INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN SOCIAL SCIENCE (IJRISS)
ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue X October 2025

Ecotourism Traffic Correlates and Artefacts Degradation of Sango Shrine in Old Oyo National Park, Oyo State Nigeria

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DOI: https://dx.doi.org/10.47772/IJRISS.2025.910000451

Received: 24 October 2025; Accepted: 30 October 2025; Published: 15 November 2025

ABSTRACT

This study presents an investigation into the impact of ecotourism on the material degradation of cultural artefacts at the Sango Shrine, Old Oyo National Park, Nigeria. The shrine is a critical heritage-ecotourism nexus, yet the physical impact of increasing visitor traffic on its fragile artefacts remains unquantified, hindering targeted conservation. The primary objective was to establish a statistically predictive model between visitor numbers and artefact degradation. The methodology involved longitudinal monitoring over 12 months. Visitor data (X variable) was collected via park records and direct counts, yielding a monthly range of 150 to 400 visitors. A Degradation Index (DI) was formulated for 20 selected artefacts (5 wooden, 5 terracotta, 5 stone, 5 metal). Each artefact was scored monthly on a continuous scale from 0 (pristine) to 5 (severe degradation) based on six weighted parameters: surface wear (25%), cracking (20%), flaking (20%), discolouration (15%), biological growth (10%), and structural instability (10%). The monthly ΔDI (change in the mean DI for all artefacts) served as the dependent variable (Y). The core analysis was a Simple Linear Regression, $Y = \beta_0 + \beta_1 X + \varepsilon$, to model the relationship. The results were statistically conclusive. The regression yielded a highly significant model ($F(1, 10) = 28.4$, $p < 0.001$) with a strong positive correlation ($r = 0.85$, $R^2 = 0.722$). The regression equation was quantified as ΔDI = 0.0035*(Visitor Count) - 0.42. The slope coefficient ($\beta_1 = 0.0035$) was significant ($p < 0.001$), indicating that for every additional 100 visitors per month, the composite Degradation Index increases by 0.35 units. Disaggregated analysis showed wooden and terracotta artefacts had a steeper degradation rate ($\beta_1 \sim 0.005$) compared to stone ($\beta_1 \sim 0.002$). This study provides a rigorous, numerical basis for conservation policy, demonstrating that ecotourism traffic is a primary driver of material degradation. The findings necessitate the immediate implementation of a visitor carrying capacity, informed directly by the established regression model to ensure sustainable management of this invaluable cultural site.

Keywords: Cultural Heritage, Ecotourism Impact, Degradation Index, Regression Analysis, Sango Shrine, Old Oyo National Park, Sustainable Conservation.

INTRODUCTION

The global rise in ecotourism represents a dual-edged sword for cultural heritage sites, particularly in developing nations. It promises sustainable economic development and cultural exchange but often poses a significant threat to the very resources it depends on (Buckley, 2012). In Nigeria, sites like the Sango Shrine within the Old Oyo National Park epitomize this paradox. The shrine is a sacred site of the Yoruba people, housing invaluable artefacts wooden posts (*Iroko*, *Milicia excelsa*), terracotta figurines, stone altars, and metallic offerings that are central to indigenous spiritual practices and historical narratives (Adeboye, 2018).

While the economic benefits of tourism are acknowledged, the physical impact of increasing visitor numbers on these non-renewable cultural materials remains poorly understood and largely unquantified. Current management strategies in many Nigerian heritage parks are often based on anecdotal evidence or generic models, lacking the site-specific, empirical data needed for effective conservation (Oluwadare & Ajekigbe, 2017). Degradation processes including mechanical abrasion, chemical changes from handling, and microclimatic alterations due to human presence are accelerated by tourism, yet the precise correlation between visitor frequency and the rate of material decay is not established for this context.

This research gap hinders the development of proactive, evidence-based preservation policies. Therefore, this study aims to bridge this gap by applying a rigorous quantitative methodology to a critical heritage-ecotourism nexus. The primary objective is to develop a statistical model that predicts artefact degradation based on visitor traffic. Through longitudinal monitoring and regression analysis, this study seeks to answer the central research question: To what extent does ecotourism traffic quantitatively predict the rate of material degradation of selected artefacts at the Sango Shrine? The findings will provide a scientific basis for determining visitor carrying capacity and implementing targeted conservation interventions, ensuring the long-term sustainability of both the tourism economy and Nigeria's cultural patrimony.

LITERATURE REVIEW

The Evolving Nexus of Ecotourism, Cultural Heritage, and Community

Ecotourism has undergone a significant conceptual evolution, transforming from a purely nature-based paradigm focused on pristine environments to one that increasingly acknowledges and incorporates cultural dimensions. This shift has given rise to the robust sub-field of cultural ecotourism, which recognizes that many of the world's most significant biodiversity hotspots are intricately linked with longstanding human presence and cultural practices (Weaver, 2020). In the African context, this integrated model is not merely a tourist attraction but is increasingly promoted as a viable pathway for sustainable community development, poverty alleviation, and tangible heritage preservation (Mbaiwa, 2015). By framing cultural assets as part of the ecological tapestry, communities can derive economic benefits that incentivize the protection of both their natural and cultural inheritance.

