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Exploring community willingness and barriers to digital solutions and training for dengue prevention: a cross-sectional study in major urban areas of Malaysia

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Abstract

Background Dengue fever is a significant public health concern in urban Malaysia, driven by high population density and rapid urbanization. Effective prevention requires community engagement in both digital and training-based interventions. This study aims to evaluate the sociodemographic and perception-based factors associated with the willingness to adopt a dengue prevention application and participate in dengue prevention training programs in major urban areas of Malaysia.

Methods A cross-sectional study was conducted from February to May 2024 in four major urban areas of Malaysia; Selangor, Wilayah Persekutuan, Perak, and Johor selected due to their high dengue incidence rates, large urban populations, and active public health interventions. A multistage stratified random sampling method, followed by systematic random sampling at the household level, was used to select participants. A structured questionnaire was then administered to collect data on sociodemographic characteristics, perceptions of drone use, and willingness to adopt dengue prevention interventions. Descriptive and multinomial logistic regression analyses were performed to identify factors associated with willingness to adopt a dengue prevention application and participate in training programs.

Results A total of 261 respondents participated, with a mean age of 34.3 years (SD = 12.7). Younger respondents (< 40 years) were significantly more willing to participate in dengue prevention training ("Yes" vs. "No": OR = 2.506, 95% CI: 1.074–5.847, $p = 0.034$), while age was not significantly associated with willingness to adopt the application. Respondents who held negative perceptions of drone use were significantly less likely to consider downloading the dengue prevention application ("Maybe" vs. "No": OR = 0.237, 95% CI: 0.058–0.962, $p = 0.044$), indicating that mistrust or concerns about drone technology may act as a barrier to digital intervention adoption. Other factors, including gender, duration of residence, housing type, and general concerns about drone use, were not significantly associated with willingness to engage in either intervention.

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Conclusions Younger age was associated with greater willingness to participate in dengue prevention training, while negative perceptions of drone use were linked to reduced likelihood of app adoption. Gender, duration of residence, and type of housing were not significantly associated with engagement. These findings suggest the potential value of targeted strategies that encourage youth involvement and address public concerns about drone technology to improve community participation in dengue prevention efforts in urban Malaysia.

Keywords Dengue prevention, Community engagement, Digital health, Training programs, Sociodemographic factors, Urban Malaysia, Drone use, Public health interventions

Introduction

Dengue fever, a mosquito-borne viral disease, remains a major public health challenge, with an estimated 390 million infections annually, of which 96 million are symptomatic [1]. Urban regions are particularly vulnerable due to dense populations, rapid urbanization, poor waste management, and the presence of artificial containers, which create ideal breeding sites for Aedes mosquitoes—the primary dengue vectors [2, 3]. In Malaysia, dengue is endemic, with frequent outbreaks reported in urban areas such as Selangor and Kuala Lumpur, placing a significant strain on healthcare systems and the economy [4, 5]. Climate variability, including rising temperatures and rainfall, further amplifies mosquito activity and complicates control efforts [6].

Despite the widespread use of traditional control methods such as fogging, larviciding, and public awareness campaigns, their long-term effectiveness is undermined by limited community participation [7]. Urban populations often face challenges such as socioeconomic disparities, low health literacy, and cultural attitudes that reduce personal responsibility in vector control [8–10]. As a result, there is a growing need for innovative and targeted strategies that extend beyond conventional approaches. Digital health technologies, including mobile applications, offer new opportunities for dengue prevention. These tools facilitate real-time surveillance, enhance health communication, and enable community reporting [11, 12]. Likewise, community-based training programs promote awareness and empower residents to take an active role in dengue prevention efforts [13]. However, the adoption of these interventions is influenced by sociodemographic factors, digital access, and public perception—particularly regarding emerging technologies like drones [14]. Drones (unmanned aerial vehicles) have been explored for their potential in mosquito habitat surveillance, larvicide delivery, and environmental monitoring. Their ability to access hard-to-reach areas and provide real-time visual data makes them a promising tool for integrated vector control. Nonetheless, public concerns about safety, privacy, and effectiveness may hinder their acceptance [15–18]. As Malaysia advances toward digital and smart public health solutions, understanding community perceptions of such technologies is crucial for real-world deployment.

This study aims to examine the sociodemographic and perception-based factors associated with community willingness to adopt a dengue prevention mobile application and participate in community-based training programs in urban Malaysia. Uniquely, this study investigates both digital and non-digital intervention pathways in parallel, providing a more comprehensive understanding of public engagement in dengue prevention efforts. By incorporating perceptions of emerging technologies such as drone use for mosquito control this study offers novel insights into the enablers and barriers to technology adoption in public health. The findings aim to inform the development of more targeted, inclusive, and effective dengue control strategies tailored to Malaysia's urban population.

Materials and methods

Study design and setting

The study employed a multistage stratified random sampling method, followed by systematic random sampling at the household level, to ensure a representative selection of participants across four major urban areas in Malaysia. The four urban areas selected for this study; Selangor, Wilayah Persekutuan (Kuala Lumpur), Perak (Ipoh), and Johor (Johor Bahru) were purposively chosen due to their consistently high dengue incidence rates and strategic public health relevance (Fig. 1). These locations also represent a diverse cross-section of urban Malaysia in terms of geographic distribution, population density, socioeconomic status, and levels of digital infrastructure. Selangor and Kuala Lumpur are among the most digitally connected states, with high smartphone and internet penetration, while Johor and Perak provide insights into urban populations with varying degrees of community engagement and public health intervention exposure. This combination enhances the representativeness of the sample and allows for a more nuanced understanding of public readiness to adopt both digital and community-based dengue prevention strategies in Malaysia's urban settings.

Data were collected from February to May 2024 using a structured survey. The urban focus of the study allowed for the examination of community readiness and barriers within contexts characterized by higher digital connectivity, diverse sociodemographic profiles, and significant

Fig. 1 Map showing the study locations: Shah Alam (Selangor), Kuala Lumpur (Federal Territory), Ipoh (Perak), and Johor Bahru (Johor), which represent major urban districts within their respective states or territories in Malaysia. These cities were selected due to their high dengue burden, urban density, and diverse sociodemographic characteristics

exposure to public health interventions. The selection of urban areas ensured the relevance of findings to regions where the burden of dengue is most pronounced and where interventions could be most impactful. The study adhered to ethical guidelines and ensured participant confidentiality throughout the data collection process.

