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Household Hygiene Behaviors, Perceived Responsibility for Vector Control, and Vulnerability to Rat and Mosquito Sightings in Disadvantaged Urban Communities

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Abstract

Background

Disadvantaged urban communities (called favelas in Brazil) are widespread across low- and middle-income regions, and are characterized by inadequate infrastructure, poor sanitation, and socioeconomic vulnerability. These conditions, combined with suboptimal household hygiene behaviors, promote rat and mosquito proliferation, increasing the risk of rodent-borne zoonotic and arboviral diseases. However, evidence remains limited on how household, particularly backyard hygiene behaviors and perceptions of responsibility for pest control influence exposure, especially in settings with precarious infrastructure, where hygiene behaviors may be shaped by structural, socioeconomic, and environmental determinants. This study evaluated how household demographics, backyard hygiene behaviors, and perceived responsibility for reservoir and vector control are associated with the frequency of rat and mosquito sightings in disadvantaged urban communities of Salvador, Brazil.

Methods

This cross-sectional study was conducted nested within an ongoing eco-epidemiological project in disadvantaged urban communities with historically high transmission of leptospirosis and dengue. Between March and August 2025, a modified, previously validated semi-structured questionnaire was administered to 136 heads of household (HoH) across four socio-environmentally similar communities. Structured backyard inspections documented environmental conditions, including waste presence and backyard use. Ordinal regression analyses were performed using univariable and multivariable cumulative link models with a logit link function, with model selection guided by Akaike Information Criterion, and most parsimonious model with $\Delta AIC < 2$ compared to the minimum as the final model.

Results

Lower socioeconomic status and poor backyard hygiene were associated with more frequent rats and mosquitoes sightings. Increasing age of HoH was associated with higher odds of frequent rat sightings (OR = 1.05; $p < 0.001$). Prior participation in hygiene awareness programs (OR = 0.39; $p = 0.022$), and attributing pest control responsibility to the community (OR = 0.26; $p = 0.008$) or the government (OR = 0.32; $p = 0.017$) were protective. Frequent mosquito sightings were associated with unclean backyards (OR = 3.53; $p = 0.005$), backyard gardening (OR = 3.37; $p = 0.007$), and reliance on community central bins for household waste disposal (OR = 3.61; $p = 0.005$), while installation of window net as mosquito control served as a protective factor (OR = 0.27; $p = 0.012$).

Conclusion

Exposure to rats and mosquitoes in disadvantaged urban communities is shaped by structural vulnerabilities and modifiable household behaviors, phenomena that often reinforce each other. Integrated interventions combining improvements in sanitation, waste management, and environmental infrastructure with community-based education are essential to reduce exposure and improve public health outcomes.

Introduction

Rat and mosquito proliferation remains a persistent challenge in disadvantaged urban communities (called favelas in Brazil), where rapid and unplanned urbanization creates ecological conditions that favor synanthropic disease reservoirs and vectors (1–3). As the global urban population is projected to exceed three billion residents by 2050 (4), existing

structural vulnerabilities, including high population density, inadequate sanitation, deficient waste management, and limited access to basic services, are likely to intensify. These conditions facilitate the persistence and adaptation of rat and mosquito populations within anthropogenic environments, often surpassing the capacity of local environmental and public health control systems (5). Notably, the distribution of these pest and vector is not uniform across landscape. Higher infestation and vector densities are consistently concentrated in disadvantaged settlements characterized by sanitation deficits, socioeconomic deprivation, and limited government investments/interventions, such as favelas in Brazil and slums in many low- and middle-income countries (LMICs) (5, 6). In these settings, decades of structural neglect by public authorities contribute to disproportionately high exposure to disease reservoirs and vectors, and consequently to zoonotic and vector-borne diseases (ZVDs), reflecting broader patterns of environmental injustice and environmental racism (7, 8).

Although urban settings are not entirely exempted from rat and mosquito infestations, their impacts are generally mitigated by adequate infrastructural and public services, including the provision of waste containers, regular and reliable waste collection, and satisfactory accessible pest and vector management agencies (9). However, when these systems are inconsistent or inefficient, they may contribute to waste accumulation, and potentially increase exposure to contaminated environments. In contrast, residents of disadvantaged urban settlements frequently experience substantial disparities in the distribution, quality, and continuity of these essential services. Housing is often located near open sewers, and overcrowded living conditions further exacerbate environmental health risks. Also, residents may have limited access to reliable information on effective rat and mosquito control measures, and therefore rely on locally available or improvised strategies to manage infestations (10). In the event where such information is available, poverty, socioeconomic inequalities, and financial constraints often limit households' ability to prioritize pest and vector control over more immediate livelihood needs, particularly in LMICs (11). These challenges are further compounded by poor backyard hygiene conditions in households with backyard/peridomestic spaces, commonly a reflection of socioeconomic and contextual limitations. Such areas frequently accumulate organic waste and discarded materials, including old appliances, scrap metals, furniture, toys, plastic containers, and used vehicle tires, which provide suitable harborage for rat populations (12), and create water-holding habitats that facilitate mosquito breeding. Consequently, residents may experience frequent contact with these pests and potentially contaminated environments, increasing their risk of exposure to pathogens associated with rat- and mosquito-borne diseases.

High levels of rat and mosquito infestation pose substantial public health risk. These risks usually arise either directly through contact with infected reservoirs or vectors (13, 14), or indirectly via exposure to contaminated environment (13), household surfaces, foodstuffs, and other environmental materials (15) particularly in the case of rats. Rats are known reservoirs for several pathogens of public health importance, including *Leptospira* spp. and *Orthohantavirus* spp. (16), *Toxoplasma gondii* (17), *Barthonella* spp. (18), and Lassa virus (15) among others. Beyond their role in disease transmission, rat infestations can also disrupt local ecosystems by contributing to the extinction of native species, damaging household infrastructure, and causing significant agricultural losses (19). Similarly, rats' presence may adversely affect residents' psychological well-being. Direct encounters or even mere sightings of rats have been associated with chronic stress, anxiety, depressive symptoms, and feelings of shame, helplessness, and insecurity within the home environment, an environment typically expected to provide safety and comfort (20, 21). Also, frequent mosquito sightings have been linked to psychological and mental health distress, including frustration, discomfort, helplessness, anxiety, and fear related to perceived risk of mosquito-borne disease transmission (22).