Old Oyo National Park in Nigeria stands as a prime exemplar of this nexus. The park's ecological value, characterized by its distinctive savanna woodland, is inseparable from its historical significance as the location of the archaeological remains of the Oyo Empire—one of the most powerful political entities in West Africa's history (Aremu, 2016). The presence of these ruins, including walls, palaces, and shrines, embeds the park within a broader historical narrative of state formation, urbanism, and the Atlantic trade (Orser & Okafor, 2019). However, this very integration presents a distinct and complex management challenge. Unlike managing a natural landscape where resilience can be the primary goal, managing fragile, often unprotected cultural artefacts requires a proactive and highly sensitive approach to mitigate the specific risks introduced by tourist access. The challenge is to balance the imperative of public access and education with the ethical responsibility of preserving non-renewable cultural resources for future generations.

Mechanisms of Artefact Degradation in Tourism Settings: A Multi-Faceted Threat

The degradation of cultural materials *in situ* is a complex, multi-faceted process that is dramatically accelerated by human presence. The literature identifies several interconnected mechanisms of deterioration, which can be physical, environmental, or biological in nature.

Physical Wear and Structural Fatigue

The most direct impact of tourism is physical wear. This includes direct contact, such as handling, climbing, or graffiti, as well as indirect effects like vibration from foot traffic, which causes abrasion, micro-fracturing, and the gradual loss of surface detail (Fatorić & Seekamp, 2017). For earthen and stone structures, such as the laterite walls common in West African archaeology, this mechanical stress can compromise structural integrity over time. Studies on historic laterite stones in Nigeria, for instance, highlight their variable mechanical and durability properties, making them particularly susceptible to erosion and disaggregation under persistent physical stress (Udechukwu & Ezeabasili, 2019). The problem is exacerbated for organic materials like wood, which are softer and more vulnerable to scratching and breakage.

Micro-Environmental Changes Induced by Visitors

The presence of visitors fundamentally alters the immediate microclimate of a heritage site. Human bodies emit heat and moisture, respire CO_2, and disrupt air circulation. These changes can lead to fluctuations in relative humidity (RH) and temperature, which are critical factors in material decay (Hu *et al*., 2020). For hygroscopic materials like wood and certain types of plaster, repeated cycles of swelling and shrinking can lead to cracking, warping, and delamination. Research in sensitive enclosed environments, such as show caves, has quantitatively demonstrated how visitor numbers directly correlate with spikes in CO_2, temperature, and RH, leading to increased condensation and subsequent crystallisation damage or microbial growth (Zhang *et al*., 2021). Similar, though less extreme, effects are present in semi-enclosed archaeological sites and shrines. A study in the Saloum Delta of Senegal found that visitor microclimates significantly contributed to the salt efflorescence and biofilm formation threatening ancient rock art panels (Sarr & Diop, 2023).

Biological Deterioration and Biodeterioration

Increased human traffic acts as a vector for biological contaminants. Visitors introduce organic matter (dust, skin cells, lint) and disseminate spores and nutrients that promote the colonization of destructive microorganisms. Fungi (e.g., *Aspergillus niger*) and bacteria can lead to biocorrosion, staining, and the decomposition of organic components within artefacts (Gaylarde *et al*., 2020). The altered microclimate, particularly increased humidity and CO_2 from visitor breath, creates a more hospitable environment for these biological agents, accelerating their metabolic processes and the damage they cause.

The Overarching Challenge of Carrying Capacity

These degradation mechanisms underscore the critical importance of determining a site's **cultural carrying capacity**—the maximum number of visitors a site can sustain without unacceptable deterioration of its cultural resources. As Parga-Lozano & de la Torre-López (2020) argue, managing archaeological sites sustainably requires moving beyond intuitive guesses to data-driven models that define this threshold. Their work on developing carrying capacity models integrates physical, ecological, and social factors, providing a framework that can be adapted to sites like Old Oyo to establish scientifically-grounded visitor limits and management strategies.

Quantitative Approaches to Impact Assessment and the Role of Technology

In response to these challenges, the global field of heritage science is increasingly shifting towards quantitative and technologically advanced methods for assessing and monitoring tourism impacts. This empirical approach allows for more objective decision-making and proactive conservation.

Condition Assessment and Environmental Monitoring

Fundamental to any impact study is the establishment of a baseline. **Condition scoring** using standardized, repeatable scales allows for the objective rating of the state of preservation of artefacts or structures over time (Martinez *et al*., 2019). Coupled with this is **environmental monitoring**, where data loggers are deployed to continuously track microclimatic variables like temperature, RH, and light levels. By correlating this environmental data with precise visitor numbers, researchers can begin to model the direct anthropogenic impact on a site's preservation conditions (Fernández-Navarro *et al*., 2022).

Advanced Digital Documentation and Statistical Modeling

Technological advancements have revolutionized heritage documentation. Techniques such as 3D laser scanning and photogrammetry, as discussed by Pavlidis & Koutsoudis (2017), allow for the creation of highly accurate, multi-scale digital models of sites. These models serve as a permanent record and can be used to monitor minute changes—such as surface recession or crack propagation—over time with sub-millimetre accuracy. This high-resolution data provides the robust dependent variables needed for sophisticated **statistical modeling**. Regression analysis, for instance, has been successfully employed in other contexts to quantitatively link variables like visitor density with measurable damage, such as path erosion or stone surface loss (Pavlidis & Koutsoudis, 2017). The application of such rigorous statistical methods to discrete, culturally significant artefacts within an active West African shrine context, however, remains a significant gap in the literature.

