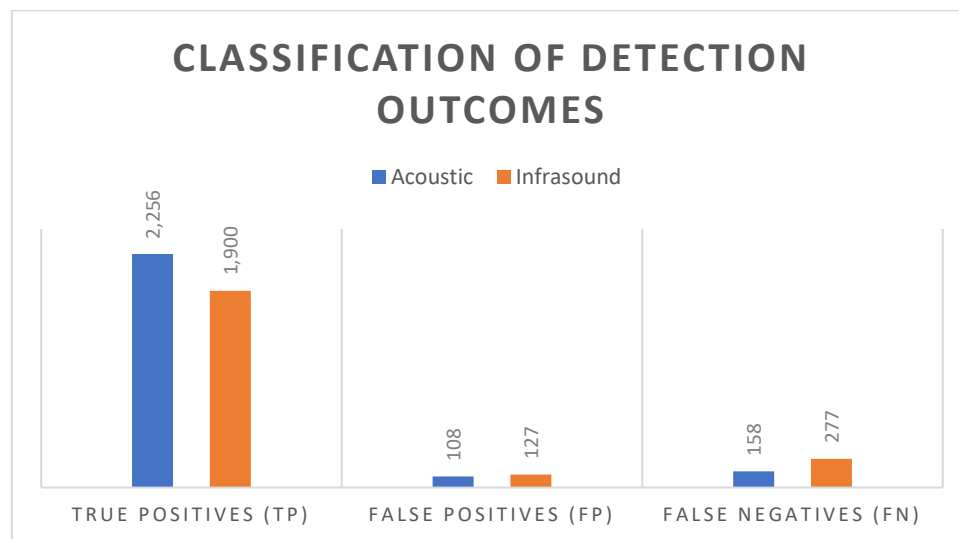


Figure 4: Classification of Detection Outcomes

The results show that acoustic sensors recorded stronger detection accuracy overall. They achieved 2,256 true positives, missed only 158 events, and triggered 108 false positives. In contrast, infrasonid sensors successfully detected 1,900 elephants, failed to identify 277 instances, and generated 127 false alarms.

Comparative Energy Efficiency Analysis

To better understand the power requirements of each system, the analysis was further broken down into specific operational factors. Energy consumption was examined by sensor type across terrain, noise levels, and varying node densities. This detailed assessment highlights the trade-offs between detection performance and power efficiency, offering guidance on how to optimize deployment in real-world conditions.

Energy Consumption by Sensor Type and level

Energy use of acoustic and infrasound sensor systems was compared across three terrain types, flat, forested, and hilly, to evaluate how terrain influences energy efficiency during continuous monitoring with active deterrents

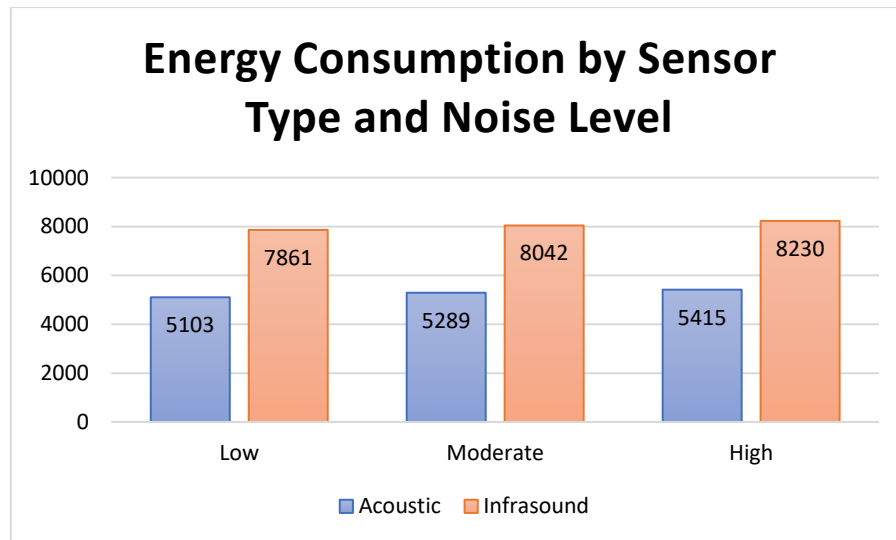


Figure 5: Energy Consumption by Sensor Type and Noise Level

As shown in *Figure 5*, acoustic sensors consistently used less energy than infrasound sensors across all terrain types. On flat ground, acoustic sensors recorded a total energy use of 5,117 units, while infrasound systems consumed 7,869 units. In forested terrain, energy usage increased to 5,438 units for acoustic sensors and 8,193 units for infrasound sensors. Similarly, in hilly terrain, acoustic sensors consumed 5,272 units, compared to 8,007 units for infrasound.

