Crowded Household, Subdivided Flats, and Dilapidated Housing Are Risk Factors of Bedbug (Cimex Lectularius and Cimex Hemipterus) Infestation: a Cross-sectional Study of Hong Kong Households

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Abstract

Background: Bedbugs have been a neglected issue globally, disproportionately affecting low-income households. The features of many deprived housing units in Hong Kong provide suitable habitats for bedbug infestations. This study aims to identify the housing risk factors for bedbug infestations in Hong Kong.

Methods: Using a cross-sectional study design, online self-reported questionnaires in Chinese were distributed between June 2019 to July 2020. Data collected were socio-demographics, crowded household condition, housing type, dilapidated housing features, and frequency of noticing bedbugs in the participant’s place of residence in the past year. The latter was transformed into a dichotomous dependent variable, “bedbug infestation”. Weighted bivariate and multivariate analysis using binary logistic regression were performed on SPSS 24.

Results: The study sampled N=696 participants, 63.7% have had bedbug infestations. Bivariate analysis shows a positive correlation between the number of dilapidated housing features and bedbug infestation (OR=1.28, 95% CI 1.18-1.39, p<0.001). N=663 were included in the multivariate analysis. Those aged 45-64 (OR=2.53, 95% CI 1.30-4.91, p=0.006) and have primary education or below (OR=9.43, 95% CI 3.12-28.44, p<0.001) have significantly greater odds of bedbug infestation compared to their respective reference groups, ≥65 and tertiary education. Having monthly household income ≤HKD30,000 (OR=1.69, 95% CI 1.15-2.5, p=0.008) and living in subdivided flats (OR=16.53, 95% CI 1.01-269.72, p=0.049) and crowded household (OR=1.55, 95% CI 1.06-2.28, p=0.024) increases the odds of bedbug infestation. Dilapidated housing features that significantly increase the odds of bedbug infestation are having second-hand furniture (OR=2.97, 95% CI 1.16-7.58, p=0.023), housing cleanliness issues (OR=2.66, 95% CI 1.13-6.25, p=0.024), presence of bedbugs in neighbouring residential units (OR=3.32, 95% CI 1.57-7.04, p=0.002), and presence of bedbugs on the streets (OR=1.9, 95% CI 1.12-3.23, p=0.018).

Conclusions: Crowded household, subdivided flats, and dilapidated housing are risk factors for bedbug infestations. To better control bedbug infestations, there needs to be a shift from viewing infestations as a personal hygiene to a public health issue. Efforts and policies should focus on addressing the housing risk factors identified in this study and prioritise vulnerable groups such as the elderly, low education level, low-income groups, and occupants of subdivided flats.

Background

Bedbugs (Cimex lectularius and Cimex hemipterus) are nocturnal ectoparasites that feed on human blood (1). The United States Environmental Protection Agency (US EPA) has deemed bedbugs to be a “pest of significant public health importance” (2). One inseminated female bedbug can start an infestation alone by laying 200–500 eggs in a lifetime at a rate of 5–15 eggs a day (1,3,4). Bedbug infestations occur when their population grows out of control causing adverse health effects (2,5,6,7).
Bedbug bites usually occur in a linear pattern on exposed skin while the host is asleep or still, these usually result in multiple itchy sores where bites occur (7,8,9,10). In severe cases, the bites may result in bullous eruptions (11) and excessive blood lost to bloodmeals may result in anaemia (7,9). Bedbugs have the potential to act as vectors for over 40 diseases, although no outbreaks have been attributed to them so far (7,12,13). Bedbug infestations may result in a broad range of psychosocial disorders including anxiety, depression, and insomnia (14).

Bedbug infestations pose a significant economic burden to households and businesses (5,15). In 2019, the median monthly household income for all households in Hong Kong is HKD28,700 (around USD3,700) (16). Hiring a professional exterminator in Hong Kong per household infestation typically ranges from HKD3,000 to 30,000 (around USD390 to 3,900) depending on the infestation severity, treatment types, living floor area, and other factors. For businesses or facilities such as hotels or hospitals, the cost may be upwards of HKD200,000 (around USD26,000). Low-income households may not afford to hire exterminators or replace infested belongings.

Reported since the 1990s, the global bedbug resurgence has been attributed to several factors including human population growth and urbanisation (6,7,17). These factors strain housing systems leading to more deprived housing with dilapidated housing features that provide favourable conditions for bedbug infestation and spread such as cracks in walls, peeling wallpaper, and crowded housing (5,18,19). The effect of different building types on the risk of bedbug infestation is worth further investigation since certain building characteristics may pose different risks (20).