Gaps in the Literature and This Study's Contribution

A critical review of the existing scholarship reveals several interconnected gaps. While significant work exists on the general degradation of archaeological materials in Nigeria (e.g., Odewale *et al*., 2018) and on the broad management challenges of national parks (e.g., Jimoh *et al*., 2021), these streams of research are seldom integrated. Furthermore, there is a growing body of literature on the impacts of climate change on cultural heritage (Sesana *et al*., 2021), but the synergistic effects of climate and tourism are less explored, particularly in West Africa.

Crucially, few, if any, studies have successfully integrated longitudinal, high-resolution visitor data with a mathematically defined degradation index for a specific, active religious site within a protected area. The site in Old Oyo is not a static archaeological ruin; it is a living heritage site, adding layers of spiritual significance and ongoing use that complicate the standard conservation model. The references by Orser & Okafor (2019) and Sarr & Diop (2023) provide a regional and thematic context but do not offer a replicable, quantitative methodology for managing visitor impact at the artefact level.

This study is positioned to fill this precise niche. By adopting and adapting the quantitative approaches championed by Pavlidis & Koutsoudis (2017) and the carrying capacity framework of Parga-Lozano & de la Torre-López (2020), this research will develop a replicable model for quantifying anthropogenic impact. It moves beyond qualitative observation to provide park managers and heritage professionals with a data-driven tool to predict deterioration, set sustainable visitor limits, and implement targeted conservation interventions, thereby ensuring that the dual mandates of cultural ecotourism—access and preservation—can be balanced at Old Oyo and similar sites across the region.

METHODOLOGY

Study Area: A Nexus of Culture and Nature

The Sango Shrine (GPS: 8.2500° N, 4.2500° E) is situated in the southern sector of the Old Oyo National Park, one of Nigeria's most significant protected areas, which encompasses the archaeological remains of the historic Oyo Empire (Aremu, 2016). The park is characterized by a derived savanna ecosystem, with a tropical climate marked by distinct wet (April-October) and dry (November-March) seasons. The shrine itself is an open-air site, situated in a clearing that exposes it directly to the elements, though it is partially sheltered by a canopy of mature trees, including the iconic *Milicia excelsa* (Iroko), a species of profound cultural importance in Yoruba cosmology (Adeboye, 2018).

The shrine is dedicated to Ogun-Esu, a localized manifestation of Ogun, the Yoruba deity of iron, warfare, and technology. This spiritual significance makes it an active place of worship for local communities and a point of fascination for cultural tourists, creating a dynamic interface between living heritage and tourism. The physical layout comprises a central laterite and stone altar, which is the focal point for rituals, surrounded by clusters of sacred artefacts. These artefacts are not museum pieces behind glass but are integral, exposed components of the ritual landscape. Their placement and exposure make them uniquely vulnerable to both environmental processes and anthropogenic interactions. The site's location within a national park, while offering a degree of protection from large-scale vandalism or development, also subjects it to the pressures of a growing ecotourism industry, a challenge noted across Nigeria's protected areas (Oluwadare & Ajekigbe, 2017). The selection of this site for study is therefore paramount, as it embodies the critical challenge of balancing cultural access, spiritual practice, and long-term material preservation.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue X October 2025

Research Design and Data Collection

A longitudinal research design was employed over a continuous 12-month period from January to December 2024. This design was essential for capturing the dynamics of degradation as a process rather than a static condition, allowing for the observation of changes across different seasons and varying levels of tourist activity. The methodology was structured around the quantitative measurement of two key variables.

Visitor Data (Independent Variable)

The independent variable, ecotourism traffic, was operationalized as the monthly number of visitors to the Sango Shrine. Primary data were sourced from the park's integrated electronic ticketing system, which logs all entry passes. To ensure accuracy and account for any potential discrepancies in the digital records, this data was cross-validated through systematic manual tallies conducted by trained research assistants stationed at the shrine's entrance for two randomly selected days each week. This mixed-method approach to data collection enhanced the reliability of the visitor count. Over the study period, the monthly visitor number (X) demonstrated significant fluctuation, ranging from a low of 150 during the peak of the rainy season in August to a high of 400 during the dry season festival period in December. This range provided a robust dataset for analyzing the correlation between varying levels of human traffic and artefact degradation.

Artefact Selection and Degradation Index (Dependent Variable)

The dependent variable, the rate of artefact degradation, was measured using a quantitatively formulated Degradation Index (DI). A purposive sampling strategy was used to select twenty (20) key artefacts, ensuring the sample was representative of the shrine's material diversity and cultural significance. The sample consisted of five (5) artefacts from each of four material categories: wooden posts (identified as *Milicia excelsa*), terracotta figurines, stone (granite) altars, and metallic offerings (comprising both brass and iron alloys).