Despite documented evidence of substantial rat and mosquito infestations in many disadvantaged urban communities of Salvador (6, 12, 23), and the likelihood that poor backyard hygiene may lead to the accumulation of discarded appliances and other materials that creates favorable conditions for sustained pest proliferation, few studies have systematically examined how household waste management practices and socioeconomic factors shape the distribution of these reservoirs and vectors. Existing evidence is largely derived from high-income countries (HICs),

highlighting a critical gap in understanding the determinants of pest and vector proliferation in disadvantaged urban communities of LMICs, where structural vulnerabilities and environmental conditions may differ substantially and influence the effectiveness of foreign-adapted interventions (1). This study therefore evaluates how urban infrastructure, socioeconomic conditions, domestic backyard hygiene behaviors, and peridomestic environmental characteristics influence residents' exposure to rat and mosquito infestations. Specifically, we evaluate how household demographics, backyard hygiene behaviors, and perceptions of responsibility for reservoir and vector control are associated with the frequency of rat and mosquito sightings in disadvantaged urban communities of Salvador, Bahia, Brazil. By elucidating the environmental and social determinants shaping exposure to these synanthropic pests, this study aims to inform context-specific, integrated sanitation-based interventions to reduce infestations and mitigate the zoonotic, infectious, and mental health outcomes associated with frequent rat and mosquito sightings among vulnerable populations. We hypothesize that rat and mosquito sightings will be highly prevalent in the study communities that residents will report substantial concern regarding their frequent sightings around households, and that, given limited financial resources and historical infrastructural deficiencies, residents will largely rely on government-led interventions to address the proliferation of synanthropic reservoirs and vectors.

Methods

Study area

The study was conducted in four disadvantaged urban communities (Nova Sussuarana, Arenoso, Jardim Santo Inacio, and Calabetao) located on the periphery of Salvador, Bahia, Brazil, between March and August 2025. These communities are geographically independent, separated by spatial buffers of approximately 1 to 1.5 km (Fig. 1). All four of the communities are densely populated, low-income vulnerable settlements characterized by similar socio-environmental conditions, including inadequate housing facilities, poor sanitation infrastructure, improper solid waste management, and a high risk of vector-borne and zoonotic diseases transmission (24).

Study design

This cross-sectional study was conducted as a nested component of a larger research project designed to evaluate the effectiveness of a sanitation intervention targeting selected ZVDs in vulnerable urban communities with comparable socio-environmental characteristics and zoonotic disease burden. Briefly, the intervention involved the installation of a household-level piped sewerage network by the “Empresa Baiana de Águas e Saneamento S.A.”, with active community engagement to enhance acceptability, ownership, and sustainability. Further details of the parent study are provided by (24).

Eligibility criteria: Participants from the parent study were invited to participate if they met the following inclusion criteria: i) were the head of household (HoH), ii) had a backyard at their residence (**“backyard”** here is defined as a private, exclusive outdoor area adjacent to the household and under the sole control and use of immediate household members), iii) were aged 18 years or older, iv) had resided in the community for at least six months, v) slept in the household at least three nights per week, and vi) provided verbal informed consent to participate. On the other hand, participants were excluded if they: i) did not meet all inclusion criteria, ii) were unable or unwilling to provide verbal consent, iii) refused or were unable to provide demographic information or permit backyard inspection, iv) were deemed mentally incapable of providing informed consent or responding to study questions, and v) could not be encountered after three household visits.

The selection of the HoH was based on the assumption that this individual holds primary responsibility within the household and is recognized as such by other family members. As a central figure in the household decision-making and daily management, the HoH was considered the most appropriate respondent for data collection in this study.

Sample frequency and data collection

A total of one hundred and thirty-six consenting participants were interviewed between 18th March and 16th August 2025, comprising 33 participants from Nova Sussuarana, 32 from Arenoso, 34 from Jardim Santo Inacio, and 37 from Calabetao respectively. This sample size is consistent with previously used and validated approaches. For example, India Council of Medical Research (CMR) recommended a minimum of 25 households per community for studies conducted in similar community settings (25).

Data were collected using a semi-structured questionnaire developed based on a previously validated protocol emphasizing the role of sanitation in the control of insects and rodents of public health importance (26). The questionnaire included key domains covering: (a) rat and mosquito exposure risk, measured as the frequency of reported rat and mosquito sightings, (b) sociodemographic and economic characteristics, (c) perception and opinion regarding responsibility for vector control, (d) household backyard hygiene conditions, (e) household waste management practices, and (f) vector control practices. A summary of the questionnaire items is presented in Table 1, and a full sample of the questionnaire is provided as supplementary material (Supplementary Material I).

To ensure data standardization and consistency across study communities, data were collected using the web-based Research Electronic Data Capture (REDCap) platform. Questionnaire administration lasted approximately 20–30 minutes. REDCap provides a secure environment for data entry, storage, and export to statistical software packages, such as R, Stata, SPSS, and EpiInfo, for subsequent analyses.

Prior to data collection, field staff received standardized training on questionnaire administration, variable definitions, and interpretation to minimize inter-observer variability. Trained interviewers administered the semi-structured questionnaire to eligible, consenting participants who met all the study inclusion criteria. Following questionnaire administration, systematic on-site inspections of participants' backyards were conducted to assess environmental hygiene conditions. In this study, "**hygiene**" was operationally defined as the condition and management of household, specifically backyard environments, with emphasis on waste disposal behaviors, the presence or absence of solid waste or residue, and overall environmental cleanliness, factors considered critical for rat and mosquito proliferation and control. Backyards were classified as "**unclean**" if any residue or other conditions that favor the proliferation of pests were observed and as "**clean**" if no residue was present or if the residue was kept in a properly closed trash can. Representative examples of clean and unclean backyards are shown in Fig. 2.

Table 1
Description of key variables considered in the multivariable analysis of determinants of rat and mosquito sighting frequency among residents with backyard areas in vulnerable urban communities.