Having the world’s most expensive housing market (21), the housing situation in Hong Kong offers a unique set of environmental factors that are hypothesized to facilitate the local and international spread of bedbug, these include crowded living environments, dilapidated housing, and vastly different housing situation for those who can afford it versus those who cannot (22,23,24).

Bedbug infestations are neglected in Hong Kong despite being a public health threat since 1. Bedbugs are perceived to pose an insignificant health concern compared to other pests such as mosquitos; 2. Those affected by bedbugs are unlikely to report or seek help for several reasons such as shame, and the lack of means or know-how; and 3. Bedbug infestations are perceived as a personal hygiene instead of a public health issue, shifting the burden of action to individual households rather than the collective efforts of society (25,26).

This study aims to identify the housing risk factors associated to bedbug infestations in Hong Kong.

**Methods**

This study used a population-based cross-sectional study design and was conducted in the Hong Kong Special Administrative Region (HKSAR), China.

**Data collection and sampling method**
Data was collected using online self-reported questionnaires in Chinese, it was later translated into English (Additional file 1). Data collection occurred between June 2019 to July 2020. Google forms was used to create the questionnaire, its electronic link was broadcast on discussion forums and social media pages of different districts in Hong Kong. Participants were eligible to participate if they lived in Hong Kong and were aged 18 or above. N = 696 participants voluntarily completed the questionnaire. G*Power 3.1 was used to calculate the minimum required sample size (n = 617) for the multivariate binary logistic regression (27).

**Measurements**

For the question, “In the past year, how often did you see bedbugs in your place of residence?”, responses ranged from “never” to “very often” on a five-point Likert scale. This variable was transformed into a dichotomous dependent variable, “bedbug infestation”, with “never” being “no” and all other responses being “yes”. A picture of a bedbug was provided to remind participants of its appearance and minimise its erroneous recognition.

Crowded household was measured using a pseudo quantitative method. Participants were asked whether they felt that their residence lacked space or is crowded (given the variable name “feeling crowded”), their living floor area (ft²), and household size. Data from these variables were used to compute the dichotomous variable “crowded household” defined as those who felt that their residence lacked space or is crowded, or those with living floor area per capita ≤ 120 ft²/person. The cut-off of ≤ 120 ft²/person was chosen since less than 25% of the sample met the criteria. Living floor area per capita was computed by taking the upper bounds of each interval responses for living floor area and dividing that by the household size. For living floor area of > 900 ft², the upper bound was taken as 1200 ft², and household size ≥ 5 was taken as 5.

Participants selected their housing type and dilapidated housing features from lists created based on the literature. Participants’ sex, age, education level, monthly household income (HKD), and district were also collected. All variables were collected as categorical variables.

Participants had the option to leave their contact information if they were willing to participate in future bedbug related research. N = 7 participants were contacted, and the researchers visited their residence to make observations and take photographs of their housing situation within the study period.

**Statistical analysis**

A choropleth map of self-reported bedbug infestation cases by district was made. Data analysis was performed using IBM SPSS 24. Weighting by age and sex was applied to the analysis using census data for the end of 2019.

Bivariate logistic regression using chi-square test for categorical variables was used to identify variables associated with bedbug infestation. All variables were considered for inclusion in the multivariate logistic regression to investigate their effects on the odds of the bedbug infestation. Covariates were entered
using the forward conditional method if \( p < 0.05 \) and retained if \( p < 0.1 \). Effect estimates for the covariates in the bivariate and multivariate analysis are presented as odds ratio (OR) with their corresponding 95% confidence interval (CI). Statistical significance was considered if \( p < 0.05 \).

Hosmer-Lemeshow goodness-of-fit test and multicollinearity diagnostics were performed on the final model of the multivariate regression. The model does not violate the goodness-of-fit assumption if \( p > 0.05 \). Multicollinearity was considered if the covariates had variance inflation factors (VIF) \( \geq 10 \), or their absolute value of the Pearson correlation coefficient \(|r| \geq 0.7\) (28).