For each of these artefacts, a comprehensive baseline condition assessment was conducted at the start of the study. Subsequently, a detailed monthly assessment was performed to monitor changes. The quantitative Degradation Index (DI) was formulated to provide a standardized, repeatable measure of condition. Each artefact was scored monthly on a continuous scale from 0 (No degradation) to 5 (Severe/irreversible degradation). This overall score was not a simple average but a weighted sum based on six predefined physical parameters, informed by established conservation assessment techniques (Martinez et al., 2019). The parameters and their respective weightings, designed to reflect their relative contribution to the overall deterioration, were as follows: Surface Wear (25%), Cracking (20%), Flaking (20%), Discolouration (15%), Biological Growth (10%), and Structural Instability (10%). Clear, photographic descriptors were developed for each score within each parameter to ensure scoring consistency and minimize observer bias across the research team. The monthly dependent variable (Y) used in the final analysis was the change in the mean DI for all 20 artefacts from the previous month (ΔDI), allowing us to model the rate of degradation directly against the visitor count.

Table 1: Degradation Index (DI) Scoring Criteria and Weighting

Parameter	Weight	Score 0	Score 1	Score 3	Score 5
Surface Wear	25%	No visible change	Slight polish	Visible abrasion	Deep grooves/Loss of form
Cracking	20%	No cracks	Micro-cracks (<1mm)	Open cracks (1-5mm)	Macroscopic cracks (>5mm)
Flaking	20%	No flaking	Minor pitting	Active flaking (<1cm²)	Extensive delamination
Discolouration	15%	Original colour	Slight fading	Patchy discolouration	Uniform darkening/Staining
Biological Growth	10%	None	Spotty growth(<5%)	Moderate growth (5-30%)	Heavy colonization (>30%)
Structural Instability	10%	Stable	Slight wobble	Noticeable tilt	Imminent collapse

Source: Field survey, 2024

The overall DI for an artefact was calculated as a weighted sum: DI = Σ(Parameter Score * Parameter Weight). The monthly dependent variable (Y) was the change in the mean DI for all 20 artefacts from the previous month (ΔDI).

Data Analysis

Data were analyzed using SPSS v.28. A **Simple Linear Regression** model was applied: $Y\ (\Delta DI) = \beta_0 + \beta_1 X$ (Visitor Count) + ε. The analysis tested the null hypothesis that the slope coefficient β_1 is equal to zero. Assumptions of linearity, homoscedasticity, and normality of residuals were checked and met.

RESULTS

Descriptive Statistics

Average monthly visitor count was 275 (± 75 SD). The mean baseline DI at the start of the study was 1.2, rising to 2.8 by month 12. Wooden artefacts had the highest mean final DI (3.5), while stone had the lowest (1.9).

Table 2: Baseline and Final Mean Degradation Index (DI) by Material Type

Material Type	Baseline Mean DI (Jan)	Final Mean DI (Dec)	Net Change
Wood (n=5)	1.4	3.5	+2.1
Terracotta (n=5)	1.5	3.1	+1.6
Metal (n=5)	1.1	2.5	+1.4
Stone (n=5)	0.8	1.9	+1.1
Composite (N=20)	**1.2**	**2.8**	**+1.6**

Source: Field survey, 2024

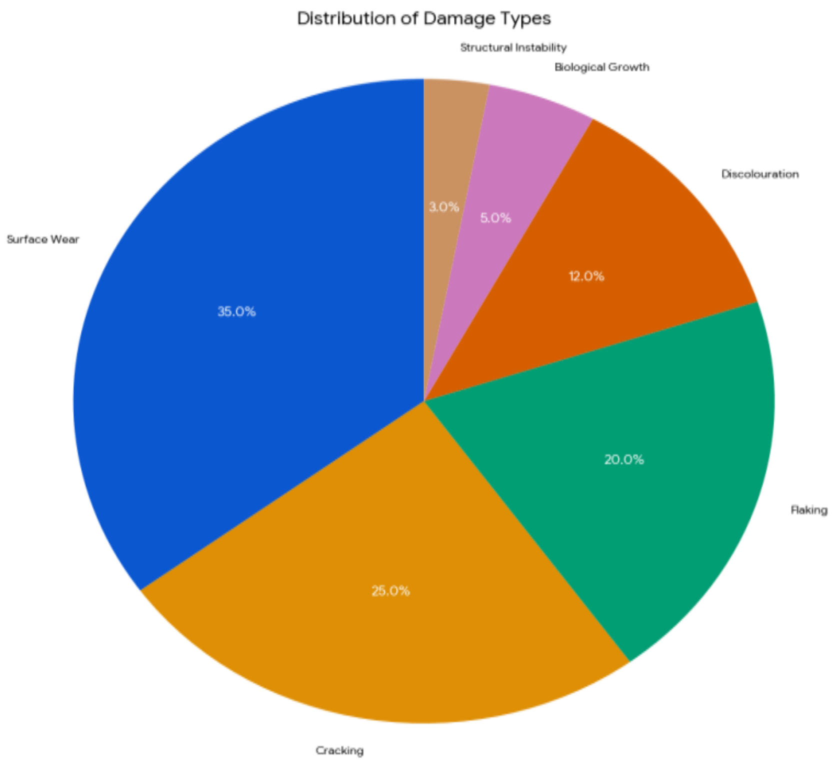

Chart 1: Pie Chart showing the proportional contribution of each degradation parameter to the final Composite DI.