Variable	Category and meaning
Frequency of reported rat/mosquito sightings	Categorical (ordinal): Frequency of rat and mosquito sightings in or around the participant's household during the past year.
Monthly household per capita income	Categorical (continuous): Total monthly household income divided by the number of household members, categorized using a threshold of 249 USD, using the World Bank definition
Age of HoH	Numerical (continuous): Age of the participant (HoH).
Sex of HoH	Binary (Male/Female): Sex of the participant (HoH).
Study community	Categorical: Study community.
Education attainment of HoH	Categorical: Highest education attainment of the participant (HoH).
Prior participation in hygiene awareness programs	Categorical: Prior participation in community awareness programs promoting hygiene and household sanitation.
Waste type most difficult to manage	Categorical: Type of waste most challenging to manage in the participant's (HoH) backyard.
Perceived body responsible for rat/mosquito control	Categorical: Perceived responsibility for controlling rats and mosquitoes in the community, as reported by the participant (HoH).
Backyard hygiene conditions	Categorical: Classification of the participant's (HoH) backyard hygiene condition.
Final HH waste-disposal practices	Categorical: Method used for the final household waste disposal.
Perception of bad household backyard hygiene	Categorical: Participant's perception of what constitutes poor household hygiene.
Poison for rat control	Binary (No/Yes): Use of rodenticide for rat control.
Net installation for mosquito control	Binary (No/Yes): Installation of window nets for mosquito control.
Solid waste in the backyard	Binary (No/Yes): Presence of solid waste in the backyard.
Concern about backyard status	Categorical: Participant's concern regarding the condition of their backyard.
Primary use of the backyard	Categorical: Primary use of the backyard.
Household altitude	Numerical (continuous): Household elevation gradient.
Household temperature	Numerical (continuous): Satellite derived land surface temperature at household level.

Data analysis

Descriptive statistics were used to evaluate the distribution of reported rat and mosquito sightings relative to participants' sociodemographic and socioeconomic characteristics, and perceived responsibility for vector control. For categorical explanatory variables, the associations with sighting frequency were summarized using counts and percentages. Statistical dependence was additionally assessed using Fisher's exact test, with P-values estimated via Monte Carlo simulation (10,000 replicates) to accommodate sparse cell counts. To account for multiple comparisons, p-values were adjusted using the Benjamini-Hochberg false discovery rate method. For continuous variables,

distributions were summarized using means and standard deviations. Associations between continuous variables and sighting frequency were evaluated using Spearman's rank correlation coefficient, given the ordinal nature of the outcome variables.

The frequency of rat and mosquito sightings was recorded as an ordinal variable (daily, sometimes, rarely, and never), reflecting levels of reported sightings in or around participants' households over the past year. This method of using reported sighting frequency has been validated as a reliable tool for measuring animal activity, infestation levels, and relative abundance in several previous studies (7, 27–30).

To identify the influence of participants' socioeconomic status, backyard hygiene behaviors, and perceived responsibility for vector control on the frequency of rat and mosquito sightings, we first fitted univariable ordinal logistic regression models using cumulative logit models. Variables showing a univariable association at $p < 0.15$, as well as those deemed epidemiologically relevant based on prior literature and theoretical plausibility, were considered for inclusion in the multivariable models. This threshold was chosen because the conventional level of 0.05 may fail to identify important variables during the initial selection stage (31)

Subsequently, multivariable ordinal regression analysis was conducted using cumulative link models with a logit link function to identify independent determinants of rat and mosquito sighting frequency. Prior to model fitting, continuous variables, specifically household income and temperature, were standardized (z-score) to facilitate model convergence and interpretation. To minimize multicollinearity, variance influence factors (VIFs) were assessed using linear regression approximations. All variables remained within accepted thresholds (see Supplementary Materials IIa and IIb), and thus only non-collinear predictors were retained. Community was included as a fixed effect to account for clustering and spatial heterogeneity among study communities. Household elevation was included as household-level environmental covariates due to its potential influence on drainage and habitat suitability for rats and mosquitoes. Model selection was guided by the Akaike Information Criterion (AIC). Candidate models were further evaluated based on empirical evidence and theoretical relevance to ensure biological and epidemiological plausibility. We selected the most parsimonious model with $\Delta AIC < 2$ relative to the minimum AIC as the final model (32). This approach reduces the risk of overfitting while ensuring that key predictors with established relevance to the study outcome are appropriately represented in the final models. Statistical significance was defined as $p < 0.05$. All analyses were performed using R version 4.5.2 (R Core Team. (2019).

Results

Descriptive patterns of rat and mosquito sightings by socioeconomic characteristics and perceived responsibility for vector control

Overall, descriptive analyses indicated a high frequency of both rat and mosquito sightings among participants. Frequent sightings were reported across all socioeconomic strata, however, a consistent pattern of particularly higher daily sightings were observed among participants with lower educational attainment, those residing in households with a monthly per capita income below USD 249, participants who were informally employed or unemployed, and women (Fig. 3). Despite these observable gradients, formal inferential analyses using Fisher's Exact test and Spearman's rank correlation did not identify statistically significant associations between sighting frequency and socioeconomic indicators (all p-values > 0.05).

With respect to rat sightings, the highest frequency of daily sightings was documented among participants with lower educational attainment (55.5%). Similarly, participants residing in low-income households (i.e. < USD 249 per capita/month) reported a higher frequency of daily rat sightings compared to those in higher-income households (46.7% vs. 29.2%; $p > 0.05$). Daily rat sightings were also more frequently reported among informally employed (54.5%) and

unemployed participants (44.4%) relative to retired (32.3%) and formally employed participants (38.7%). Women reported a higher frequency of daily rat sightings than men (47.7% vs 35.4%; $p > 0.05$). Notably, participants who perceived rat control as primarily an individual responsibility reported a lower frequency of daily rat sightings (21.9%) compared with those who attributed responsibility to community (54.2%) or government actors (46.4%). This pattern may reflect differences in vigilance or engagement in control actions.