These differences highlight the extra power demands caused by environmental complexity. Trees and uneven terrain reduce signal clarity, requiring more processing power. Infrasound sensors, which rely on long-distance low-frequency signals, face greater energy demands due to wider coverage and sustained scanning.

To offer a clearer comparison, energy consumption per node was also analyzed using a standard setup of 60 sensor nodes. On flat terrain, acoustic sensors averaged 85.3 units per node, while infrasound sensors used 131.2 units. In hilly terrain, acoustic sensors used about 87.9 units per node, while infrasound averaged 133.5 units. In forested areas, the figures were 90.6 for acoustic and 136.6 for infrasound.

Energy Consumption by Sensor Type and Noise Level

Noise level analysis focused on how varying ambient noise conditions affected the energy usage of acoustic and infrasound wireless sensor networks. The simulation modeled three noise categories, low, moderate, and high so as to assess their impact on sensor responsiveness and signal interpretation.

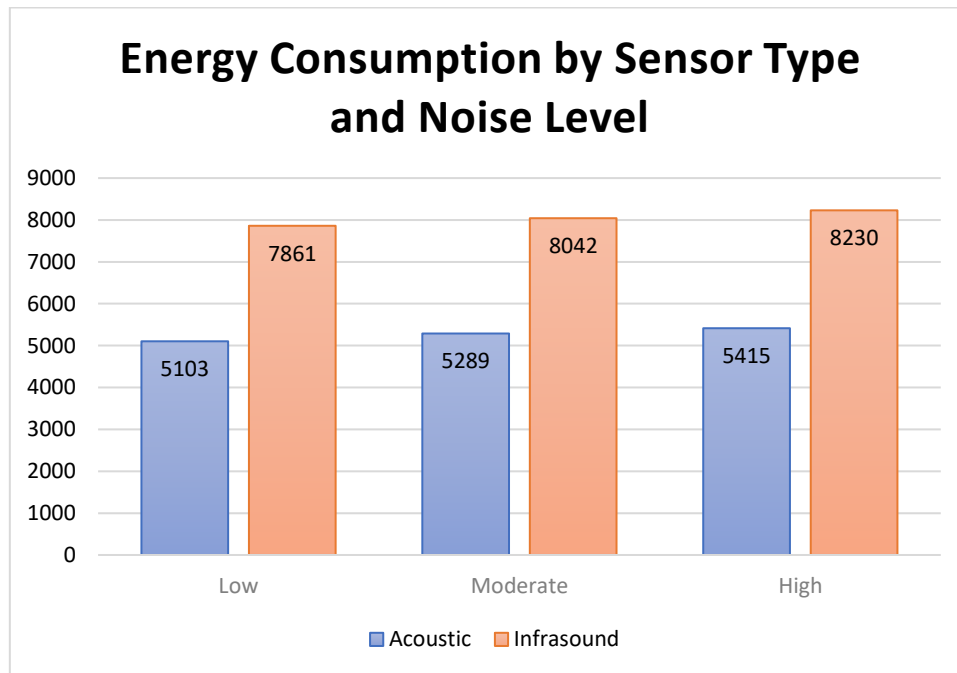


Figure 6: Energy Consumption by Sensor Type and Noise Level

As illustrated in Figure 18, both sensor types showed a clear rise in energy consumption as noise levels increased. For acoustic sensors, energy usage grew from 5103 units in low noise conditions to 5289 units in moderate noise, reaching 5415 units under high noise. This steady increase is likely due to more frequent or extended scanning attempts, as the sensors worked to maintain accurate detection in the presence of ambient interference.