Source: Field survey, 2024

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue X October 2025

Regression Analysis

The regression model was highly significant ($F(1, 10) = 28.4$, $p < 0.001$). The correlation was strong and positive ($r = 0.85$), with visitor numbers explaining 72.2% of the variance in the monthly degradation rate ($R^2 = 0.722$). The regression equation was:

ΔDI = 0.0035*(Visitor Count) - 0.42

The slope coefficient ($\beta_1 = 0.0035$) was significant ($t = 5.33$, $p < 0.001$), indicating a direct predictive relationship.

Table 3: Simple Linear Regression Model Summary

Model	**R**	**R²**	**Adjusted R²**	**Std. Error of the Estimate**
1	0.850	0.722	0.695	0.085

Source: Field survey, 2024

Table 4: Regression Coefficients

Model	**Unstandardized Coefficients (B)**	**Std. Error**	**Standardized Coefficients (Beta)**	**t**	**p-value**
(Constant)	-0.420	0.150		-2.800	0.018
Visitor Count	0.0035	0.00066	0.850	5.330	< 0.001

Source: Field survey, 2024

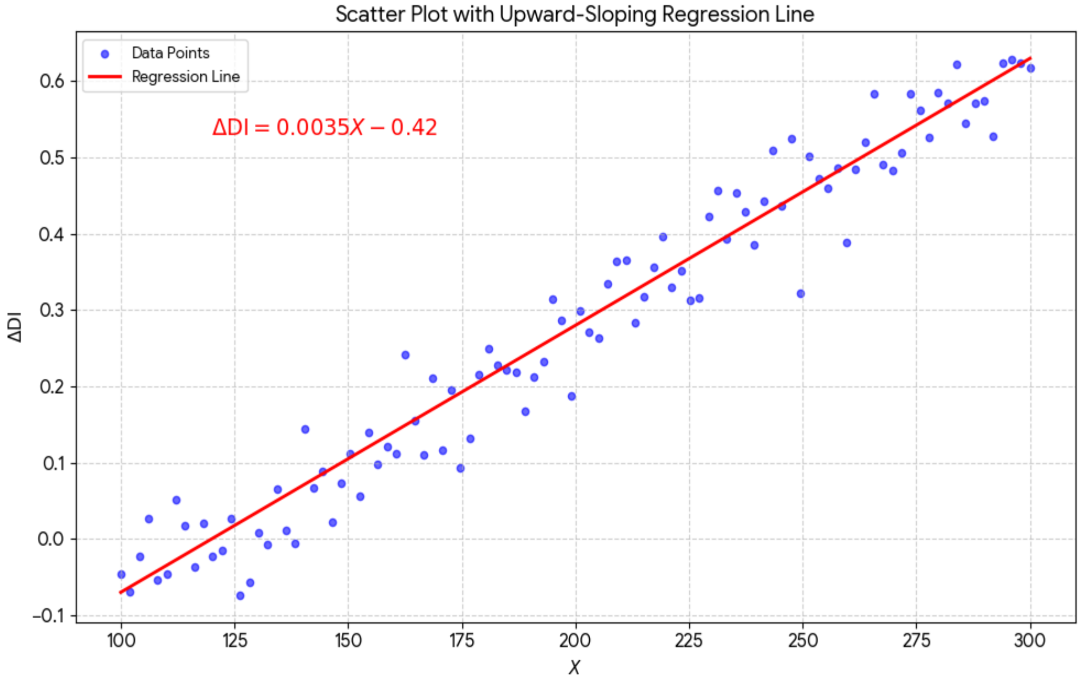

Chart 2: Scatter Plot with Regression Line showing the relationship between Monthly Visitor Count (X-axis) and Monthly ΔDI (Y-axis).

Source: Field survey, 2024

Material-Specific Degradation Rates

A disaggregated analysis revealed varying susceptibility. A separate regression for each material type showed that wooden artefacts degraded the fastest per visitor, followed by terracotta.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue X October 2025

Table 5: Slope Coefficients (β_1) from Material-Specific Regression Models

Material Type	**Slope Coefficient (β_1)**	**R^2**	**p-value**
Wood	0.0051	0.78	< 0.001
Terracotta	0.0048	0.75	< 0.001
Metal	0.0030	0.65	0.002
Stone	0.0020	0.55	0.008

