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Assessing Human Disturbance Threats in Caves on Community Lands in Kenya

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Abstract

Caves in Kenya provide critical habitats for diverse bat species, supporting roosting, breeding, and foraging activities essential for their survival. Despite their ecological importance, many caves, particularly those located on unprotected community lands, are increasingly exposed to human disturbance, which can compromise habitat quality and bat population viability. This study assessed the type and intensity of disturbance threats across twelve caves, nine of which are in community lands caves in Kenya, aiming to identify high-risk sites and inform conservation priorities. Observations were quantified using a standardized scoring protocol (0–3) across nine categories of threats, including tourism, vegetation removal, plastic waste, artificial lighting, construction, agriculture/livestock, guano mining, religious use, and firewood collection. Descriptive statistics were used to summarize per-cave and per-threat metrics, while heatmap visualization and cluster analysis revealed patterns of shared and unique disturbances among sites. Tourism, plastic waste, and vegetation removal emerged as the most prevalent threats, whereas guano mining and firewood collection were less frequent. Shimoni cave recorded the highest cumulative threat score, reflecting intense human pressures, while caves such as Makuruhu exhibited relatively low disturbance levels. These results highlight that caves in community lands are subject to diverse anthropogenic pressures that, if unmanaged, could undermine bat conservation. Conservation interventions should prioritize high-risk caves through targeted and cluster-based strategies to mitigate human impacts and preserve cave ecosystem integrity. Conservation interventions should prioritize high-risk caves through targeted and cluster-based strategies to mitigate human impacts, integrate cave protection into local biodiversity management plans, and preserve bat populations that depend on these fragile ecosystems.

Keywords: *Bat conservation, cave ecosystems, human disturbance, Kenya.*

Introduction

Globally, caves have been recognized as keystone ecosystems that sustain unique food webs and fauna, including invertebrates, reptiles, and microbial communities that are tightly coupled with bat guano deposits (Venarsky & Huntsman, 2019). Their isolation and microclimatic stability make them biodiversity hotspots, yet these same characteristics render them highly vulnerable to even small-scale human disturbances (Nicolosi, 2023). For bats in particular, caves serve as critical sites for day roosting, breeding, and hibernation, offering the stable microclimates necessary for their survival (Furey & Racey, 2016). These habitats often support high bat species richness and abundance, including threatened and endemic taxa, thereby making caves irreplaceable for global bat conservation (Frick *et al.,* 2020). Beyond their ecological significance, bats contribute important ecosystem services such as pollination, seed dispersal, and insect population regulation, linking cave protection directly to wider biodiversity and human well-being (Kunz *et al.,*2011).

Despite their importance, cave ecosystems are increasingly threatened by anthropogenic activities. Globally, cave-dwelling bats have been affected by guano mining, unregulated tourism, religious activities, agricultural encroachment, and pollution from wastes (Furey & Racey, 2016). Such disturbances can alter the cave environment, degrade habitat quality, and in severe cases, cause the abandonment of roosts(Ingala *et al*., 2025). The scale of these threats is often greater in caves situated outside formally protected areas, where enforcement of conservation measures is minimal and local livelihoods frequently depend on resource extraction and land-use practices incompatible with bat conservation(Pretorius et al., 2021).

For example, studies in Southeast Asia and Latin America have documented widespread roost abandonment following repeated human incursions into caves, with cascading effects on regional bat populations (Kingston, 2013). In tourist-heavy cave systems of Turkey and Vietnam, artificial lighting and high visitor traffic have been linked to physiological stress responses in bats and reduced reproductive success (Furey & Racey, 2016). Similar patterns have been observed in the Neotropics, where deforestation and mining around caves not only threaten bats but also undermine cave-dependent ecosystem services (Phelps,2016).