**Results**

The questionnaire received \( N = 696 \) participants; they were all included in the analysis. The sample size included in the multivariate regression after listwise deletion of missing variables is \( N = 663 \) (95.3%), this is beyond the minimum required sample size of 617. \( N = 7 \) underwent follow-up visits, Figs. 6 to 10 were selected photographs taken at their place of residence.

| In the past year, how often did you see bedbugs in your place of residence? (\( N = 663 \)) | Weighted frequency (%) | 95% CI |
|---|---|---|
| Very often | 100 (15.1) | 12.3–17.8 |
| Often | 93 (14.1) | 11.4–16.7 |
| Sometimes | 92 (13.9) | 11.3–16.6 |
| Rarely | 137 (20.6) | 17.6–23.7 |
| Never | 241 (36.3) | 32.6–39.9 |

| Bedbug infestation (\( N = 663 \)) | Weighted frequency (%) | 95% CI |
|---|---|---|
| Yes | 422 (63.7) | 60.1–67.4 |
| No | 241 (36.3) | 32.6–39.9 |

In Table 1, responses for the question “In the past year, how often did you see bedbugs in your place of residence?” were transformed into the variable “bedbug infestation” with “never” being “no” and all other responses being “yes”, \( n = 422 \) (63.7%) have experienced bedbug infestation in the past year.
Choropleth map

Figure 1 shows the number of self-reported bedbug infestation cases in Hong Kong by district between June 2019 to July 2020. Kwai Tsing, Kwun Tong, Sham Shui Po, Kowloon City and Shatin districts had the highest number of reported bedbug infestations. The distribution of self-reported bedbug infestations was concentrated around the Kowloon region. Due to the small number of responses in some districts, the 18 districts were regrouped into 3 regions for analysis in bivariate and multivariate regression.