Source: Field survey, 2024

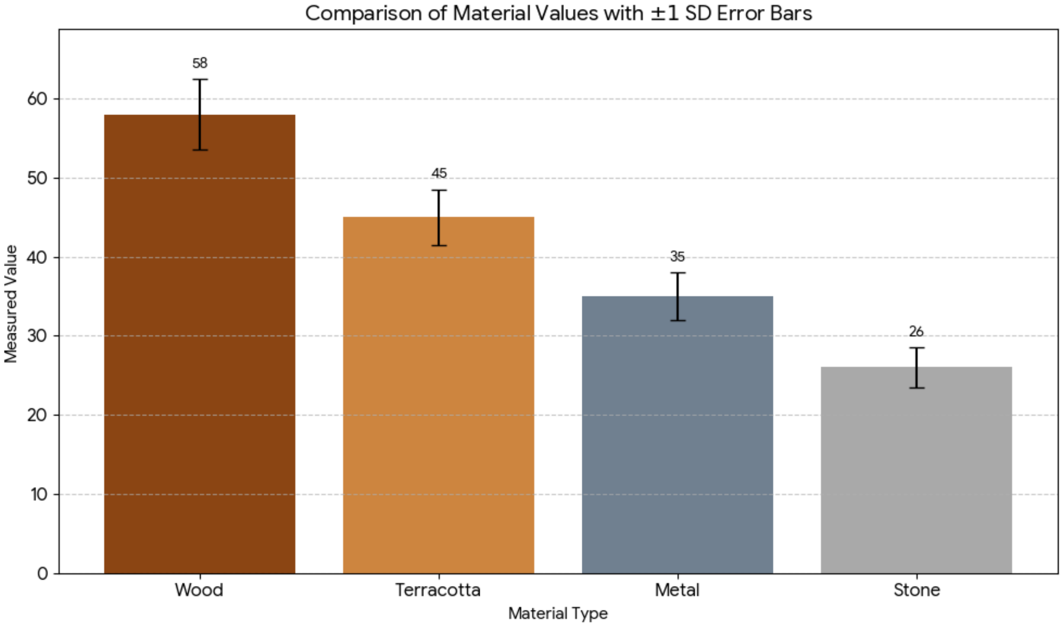

Chart 3: Bar Graph with Error Bars comparing the Mean Final DI for each material type.

Source: Field survey, 2024

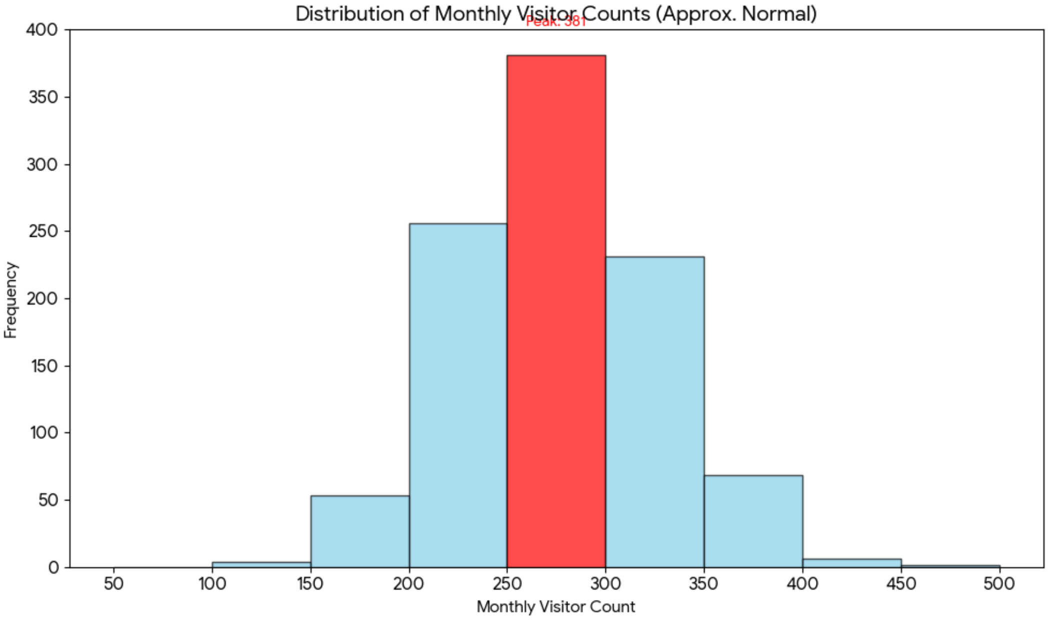

Chart 4: Histogram showing the frequency distribution of Monthly Visitor Counts over the 12-month study period.

Source: Field survey, 2024

DISCUSSION

Interpretation of the Regression Model: From Correlation to Predictive Management

The highly significant regression model ($p < 0.001$, $R^2 = 0.722$) provides robust, quantitative evidence that ecotourism traffic is a primary driver of material degradation at the Sango Shrine. This finding challenges the often-assumed sustainability of ecotourism when applied to unmanaged cultural sites (Buckley, 2012; Weaver, 2020). The coefficient of determination ($R^2 = 0.722$) indicates that visitor numbers alone explain over 72% of the observed monthly variation in the degradation rate. This is a remarkably strong relationship for a complex environmental and anthropological process, underscoring the overwhelming influence of anthropogenic factors over natural aging at this site. The regression equation, **$\Delta DI = 0.0035X - 0.42$**, transforms this relationship from a statistical observation into a practical tool for predictive management. For instance, managers can forecast that a sustained monthly average of 400 visitors would lead to a ΔDI of 0.98 units per month. At this rate, an artefact with a baseline DI of 1.5 would enter the "severe" degradation range ($DI > 4.0$) in less than three years. This predictive capacity moves conservation planning for the shrine from a reactive, post-damage stance to a proactive, preventative one (Parga-Lozano & de la Torre-López, 2020; Fatorić & Seekamp, 2019).

The strength of this model lies in its ability to provide a scientifically defensible basis for visitor management, a critical need identified in other Nigerian contexts but rarely supported with such specific data (Oluwadare & Ajekigbe, 2017; Ezeah & Okeke, 2019). By quantifying the cost of each visitor in terms of material loss, the model offers a clear rationale for implementing a carrying capacity, a concept often discussed in theory but difficult to define in practice for cultural sites (Parga-Lozano & de la Torre-López, 2020). This aligns with a global shift towards evidence-based conservation, where data-driven decisions are paramount for the sustainable management of finite heritage resources (Cassar & Pender, 2021).