In Kenya, most of the caves known to host diverse bat assemblages, occur in community lands where they remain vulnerable to unregulated human access and use (Webala et al., 2019).Community caves are often subject to diverse pressures yet systematic assessments of these threats remain scarce. This gap is particularly concerning in East Africa, where caves are embedded within landscapes of mixed land uses, including agriculture, grazing, and cultural practices. The Wildlife Conservation and Management Act of 2013 provide general protection for species and habitats but does not explicitly address caves, creating a policy vacuum in which local use often overrides ecological concerns (Kenya Wildlife Service, 2021). However, the Kenya Biodiversity Strategy and Action Plan 2022–2030 (Ministry of Environment and Forestry, 2020) emphasizes the protection of critical habitats and ecosystems, including subterranean environments, as part of Kenya's obligations under the Convention on Biological Diversity. This framework provides an opportunity to integrate cave conservation into national biodiversity targets and local management planning. Previous studies in Kenya have primarily focused on species checklists and diversity assessments (Webala *et al*., 2019), with little attention given to quantifying human-induced pressures or evaluating their conservation implications. This lack of empirical evidence hampers the development of effective interventions for caves most at risk.

Given these gaps, this study sought to evaluate the prevalence and intensity of human disturbance threats in caves situated in unprotected community lands of Kenya. By quantifying nine categories of disturbance including: tourism use, vegetation removal, plastic waste accumulation, artificial lighting, construction, agriculture/livestock, guano mining, religious use, and firewood collection .This study provides the first comprehensive threat assessment for these caves. Specifically, we described the relative intensity of different disturbance types, identified caves facing the greatest cumulative pressures, and visualized threat profiles to highlight shared and unique patterns across sites. These findings provide an evidence base for cave and bat conservation in Kenya, offering insights into targeted and cluster-based management strategies in community contexts.

Methodology

Study Area and Cave Selection.

A total of nine caves located on community lands were purposively selected for threat assessment. These included Shimoni, Mwanangoto, Kaboga, Kapsetai, Mdenyenye, Mt Suswa, Mau Mau, Kisimani, and Makuruhu.These caves were distributed across three regions of Kenya: The Coastal, the Rift Valley, and the Western regions (Fig.1). The caves vary in size, accessibility, and degree of human interaction, and they provide critical roosting habitats for multiple bat species.