Study population and sampling strategy

The study population consisted of residents from four major urban areas in Malaysia: Selangor, Wilayah Persekutuan, Perak, and Johor. These regions were chosen due to their high dengue incidence rates, dense urban populations, and significant public health intervention activities. The target population included adults aged 18 years and above who were permanent residents of the

selected areas, ensuring that participants had sufficient exposure to local dengue control programs and environmental factors influencing Aedes mosquito proliferation. A multistage sampling strategy was employed to ensure representativeness across the study areas. In the first stage, districts within each urban area were stratified based on population density and reported dengue cases. In the second stage, enumeration blocks within each district were randomly selected. Finally, households within the selected blocks were approached, and one eligible adult per household was invited to participate using a systematic random sampling method. Participants were selected based on their willingness to provide informed consent and their availability during the survey period. The required sample size was calculated using standard guidelines for multinomial logistic regression, assuming a moderate effect size, 95% confidence level, 80% power, and up to seven predictor variables. A minimum sample size of 236 was estimated, and a target of 260 respondents was set to account for potential non-response. Ultimately, 261 participants were successfully recruited, ensuring sufficient statistical power for analysis. This sampling approach ensured a diverse and representative sample, capturing variations in sociodemographic characteristics, housing types, and perceptions of dengue prevention strategies across urban Malaysia. The methodology was designed to provide comprehensive insights into the factors influencing community engagement in dengue prevention interventions.

Although the minimum required sample size was calculated based on the total urban population to achieve adequate statistical power for the overall analysis, no strict minimum sample size was set per individual study site. The total sample was proportionally distributed across the four urban areas; Selangor, Wilayah Persekutuan, Perak, and Johor based on estimated population size and logistical feasibility. This approach was chosen to allow for sufficient representation across sites while focusing on pooled data analysis to identify generalizable patterns associated with willingness to adopt dengue prevention interventions. The final number of respondents from each site is reported to ensure transparency in sample distribution.

Data collection tool and procedure

Data collection for this study was conducted using a structured questionnaire (Supplementary File 1). designed to assess sociodemographic characteristics, perceptions of dengue prevention strategies, and willingness to adopt a dengue prevention application or participate in training programs. The questionnaire used in this study was adopted from the validated instrument published by Annan et al. (2022), ensuring relevance and reliability in capturing the targeted variables [19]. The questionnaire was developed based on an extensive review of relevant literature and adapted from validated tools to ensure its relevance and comprehensiveness. It was divided into four main sections: (1) sociodemographic information, including age, gender, race, education level, employment status, type of housing, and duration of residence; (2) perceptions of dengue prevention strategies, focusing on awareness of preventive methods and attitudes toward the use of drones for mosquito control; (3) willingness to adopt interventions, measured on a three-point scale ("No," "Maybe," or "Yes") for downloading a dengue prevention application and participating in training programs; and (4) access to digital resources, including internet and mobile phone usage.

The questionnaire was developed in English and translated into Malay to ensure cultural and linguistic appropriateness for the target population. A back-translation process was performed to maintain accuracy, and the tool was pilot-tested with 30 respondents from a non-study area to refine question clarity, structure, and flow. Following pilot testing, necessary adjustments were made to enhance usability and validity. Trained enumerators conducted face-to-face interviews at participants' homes to administer the questionnaire. Each enumerator was provided with detailed training on the study objectives, ethical considerations, and standardized procedures for questionnaire administration to ensure consistency across study sites. Before starting the interview, participants were briefed on the study objectives and provided written informed consent. Confidentiality and anonymity were emphasized to reduce potential response bias, and participants were informed of their right to withdraw at any time. Data were recorded electronically using tablets equipped with survey software, which incorporated skip logic and consistency checks to minimize data entry errors. Daily uploads and reviews of the collected data were performed to ensure completeness, accuracy, and quality. The collected data were securely stored and accessible only to authorized research personnel. This rigorous approach to data collection ensured the reliability and validity of the findings while capturing the diverse perspectives of urban residents in Malaysia.

Variables and measurement

The variables in this study were categorized into sociodemographic characteristics, perceptions, and outcomes related to dengue prevention strategies. Sociodemographic variables included age, which was measured continuously and categorized into two groups (<40 years and ≥ 40 years), and sex at birth, which was coded as male or female. Race was classified into four categories: Malay, Chinese, Indian, and Others. Type of housing was reported by participants and categorized into six types: bungalow, semi-detached, terrace, townhouse,

flat/apartment/condominium, and single-family house, following typical classifications used in Malaysian urban planning and national surveys [20]. These categories reflect the diversity of urban housing structures and have been associated with varying environmental conditions and vector breeding risks. Duration of residence was recorded as a continuous variable (in years) and subsequently categorized into two groups (< 3 years and ≥ 3 years) based on prior literature indicating that longer duration of residence often correlates with increased environmental awareness and community engagement in health interventions [21].

Perception variables focused on participants' attitudes toward drone use for mosquito control. Perceptions of drone use were assessed on a three-point scale (No, Unsure, Yes), capturing levels of trust and acceptance. Concerns about drone use, including privacy, safety, and effectiveness, were measured as a binary variable (Yes, No). Negative perceptions of drone use were recorded as a categorical variable (No, Unsure, Yes) to capture broader attitudes and potential barriers to technology adoption. The primary outcome variables were participants' willingness to adopt dengue prevention strategies. Willingness to download a dengue prevention application and willingness to participate in dengue prevention training were each measured on a three-point scale ("No," "Maybe," and "Yes"). Additional variables included digital access, recorded as a binary variable (Yes, No) to assess participants' internet and mobile device accessibility, and household size, which was measured continuously and categorized for subgroup analysis. All variables were defined and measured to align with existing literature and facilitate comparison with similar studies. Pilot testing ensured the clarity and reliability of these measurements, while built-in checks in the electronic survey system minimized data entry errors. These variables provided a comprehensive framework for analysing the factors influencing community willingness to engage in dengue prevention interventions.