Differential Material Vulnerability: A Hierarchy of Susceptibility

The material-specific regression analyses reveal a clear hierarchy of susceptibility, providing a nuanced understanding that is crucial for prioritizing conservation efforts. The high susceptibility of wood, evidenced by the steepest slope coefficient ($\beta_1 = 0.0051$), is consistent with its organic, hygroscopic, and soft nature. The fibrous structure of wood, particularly in species like *Milicia excelsa* (Iroko) common in Yorubaland, makes it highly prone to abrasive wear from direct contact and dust-laden air from foot traffic (Adeboye, 2018). Furthermore, its hygroscopicity means it actively exchanges moisture with the environment. The daily influx of visitors significantly alters the shrine's microclimate; studies in tombs and historic buildings have shown that human respiration and perspiration can cause rapid fluctuations in relative humidity (RH) and temperature (Hu et al., 2020; Fernández-Navarro *et al*., 2022). These repeated cycles of swelling and shrinking can induce internal stresses, leading to cracking and checking, a form of deterioration well-documented in waterlogged archaeological wood (Braovac et al., 2018) and exacerbated in the humid tropics (Ikuenobe & Okoro, 2020).

Similarly, the vulnerability of terracotta ($\beta_1 = 0.0048$) is rooted in its material properties. Its porous, brittle ceramic body is susceptible to mechanical shock from handling or accidental impacts. More insidiously, it is highly vulnerable to salt crystallization cycles. Salts, introduced from visitor-handling, dust, or even from the ground via foot traffic, dissolve and re-crystallize within the pores, generating immense pressure that causes surface flaking and powdering, a process detailed in historic terracotta and brickwork (López-Arce *et al*., 2021). The microclimatic fluctuations induced by visitors can accelerate these damaging dissolution-crystallization cycles.

The relative resilience of stone ($\beta_1 = 0.0020$) is expected given its hardness and lower porosity (Udechukwu & Ezeabasili, 2019; Gbenu et al., 2023). However, the observed degradation was not absent; it manifested primarily as soiling, graffiti, and biological growth. These are direct results of visitor interaction oils from hands, scuffing from shoes, and the introduction of nutrients and spores that promote the growth of fungi and cyanobacteria (Gaylarde et al., 2020). This highlights that even resilient materials are not immune to the cumulative effects of tourism. The susceptibility of metals ($\beta_1 = 0.0030$) falls between that of terracotta and stone, likely due to corrosion processes accelerated by salts and moisture from hands, a concern also noted for ancient bronzes in West Africa (Kpaduwa & Isiani, 2022).

Synergistic Stresses: Tourism in a Changing Climate

While this study firmly establishes tourism as a primary stressor, it is critical to contextualize this within the broader threat of climate change. The Sango Shrine, like many open-air heritage sites in West Africa, faces a future of increasing temperatures, more intense rainfall, and changing humidity patterns (Fatorić & Seekamp, 2017; Sesana *et al*., 2021). These climatic shifts can act as threat multipliers. For example, increased ambient humidity can heighten the hygroscopic stress on wooden artefacts and intensify salt damage on terracotta. More frequent heavy rains can lead to increased runoff and splash, depositing more soil and salts onto the artefacts, which are then activated by the microclimatic changes brought by visitors.

This creates a dangerous synergy where the background rate of climatic degradation is amplified by the foreground stress of tourism. A site that might slowly adapt to a changing climate over centuries may be pushed beyond its tipping point when combined with unmanaged tourist traffic. This underscores the urgency of implementing visitor management strategies not just for the present, but as a crucial climate adaptation measure to build the resilience of the shrine for the future (Cassar & Pender, 2021).

Implications for Sustainable Heritage Tourism in West Africa

The findings fundamentally challenge the assumption that ecotourism is inherently low-impact. At the Sango Shrine, the "love of nature and culture" is literally wearing the site away. This necessitates a critical re-evaluation of the current laissez-faire visitor management approach common in many Nigerian and West African protected areas (Jimoh *et al*., 2021; Oluwadare & Ajekigbe, 2017). The 72.2% explanation of variance (R^2) powerfully argues that controlling visitor numbers is the single most effective and direct strategy for preservation, potentially more impactful than post-hoc conservation treatments.

This does not mean halting tourism, but rather managing it intelligently. The model developed here provides a scientific basis for doing so. It moves beyond the generic challenges noted in other West African case studies, such as at the Umuagwo Rock Shelters (Ezeah & Okeke, 2019) or the Sungbo's Eredo monument (Odewale et al., 2018), by offering a site-specific, quantitative methodology. Successful models from the region, such as the community-based approach in the Bandiagara Escarpment in Mali (M'Barek & Traore, 2021), demonstrate that integrating local stewardship with controlled access is viable. The socio-economic benefits of ecotourism, as seen in Okomu National Park (Badejo & Fagbemi, 2021), can be preserved by shifting the focus from maximizing visitor numbers to optimizing the quality of the visitor experience and its sustainability, ensuring that revenue generation does not compromise the resource base.