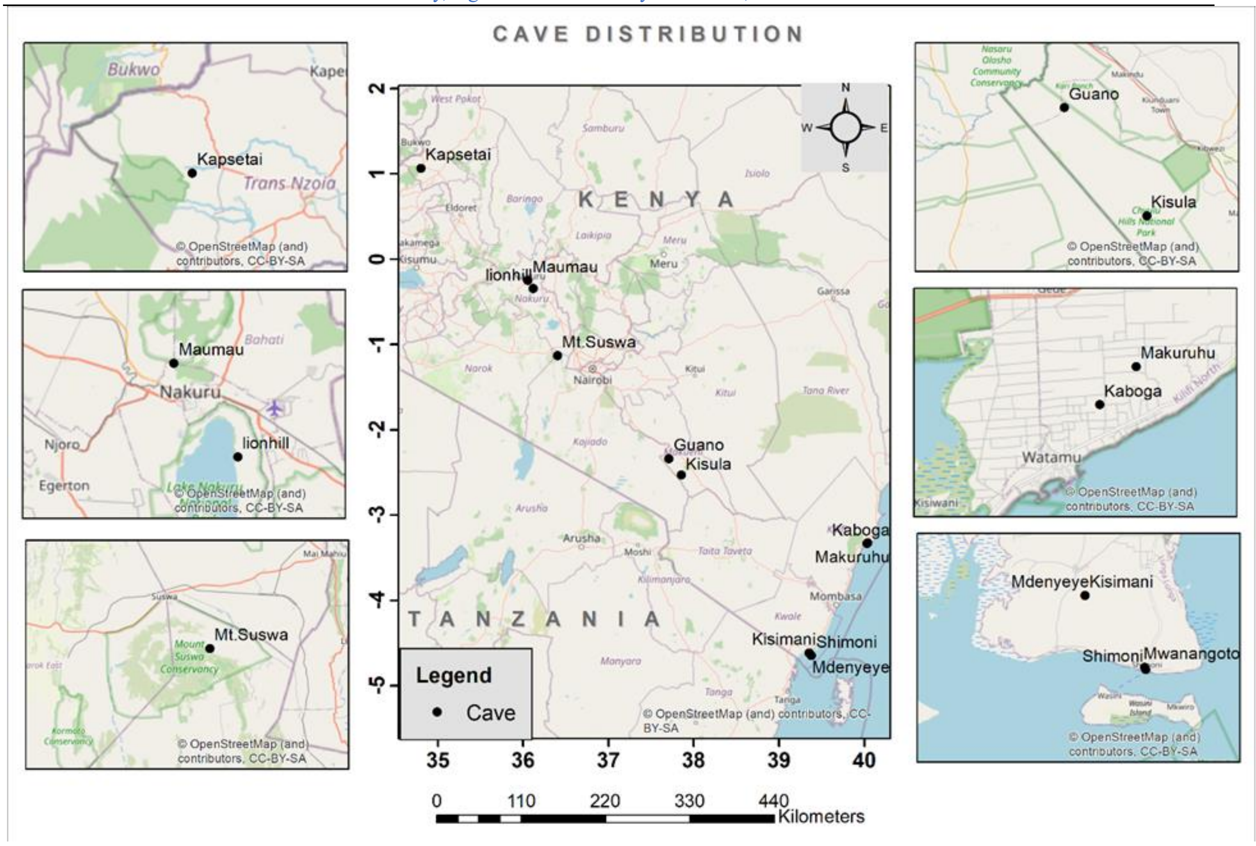

Figure 1: Map showing spatial arrangement of study caves; Shimoni, Mwanangoto, Kaboga, Kapsetai, Mdenyenye, Mt. Suswa, Mau Mau, Kisimani, and Makuruhu, in Kenya. Base map data © OpenStreetMap contributors (www.openstreetmap.org), available under ODbL.

Threat Assessment

Human disturbance threats were assessed using direct observations conducted between September 2024 and February 2025. Nine disturbance categories were recorded for each cave: tourism use, vegetation removal, plastic waste accumulation, religious use, artificial lighting, construction activities, agriculture/livestock encroachment, guano mining, and firewood collection. Each category was scored on an ordinal scale from 0 (absent) to 3 (high frequency), adapting frameworks commonly used in cave impact assessments in karst and subterranean ecology (Phelps *et al.,*2018). Each cave had two-day time visits every month to capture variation in human disturbance parameters.

Two trained observers participated in the threat assessments. Prior to data collection, both observers underwent a calibration exercise to harmonize the interpretation of threat categories and scoring criteria. Consistency was maintained through joint assessments and periodic cross-checks were conducted during fieldwork to minimize observer bias and ensure reliable scoring across all sites.

Computation of Cumulative Threat Scores

For each cave, the cumulative threat score (CTS) was calculated as the sum of all threat category scores recorded, following approaches commonly used in cave and habitat impact assessments (Phelps *et al.,* 2018;Nicolosi *et al.,* 2023).

$$\mathrm{CTS}_i = \sum_{j=1}^{n} S_{ij}$$

where:

- CTS_i= cumulative threat score for cave i,
- S_{ij}= score for threat category j at cave i, and
- n= total number of threat categories (nine in this study).

Descriptive Statistics of Human Disturbance Threats

The threat scores were compiled into a cave-by-threat matrix. Data analysis was performed in R-Studio. First, descriptive statistics were calculated to summarize disturbance intensity across threats. For each threat category, the mean and standard deviation (SD) were computed to evaluate their relative prevalence (Table 1). At the cave level, cumulative threat scores were generated by summing all recorded disturbance intensities per cave, and caves were ranked from highest to lowest cumulative scores (Table 2).To explore similarities in disturbance profiles among caves, the threat matrix was visualized using a heatmap with hierarchical clustering.