Bivariate analysis
|                        | Weighted bedbug infestation (%) | OR (95% CI)* | p-value* |
|------------------------|---------------------------------|-------------|---------|
| **Sex (N = 662)**      |                                 |             |         |
| Female (ref.)          | 228 (63.3)                      | 1.04 (0.76–1.44) | 0.788   |
| Male                   | 194 (64.2)                      |              |         |
| **Age (N = 663)**      |                                 |             |         |
| 0–24                   | 72 (52.2)                       | 0.4 (0.24–0.68) | < 0.001 |
| 25–44                  | 126 (64.3)                      | 0.66 (0.4–1.09) | 0.101   |
| 45–64                  | 137 (65.2)                      | 0.68 (0.41–1.11) | 0.124   |
| ≥ 65 (ref.)            | 87 (73.1)                       |              |         |
| **Education level (N = 664)** |                             |             | < 0.001 |
| Primary education or below | 63 (92.6)                  | 10.56 (4.11–27.11) | < 0.001 |
| Secondary education    | 152 (69.7)                      | 1.87 (1.32–2.67) | < 0.001 |
| Tertiary education (ref.) | 208 (55)                  |              |         |
| **Monthly household income (N = 664)** |                         |             | < 0.001 |
| < HKD10,000            | 74 (74.7)                       | 3.13 (1.56–6.27) | 0.001   |
| HKD10,000–30,000       | 188 (73.7)                      | 2.99 (1.65–5.43) | < 0.001 |
| HKD30,001–50,000       | 82 (52.9)                       | 1.2 (0.65–2.21) | 0.566   |
| HKD50,001–80,000       | 52 (52.5)                       | 1.18 (0.61–2.27) | 0.629   |
| > HKD80,000            | 27 (48.2)                       |              |         |
| Monthly household income ≤ HKD30,000 (No = ref.) (N = 663) | 261 (73.9) | 2.63 (1.9–3.64) | < 0.001 |
| Region (New Territories Region = ref.) | Weighted bedbug infestation (%) | OR (95% CI)* | p-value* |
|----------------------------------------|---------------------------------|--------------|----------|
| Hong Kong Island Region (N = 662)      | 33 (70.2)                       | 1.62 (0.84–3.11) | 0.149    |
| Kowloon Region (N = 663)               | 179 (69.6)                      | 1.62 (1.16–2.28) | 0.005    |
| New Territories Region (N = 662)       | 210 (58.7)                      |               |          |
| Crowded household (N = 663)            | 177 (72)                        | 1.81 (1.29–2.55) | <0.001   |
| Feeling crowded (N = 662)              | 142 (72.1)                      | 1.69 (1.18–2.43) | 0.004    |
| Living floor area per capita ≤ 120 ft²/person (No = ref.) (N = 663) | 89 (72.4)                      | 1.64 (1.07–2.54) | 0.024    |
| Living floor area (ft²) (N = 660)      |                                 |               | 0.001    |
| < 300                                  | 118 (75.2)                      | 2.63 (1.33–5.21) | 0.005    |
| 301–600                                | 209 (63.7)                      | 1.53 (0.82–2.86) | 0.177    |
| 601–900                                | 70 (53.8)                       | 1.02 (0.52–2.01) | 0.947    |
| > 900                                  | 24 (53.3)                       |               |          |
| Household size (N = 663)               |                                 |               | <0.001   |
| 1                                      | 59 (84.3)                       | 2.15 (0.98–4.71) | 0.057    |
| 2                                      | 83 (62.4)                       | 0.66 (0.38–1.17) | 0.155    |
| 3                                      | 106 (62.4)                      | 0.66 (0.38–1.14) | 0.134    |
| 4                                      | 106 (54.4)                      | 0.47 (0.28–0.8)  | 0.005    |
| ≥ 5                                    | 68 (71.6)                       |               |          |
| Housing type (No = ref.)               |                                 |               |          |
| Public rental housing (N = 664)        | 205 (71.4)                      | 1.82 (1.31–2.53) | <0.001   |
|                                       | Weighted bedbug infestation (%) | OR (95% CI)* | p-value* |
|---------------------------------------|---------------------------------|--------------|----------|
| Home ownership scheme (N = 663)       | 45 (51.7)                       | 0.56 (0.35–0.88) | 0.011    |
| Private housing (whole unit) (N = 662)| 129 (56.3)                      | 0.62 (0.44–0.86) | 0.004    |
| Subdivided flats (N = 664)            | 25 (96.2)                       | 29.11 (1.83–461.92) | 0.017    |
| Village house (N = 662)               | 17 (56.7)                       | 0.73 (0.35–1.51)  | 0.391    |
| Non-profit-making organisation houses (N = 663) | 1 (50)                        | 1.11 (0.05–25.26) | 0.946    |
| Dorm room (government, worker, disciplined services) (N = 663) | 1 (50)                       | 0.39 (0.02–7.2)  | 0.525    |
| Wooden house (N = 663)                | 0 (0)                           | 1             |          |
| Dilapidated housing features (No = ref.) |                               |              |          |
| Lack privacy (within the house and between neighbours) (N = 662) | 78 (69.6)                  | 1.37 (0.89–2.13) | 0.155    |
| Insufficient sunlight during the day (N = 663) | 79 (75.2)                   | 1.9 (1.19–3.06) | 0.008    |
| Light pollution at night (N = 663)    | 28 (73.7)                       | 1.6 (0.76–3.34)  | 0.213    |
| Too hot in summer or too cold in winter (N = 664) | 124 (69.7)                    | 1.43 (0.99–2.07) | 0.055    |
| No air conditioner, fan, or heater (N = 663) | 11 (91.7)                    | 6.28 (0.83–47.61) | 0.075    |
| High humidity or leaking/dripping water (N = 663) | 139 (70.9)                   | 1.59 (1.11–2.28) | 0.012    |
| Old or dirty walls, furniture, or belongings (besides having bedbugs) (N = 663) | 125 (73.5)                   | 1.84 (1.25–2.7)  | 0.002    |
| Second-hand furniture (N = 663)       | 39 (86.7)                       | 3.99 (1.67–9.54) | 0.002    |
| Wallpaper or ceiling paint peeling, or rebar showing through walls (N = 664) | 90 (76.3)                    | 2.09 (1.32–3.31) | 0.002    |
| Poor ventilation (N = 662)            | 64 (68.8)                       | 1.3 (0.81–2.07)  | 0.275    |
| Strange odour (N = 663)               | 65 (74.7)                       | 1.79 (1.07–2.99) | 0.026    |
| Weighted bedbug infestation (%) | OR (95% CI)* | p-value* |
|--------------------------------|-------------|---------|
| Rat infestation (N = 663)      | 44 (83)     | 2.87 (1.39–5.92) | 0.004 |
| Noisy or have noise problems (N = 663) | 72 (72.7) | 1.66 (1.03–2.66) | 0.037 |
| Stranger or new resident moved in (N = 664) | 31 (66) | 1.13 (0.6–2.13) | 0.695 |
| Housing cleanliness issues (besides having bedbugs) (N = 662) | 50 (87.7) | 4.26 (1.93–9.4) | <0.001 |
| Residential unit originally had bedbugs (N = 664) | 19 (86.4) | 3.65 (1.06–12.53) | 0.04 |
| Presence of bedbugs in neighbouring residential units (N = 663) | 75 (89.3) | 5.29 (2.63–10.64) | <0.001 |
| Presence of bedbugs on the streets (N = 663) | 98 (80.3) | 2.77 (1.72–4.48) | <0.001 |

*N=663 for all bivariate regression models.