Ethical considerations

This study adhered to the ethical guidelines outlined by the International Conference on Harmonisation Good Clinical Practice (ICH-GCP), the Malaysian Good Clinical Practice Guidelines, and the Declaration of Helsinki. Ethical approval was obtained from the Universiti Teknologi MARA (UiTM) Research Ethics Committee (Reference: REC/07/2023 (ST/MR/183), dated 21 July 2023). All participants were briefed on the study objectives and procedures, and written informed consent was obtained prior to data collection. Participation was entirely voluntary, and respondents were informed of their right to withdraw at any stage without any consequences.

Data analysis and statistical methods

Data analysis was conducted using SPSS version 28.0. Descriptive statistics summarized respondents' sociodemographic characteristics and key outcomes, reporting frequencies and percentages for categorical variables and means with standard deviations for continuous variables. Multinomial logistic regression was used to identify factors associated with willingness to adopt dengue prevention strategies, using "No" as the reference category against "Maybe" and "Yes" responses. Independent variables included age, gender, race, housing type, duration of residence, and perceptions of drone use. Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated, with significance set at $p < 0.05$. Both unadjusted and adjusted models were generated. Cases with missing data were excluded, and sensitivity analyses ensured result robustness. Findings were visualized using forest plots to clearly illustrate key predictors of community engagement.

Operational definitions

The operational definitions for this study were designed to ensure consistency and clarity in measuring the variables under investigation. Willingness to adopt dengue prevention strategies was assessed using two key outcomes: willingness to download a dengue prevention application and willingness to participate in dengue prevention training programs. Negative perceptions of drone use were assessed using a three-point Likert scale ("agree," "neutral," "disagree") to capture varying levels of attitude and skepticism toward drone-based interventions. This scale allowed for more nuanced interpretation of community sentiment, accommodating respondents who held uncertain or ambivalent views. In contrast, concerns about privacy, safety, and effectiveness were measured using binary response options ("agree" or "disagree") to simplify the interpretation of these more direct and specific concerns. This approach was intended to reduce respondent burden and ensure clarity for items that required clear positions on perceived risks. The use of both scales allowed for a balance between capturing nuanced attitudes and obtaining clear indicators of concern.

Sociodemographic variables included age, recorded as a continuous variable and categorized into two groups (< 40 years and ≥ 40 years), and gender, classified as male or female. Race was self-identified by participants and categorized as Malay, Chinese, Indian, or Others. Type of housing was reported by participants and categorized into six dwelling types: bungalow, semi-detached, terrace, townhouse, flat/apartment/condominium, and single-family house. Duration of residence, defined as the length of time participants had lived in their current residence, was recorded as a continuous variable in years

and later categorized into two groups (< 3 years and ≥ 3 years). Additional variables included digital access, which assessed participants' daily access to internet and mobile devices as a binary variable (Yes/No), and household size, recorded as the number of individuals residing in the household. Household size was analyzed as a continuous variable and further categorized for subgroup analysis. These operational definitions provided a clear framework for capturing the factors influencing community willingness to adopt dengue prevention strategies, ensuring accurate and meaningful interpretation of the study's findings.

Results

Sociodemographic profile and living conditions of respondents

A total of 261 respondents were included in this study, representing a diverse range of sociodemographic characteristics (Table 1). Females constituted the majority (77.4%), with males making up only 22.6%. The sample was predominantly young, with 55.9% of participants aged 18–30 years, followed by 16.9% in the 41–50 age group and 16.5% aged 51–60 years. A smaller proportion (10%) were aged 31–40 years, while only 0.8% were over 61 years old. The study population was largely Malay (95.4%), with minor representation from Chinese (3.4%), Indian (0.8%), and other ethnicities (0.4%). Housing data showed that most respondents resided in terrace houses (55.2%), followed by flats, apartments, or condominiums (20.7%). Other housing types included bungalows (10.3%), semi-detached houses (9.6%), townhouses (2.7%), single-family houses (1.1%), and others (0.4%). Regarding residential duration, a significant majority (86.2%) had lived in their current area for more than three years, while smaller proportions had lived there for

Table 1 Sociodemographic characteristics for Selangor, Wilayah Persekutuan, Perak and Johor

Characteristics		States, *n* (%)				Total
		Selangor	Wilayah Persekutuan	Perak	Johor	
Gender	Male	41 (22.7)	10 (25.6)	5 (18.5)	3 (21.4)	59 (22.6)
	Female	140 (77.3)	29 (74.4)	22 (81.5)	11 (78.6)	202 (77.4)
Age Group	18–30 years old	88 (48.6)	27 (69.2)	19 (70.4)	12 (85.7)	146 (55.9)
	31–40 years old	22 (12.2)	2 (5.1)	1 (3.7)	1 (7.1)	26 (10.0)
	41–50 years old	33 (18.2)	7 (17.9)	4 (14.8)	0 (0.0)	44 (16.9)
	51–60 years old	36 (19.9)	3 (7.7)	3 (11.1)	1 (7.1)	43 (16.5)
	> 61 years old	2 (1.1)	0 (0.0)	0 (0.0)	0 (0.0)	2 (0.8)
Race	Malay	173 (95.6)	37 (94.9)	26 (96.3)	13 (92.9)	249 (95.4)
	Chinese	6 (3.3)	1 (2.6)	1 (3.7)	1 (7.1)	9 (3.4)
	Indian	1 (0.6)	1 (2.6)	0 (0.0)	0 (0.0)	2 (0.8)
	Others	1 (0.6)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.4)
Duration of living in the area	Below 6 months	2 (1.1)	0 (0.0)	1 (3.7)	1 (7.1)	4 (1.5)
	6 months to 1 year	6 (3.3)	1 (2.6)	1 (3.7)	1 (7.1)	9 (3.4)
	1 to 3 years	15 (8.3)	3 (7.7)	3 (11.1)	2 (14.3)	23 (8.8)
	Above 3 years	158 (87.3)	35 (89.7)	22 (81.5)	10 (71.4)	225 (86.2)
Type of House	Bungalow	17 (9.4)	4 (10.3)	4 (14.8)	2 (14.3)	27 (10.3)
	Semi-Detached	17 (9.4)	3 (7.7)	3 (11.1)	1 (7.1)	25 (9.6)
	Terrace	99 (54.7)	19 (48.7)	16 (59.3)	10 (71.4)	144 (55.2)
	Townhouse	5 (2.8)	1 (2.6)	1 (3.7)	1 (7.1)	7 (2.7)
	Flat/Apartment/Condominium	39 (21.5)	12 (30.8)	2 (7.4)	0 (0.0)	54 (20.7)
	Single family house	3 (1.7)	0 (0.0)	1 (3.7)	0 (0.0)	3 (1.1)
	Other	1 (0.6)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.4)
Number of Households	1	3 (1.7)	0 (0.0)	0 (0.0)	0 (0.0)	3 (1.1)
	2	11 (6.1)	0 (0.0)	3 (11.1)	2 (14.3)	16 (6.1)
	3	22 (12.2)	5 (12.8)	3 (11.1)	1 (7.1)	31 (11.9)
	4	36 (19.9)	3 (7.7)	7 (25.9)	3 (21.4)	49 (18.8)
	5 or more	109 (60.2)	31 (79.5)	14 (51.9)	8 (57.1)	162 (62.1)
Access to Internet	Yes	179 (98.9)	39 (100)	27 (100)	14 (100)	259 (99.2)
Access to Mobile Phone	Yes	180 (99.4)	39 (100)	27 (100)	14 (100)	260 (99.6)
Total		181	39	27	14	261

