

Original Article

Behavioral, Environmental, and Climatic Factors Associated with Dengue Hemorrhagic Fever Incidence in Limboto District, Gorontalo, Indonesia

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ABSTRACT

Background: Dengue hemorrhagic fever (DHF) remains endemic in Southeast Asia, with Indonesia reporting more than 131,000 cases and 1,135 deaths in 2022. In 2019, Gorontalo Province ranked fourth nationally in terms of incidence rate (101.53 per 100,000 population), with Gorontalo Regency accounting for 31.4% of the provincial cases in 2021. **Objective:** This study aimed to determine the factors associated with the incidence of dengue fever in the Limboto Health Center Working Area, Gorontalo Regency, in 2022. **Methods:** A cross-sectional research design was used. The research was conducted from April to July 2022 in the working area of the Limboto Health Center. The population and sample were people who lived in Limboto District, with 124 respondents. Simple random sampling was used. The independent variables were knowledge, attitude, action, water reservoir, air temperature, air humidity, and occupancy density. The dependent variable was the incidence of dengue hemorrhagic fever. The research instruments used were questionnaires, observation sheets, and hygrometers. The data were processed using univariate and bivariate analyses with SPSS at the 95% confidence level ($p < 0.05$). **Results:** Among the 124 participants, 33.1% ($n=41$) reported DHF infection during the study period. Chi-square analyses revealed no statistically significant associations between DHF incidence and knowledge ($p=0.499$, $\chi^2=0.456$), attitudes ($p=0.526$, $\chi^2=0.401$), preventive actions ($p=1.000$, $\chi^2=0.000$), water storage practices ($p=0.763$, $\chi^2=0.091$), ambient temperature ($p=0.688$, $\chi^2=0.161$), humidity ($p=1.000$, $\chi^2=0.000$), or household density ($p=0.788$, $\chi^2=0.072$). All p values exceeded the 0.05 significance threshold, indicating insufficient evidence to reject the null hypotheses. **Conclusion:** No factors were significantly associated with DHF incidence in this cross-sectional analysis.

KEYWORDS

Dengue virus, infectious disease, physical environment, vector-borne disease, climate changes

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INTRODUCTION

Dengue fever is a public health problem because the number of cases and their spread tend to increase, often leading to outbreaks [1]. The World Health Organization estimates 100–400 million annual dengue infections globally, representing a fourfold increase from pre-2000 estimates, driven primarily by urbanization, climate change, and the expansion of *Aedes* mosquito habitats into previously non-endemic regions [2]. Global analyses have shown that the burden of dengue has significantly increased in the past decade, with the largest contributions from Southeast Asia and Latin America [3,4]. The disease is now endemic in more than 100 countries across Africa, the Americas, the Eastern Mediterranean, Southeast Asia, and the Western Pacific and has begun to emerge in parts of Europe [2].

Indonesia ranks among the top five dengue-endemic nations globally, with transmission dynamics shaped by multiple determinants [5]. Individual-level factors include education, socioeconomic status, and immunity profiles, whereas household-level factors encompass water storage practices and environmental sanitation [6,7]. Community-level transmission is further modulated by climatic variables (temperature, humidity, and rainfall patterns) that directly influence *Aedes aegypti* breeding cycles and viral replication rates. This ecological complexity necessitates a comprehensive risk factor assessment at multiple scales [8].

Gorontalo Province had the fourth highest incidence rate (IR) in 2019, at 101.53% per 100,000 population, with a case fatality rate (CFR) of 1.88%. Gorontalo Regency is the district/city with the highest incidence of DHF out of 5 other districts. Based on the last three years of data, in 2020, there were 954 cases consisting of six districts in Gorontalo Province. In 2021, 347 DHF cases were reported in six districts. This represents a decrease in the number of cases in 2021. The highest incidence of DHF was in Gorontalo Regency with 109 cases (31.4%), Bone Bolango Regency with 88 cases (25.4%), Pohuwato Regency with 77 cases (23%), Gorontalo City with 48 cases (13.8%), North Gorontalo Regency with 18 cases (5.2%), and Boalemo Regency with 7 cases (2%) [9]. Given Gorontalo Regency's persistently elevated DHF burden and the urban-rural interface characteristics of Limboto District, which may present unique transmission dynamics, we conducted this cross-sectional analysis to identify modifiable risk factors amenable to targeted public health interventions. This study aimed to determine the factors associated with the incidence of dengue fever (DHF) in the working area of the Limboto Health Center, Gorontalo Regency, in 2022.