Results and Discussion

Overall Prevalence of Threats

Nine categories of human disturbance were recorded across the caves situated in unprotected community lands. Tourism use (mean = 2.33 ± 0.50) and plastic waste accumulation (2.11 ± 0.60) were the most intense and consistently observed threats across sites (Table 1). Vegetation removal (1.67 ± 0.71) was also widespread. In contrast, guano mining (0.22 ± 0.67) and firewood collection (0.33 ± 0.50) were less prevalent and generally restricted to fewer caves.

Table 1: Mean ± standard deviation (SD) of disturbance intensity scores (0–3 scale) across the nine surveyed caves in Kenya.

Threat	Mean ± SD	mean	sd
Guano mining	0.22 ± 0.67	0.22	0.67
Tourism use	2.33 ± 0.5	2.33	0.50
Agriculture/livestock	0.44 ± 1.01	0.44	1.01
Vegetation removal	1.67 ± 0.71	1.67	0.71
Artificial lighting	0.56 ± 1.13	0.56	1.13
Construction	0.89 ± 1.36	0.89	1.36
plastic wastes	2.11 ± 0.6	2.11	0.60
Religious use	0.89 ± 0.93	0.89	0.93
Firewood collection	0.33 ± 0.5	0.33	0.50

This study assessed disturbance threats across community-managed caves in Kenya, highlighting the diversity and intensity of human pressures that may compromise the ecological integrity of these important bat roosts. Our findings reveal that tourism use, and plastic waste pollution were the most prevalent threats across sites, while guano mining and firewood collection were comparatively minor. Among the caves, Shimoni recorded the highest cumulative threat score, distinguishing it as a site of conservation concern.

The dominance of tourism-related disturbance aligns with previous studies showing that recreational cave visitation can significantly alter bat roosting behaviour and population persistence (Debata,2021). Increased human presence introduces light, noise, and microclimatic changes that may drive sensitive species away from caves (Nicolosi,2023). Similarly, plastic pollution, which scored consistently high across sites, reflects broader anthropogenic pressures documented in tropical cave systems, where unmanaged waste compromises both roost quality and surrounding habitat integrity (Vasconcelos *et al.,* 2021).

Globally, studies have shown that caves near urban or tourist areas exhibit similar patterns of stress on bat populations, including altered emergence timing, reduced colony size, and lower reproductive success (Kingston, 2019; Medellín *et al*., 2020). Our findings suggest that caves on community lands in Kenya are experiencing comparable pressures, indicating that even non-industrialized human activities can have measurable ecological impacts.

Cumulative Threat Scores per Cave

Cumulative disturbance scores varied across caves, reflecting differences in the overall intensity of human activities. Shimoni cave exhibited the highest cumulative score (16) whereas Makuruhu registered the lowest scores, with minimal documented disturbances (Table 2).

Table 2: Cumulative disturbance scores and ranks of caves in unprotected community lands of Kenya.

Cave	Total_score	Rank
Shimoni	16	1
Kaboga	13	2
Mwanangoto	10	3
Kapsetai	10	4
Mt Suswa	9	5
Mdenyenye	8	6
Mau Mau	7	7
Kisimani	6	8
Makuruhu	6	9

Vegetation removal and small-scale agriculture were moderately intense but widespread, underscoring the influence of land-use change around cave landscapes. Habitat degradation adjacent to caves has been shown to reduce bat foraging opportunities and increase vulnerability to predation (Frick et *al.,* 2020). Construction and artificial lighting, concentrated in a few sites such as Shimoni and Mwanangoto, also represent emerging threats, consistent with evidence that infrastructural expansion near caves modifies microhabitat conditions and disrupts bat activity patterns (Medellín *et al.,* 2020).