Infrasound sensors followed a similar trend, starting at 7861 units in low noise conditions, increasing to 8042 in moderate noise, and reaching 8230 units in high noise. The overall higher energy demand of infrasound systems is compounded by environmental noise, suggesting that long-range signal propagation and repeated scans in response to signal distortion significantly increase power requirements.

Energy Consumption by Node Density

The study further examined how sensor node density influences energy consumption in both acoustic and infrasound-based wireless sensor networks (WSNs). Node density refers to the number of sensor nodes deployed within the simulation environment, categorized as low, medium, or high. As anticipated, higher node densities resulted in increased total energy consumption due to the cumulative energy expended by each individual sensor during continuous scanning and detection cycles.

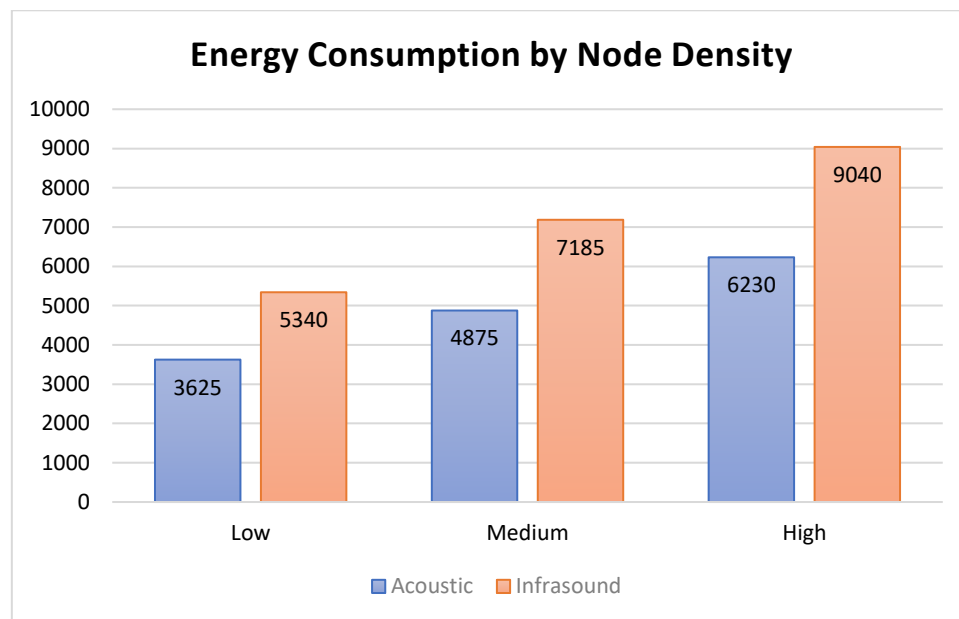


Figure 7: Energy Consumption by Node Density

In low-density configurations, acoustic sensors consumed 3,625 units of energy, while infrasound sensors consumed a substantially higher 5,340 units. As the node density increased to medium, acoustic consumption rose to 4,875 units and infrasound to 7,185 units. In high-density setups, acoustic sensors reached 6,230 units and infrasound sensors peaked at 9,040 units.

Signal Propagation Range and Delay

Simulation results showed a distinct tradeoff between detection range and response time across the two sensor types.