Note:

Duration of Living: Duration of living in the area refers to the length of time participants have resided at their current location

Type of Housing: Housing types are classified as bungalow, semi-detached, terrace, townhouse, flat/apartment/condominium, single-family house, and other, based on self-reported data

Household Size: Household size is defined as the number of individuals residing together in the same house

Digital Access: Access to the internet and mobile phones is self-reported and indicates daily accessibility and usage

1–3 years (8.8%), 6 months to 1 year (3.4%), or less than 6 months (1.5%).

Household size trends indicated that larger families were common, with 62.1% of households comprising five or more members. Households with four members (18.8%), three members (11.9%), and two members (6.1%) were less prevalent, while single-member households were rare (1.1%). Nearly all respondents reported access to the internet (99.2%) and mobile phones (99.6%), underscoring the high level of digital connectivity among participants. Geographically, respondents were distributed across Selangor, Wilayah Persekutuan, Perak, and Johor, with Selangor being the most represented state. These findings provide valuable insights into the demographic, residential, and technological characteristics of the study population, offering a foundation for tailored interventions and future research.

Based on the descriptive analysis, the willingness to download the app demonstrated significant variations across states and between genders, reflecting the sociodemographic characteristics of the respondents (Table 1). In Selangor, 54% of female respondents expressed willingness to download the app, compared to only 17% of males. Similarly, in Wilayah Persekutuan, 51% of females indicated willingness, while only 16% of males expressed the same. Perak exhibited the highest percentage of female willingness (59%), while male willingness remained lower at 13%. In Johor, all willing respondents were female (57%), with no male respondents indicating willingness. Across all states, respondents who were uncertain ("Not sure") were minimal, ranging from 0 to 10%, and those rejecting outright ("No") were negligible.

Figure 2 further highlights the strong gender-based disparity in app willingness, with females consistently demonstrating significantly higher willingness across all states. This trend aligns with the sociodemographic data presented in Table 1, where females constitute 77.4% of the total sample. The high proportion of younger respondents (55.9% aged 18–30 years) and near-universal access to the internet (99.2%) and mobile phones (99.6%) further supports the feasibility of app-based health interventions. These findings lead to the formulation of the hypothesis: "Females are more likely than males to express willingness to adopt digital health solutions, such as mobile applications, regardless of geographic location." This hypothesis is grounded in the observed descriptive trends and highlights the importance of gender-targeted strategies for increasing app adoption rates. Addressing potential barriers for male respondents could further enhance engagement and promote inclusivity in digital health interventions.

The willingness to participate in dengue prevention training demonstrates notable gender-based and regional disparities across the four states, as illustrated in Fig. 3.