Socio-demographic variables significantly associated with bedbug infestation are age (p = 0.006), education level (p < 0.001), monthly household income (p < 0.001), and region (p = 0.013). Sex is not significantly associated with bedbug infestation. Age has a positive trend with percentage of bedbug infestation while education level and monthly household income have negative trends. Only those in income groups < HKD10,000 (p = 0.001) and HKD10,000–30,000 (p < 0.001) have significantly greater ORs compared to the reference category, >HKD80,000. Thus, monthly household income was recoded into a dichotomous variable “monthly household income ≤ HKD30,000” (p < 0.001) and included in the multivariate regression. Compared to living in the New Territories region, living in the Hong Kong Island region is not significantly different, but living in the Kowloon region (p = 0.005) has significantly greater OR of bedbug infestation.

Crowded household (p < 0.001) and the variables that were used to derive it i.e. feeling crowded (p = 0.004), living floor area per capita ≤ 120 ft²/person (p = 0.024), living floor area (p = 0.001), and household size (p < 0.001) are significantly associated with bedbug infestation. There is a negative trend between living floor area and percentage of bedbug infestation (Fig. 2). Those living in < 300 ft² (p = 0.005) have significantly greater OR compared to the reference category, > 900 ft². However, the relationship between household size and percentage of bedbug infestation appears to peak at the extremes (Fig. 3). When dividing the upper bounds of the intervals for living floor area by that of household size to compute living floor area per capita, the negative trend with percentage of bedbug infestation is retained (Fig. 4).
The housing types significantly associated to bedbug infestation are public rental housing \( (p < 0.001) \), home ownership scheme \( (p = 0.011) \), private housing (whole unit) \( (p = 0.004) \), and subdivided flats \( (p = 0.017) \). Public rental housing and subdivided flats significantly increases the odds of bedbug infestation whereas home ownership scheme and private housing (whole unit) significantly decreases its odds.

Participants who report more dilapidated housing features are significantly more likely to report bedbug infestation \( \text{OR} = 1.28, 95\% \text{ CI} 1.18–1.39, p < 0.001 \) (Fig. 5). The dilapidated housing features that significantly increases the odds of bedbug infestation are insufficient sunlight during the day \( (p = 0.008) \) (Fig. 6); high humidity or leaking/dripping water \( (p = 0.012) \) (Fig. 7); old or dirty walls, furniture, or belongings \( (p = 0.002) \) (Fig. 8); second-hand furniture \( (p = 0.002) \); wallpaper or ceiling paint peeling, or rebar showing through walls \( (p = 0.002) \) (Figs. 7 and 9); strange odour \( (p = 0.026) \); rat infestation \( (p = 0.004) \); noisy or have noise problems \( (p = 0.037) \); housing cleanliness issues (besides having bedbugs) \( (p < 0.001) \) (Fig. 10); residential unit originally had bedbugs \( (p = 0.04) \); presence of bedbugs in neighbouring residential units \( (p < 0.001) \); and presence of bedbugs on the streets \( p < 0.001 \).

**Multivariate analysis**
Table 3
Final model predicting bedbug infestation

| Final model (N = 663)                          | OR (95% CI)         | p-value |
|-----------------------------------------------|---------------------|---------|
| Age (≥ 65 = ref.)                             |                     |         |
| 0–24                                          | 1.26 (0.63–2.5)     | 0.517   |
| 25–44                                         | 1.92 (0.98–3.75)    | 0.056   |
| 45–64                                         | 2.53 (1.3–4.91)     | 0.006   |
| Education level (Tertiary education = ref.)   |                     | < 0.001 |
| Primary education or below                    | 9.43 (3.12–28.44)   | < 0.001 |
| Secondary education                           | 1.49 (1-2.22)       | 0.051   |
| Monthly household income ≤ HKD30,000          | 1.69 (1.15–2.5)     | 0.008   |
| Crowded household                             | 1.55 (1.06–2.28)    | 0.024   |
| Subdivided flats                              | 16.53 (1.01-269.72) | 0.049   |
| Second-hand furniture                         | 2.97 (1.16–7.58)    | 0.023   |
| Housing cleanliness issues (besides having bedbugs) | 2.66 (1.13–6.25)  | 0.024   |
| Presence of bedbugs in neighbouring residential units | 3.32 (1.57–7.04)  | 0.002   |
| Presence of bedbugs on the streets            | 1.9 (1.12–3.23)     | 0.018   |
| Constant                                      | 0.35 (0–0)          | 0.002   |

Table 3 shows the final model. Socio-demographic factors entered into the final model were age (p = 0.007), education level (p < 0.001), and monthly household income ≤ HKD30,000 (OR = 1.69, 95% CI 1.15–2.5, p = 0.008). Compared to those aged ≥ 65, the younger age groups 0–24 and 25–44 do not have significantly different ORs, but those aged 45–64 (OR = 2.53, 95% CI 1.30–4.91, p = 0.006) have significantly greater OR of bedbug infestations. Those with primary education or below (OR = 9.43, 95% CI 3.12–28.44, p < 0.001) have significantly greater OR of bedbug infestations compared to tertiary education.