Analysis of cumulative threat scores revealed that Shimoni faced the highest levels of disturbance, while Kisimani and Makuruhu scored lowest. The ranking of caves provides insight into site-specific management priorities. Shimoni's elevated score indicates urgent intervention needs, including regulating visitor access, improving waste management, and restoring vegetation. Conversely, caves with lower scores, although currently less disturbed, should be proactively monitored to prevent future degradation. Notably, less frequent threats such as guano mining, while minor in occurrence, may exert disproportionate ecological effects in particular caves (Nicolosi, 2023).

Threat Profiles and Clustering

The heatmap (Fig.2) illustrates the relative intensity of threats across caves, with the dendrogram grouping sites by similarity in disturbance profiles. Shimoni stood out as the most distinct, driven by consistently high tourism use and vegetation removal. Mwanangoto and Kaboga clustered closely, reflecting similar disturbance patterns. Mdenyenye and Kapsetai grouped together due to moderate levels of plastic wastes and religious use, while Mt Suswa, Mau Mau, Kisimani, and Makuruhu formed a broader cluster with lower and more evenly distributed disturbances(Fig.2).

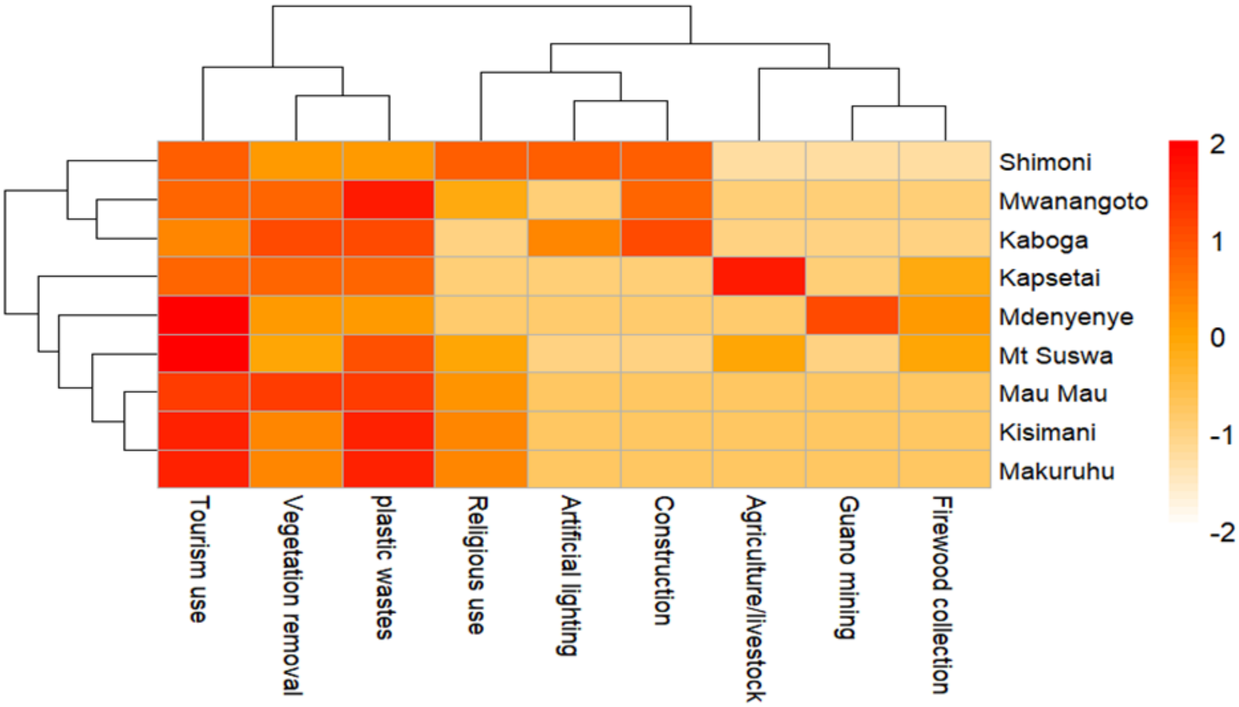

Figure 2: Heatmap of disturbance threats across caves in unprotected community lands of Kenya. The colour gradient (red–yellow, scaled from –2 to 2) represents relative threat intensities, and the dendrogram indicates clustering based on similarity.