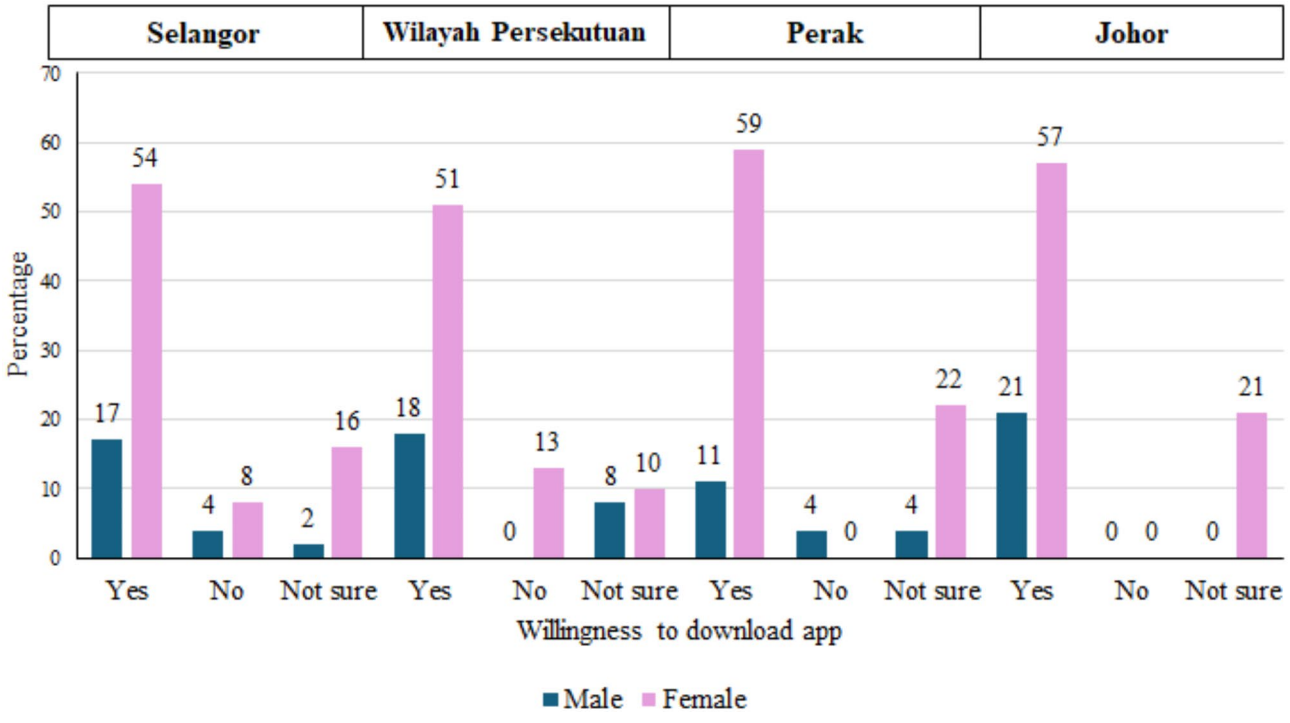


Fig. 2 Gender-based willingness to download the mobile application across four Malaysian states (Selangor, Wilayah Persekutuan, Perak, and Johor). The figure highlights the percentage distribution of responses ("Yes," "No," and "Not sure") for males and females, reflecting significant gender disparities in app adoption willingness

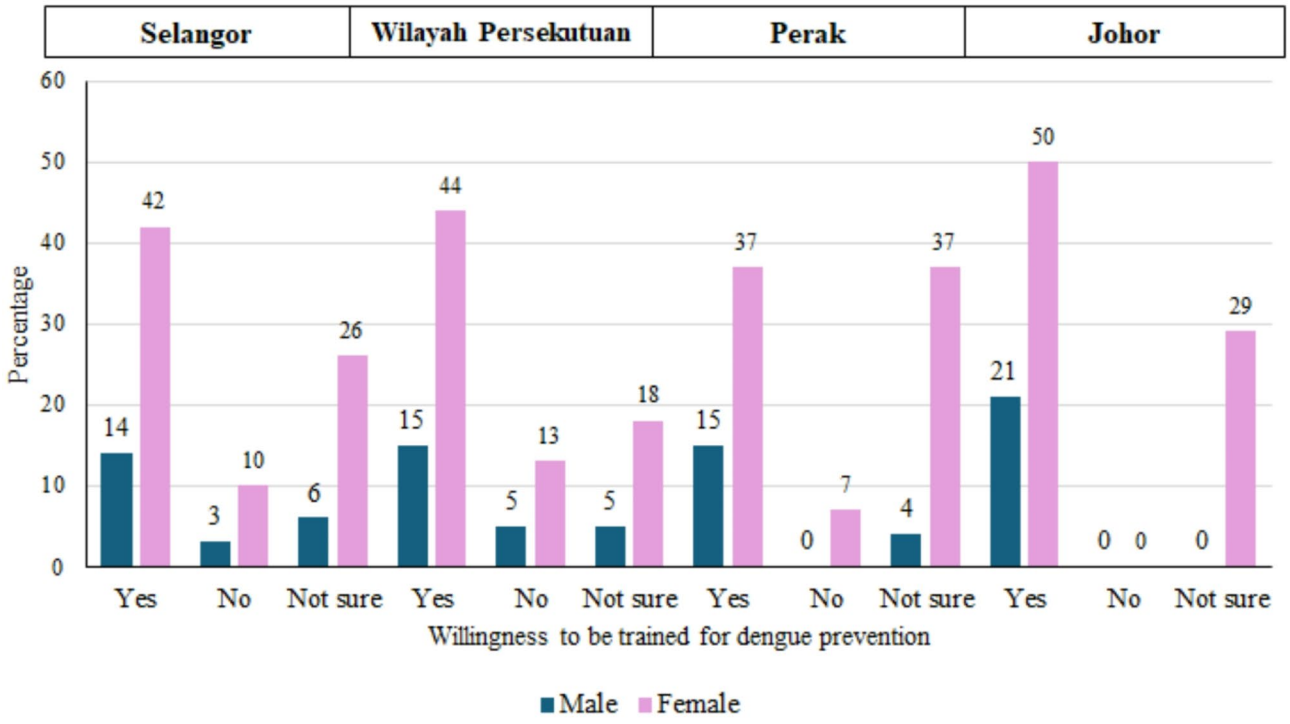


Fig. 3 Gender-based willingness to participate in dengue prevention training across four Malaysian states (Selangor, Wilayah Persekutuan, Perak, and Johor). The figure illustrates the percentage distribution of responses ("Yes," "No," and "Not sure") for males and females, highlighting significant gender and regional disparities in training participation

Female respondents consistently exhibited higher willingness to be trained compared to males in all regions. In Selangor, 42% of females expressed willingness, compared to 14% of males. A small percentage of respondents were uncertain ("Not sure"), with 6% of females and 15% of males indicating indecision, while rejection rates ("No") were higher among females (26%) than males (10%). In Wilayah Persekutuan, 44% of females indicated willingness to participate, whereas only 13% of males showed similar interest. Uncertainty was reported by 5% of females and 18% of males, with rejection rates of 15% and 13%, respectively. In Perak, 37% of females expressed willingness, but no male respondents indicated interest in participating. A small proportion (4%) of females and 7% of males reported uncertainty, while rejection was negligible among females but present for males. Johor had the highest proportion of female respondents willing to be trained (50%), with no male respondents indicating willingness. A considerable proportion of respondents in Johor expressed uncertainty (29%) or rejected participation (21%), reflecting mixed attitudes toward training in this region. These findings align with the overall gender-based trends in app adoption willingness, where females consistently showed greater engagement. Younger respondents (18–30 years), who are generally more receptive to health interventions, likely influenced the positive response. These results underscore the importance of addressing barriers to male participation and reducing uncertainty, particularly in Perak and Johor, to ensure more inclusive engagement in dengue prevention training efforts.