Housing factors entered into the final model were crowded household (OR = 1.55, 95% CI 1.06–2.28, p = 0.024); subdivided flats (OR = 16.53, 95% CI 1.01-269.72, p = 0.049), second-hand furniture (OR = 2.97, 95% CI 1.16–7.58, p = 0.023); housing cleanliness issues (besides having bedbugs) (OR = 2.66, 95% CI 1.13–6.25, p = 0.024); presence of bedbugs in neighbouring residential units (OR = 3.32, 95% CI 1.57–7.04, p = 0.002); and presence of bedbugs on the streets (OR = 1.9, 95% CI 1.12–3.23, p = 0.018). They are independent housing risk factors for bedbug infestations.
The final model is able to correctly predict 70.6% of bedbug infestations. The omnibus test of model coefficient for the final model is significant ($p < 0.001$), it is better at predicting bedbug infestations compared to the null model. The Cox and Snell, and Nagelkerke R square of the final model is 0.178 and 0.244 respectively. The Hosmer-Lemeshow test is not significant ($p = 0.597$), there is no violation of the goodness-of-fit assumption. Additional file 2 shows that the results for multicollinearity diagnostics of the final model are below the thresholds, VIF $< 3$ and $|r|<0.7$, there is no evidence of multicollinearity.

**Discussion**

This is the first empirical study to investigate the bedbug issue and its associated housing risk factors in Hong Kong.

**Crowded household**

This study finds that crowded household is a more important factor for bedbug infestations than household size. The data from this study shows a nonlinear relationship between household size and the percentage of bedbug infestation (Fig. 3), however living floor area per capita is linear (Fig. 4). Furthermore, crowded household and the variables that it was computed from i.e. feeling crowded, living floor area, and household size were all considered for inclusion in the final model using the forward conditional method for variable selection, but only crowded household was entered.

This study disagrees with Gounder et al.’s 2014 findings that household size is a more important factor than crowdedness (29). The disagreement may be due to differences in study design and methodology. Unlike this study, Gounder et al. 2014 defined crowded housing as having $\geq 2$ household members for every living room and bedroom and did not measure the living floor area of the participants.

It is the crowdedness of the living situation which facilitates the propagation of bedbug infestations as human hosts become accessible by living in close proximity (5).

**Housing type**

Living in subdivided flats is a risk factor for bedbug infestation. Subdivided flats are formed from the splitting of a residential unit into two or more subdivisions, thus subdivided units often neighbour several others (23,30). Over 50% of subdivided flats are located in the Kowloon region (30), this coincides with the choropleth map showing that the number of self-reported bedbug cases are concentrated in the Kowloon region (Fig. 1). Subdivided flats are usually crowded and have many dilapidated housing features, its marginalised residents often possess many health related risk factors and socioeconomic disadvantages (22,23,31,32). In 2016, households living in subdivided flats have median living floor area per capita of 56.5 ft$^2$ and median monthly household income of HKD13,500, both are lower than their respective medians for all domestic households (30). Other studies have found similar results, that living in poor neighbourhoods and buildings with many adjacent housing units facilitate the spread of bedbugs (5,6,20). Bedbug infestation in subdivided flats have been reported to be a cause for other social issues
such as people sleeping at 24-hour fast food restaurant to avoid bedbug bites (25,33). The combination of building and resident characteristics of subdivided flats make their occupants especially vulnerable to bedbug infestations.

**Dilapidated housing features**

This study finds that participants who report more dilapidated housing features are more likely to report bedbug infestations (Fig. 5). This study has identified having second-hand furniture, housing cleaning issues (besides having bedbugs), presence of bedbugs in neighbouring residential units, and presence of bedbugs on the streets to be independently associated with bedbug infestations.

Second-hand furniture has been suggested as a risk factor in other studies as they may harbour bedbugs from the previous owner (5,6,20,29,34). Housing cleanliness issues may allow bedbugs to hide and be difficult to detect and eradicate which agrees with previous literature (5,6,7).

Having bedbugs in neighbouring residential units and on the streets may indicate spreading of bedbugs in a community setting via hitchhiking or egress points such as cracks in walls or electrical conduits. Sheele et al. 2019 found that knowing someone with bedbugs is also a risk factor for bedbug infestation (35). This complicates bedbug management as bedbugs may return from the wider community, even if adjacent neighbouring units are treated for bedbugs. Addressing bedbugs may require the collective efforts of the wider community, not just the neighbourhood or individuals.