MATERIALS AND METHODS

Study design and setting

This analytical cross-sectional study was conducted from April to July 2022 at the Limboto Health Center, Limboto District, Gorontalo Regency, Indonesia. The Limboto District encompasses approximately 124 households with mixed urban and peri-urban settlement patterns and is located in the lowland region at elevations ranging from 5–50 m above sea level. The district experiences a tropical monsoon climate with a mean annual temperature of 27°C and a bimodal rainfall distribution (Figure 1).

Population and sampling

The study population comprised families (households) residing in Limboto District. A simple random sampling technique was employed to ensure that each household had an equal probability of being selected as a respondent. In total, 124 heads of household participated in this study.

Variables and operational definitions

The dependent variable was DHF incidence, defined as self-reported physician-diagnosed DHF infection within 12 months preceding the interview, verified against health center records where available. The independent variables included behavioral and environmental factors. Behavioral factors included knowledge, assessed through a 15-item questionnaire covering DHF transmission, vector biology, and prevention (scored 0–15; categorized as poor: 0–7, adequate:

8–15 on the basis of median split); attitude, measured via a 10-item Likert scale addressing dengue prevention willingness and perceived susceptibility (categorized as negative: <6-/10 positive responses, positive: ≥6-/10); and action, evaluated through a 12-item checklist of vector control practices, including 3 M Plus behaviors (draining, covering, burying), larviciding, and biological control performed within the past month (negative: <6-/12 practices, positive: ≥6-/12). The environmental factors included water storage containers, classified as inadequate if any uncovered containers or containers not cleaned weekly were present during home inspection, or adequate if all containers were covered and cleaned weekly; air temperature, measured via a calibrated digital thermometer ($\pm 0.1^{\circ}\text{C}$ accuracy) at 1.5 m height in a shaded outdoor location between 10:00–14:00 hours, categorized as suitable for *Aedes* breeding ($26\text{--}32^{\circ}\text{C}$) or unsuitable ($<26^{\circ}\text{C}$ or $>32^{\circ}\text{C}$); relative humidity, measured via a digital hygrometer ($\pm 2\%$ accuracy) simultaneously with temperature, categorized as suitable for *Aedes* survival ($>60\%$) or unsuitable ($\leq 60\%$); and household density, calculated as persons per room, categorized as dense (>2 persons/room) or not dense (≤ 2 persons/room).