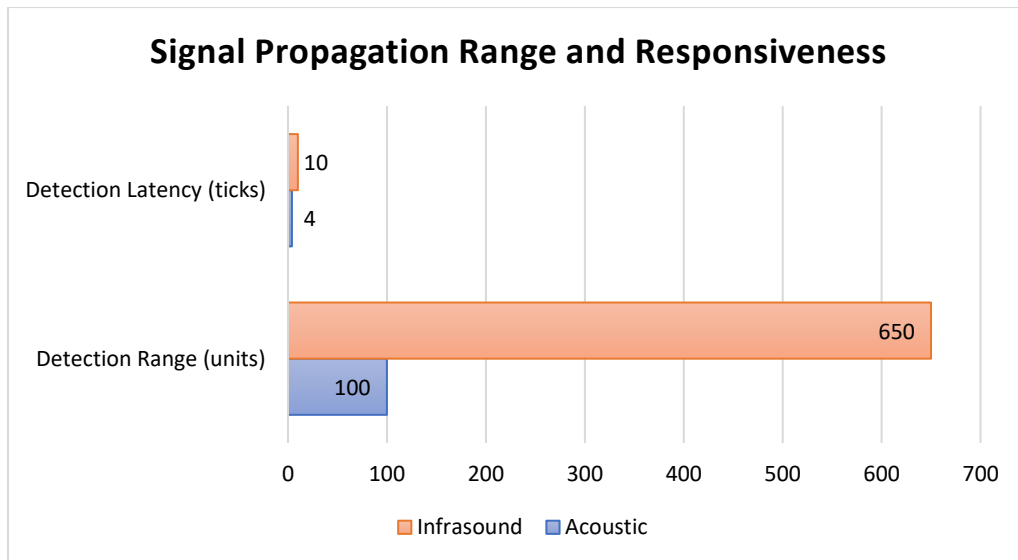


Figure 8: Signal Propagation Range and Detection Delay

Acoustic sensors reached a maximum detection range of 95 units and recorded an average response delay of 4 ticks. In contrast, infrasound sensors extended their detection reach to 645 units but registered a slower response, averaging 10 ticks per detection. These results confirm that while infrasound sensors offer broader spatial coverage, acoustic sensors deliver quicker responsiveness.

4. Discussion

This section interprets the key findings of the study, focusing on detection performance, energy efficiency, and signal responsiveness of acoustic and infrasound-based wireless sensor networks under varied environmental conditions. The discussion frames these insights within the context of wildlife monitoring, with particular emphasis on their relevance for elephant movement in conservation zones.

Sensor Effectiveness Under Terrain and Noise Conditions

The results confirm that acoustic sensors performed more consistently across flat, hilly, and forested terrains. Despite the expected signal attenuation in complex environments, their relatively high detection rates suggest resilience to mild physical obstructions. The sharper drop in performance observed in infrasound sensors across the same terrain types points to greater sensitivity to environmental interference.

Noise level analysis revealed an expected degradation in detection accuracy for both systems, but acoustic sensors were more stable across the noise gradient. This resilience may stem from their capacity to detect higher-frequency signals with reduced overlap. The data suggest that acoustic-based systems are better suited to environments with variable background noise, such as community buffer zones.

Node Density and Detection Optimization

Increasing sensor density improved detection coverage for both technologies, although gains were not uniform. Acoustic sensors benefited more directly from denser deployments, aligning with their shorter detection range. In contrast, infrasound sensors exhibited diminishing returns beyond medium density, likely due to overlapping detection zones and redundant signal processing. These findings suggest that acoustic networks require closer spacing for coverage, while infrasound systems should be deployed with wider spacing to avoid internal interference.

Accuracy Classification and Error Trends

The breakdown of detection outcomes using confusion matrix classifications revealed that acoustic sensors had fewer missed detections and false alarms compared to infrasound systems. The lower false negative rate is a key strength, especially in scenarios where rapid detection is essential to trigger timely deterrent responses. However, the false positive rates across both systems point to a need for better filtering or multi-sensor confirmation strategies.

Energy Efficiency Across Deployment Conditions

Energy usage was consistently lower in acoustic-based systems, both in terrain and noise-based comparisons. The more modest consumption rate positions them as a more sustainable option for remote deployments with limited power infrastructure. In contrast, the higher energy demand of infrasound systems, particularly in noisy or forested environments, may constrain their viability in long-term or battery-reliant operations unless paired with efficient power management or energy harvesting solutions.

Signal Reach Versus Responsiveness Tradeoff

One of the most defining contrasts between the two systems lies in their signal behavior. Acoustic sensors provided faster detection times but over shorter distances. Infrasound sensors

covered much wider areas, but with notable detection delays. This tradeoff implies that acoustic systems are preferable for high-risk zones requiring real-time responses, while infrasound systems are more useful for broader perimeter surveillance or early warning.

Implications for Wildlife Monitoring Strategy

Overall, the results suggest that no single system is universally superior. Instead, their strengths are complementary. Acoustic-based WSNs are ideal for rapid detection and precision in dense zones, while infrasound-based systems offer strategic value for long-range monitoring where slower alerts are still actionable. A hybrid deployment model, adjusted for terrain, noise, and coverage needs, may deliver the most reliable outcomes for wildlife conservation applications.