A comparable pattern was observed for mosquito sightings, with an even stronger frequency of daily sightings. Daily mosquito sightings were more frequently reported among participants with lower educational attainment (66.7%). Participants in lower-income households reported a higher frequency of daily mosquito sightings compared with those in higher-income households (70.1% vs. 54.2%; $p > 0.05$). Informally employed (69.7%) and unemployed participants (66.7%) also reported higher daily mosquito sightings compared to retired participants (54.8%). Women again reported a higher frequency of daily mosquito sightings than men (75% vs. 62.5%; $p > 0.05$). In contrast to the pattern observed for rat sightings, participants who perceived mosquito control as an individual responsibility reported a higher frequency of daily mosquito sightings (68.8%).

Determinants of rat sighting frequency across socioeconomic characteristics, backyard hygiene behaviors, and perceived responsibility for vector control

To examine factors potentially influencing frequent rat sightings reported by participants, fourteen variables with p-values ≤ 0.15 from initial separate univariable analyses were considered for inclusion in the potential final multivariable model (Supplementary Material IIIa). Among competing models, the final model was selected based on the lowest Akaike Information Criterion (AIC), while retaining variables supported by prior empirical evidence, thereby achieving an optimal balance between model fit and parsimony (Supplementary Material IIIb).

From the final model (Table 2), increasing participant (HoH) age was significantly associated with a higher frequency of daily rat sightings. Each additional year of participant's age was associated with a 5% increase in the odds of reporting more frequent rat sightings (OR = 1.05; 95% CI: 1.02, 1.08; $p < 0.001$). Prior participation in hygiene awareness programs (e.g. actions carried out by community health workers, schools, or the community engagement activities facilitated by the larger project that specifically aimed at addressing topics related to prevention of zoonotic and vector-borne diseases, natural disasters and good household and individual practices) was inversely associated with rat sightings. Participants reporting previous participation in such programs had 61% lower odds of reporting more frequent rat sightings compared with those without prior participation (OR = 0.39; 95% CI: 0.17, 0.86; $p = 0.022$). Perceived waste-management difficulty was also associated with rat sightings. Compared with participants identifying solid waste as the most difficult to manage, those reporting electronic waste had significantly lower odds of reporting frequent rat sightings (OR = 0.26; 95% CI: 0.07, 0.95; $p = 0.046$). No statistically significant association were observed for participants reporting glass (OR = 2.34; 95% CI: 0.78, 7.10; $p = 0.129$) or other waste type (OR = 0.54; 95% CI: 0.20, 1.40; $p = 0.205$) as the most difficult waste to manage. Perceptions of responsibility for rat control were also significantly associated with the frequency of rat sighting. In contrary to the descriptive analysis, participants who attributed rat control responsibility to the community (OR = 0.26; 95% CI: 0.09, 0.70; $p = 0.008$) or the government (OR = 0.32; 95% CI: 0.12, 0.80; $p = 0.017$) had significantly lower odds of reporting frequent rat sightings compared with those who considered rat control to be an individual household responsibility. No statistically significant differences in the frequency of rat sightings were observed across study communities after adjustment for individual- and household-level covariates.

Table 2
Ordinal Logistic Regression Indicating Determinants of Rat Sightings Frequency among Residents with Backyards

Characteristic	OR	95% CI	p-value
Age of HoH	1.05	1.02, 1.08	**< 0.001**
Prior participation in hygiene awareness programs?			
No	—	—	
Yes	0.39	0.17, 0.86	**0.022**
Waste type most difficult to manage			
Solid	—	—	
Glass	2.34	0.78, 7.10	0.129
Electronic	0.25	0.06, 0.90	**0.038**
Others	0.54	0.20, 1.40	0.205
Perceived body responsible for rat control			
Individual household	—	—	
The community	0.26	0.09, 0.70	**0.008**
The government	0.32	0.12, 0.80	**0.017**
Study community			
Nova Sussuarana	—	—	
Arenoso	1.34	0.46, 3.87	0.590
J. Santo Inácio	0.95	0.31, 2.86	0.927
Calabetão	0.74	0.22, 2.42	0.615
Abbreviations: CI = Confidence Interval, OR = Odds Ratio			

Determinants of mosquito sighting frequency across socioeconomic characteristics, backyard hygiene behaviors, and perceived responsibility for vector control

To identify factors associated with frequent mosquito sightings reported by participants, variables with p-values ≤ 0.15 in initial univariable analyses were considered for inclusion in the multivariable model (Supplementary Material IVa). Thirteen candidate variables met this criterion and were evaluated in the multivariable analysis. The final model retained six variables, representing the most parsimonious model with the lowest AIC (Supplementary Material IVb).

From Table 3, household environmental conditions were strongly associated with the frequency of mosquito sightings. Unclean backyard hygiene conditions were associated with more than threefold higher odds of reporting frequent mosquito sightings compared with households with clean backyards (OR = 3.53; 95% CI: 1.48, 8.84; $p = 0.005$). Preventive measures were inversely associated with frequent mosquito sightings. Participants reporting net installation had approximately 73% lower odds of reporting frequent mosquito sightings when compared with others without the report of net installation (OR = 0.27; 95% CI: 0.10, 0.76; $p = 0.012$). Waste-disposal practices were also relevant in the final model. Compared with reliance on municipal waste pickup, disposal via community central bins was associated with a higher odds of frequent mosquito sightings (OR = 3.61; 95% CI: 1.49, 9.15; $p = 0.005$). Other waste-disposal

methods were not significantly associated with mosquito sightings (OR = 0.43; 95% CI: 0.05, 2.16; *p* = 0.345). Higher temperature demonstrated a positive but borderline association with the frequency of mosquito sightings (OR = 1.80; 95% CI: 0.97, 3.44; *p* = 0.066). Backyard gardening was independently associated with increased mosquito sightings, with participants reporting gardening activities exhibiting more than threefold higher odds of reporting frequent mosquito sightings (OR = 3.37; 95% CI: 1.42, 8.46; *p* = 0.007). As observed for rat sightings, no statistically significant community-level differences were detected in the frequency of mosquito sightings after multivariable adjustment.