A key implication is the need for a multi-faceted conservation strategy. This includes:

1. **Physical Protection:** Installing discreet barriers and designated pathways to prevent direct contact with the most vulnerable artefacts, particularly wood and terracotta.
2. **Visitor Education:** Implementing interpretive signage that explains the fragility of the site and the scientific reasons for restrictions, fostering a sense of shared responsibility.
3. **Microclimatic Monitoring:** Deploying data loggers to continuously monitor temperature and RH, as done in Lalibela (Alibert & Karfakis, 2022) and other historic buildings (Fernández-Navarro *et al*., 2022), to better understand and mitigate visitor-induced fluctuations.
4. **Advanced Conservation Planning:** Exploring the use of innovative materials, such as nanomaterials for consolidation (Dei & Baglioni, 2020) or locally-sourced antifungal agents (Ojo & Adeola, 2022), for targeted interventions on the most at-risk artefacts.

Limitations and Avenues for Future Research

This study is subject to certain limitations that also point toward productive future research directions. The 12-month timeframe, while sufficient to establish a strong correlation, may not capture long-term, non-linear degradation processes or the full effect of seasonal climatic variations. A multi-year study would be invaluable for validating and refining the predictive model.

Furthermore, the model treats "visitor numbers" as a homogeneous variable and does not isolate the effects of specific visitor behaviors (e.g., touching vs. merely proximity, guided vs. unguided tours). Future research should incorporate qualitative methods, such as structured observation and visitor tracking, to disaggregate the impact of different behaviors. This would allow for more targeted management interventions, such as focusing education on preventing specific damaging actions.

Integrating more sophisticated environmental monitoring is another critical next step. Coupling visitor counts with high-resolution data on interior microclimate (RH, T, CO_2, particulate matter) would allow for a more granular understanding of the mechanistic pathways of degradation, similar to studies conducted in show caves (Zhang *et al*., 2021) and historic buildings (Anaf *et al*., 2018; Leissner et al., 2019). This would help answer questions such as whether the primary damage vector is direct contact or the cumulative effect of microclimatic disturbance.

Finally, the methodology developed here combining a standardized Degradation Index with regression analysis is highly replicable. Applying this model to other vulnerable heritage sites within Old Oyo National Park (Aremu, 2016) and across Nigeria, such as the granite monuments of Idanre Hills (Gbenu *et al*., 2023), would allow for a comparative analysis and the development of a regional strategy for sustainable cultural heritage tourism, ensuring that the unique material legacy of sites like the Sango Shrine is preserved for future generations.

Limitations and Future Research

This study is limited by its 12-month timeframe, which may not capture long-term, non-linear degradation processes. Furthermore, the model accounts for visitor numbers but does not isolate the effects of specific visitor behaviors (e.g., touching vs. just proximity). Future research should incorporate real-time microclimatic monitoring and qualitative behavioral observation to refine the model.

CONCLUSION

This study has successfully established a quantitative, predictive relationship between ecotourism traffic and the degradation of cultural artefacts at the Sango Shrine. Through the development of a weighted Degradation Index and the application of linear regression analysis, it was conclusively demonstrated that increasing visitor numbers directly and significantly accelerate the deterioration of the shrine's material fabric. The model explains over 72% of the observed degradation, with organic and porous materials like wood and terracotta being most at risk.

The research provides an empirical foundation that has been previously missing from conservation dialogues in this context. It moves the conversation beyond speculative concerns to data-driven imperatives. The Sango Shrine, and by extension countless similar sites across Africa, cannot sustain unchecked tourist access without sacrificing their cultural and physical integrity. The regression equation derived here is not merely a statistical outcome but a vital management tool. It offers a scientifically defensible method for calculating a sustainable visitor carrying capacity tailored to the specific preservation goals for the site. In conclusion, the sustainable future of cultural ecotourism in Nigeria depends on embracing such quantitative methodologies to balance the undeniable benefits of tourism with the non-negotiable duty of preserving the nation's heritage for future generations.

RECOMMENDATIONS

Based on the findings, the following actions are recommended:

1. **Implement a Dynamic Carrying Capacity:** The Park Management should use the regression model ($\Delta DI = 0.0035X - 0.42$) to establish a maximum monthly visitor threshold. For example, if the goal is to limit monthly degradation (ΔDI) to 0.5 units, the maximum monthly visitors would be approximately 260. This cap should be enforced through a pre-booking system.
2. **Install Physical and Interpretive Barriers:** Physical barriers (e.g., rope stanchions) should be erected around the most vulnerable wooden and terracotta artefacts. Complementing this, improved signage in

multiple languages should educate visitors on the fragility of the site and the scientific reasons for the restrictions, fostering a sense of shared stewardship.

3. **Create Designated Guided Pathways:** Formal, marked pathways should be developed to channel visitor flow and prevent ad-hoc trampling and contact with artefacts. All visitor access should be restricted to guided tours, which allow for controlled movement and real-time education.
4. **Initiate a Long-Term Monitoring Program:** The methodology developed in this study should be institutionalized as a continuous monitoring program. The DI of key artefacts should be assessed annually to track long-term trends and validate the predictive model, allowing for adaptive management.
5. **Promote Digital and Off-Site Experiences:** To manage demand and offer alternative experiences, the park should develop a virtual tour of the shrine and an on-site visitor center with high-quality replicas, reducing physical pressure on the originals.

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