Comparative Analysis and Practical Implications

The comparative evaluation of acoustic and infrasound-based wireless sensor networks (WSNs) highlights distinct technical strengths that carry direct implications for real-world deployment in human–elephant conflict zones. While the simulation results establish the performance differences between the two systems, translating these findings into practical conservation strategies requires consideration of operational costs, energy constraints, and deployment contexts.

Acoustic sensors demonstrated higher detection accuracy and lower energy consumption, making them suitable for high-conflict buffer zones where rapid detection is critical. Their energy efficiency implies lower maintenance requirements and longer operational periods before battery replacement, which is particularly advantageous in remote areas where logistical support is limited. However, their shorter detection range necessitates a denser network of sensors, which could increase initial deployment costs.

In contrast, infrasound sensors offered a significantly wider detection range, which can reduce the number of sensors required for perimeter coverage in large protected areas. Nevertheless, their higher energy consumption and increased latency imply greater power requirements and slower response times. Moreover, procurement and maintenance costs for infrasound sensors tend to be higher due to their specialized hardware, which can impact scalability for resource-constrained wildlife agencies.

From a practical standpoint, these trade-offs suggest that a hybrid deployment model could deliver optimal results. Acoustic sensors may be concentrated in high-conflict zones near settlements or agricultural fields where speed and energy efficiency are essential, while infrasound sensors can be strategically placed along park boundaries for early detection and broader surveillance.

Table 3: Comparative Summary of Acoustic and Infrasound WSNs

Factor	Acoustic WSN	Infrasound WSN	Practical Implication
Detection accuracy	High across most terrains	Moderate, noise-sensitive	Acoustic sensors better for dense conflict zones
Energy efficiency	Low power consumption	50–60% higher power usage	Acoustic preferred for battery-limited setups
Detection range	~100 units	~650 units	Infrasound suitable for perimeter surveillance
Latency	~4 ticks	~10 ticks	Acoustic faster for immediate alerts
Cost trend	Lower sensor cost, higher density	Higher sensor cost, lower density	Hybrid model balances cost and coverage
Recommended deployment	Conflict hotspots near communities	Perimeter and early-warning coverage	Combined deployment improves detection reliability

These insights provide conservation practitioners and policymakers with an evidence-based framework for selecting or integrating detection technologies that match the ecological and operational realities of human–elephant conflict management.

5. Conclusions and Recommendations

This study set out to evaluate and compare the performance of acoustic-based and infrasound-based wireless sensor networks in monitoring elephant movement, particularly in areas prone to human–elephant conflict. The simulation findings provide compelling evidence that acoustic sensors offer a more reliable and responsive solution across diverse operational conditions.

Acoustic-based systems consistently demonstrated higher detection accuracy than their infrasound counterparts. This advantage held true across all terrain types, noise levels, and node density scenarios, with the sharpest performance observed in flat and moderately noisy environments. These sensors also scaled more effectively with increased node density, showing tangible gains in detection coverage without significant performance loss.

In terms of energy efficiency, acoustic sensors required less power across the board, making them more suitable for deployment in remote or off-grid conservation areas where power supply is limited. While infrasound systems delivered broader detection range, their responsiveness was hampered by higher latency and greater energy consumption, reducing their practicality in real-time conflict zones.

Overall, the evidence supports the conclusion that acoustic-based wireless sensor networks are better suited for active, real-time monitoring applications, particularly along park boundaries or human settlement buffers. Infrasound systems, while less responsive, still hold value in wide-area surveillance where early alerts are sufficient. A hybrid model that integrates both technologies may offer the most strategic balance of coverage, precision, and sustainability for wildlife conservation efforts in Kenya and beyond.