Table 3
Ordinal Logistic Regression Indicating Determinants of Mosquito Sightings Frequency among Residents with Backyards

Characteristic	OR	95% CI	p-value
Backyard hygiene conditions			
Clean	—	—	
Unclean	3.53	1.48, 8.84	**0.005**
Net installation for mosquito control			
No	—	—	
Yes	0.27	0.10, 0.76	**0.012**
HH waste-disposal practices			
Municipal pickup	—	—	
Community central bin	3.61	1.49, 9.15	**0.005**
Others	0.43	0.05, 2.16	0.345
Land surface temperature	1.80	0.97, 3.44	0.066
Backyard used for gardening			
No	—	—	
Yes	3.37	1.42, 8.46	**0.007**
Study community			
Nova Sussuarana	—	—	
Arenoso	0.76	0.22, 2.57	0.662
J. Santo Inácio	2.78	0.91, 8.83	0.077
Calabetão	0.89	0.25, 3.09	0.853
Abbreviations: CI = Confidence Interval, OR = Odds Ratio			

Discussion

We reported common frequent rat and mosquito sightings across the four disadvantaged urban communities studied in Salvador, indicating persistent exposure of residents to synanthropic reservoirs and vectors in these settings (Fig. 3). Although descriptive patterns suggested frequent sightings across all socioeconomic strata, daily sightings were somewhat higher among participants with lower educational attainment, lower household income, informal employment, and women household heads, however, these gradients were not statistically significant in inferential

analyses. This pattern likely reflects the broadly shared environmental conditions within the study communities, including inadequate sanitation, inefficient waste management, open sewer, and widespread poverty, which may create favorable ecological niches that sustain pest and vector populations at high detectable levels that reinforce participants' behaviors and practices. Despite the absence of statistically significant socioeconomic gradients, these trends are consistent with previous studies indicating that socially and economically vulnerable populations often experience disproportionate exposure to environmental health risk (33–35). The widespread occurrence of rat and mosquito sightings across socioeconomic groups may therefore reflect the spatial concentration of structural vulnerabilities within these communities, where environmental risks are broadly distributed.

The findings here provide locally relevant insights into factors contributing to persistent rat and mosquito infestations in disadvantaged urban communities situated on the periphery of Salvador. Examining these dynamics helps elucidate how environmental conditions shape residents' behaviors, and perceptions regarding pest and vector control. Generating context-specific evidence is particularly important for addressing synanthropic disease reservoirs and vectors in these environments, rather than relying solely on evidence from HICs, which may not translate effectively to LMICs due to differences in structural vulnerabilities, environmental conditions, and social perceptions. For example, studies conducted in HICs, including Canada and the Unites States, have highlighted residents' feeling of unease following rat sightings (20, 21, 36). In contrast, in the present study, variables such as feeling helpless after rat or mosquito sightings or perceiving such sightings as normal part of daily life were associated with sighting frequency in the univariable analyses and in the non-parsimonious model (Supplementary Material IIIa and b, and Supplementary Material IVa and b), but were not retained in the final multivariable model. One possible explanation for this pattern is the normalization of daily coexistence with these animals in settings characterized by chronic infrastructural deficiencies and limited municipal services. In communities experiencing persistent socioeconomic hardship and longstanding neglect in sanitation, housing, and public safety, pest and vector presence and control may be perceived as a secondary concern relative to more urgent and daily immediate survival needs. Nevertheless, interview observations indicated that some participants, particularly caregivers of toddlers, elderly, and bedridden individuals, expressed heightened concern about rat and mosquito infestations, reflecting their perceived vulnerability to potential health risks. Overall, these findings suggest that the social and psychological dimensions of pest exposure may differ between LMICs and HICs, underscoring the need for locally tailored strategies to manage synanthropic pest and vector infestations in vulnerable urban settings.

Age emerged as an important determinant of frequent rat sightings, with increasing participant age associated with a 5% higher odd of reporting more frequent sightings. This association may reflect greater environmental awareness with age, longer cumulative exposure to community conditions, or increased time spent within the household environment, which may increase opportunities to observe rats around the home. For example, increased time spent at home has previously been associated with higher reporting of rat sightings during the COVID-19 stay-at-home order (36). Alternatively, older participants may be more attentive to environmental hazards, including pest presence, possibly due to prior personal or shared experiences with ZVDs, leading to higher reporting rates (37, 38). Consistent with this interpretation, Vlaanderen et al (2024) reported that older individuals, women, highly educated individuals, and those with prior participation in public health-related awareness programs were likely to engage in reporting behaviors related to zoonotic diseases prevention, suggesting greater concern and awareness regarding public health risks.

Prior participation in hygiene awareness programs, such as the weekly community popular education sessions implemented by the larger research project, was associated with lower odds of frequent rat sightings. These activities, which involve discussions between residents and the research team on community environmental conditions, household hygiene practices, and strategies to prevent disease reservoirs and vectors, suggest that participative community-based education and engagement may play an important role in reducing pest exposure in vulnerable urban settings. Similar initiatives facilitated by community health workers, schools, non-governmental organizations, or local

public health programs may improve residents' knowledge of sanitation and waste management practices and promote better backyard hygiene. Such behavioral changes can reduce the availability of food, water, and harborage that sustain rat populations, thereby lowering infestation levels and the frequency of sightings, as rat population growth is strongly dependent on access to these resources (1). Community engagement and participatory education approaches are widely recommended in eco-epidemiological studies to empower local populations and improve overall public health outcomes (39), underscoring their potential value in interventions aimed at reducing synanthropic pest exposure in vulnerable urban settings.

The lower odds of frequent rat sightings among participants, who identified electronic waste as the most difficult waste type to manage, compared with solid waste, may reflect differences in disposal practices. Many participants reported generally exchanging their electronic waste for money, which likely limit its accumulation in household backyards relative to other type of solid waste. In contrast, other waste types may accumulate more readily in these settings due to limited disposal options. Although some recycling points in the communities allow residents to exchange plastic waste for small financial incentives, expanding similar incentive-based initiatives for other waste types, as implemented in China may help reduce waste accumulation in many disadvantaged urban communities (40). The lack of significant association for glass waste may be related to the generally reported absence of household waste sorting among participants.