Community preparedness in using drones for dengue management

The multinomial regression analysis results, as summarized in Table 2A, provided valuable insights into the factors influencing willingness to download a dengue prevention application and willingness to participate in dengue prevention training. For app adoption, gender was not a significant predictor, with males being less likely than females to select "Maybe" (OR = 0.401, 95% CI: 0.120–1.339, $p = 0.137$) or "Yes" (OR = 0.658, 95% CI: 0.252–1.720, $p = 0.394$) compared to "No." While this result was not statistically significant, it highlights a potential public health insight: females may exhibit higher readiness to engage with health technologies, which could inform gender-targeted approaches to increase app adoption among males. Similarly, age did not significantly influence app adoption, with respondents under 40 years having higher odds of selecting "Maybe" (OR = 2.144, 95% CI: 0.738–6.230, $p = 0.161$) or "Yes" (OR = 1.729, 95% CI: 0.700–4.271, $p = 0.236$) compared to "No." Despite the lack of statistical significance, this trend suggests younger individuals may be more

Table 2 Multinomial regression analysis of factors influencing willingness to download a dengue application and participate in dengue prevention training programs

Independent variables	Download app (0 = No, 1 = Yes, 2 = Maybe)	A. Willingness to download dengue application			B. Willingness to be trained for dengue prevention		
		OR	95% CI	*p*-value	OR	95% CI	*p*-value
Gender							
Male vs. Female	Maybe vs. No	0.401	0.120, 1.339	0.137	0.592	0.207, 1.689	0.327
	Yes vs. No	0.658	0.252, 1.720	0.394	0.766	0.298, 1.966	0.579
Age							
< 40 years vs. > 40 years	Maybe vs. No	2.144	0.738, 6.230	0.161	1.537	0.628, 3.762	0.347
	Yes vs. No	1.729	0.700, 4.271	0.236	2.506	1.074, 5.847	0.034
Duration of living in the area							
> 3 years vs. < 3 years	Maybe vs. No	3.160	0.548, 18.224	0.198	1.185	0.322, 4.366	0.799
	Yes vs. No	0.829	0.223, 3.079	0.779	1.135	0.344, 3.743	0.836
Type of house							
Terrace vs. Others	Maybe vs. No	0.531	0.194, 1.450	0.217	1.098	0.462, 2.610	0.832
	Yes vs. No	0.762	0.322, 1.800	0.535	0.577	0.259, 1.286	0.179
Negative perceptions about drone use							
No vs. Unsure	Maybe vs. No	0.237	0.058, 0.962	0.044	0.764	0.250, 2.337	0.638
	Yes vs. No	0.776	0.252, 2.393	0.659	1.110	0.387, 3.183	0.846
Yes vs. Unsure	Maybe vs. No	0.351	0.107, 1.148	0.083	0.635	0.236, 1.708	0.368
	Yes vs. No	0.701	0.249, 1.971	0.501	1.188	0.464, 3.039	0.719
Concerns about drone use							
No vs. Unsure	Maybe vs. No	0.606	0.111, 3.315	0.563	0.589	0.154, 2.225	0.440
	Yes vs. No	0.677	0.159, 2.889	0.599	1.475	0.406, 5.368	0.555
Yes vs. Unsure	Maybe vs. No	1.045	0.215, 5.075	0.957	0.789	0.237, 2.631	0.700
	Yes vs. No	0.737	0.183, 2.974	0.668	1.170	0.354, 3.868	0.797

Note: Multinomial regression analysis of factors influencing the willingness to (A) download dengue application and (B) trained for dengue prevention. The table presents odds ratios (OR), 95% confidence intervals (CI), and *p*-values for key sociodemographic variables, housing type, and perceptions regarding drone use, categorized by responses ("No," "Maybe," and "Yes"). Significant associations are highlighted to identify potential predictors of app adoption

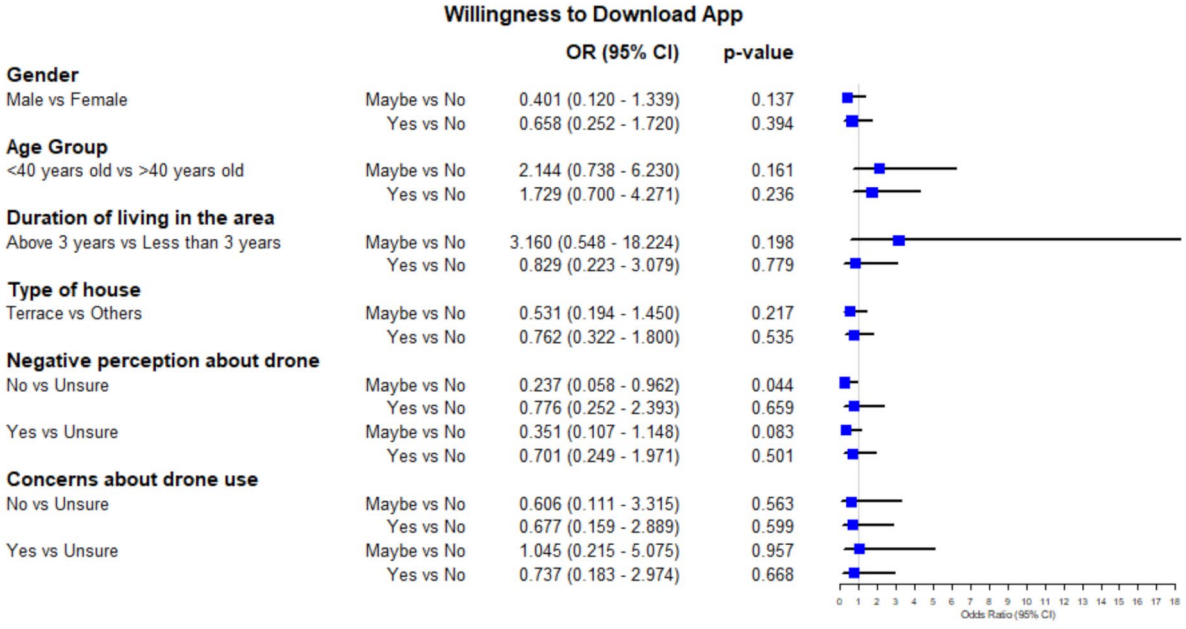
inclined toward digital health solutions, a finding that could guide future interventions focusing on technological accessibility and promotion among older populations. Notably, negative perceptions about drone use emerged as a significant barrier to app adoption, with respondents holding negative views being significantly less likely to choose "Maybe" over "No" (OR = 0.237, 95% CI: 0.058–0.962, $p = 0.044$). Other variables, such as duration of residence, type of housing, and concerns about drone use, did not significantly impact willingness to download the app, but their inclusion highlights the complexity of factors influencing digital health engagement.