The spatial clustering of threats observed in this study highlights the influence of surrounding landscape matrices. For example, caves near densely populated settlements or main roads (Shimoni) tend to experience higher pressures from plastic waste and vegetation clearance. This pattern supports the concept that both local cave management and surrounding land-use planning are essential for effective conservation (Gillieson *et al.,*2022).

The ranking analysis further highlights management priorities. Shimoni, which faces cumulative pressures from tourism, vegetation clearance, and construction, requires urgent site-specific interventions. By contrast, caves such as Kisimani and Makuruhu, which scored lowest, appear less disturbed, but their continued protection is essential to prevent future intensification of threats. The clustering of caves with similar threat profiles (e.g., Mwanangoto) suggests opportunities for developing zone-specific management plans, optimizing conservation resources by addressing shared pressures rather than site-by-site interventions.

Notably, some threat types, while less frequent (e.g., guano mining), may have disproportionate ecological effects if concentrated in specific caves (Nicolosi,2023). This underlines the need for a nuanced approach, where both cumulative threat scores and intensity of individual threats inform management decisions.

In addition, our findings offer baseline data that can be used to integrate community engagement into conservation strategies. Participatory management, environmental education, and tourism regulation could significantly mitigate identified threats, reinforcing both ecological and socio-economic benefits. This aligns with recent studies advocating for community-based approaches in Africa bat conservation, where local involvement is key to sustaining cave ecosystems (Tataw *et al.,*2024).

Although this study provides a comprehensive evaluation of human disturbance threats, it did not quantitatively link threat intensity with bat community metrics such as species richness, abundance, or roost occupancy. Future research should aim to integrate ecological response data, including colony size and behavioural or physiological indicators, to better understand how varying levels of disturbance translate into population-level impacts.

Conclusions and Recommendations

This study demonstrates that caves in unprotected community lands of Kenya are exposed to varying degrees of anthropogenic disturbance, with tourism use, plastic waste, and vegetation removal emerging as the most prevalent threats. Shimoni cave was identified as the most heavily impacted, while sites such as Kisimani and Makuruhu showed lower disturbance levels. The use of a standardized scoring approach provided a robust framework for comparing threats and identifying priority sites for intervention.

These findings underscore the urgent need for site-specific and community-driven conservation measures. Key strategies include regulating tourism activities, implementing waste management systems, and promoting habitat restoration around vulnerable caves. By highlighting threat patterns and management priorities, this study provides a foundation for integrating cave protection into broader bat conservation and landscape planning initiatives in Kenya. Sustained collaboration with local communities will be essential to balance cultural and economic uses of caves with the ecological requirements of bat populations.

Recommendations: Prioritise high-risk caves for interventions (e.g., Shimoni), Improve waste management and tourism control, implement community education programs, and Restore vegetation around caves to reduce land-use pressures.

Future research should aim to establish quantitative links between disturbance intensity and bat ecological or physiological responses (e.g., changes in colony size, reproductive success, or stress hormone levels). Such studies would enhance understanding of how human pressures translate into measurable impacts on bat populations and roost stability, strengthening the ecological relevance of threat assessments.

At the policy level, integrating cave protection and bat conservation into Kenya's national and county environmental frameworks would strengthen long-term conservation outcomes. The Kenya Biodiversity Strategy and Action Plan (2022–2030) and future revisions of the Wildlife Conservation and Management Act should explicitly recognize caves as critical habitats for biodiversity protection. Additionally, county governments should incorporate cave management into spatial and environmental plans, ensuring that community-led conservation aligns with broader national biodiversity and climate resilience objectives.

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