Perceptions of responsibility for pest control also emerged as an important determinant of rat sightings. Participants who attributed responsibility for rat control to the community or government had significantly lower odds of reporting frequent sightings compared with those who viewed control as an individual household responsibility. One possible explanation is that individuals who view pest control as a personal responsibility may be more attentive to their immediate surroundings and, therefore, more likely to notice and report rat activity. Alternatively, this pattern may reflect differences in community- or municipal-level pest control efforts across the communities, suggesting that effective and sustained rat management may require coordinated interventions beyond individual household actions. Narratives that attribute pest infestations and their control to individual responsibility are common, especially in settings historically neglected by public authorities. Such framing effectively shifts responsibility onto residents, despite the fact that ensuring adequate environmental and sanitation conditions is a fundamental responsibility of the state in safeguarding public health. Future studies should specifically examine whether there exist variations in structural facilities across communities and to determine whether this possess any differential effect on rat sightings in the communities, given that improvements in waste management systems, drainage infrastructure, and environmental sanitation have been shown to support sustainable and effective rat control strategies (23, 37).

Concerning factors influencing frequent mosquito sightings, poor backyard hygiene conditions emerged as one of the strongest predictors, with households with unclean backyards exhibiting significantly higher odds of frequent mosquito presence. This finding highlights the critical role of peridomestic environmental conditions in sustaining mosquito breeding habitats in vulnerable urban settings. The association is biologically plausible, as accumulation of waste, particularly solid waste containers and discarded materials can collect stagnant water and create suitable breeding sites for mosquitoes, thereby increasing their local abundance and the odds of frequent sightings (41).

A notable protective factor was the reported use of mosquito control strategies, particularly installation of window net, which was associated with approximately 73% lower odds of frequent mosquito sightings. Given that intradomiciliar environment can provide suitable conditions for mosquito survival and oviposition, our results suggests that household-level protective measures may reduce human-vector contact or sightings (42). Unlike rat control, which often requires more resource-intensive structural interventions (e.g., rat-proof housing), installation of window net represents a relatively low-cost household-level strategy (43, 44). Although such measures may have limited impact when surrounding environmental conditions remain conducive to mosquito proliferation, they can still contribute to reducing

household exposure, particularly in settings where governmental-led vector control programs are limited. These findings therefore suggest that household-level protective strategies should be considered as part of integrated mosquito control efforts in, particularly in disadvantaged communities.

Another notable factor potentially contributing to frequent mosquito sighting as observed in the final model (Table 3) is household reliance on community central waste bins for final waste disposal. This may reflect broader limitations in local waste management systems. Several participants reported that central waste bins were located far from their households, which may encourage waste disposal in informal or inappropriate locations. Such practices can result in the accumulation of water-holding containers and organic waste that serve as potential mosquito breeding sites, particularly in densely populated communities with limited waste management infrastructure. Implementing high-frequency and consistent waste collection services, including both household waste collection and collection from central waste bins, could contribute to lowering both rat and mosquito infestations, as improved waste management has been shown to reduce suitable habitats for synanthropic pests and vectors (1, 45).

Higher temperature showed a somewhat positive trend with frequent mosquito sightings, which is consistent with established ecological relationships between temperature and mosquito activity (14). This finding is of particularly concern in the context of ongoing climate change and rising global temperatures. Also, backyard gardening was independently associated with increased mosquito sightings, potentially reflecting the presence of irrigated plants, water-holding containers, or shaded and humid microenvironments that may facilitate mosquito breeding and resting sites. This observation aligns with previous studies reporting positive association between poorly managed backyard gardening practices and increased mosquito infestations (46).

Overall, our findings highlight the combined role of structural environmental determinants and household-level practices in shaping exposure to synanthropic pests and vectors in marginalized urban communities. Notably, structural conditions may also shape these practices, suggesting that behavioral interventions alone may have limited impact when environmental constraints hinder the adoption of protective behaviors (47). Rat infestations appeared to be more strongly influenced by broader structural and governance-related determinants, whereas mosquito infestations were more closely linked to peridomestic environmental conditions and household behavior, which may themselves be constrained by surrounding environmental and structural conditions. Notably, the absence of significant community-level differences in rat and mosquito sightings after adjustment for clustering and spatial heterogeneity suggests that exposure is widespread across the study communities. This pattern suggests that pest and vector proliferation is pervasive, reflecting shared structural vulnerabilities common in many disadvantaged urban communities. These findings underscore the need for integrated and coordinated interventions that extend beyond isolated household actions. Effective control will require sustained investment in urban infrastructure, environmental sanitation, and waste management (48). Moving away from overreliance on reactive chemical control strategies, often associated with limited long-term effectiveness, towards more sustainable, prevention-oriented approaches is essential to improving public health outcomes in these settings (49).

Despite the context-specific relevance of these findings, this study has a few limitations that should be considered when interpreting the results. First, the approach used to assess rat and mosquito infestations, although previously validated, relied on self-reported sightings and may therefore be subjected to potential misclassification. Some participants may have underreported sightings due to stigma associated with pest presence, while others may have normalized living in close proximity to these pests. In addition, recall bias may have influenced participants' ability to accurately report the frequency of sightings. Nevertheless, similar approaches have been validated and applied to estimate infestation levels over recall periods of 6–12 months in studies conducted in the United States (11) and the Netherlands (50), yielding reliable estimates. Thus, the measures used in here likely provide a reasonable approximation of rat and mosquito activity in the study communities. Second, the study was conducted in communities where the larger research project

has active presence, including public health engagement in areas such as Nova Sussuarana and Jardim Santo Inácio. This may have increased awareness among a few participants and potentially influenced their responses to questions related to sewage and zoonotic and vector-borne diseases, which may have been previously discussed with residents. Third, the cross-sectional design of the study potentially limits the ability to infer causal relationships between examined factors and reported pest or vector sightings. As such, the findings should be interpreted as associations rather than evidence of causality. Despite these limitations, the study provides contextually relevant insights from LMIC settings into the factors contributing to persistent infestations and residents' perception of synanthropic pests and vectors control. These findings offer important evidence to inform locally appropriate interventions, rather than relying on strategies derived from HIC settings, which are often less effective due to differences in structural vulnerabilities, environmental conditions, and social perceptions.