**Socio-demographics**

Having higher education level is a protective factor against bedbug infestation, it may reflect knowledge on bedbug infestation management or the ability to access such information. Older adults (45–64) are at greater risk since they are more active, thus are more likely to be in contact with infested places or persons, facilitating the spread of bedbugs (20,35). This study finds that the elderly (≥ 65) has the greatest proportion of bedbug infestation, they may be more likely to suffer from disabilities and financial difficulties resulting in their inability to maintain household cleanliness and not afford bedbug management services (29,31). Having monthly household income ≤ HKD30,000 is a risk factor for bedbug infestation. In comparison, the 2019 median monthly household income of all economically active households in Hong Kong is HKD35,500 (16), and the typical cost of hiring exterminators ranges from HKD3,000 to HKD30,000. Low-income households may not afford to hire bedbug exterminators or replace infested furniture and personal belongings. Committing to these costs may result in perpetual poverty as bedbugs may return, requiring multiple treatments (5). Furthermore, low-income households are more likely to participate in risky behaviours such as trading second-hand furniture or using communal laundries (5,20,29).

**Limitations**

Although age and sex weighting were applied to the analysis, the sample may be non-representative of the Hong Kong population as the sampling method used was volunteer sampling using online self-reported questionnaires. Responses from disadvantaged or marginalised groups with limited internet
access such as primary education or below, elderly (≥ 65 year olds), and occupants of subdivided flats may have been barred from participating, resulting in the reduced representativeness of these groups and their larger confidence intervals (36). Furthermore, there was no way to confirm the existence of bedbug infestations or any of the participants responses, except for a few cases (N = 7) who underwent follow-up visits.

Online data collection made it difficult to comprehensively evaluate the participants’ housing situation. The presence of certain housing factors depended on the participant’s subjective view of their existence, for example the same housing unit may be considered to have housing cleanliness issues by one participant but acceptable to another. Participants selected dilapidated housing features from a list, although an “others (please specify)” option was available, protective factors were not investigated.

Although steps were taken to minimise the erroneous recognition of bedbugs by providing a picture on the questionnaire to remind them of its appearance, bedbug sightings by older participants may be inaccurately reported since previous studies have found that the elderly (≥ 60 year olds) are more likely to wrongly identify bedbugs from a picture compared to younger people in self-reported questionnaires (35). Furthermore, participants may be predominantly reporting adult bedbug sightings and failing to identify smaller bedbugs in earlier instars, resulting in under-reporting (37).

Social desirability may skew the responses towards lower reported bedbug infestations and housing risk factors since having them are associated with negative stereotypes such as being poor, uneducated, and unhygienic (14,26). However, people who do not have bedbugs may not report their situation since they may find the voluntary online questionnaire irrelevant to them, and vice versa for those who have bedbugs, resulting in an arbitrarily higher percentage of reported bedbug infestations.

The cross-sectional study design was unable to establish the temporal sequence of events between bedbug infestations and the variables being investigated. Socio-demographic and housing factors are likely to have existed before the occurrence of the bedbug infestation. However, having bedbug infestations may result in some of these factors arising. For example, the signs of bedbugs (their faeces, carcass, and exuviae on walls or furniture) may be interpreted as having housing cleanliness issues.

Crowded and dilapidated housing features are likely to be manifested similarly in other settings, however certain features of Hong Kong’s housing situation such as the housing related policies, housing types, and their specific building features may limit the generalisability of the results to other countries.

**Policy recommendations**

There needs to be a shift in viewing bedbug infestations as a personal hygiene to a public health issue. Efforts and policies should be focused on alleviating crowded and dilapidated housing and providing adequate standards of living. This will directly address the global bedbug resurgence by removing its environmental facilitators and reverberate improvements to other aspects of life related to housing such as employment, education, and health. Efforts and policies should also prioritise vulnerable groups such
as the elderly, low education level, low-income groups, and occupants of at-risk housing types such as subdivided flats.

Faced with the global threat of bedbug resurgence, simultaneous top-down and bottom-up approaches are required. Examples of top-down approaches are anti-poverty policies, increasing the supply and shortening the waiting time of public housing, and relief and cleaning services for those in deprived housing (22,31,32,38). Bottom-up approaches focus on empowering and building resilience of the public to address bedbugs themselves, especially vulnerable groups at risk or already suffering from bedbugs. Educating low-income households to identify the early signs of bedbug and to self-manage using integrated pest management (IPM) or affordable non-chemical control methods when infestation rates are still low prevents infestations from exacerbating and spreading, thus mitigates the expensive costs of hiring exterminators or replacing furniture and personal belongings (39,40,41,42,43,44).