In contrast, willingness to participate in dengue prevention training showed different trends (Table 2B). Gender was not a significant predictor, with males demonstrating lower, yet non-significant, odds of selecting "Maybe" (OR = 0.592, 95% CI: 0.207–1.689, $p = 0.327$) or "Yes" (OR = 0.766, 95% CI: 0.298–1.966, $p = 0.579$) compared to "No." Although these results were not statistically significant, they reinforce the observation that males may require targeted encouragement to engage in community health initiatives. Age, however, was a significant factor for training participation, with respondents younger than 40 years being significantly more likely to select "Yes" versus "No" (OR = 2.506, 95% CI: 1.074–5.847, $p = 0.034$). This indicates a need for age-tailored strategies, as younger populations are more willing to participate in training programs. The association for "Maybe" versus "No" was not significant (OR = 1.537, 95% CI: 0.628–3.762, $p = 0.347$), but the trend again points to younger individuals being more receptive to training initiatives.

Even though some factors, such as gender, duration of residence, and housing type, did not show statistical significance, they provide valuable public health insights. For example, understanding trends in gender and age-based engagement can inform the design of more inclusive and targeted public health campaigns. The findings emphasize the importance of addressing negative perceptions of drone use to improve digital health engagement and tailoring training programs to younger populations, while also exploring methods to engage older individuals and males in dengue prevention efforts. These insights underscore the broader implications of sociodemographic factors in shaping public health strategies for urban Malaysia.

Finally, the forest plots in Fig. 4 compare the factors influencing willingness to download a dengue prevention

A



B

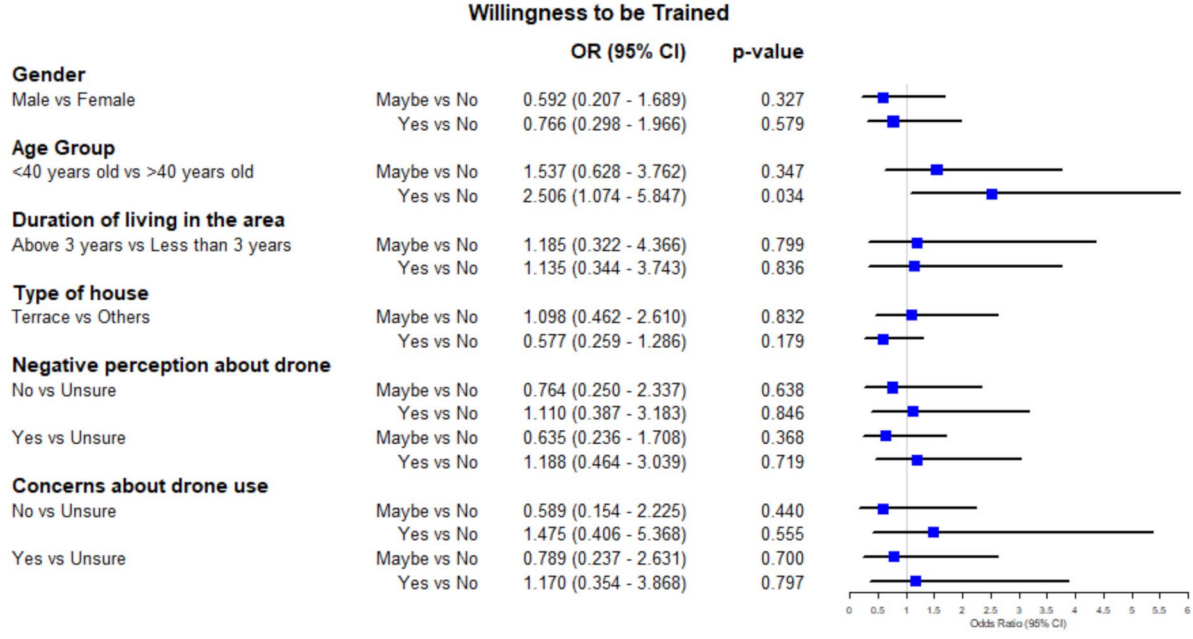


Fig. 4 Forest plots illustrating factors influencing (**A**) willingness to download a dengue prevention application and (**B**) willingness to be trained for dengue prevention. Odds ratios (OR) with 95% confidence intervals (CI) are presented for key sociodemographic variables, housing type, and perceptions regarding drone use, highlighting significant and non-significant predictors for each outcome

application (Panel A) and willingness to participate in dengue prevention training (Panel B). Gender did not significantly predict willingness in either context. Male respondents had lower odds than females for both "Maybe" and "Yes" versus "No," but the results were not statistically significant in either the app adoption or training participation analysis. Age, however, demonstrated a notable difference between the two outcomes. While age was not a significant factor for app adoption, it was a significant predictor for training participation. Respondents under 40 years were significantly more likely to express willingness to be trained ("Yes" vs. "No": OR = 2.506, 95% CI: 1.074, 5.847, $p = 0.034$), although no such association was observed for "Maybe" responses.

Duration of living in the area did not significantly influence willingness for either downloading the app or participating in training. Participants residing in their area for more than three years showed slightly higher odds for "Maybe" responses but lower odds for "Yes" responses compared to "No" in both analyses, though none of these findings were statistically significant. Similarly, type of housing was not a significant predictor for either outcome, as respondents living in terrace houses did not exhibit different levels of willingness compared to those in other housing types. Negative perceptions about drone use were significant only in the context of app adoption. Respondents with negative perceptions were less likely to consider downloading the app ("Maybe" vs. "No": OR = 0.237, 95% CI: 0.058, 0.962, $p = 0.044$), while this factor did not significantly influence willingness to participate in training. Concerns about drone use were not significant in either analysis.

In summary, younger age (< 40 years) was significantly associated with willingness to participate in training, while negative perceptions of drone use were significantly associated with lower willingness to adopt the mobile application. Gender, duration of residence, and housing type were not significant predictors in either outcome.

Discussion

This study evaluated the factors influencing community willingness to adopt a dengue prevention application and participate in dengue-related training programs in urban Malaysia. The findings identify key sociodemographic and perceptual determinants relevant for developing more inclusive and targeted dengue control strategies.