Conclusions

The findings support our hypothesis that rat and mosquito sightings would be highly prevalent in the study communities and that the limited financial resources and infrastructural and contextual barriers would result in residents primarily relying on government-led interventions to address the proliferation of synanthropic reservoirs and vectors. Contrary to our expectations, concerns regarding frequent rat and mosquito sightings were not retained in the final models. However, qualitative observations during interviews indicated that some participants, particularly caregivers of toddlers, elderly, or bedridden individuals, expressed heightened concern about infestations. This suggests that the lack of association between rat and mosquito sightings and mental health outcomes in the final models may not fully capture the experiences of specific minor section of the most vulnerable subgroups.

Our findings also highlight the importance of both structural and environmental determinants, as well as household-level backyard hygiene behaviors, in shaping exposure to rats and mosquitoes in disadvantaged urban communities. Multivariable analyses identified distinct determinants for each. Frequent rat sightings were associated with increasing age of the HoH and with residents' perceptions of responsibility for pest control, while prior participation in hygiene awareness programs was strongly protective, significantly reducing the odds of frequent sightings. These findings underscore the potential of community-based popular health education and engagement initiatives to promote knowledge of behaviors that reduce pest exposure. In contrast, frequent mosquito sightings were primarily driven by peridomestic environmental conditions and household practices, including poor backyard hygiene, reliance on community central bins for waste disposal, and backyard gardening activities. The installation of window nets was associated with substantially lower odds of frequent sightings, highlighting the effectiveness of low-cost household-level protective measures.

From a public health perspective, these results emphasize the need for integrated pest and vector management strategies that combine improvements in urban infrastructure, waste management systems, environmental sanitation with community-based popular educational and behavior change interventions. In vulnerable urban settings, effective control of rat and mosquito, particularly rats, is unlikely to be achieved through individual household actions alone, but rather requires coordinated efforts involving government authorities, community organizations, and residents. Such integrated approaches are essential for achieving sustainable and context-appropriate control measure and for addressing broader structural inequalities, including those linked to environmental racism and injustice.

Abbreviations

ZVD
Zoonotic and Vector-borne Disease
LMIC

Low- and Middle-income Country
HIC
High-income Country
HoH
Head of Household
CMR
Council of Medical Research
REDCap
Research Electronic Data Capture
VIF
Variance Influence Factors
AIC
Akaike Information Criteri
CONEP
Comissão Nacional de Ética em Pesquisa

Declarations

Ethics approval and consent to participate: The larger study was originally approved by the Research Ethics Committee of the Institute of Collective Health, Federal University of Bahia, Salvador, Brazil, under number CAEE 32361820.7.0000.5030, and by the National Research Ethics Committee (CONEP) linked to the Brazilian Ministry of Health under approval number 6.766.544. Additionally, verbal informed consent was obtained from all participants prior to participation. All procedures involving human participants were conducted in accordance with the principles of the Declaration of Helsinki.

Consent for publication: Written informed consent for publication of identifiable images was obtained from all individuals/participants depicted in Figure 2C.

Availability of data and materials: The datasets generated and/or analyzed during the current study cannot be shared publicly because of personal information of participants in the survey, at the individual and household level. Researchers who wish to access the data can contact the data manager at the Oswaldo Cruz Foundation, Dr. Nivison Nery Junior (nivison.nery@fiocruz.br).

Competing interests: The authors declare no potential conflicts of interest.

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Authors' contributions:

Conceptualization: FC & AMA;

Data curation: BIAX, ISS, VCS, NNJ & AMA;

Formal analysis: BIAX, HDA, MTE & AMA;

Investigation: BIAX, DCCS, MEOD, ACD, RHDS & AMA;

Methodology: BIAX, DCCS, FNS, MTE, CC, FC & AMA;

Validation: BIAX, HDA, FAGP, FNS, MTE, CC, FC & AMA;

Visualization: BIAX, GGM & JOS;

Writing – original draft: BIAX & AMA;

Resource: CC, FC & AMA;

Funding acquisition: FC & AMA;

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Writing – revision, review and editing: All authors.