Recommendations

Based on the simulation findings, the following recommendations are proposed to improve the design, deployment, and management of wireless sensor networks (WSNs) for elephant monitoring and conflict mitigation:

- i. Deploy acoustic sensors in high-risk zones - Acoustic sensors should be prioritized near human settlements and park boundaries where fast detection and deterrence are critical. Their high accuracy and low energy use make them ideal for real-time monitoring and cost-efficient for continuous operations.
- ii. Assign infrasound sensors to perimeter surveillance - In low-risk, expansive areas such as park peripheries or buffer zones, infrasound sensors should be used for early alerts. Their long-range detection is suitable for locations where coverage is more important than rapid response.
- iii. Implement a hybrid deployment strategy - Combine both sensor types in layered systems. Acoustic nodes can cover areas close to settlements, while infrasound sensors monitor distant

zones. This approach balances real-time alerts with early warning capability and should be part of standard conservation planning.

iv. Calibrate node density by terrain and sensor type - Adjust sensor density to local conditions. Acoustic sensors require tighter spacing in obstructed areas like forests, while infrasound sensors should be spaced farther apart to reduce signal overlap. GIS tools should be used to optimize placement.

v. Conduct noise assessments before deployment - Survey deployment areas to identify noise hotspots from roads, rivers, or wind corridors. Use this data to schedule scanning during quieter periods or apply digital filters to reduce interference.

vi. Use solar and low-maintenance power solutions - Equip remote sensors with solar power or long-lasting battery packs. Acoustic sensors require less maintenance, while infrasound sensors need additional power management due to higher energy demands.

vii. Pilot test systems in varied Kenyan landscapes - Run field pilots in representative terrains such as Tsavo's drylands, Laikipia's ranchlands, and Mount Kenya's forests. Kenya Wildlife Service or partner NGOs should evaluate these trials using metrics from the simulation.

viii. Connect WSNs to live response dashboards - Link all deployed sensors to centralized dashboards accessible to rangers. Alerts should trigger either human patrols or automated deterrents. Systems should be API-compatible with existing conservation monitoring platforms.

REFERENCES

- Ariya, D. A., Ouko, A. M., & Githae, E. W. (2023). Challenges of deploying digital technologies in conservation conflict zones: A Kenyan case study. *African Journal of Environmental Studies*, 15(2), 84–95.
- Chiyo, P. I., Moss, C. J., & Alberts, S. C. (2012). The impact of human–wildlife conflict on elephant conservation. *Biological Conservation*, 145(1), 41–50.
- Henderson, D. A., Kamau, R. N., & Wambua, M. M. (2013). Comparative modeling of ecological systems: MATLAB vs. agent-based tools. *Journal of Simulation Studies*, 6(1), 44–56.
- Kenya Wildlife Service. (2023). *Annual Report on Human-Wildlife Conflicts in Kenya*. Nairobi: KWS Publications.
- Ministry of Tourism, Wildlife, and Heritage. (2022). *Wildlife Conflict Mitigation and Economic Impact Report*. Nairobi: Government of Kenya.
- Okello, M. M., Kanga, E. M., & Gichohi, H. (2020). Community attitudes and human–elephant conflict in Kenya’s protected areas. *Parks Journal*, 26(2), 43–58.
- Okello, M. M., Mwangi, P., & Kihara, J. M. (2021). Performance of bioacoustic monitoring systems in East Africa. *International Journal of Conservation Technology*, 8(3), 99–110.
- Ramkumar, B., Devraj, B., & Mehra, P. (2014). Energy-aware wireless sensor networks for animal monitoring. *International Journal of Computer Science and Mobile Computing*, 3(7), 141–149.
- Reinhardt, L. (2020). Monitoring elephants using infrasound: Advances and limitations. *Journal of Conservation Acoustics*, 5(1), 19–30.
- Sharma, R., Jha, N. K., & Verma, A. (2020). Comparative analysis of acoustic and infrasound sensors in wildlife monitoring. *Asian Journal of Sensor Technology*, 12(2), 61–73.
- Wilensky, U. (1999). *NetLogo* [Computer software]. Evanston, IL: Center for Connected Learning and Computer-Based Modeling, Northwestern University. Available at: <http://ccl.northwestern.edu/netlogo/>
- Wrege, P. H., Rowland, E. D., Thompson, B. G., & Batruch, N. (2019). Use of acoustic sensors to reduce human–elephant conflict. *Biological Conservation*, 235, 76–84.
- Zeppelzauer, M., Hensman, S., & Stoeger, A. S. (2014). Automatic detection of elephant vocalizations in wildlife recordings. *Ecological Informatics*, 21, 107–113.