Multinomial logistic regression showed that gender was not a statistically significant predictor of willingness to adopt either intervention. However, descriptive analysis indicated that female respondents consistently expressed higher willingness to engage, a pattern also reported in regional studies from Indonesia and the Philippines [21, 22], likely reflecting women's active roles in household health decisions. This discrepancy between descriptive and inferential findings may be due to confounding factors such as age, education, and perceptions of technology—which were controlled for in the regression model. These factors may mediate or suppress the independent influence of gender on willingness. Moreover, the higher proportion of female participants may have reduced variability and limited statistical power to detect gender differences. Previous research has similarly found that gender effects often diminish after adjusting for broader sociodemographic variables [24, 25]. Despite the lack of significance, the observed gender trend underscores the importance of designing inclusive interventions that actively engage both male and female community members.

While descriptive analysis indicated that female respondents were more willing to adopt digital solutions and participate in training programs, this association was not statistically significant in the adjusted regression model. This inconsistency may be due to the influence of confounding variables such as age, education level, and perceptions of technology, which were controlled for in the multivariable analysis but not in the descriptive statistics. These factors may moderate or suppress the direct effect of gender on willingness. Furthermore, the sample included a higher proportion of female participants, potentially reducing variability and statistical power to detect significant differences. Similar findings in prior research suggest that gender effects often diminish when adjusting for broader sociodemographic and perceptual factors. Despite the non-significant results, the observed trend underscores the importance of designing inclusive dengue prevention strategies that engage all gender groups equitably.

Age was a significant predictor of willingness to participate in training programs, with younger adults (< 40 years) more likely to engage. This aligns with prior studies from Thailand, which found that younger populations tend to be more responsive to structured health programs and new learning opportunities [23]. In contrast, age was not significantly associated with app adoption, suggesting that digital health tools may be acceptable across age groups if designed to be accessible and user-friendly. Prior literature similarly notes that digital adoption depends less on age and more on perceived ease of use and relevance [24–26]. Nevertheless, both younger and older populations can be effectively engaged if interventions are tailored to their technological preferences and learning styles [27].

Negative perceptions of drone use were significantly associated with lower willingness to consider app adoption, particularly for "Maybe" responses compared to "No." This supports earlier studies in Southeast Asia, which reported that privacy, safety, and trust concerns are common barriers to drone acceptance in public

health initiatives [28, 29]. Broader research also confirms that technology adoption is highly influenced by public perception and community trust [30, 31]. Transparent communication and early community engagement can help mitigate these barriers and promote more positive attitudes toward drones [32]. Interestingly, drone perceptions did not affect willingness to participate in training programs, suggesting that traditional health education remains an effective strategy, even among technology sceptical populations [33]. This highlights the value of a hybrid strategy using trusted community platforms as entry points to build support for digital and drone-based interventions [34].

No significant association was found between duration of residence and willingness to engage in either intervention. However, long-term residents often serve as important influencers in community-based programs due to their established social networks and familiarity with local health concerns. This finding aligns with previous studies that emphasize the role of local champions in fostering participation and sustainability in health interventions [35, 36]. While pseudo R^2 values such as Nagelkerke R^2 are sometimes used to evaluate model fit in multinomial logistic regression, they can be difficult to interpret and are not equivalent to the variance explained in linear regression. To avoid potential misinterpretation and maintain the clarity and policy relevance of our findings, we focused on adjusted odds ratios and confidence intervals, which provide a more direct understanding of the strength and direction of associations between predictors and outcomes. This approach is consistent with common practices in public health research when the primary objective is to identify actionable determinants rather than predict outcomes.

Recommendation

These findings have critical implications for dengue prevention strategies in urban Malaysia. First, digital health solutions, such as mobile applications, must be designed with user-friendly interfaces and supported by public awareness campaigns to address negative perceptions and build trust. Studies have shown that user-friendly designs and targeted awareness campaigns are essential for overcoming barriers to technology adoption, particularly in diverse urban populations [37]. Second, training programs should prioritize younger populations while simultaneously developing innovative methods to engage older individuals, who may face additional barriers such as lower digital literacy or resistance to new technologies. Tailored approaches, including simplified training methods or culturally relevant materials, have been shown to improve engagement among older demographics [38]. Third, an integrated approach that combines digital tools with in-person training programs can maximize outreach and effectiveness by leveraging the strengths of each modality. Digital tools offer scalability and convenience, while in-person programs foster trust and hands-on engagement, addressing diverse community needs [39]. This dual-pronged strategy ensures that interventions are inclusive and adaptable, catering to the unique characteristics of urban populations in Malaysia. Overall, these insights highlight the need for tailored, community-centered strategies to enhance participation in dengue prevention programs and ensure long-term success.

Strength and limitation

This study has several limitations that should be acknowledged. First, its cross-sectional design limits the ability to establish causal relationships between the identified predictors and willingness to adopt dengue prevention interventions. The associations observed represent correlations at a single point in time and may be influenced by unmeasured confounding factors. Second, the study relied on self-reported data, which may be subject to social desirability bias or recall bias, particularly in responses related to perceptions and willingness. Third, although a multistage stratified random sampling method was used to enhance representativeness, the selected urban areas may not fully reflect the diversity of all urban settings across Malaysia. The findings are therefore most applicable to large, high-density urban centres with existing digital infrastructure, and caution is advised when generalizing to smaller or less connected urban areas. Fourth, the gender distribution in the sample was skewed toward female respondents, which may have limited the ability to detect statistically significant gender-based differences. This imbalance, along with the modest overall sample size, may have reduced the power of inferential analyses involving gender. Future studies should aim for more gender-balanced and geographically diverse sampling to improve generalizability and subgroup analysis.

Conclusion

This study underscores the importance of addressing sociodemographic and perceptual factors to enhance community engagement in dengue prevention. By tailoring strategies to local contexts and leveraging both digital and in-person approaches, public health initiatives can achieve greater inclusivity and effectiveness in combating dengue in urban Malaysia.

Supplementary Information

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Supplementary Material 1

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Data availability
All relevant data are within the manuscript.

Declarations

Ethics approval and consent to participate
All participants were briefed on the study objectives and procedures, and written informed consent was obtained prior to data collection. Participation was entirely voluntary, and respondents were informed of their right to withdraw at any stage without any consequences.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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