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Figures

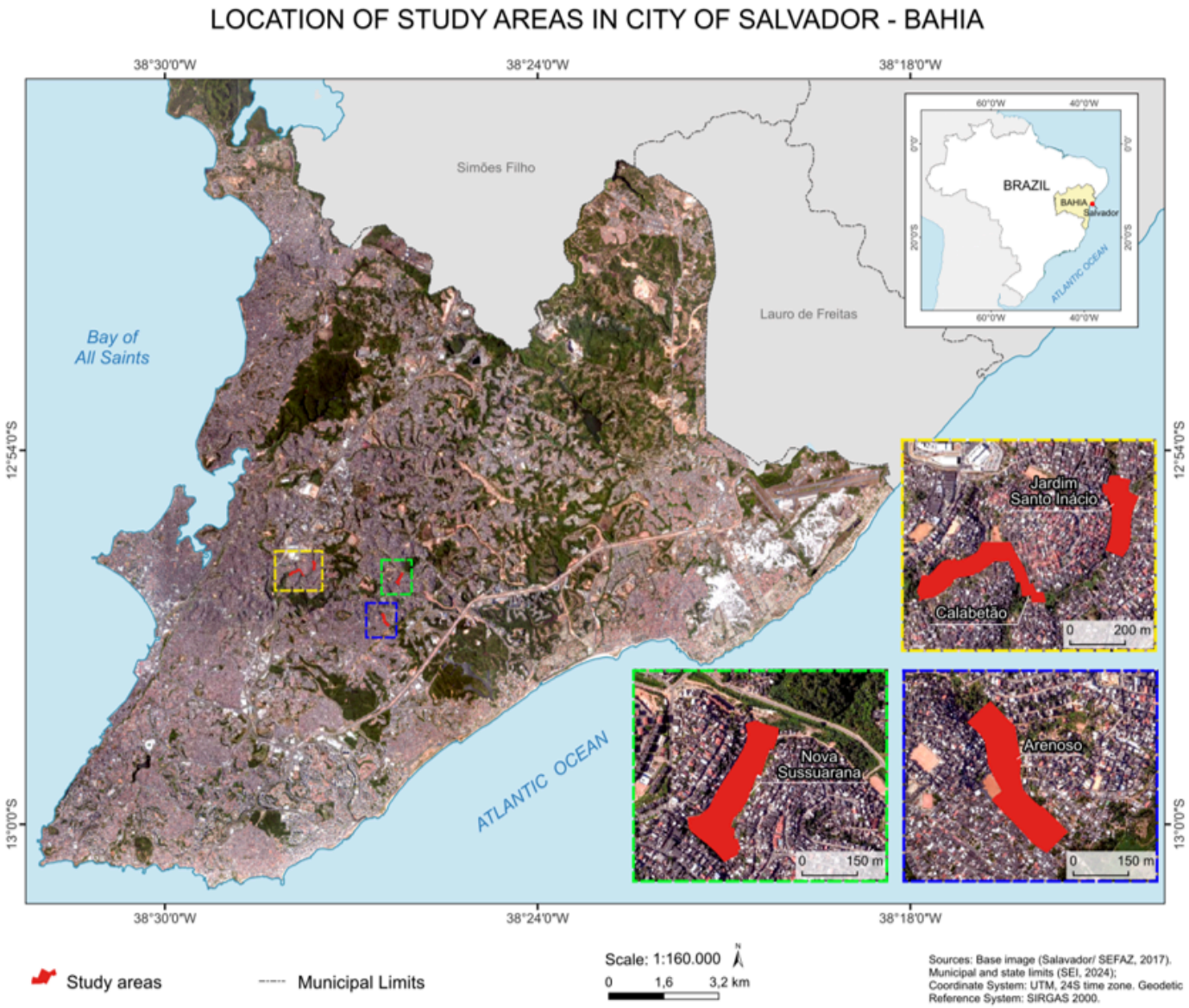


Figure 1

Location of the study communities within Bahia, Brazil and the map of South America.



Figure 2

Representative photographs of selected backyards illustrating observed hygiene conditions. Panels A and B show backyards classified as **clean**- characterized by the absence of garbage. Panels C and D depict **unclean**backyards- marked by the presence of scattered waste, with visible stagnant water in Panel D.

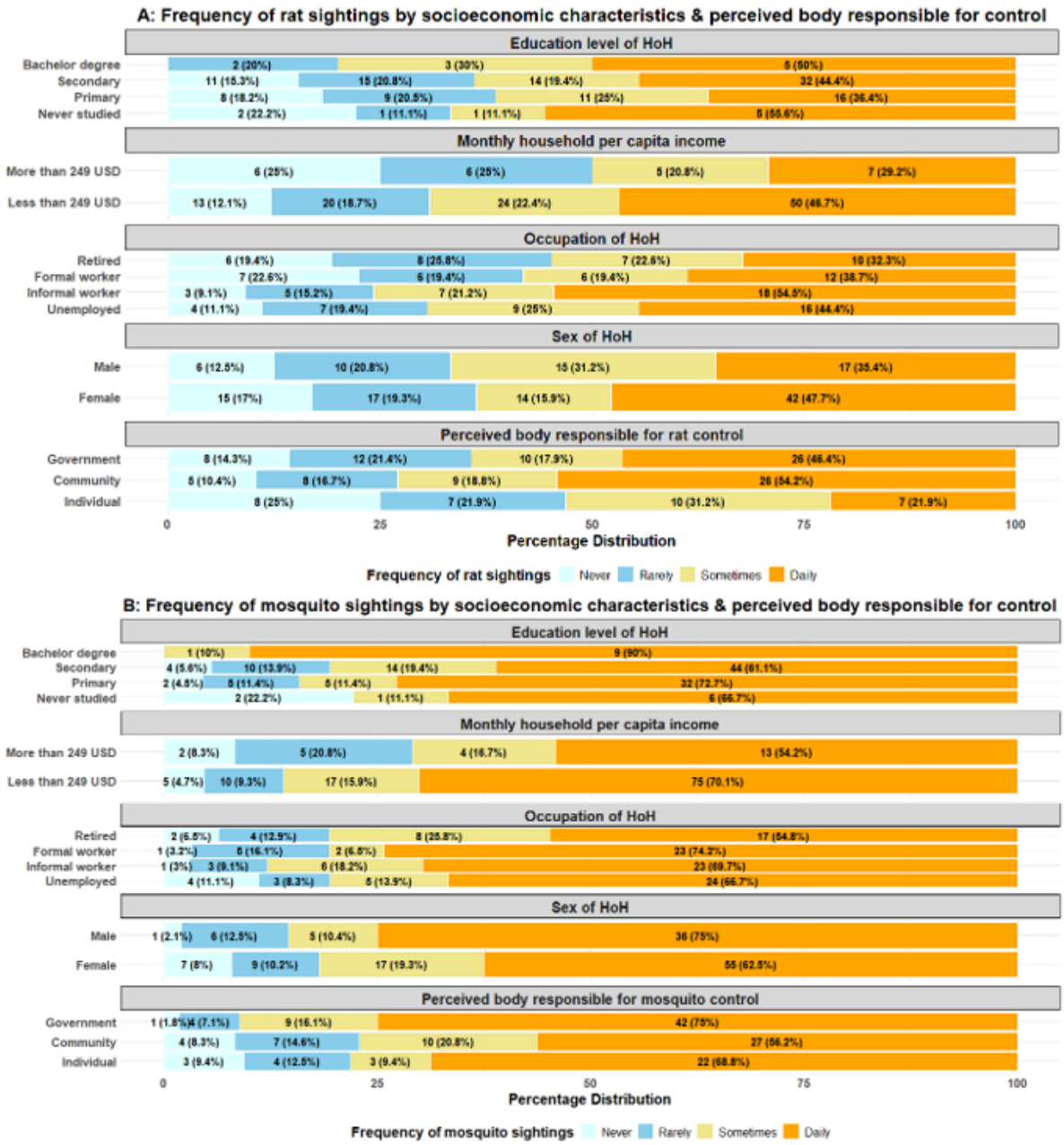


Figure 3

Distribution of rat (Panel A) and mosquito (Panel B) sighting frequencies across sociodemographic and socioeconomic characteristics, and perceived responsibility for vector control.

Supplementary Files

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