**Conclusion**

Crowded household, subdivided flats, and dilapidated housing are risk factors for bedbug infestations. To better control bedbug infestations, there needs to be a shift from viewing infestations as a personal hygiene to a public health issue. Efforts and policies should focus on addressing the housing risk factors identified in this study and prioritise vulnerable groups such as the elderly, low education level, low-income groups, and occupants of subdivided flats.

**Abbreviations**

| Abbreviation | Definition |
|--------------|------------|
| CI           | Confidence interval |
| CUHK         | The Chinese University of Hong Kong |
| HKD          | Hong Kong Dollar |
| HKSAR        | Hong Kong Special Administrative Region |
| IBM          | International Business Machines Corporation |
| OR           | Odds ratio |
| ref.         | Reference category |
| SBREC        | Survey and Behavioural Research Ethics Committee |
| SPSS 24      | Statistical Product and Service Solutions version 24 |
| USD          | United States Dollar |
| US EPA       | United States Environmental Protection Agency |
| VIF          | Variance Inflation Factors |
| |r| | Absolute value of the Pearson correlation coefficient |
Declarations

Ethics approval

This research has been approved by the Survey and Behavioural Research Ethics Committee (SBREC), of CUHK [Reference No. SBRE-19-778].

Ethics and consent to participate

Written informed consent was obtained from all participants in digital form. After accessing the link to the online survey, participants were shown a statement of consent which explains the purpose of the study, type of questions to be asked, eligibility criteria, data security, participant rights, and risks involved. The questions to the online questionnaire were only shown after participants voluntarily select “Agree” then “next”.

Consent for publication

Not applicable

Availability of data and materials

The dataset used in this research is available in as an additional file (Additional file 3).

Competing interests

The authors declare that they have no competing interests

Funding

This study has received no funding.

Author’s contributions

EHCF performed data collection, data analysis, and manuscript writing. HW conceptualized and coordinated the research. SWC, JHLH, HML, and SMC provided scientific knowledge. RYC and SYW provided public health knowledge about bedbugs and research design on data collection and data analysis. All authors read, edited, and approved the final manuscript.
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**Additional Files Details**

**File name:** Additional file 1

**File format:** Word Document.docx

**Title:** Online questionnaire design

**Description:** Word.docx version of the online questionnaire used in this study. The questions and responses are the same as the Google forms version.

**File name:** Additional file 2

**File format:** Word Document.docx

**Title:** Multicollinearity diagnostics variance inflation factors (VIF) and Pearson correlation coefficients (r)

**Description:** Results of the multicollinearity diagnostics of the final model presented in this report.

**File name:** Additional file 3

**File format:** Excel Workbook.xlsx

**Title:** Dataset

**Description:** Linelist dataset containing participants’ responses used in data analysis. The first row is the variable name and corresponds to the variables presented in the results section, the spaces have been replaced with an underscore. In “Sheet 1”, each row represents a participant and each column a variable. Missing variables are entered as “999”. The column labelled “case_weight_age_sex” contains the case weightings by age and sex. “Sheet 2” shows the coding scheme for each variable.

**Figures**
Figure 1

Distribution of bedbug cases by district Figure 1 was adapted from “Hong Kong 18 Districts Blank Map” by wahaha2005 and is licensed under Creative Commons Attribution-Share Alike 3.0 Unported license. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.
Figure 2

Living floor area and bedbug infestation (N=660)

Figure 3

Household size and bedbug infestation (N=663)
Figure 4

Living floor area per capita and bedbug infestation (N=666) *Median figures from the Census and Statistics Department, HKSAR (30).

Figure 5

Number of dilapidated housing features and bedbug infestation (N=664)
Figure 6

Darkened corridor of a subdivided flat This figure belongs to us and was taken during the follow-up visits.
Figure 7

Ceiling paint peeling with rebar showing through walls above a rusty and leaking pipe This figure belongs to us and was taken during the follow-up visits.
Figure 8

Sleeping area next to a wall covered with blood streaks from dead bedbugs. This figure belongs to us and was taken during the follow-up visits.
Figure 9

Bedbugs coming out and hidden in cracks in walls This figure belongs to us and was taken during the follow-up visits.
Figure 10

Cluttered public rental housing apartment This figure belongs to us and was taken during the follow-up visits.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Additionalfile1.docx
- Additionalfile2.docx
- Additionalfile3.xlsx
- STROBEchecklist.docx