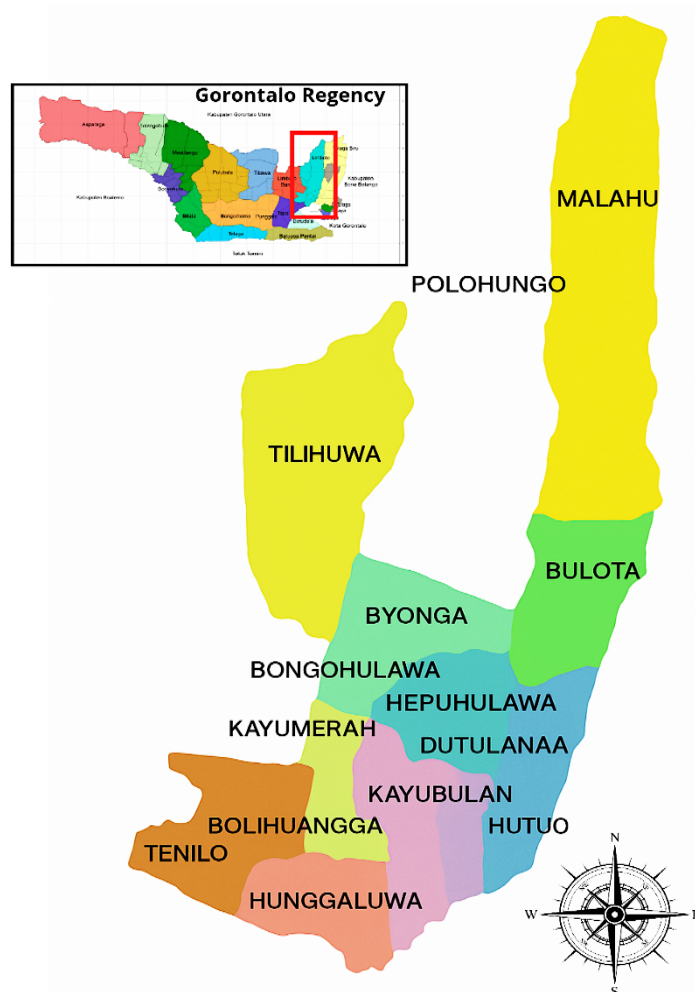


Figure 1. Study area in Limboto district

Data collection instruments

The following data were collected: (1) a structured questionnaire for sociodemographic characteristics and behavioral variables, (2) an observation checklist for water storage practices, (3) a calibrated digital thermometer for ambient temperature measurement, (4) a digital hygrometer for humidity measurement, and (5) a measuring tape for room dimensions. The knowledge, attitude, and action questionnaire was adapted from standardized tools used in prior Indonesian DHF studies and pilot tested with 30 nonparticipant households. The Cronbach's alpha values were 0.78 (knowledge), 0.71 (attitude), and 0.74 (action), indicating acceptable internal consistency.

Statistical analysis

The data were entered into Microsoft Excel 2019® with double-entry verification to ensure their accuracy. Statistical analyses were performed via IBM SPSS Statistics version 26.0. Univariate analysis was used to describe the frequency distributions and percentages of categorical variables. Bivariate associations between each independent variable and DHF incidence were examined via Pearson's chi-square test, with Fisher's exact test applied when expected cell frequencies fell below five⁵. Statistical significance was set at $p < 0.05$. Missing data (observed in <3% of the questionnaire responses) were handled through listwise deletion.

Ethical considerations

This study was approved by the Institutional Research Ethics Committee of the Faculty of Public Health, Universitas Gorontalo (approval number: 91/SK/FKM-UG/XI/2022). All participants provided written informed consent after receiving detailed explanations of the study in Bahasa, Indonesia. Data confidentiality was maintained via anonymized coding systems.

RESULTS

Sociodemographic characteristics

Among the 124 participating households (Table 1), the age distribution showed the greatest representation in the 43–52 years category, with progressively fewer respondents in younger age groups. Males constituted 78.2% of the respondents, reflecting the cultural norm of household heads serving as family representatives. With respect to educational attainment, primary school completion was the most common (42.7%), followed by high school (32.3%), whereas tertiary education (diploma and bachelor's combined) represented only 14.5% of the respondents. The occupational profile demonstrated economic diversity, with unemployment (21.0%) and farming (19.4%) being the most prevalent, followed by self-employment and private sector work.

Table 1. Sociodemographic characteristics of the study participants (n=124)

Characteristics	Total	
	Frequency (n)	Percentage (%)
Age (Years)		
23–32 years old	16	12.9
33–42 years old	27	21.8
43–52 years old	30	24.2
53–62 years old	28	22.6
>65 years old	23	18.5
Gender		
Male (M)	97	78.2
Female (F)	27	21.8
Education level		
Primary school	53	42.7
Junior secondary school	11	8.9
Senior High School	40	32.3
Diploma degree	16	12.9
Bachelor degree	2	1.6
No formal education	2	1.6
Employment		
Civil servant	13	10.5
Private sector employee	16	12.9
Trader/Merchant	7	5.6
Agricultural worker/Farmer	24	19.4
Manual laborer/Day laborer	6	4.8
Unemployed/Not employed	26	21.0
Self-employed/Independent worker	21	16.9
Retired/Pensioner	4	3.2
Professional driver	3	2.4
Motorcycle taxi operator/Bentor operator	4	3.2

DHF incidence and variable distribution patterns

The overall DHF prevalence was 33.1% in the study population (Table 2). The behavioral variables revealed that poor knowledge predominated over adequate knowledge, whereas positive attitudes (56.5%) and positive practices (54.8%) were slightly more common than negative attitudes and practices. The environmental factors revealed a marked imbalance in water storage practices, with inadequate practices accounting for more than adequate practices (90.3% versus 9.7%). Temperature and humidity measurements indicated that approximately 60% and 54% of the households presented conditions suitable for *Aedes* mosquito breeding and survival, respectively. The household density distribution was relatively balanced, with 58.1% classified as nondense.

Risk factors and DHF incidence

The DHF prevalence was 7.6 percentage points higher among those with poor knowledge (35.9%) than among those with adequate knowledge (28.3%). However, chi-square analysis revealed that this difference was not statistically significant ($\chi^2=0.456$, $df=1$, $p=0.499$), indicating insufficient evidence to establish knowledge as a protective factor in this population. The respondents with negative attitudes had a 7.0 pp higher DHF incidence (37.0%) than did those with positive attitudes (30.0%). This difference was not statistically significant ($\chi^2=0.401$, $df=1$, $p=0.526$), suggesting that attitudes did not influence DHF occurrence. The DHF prevalence was nearly identical between the negative action (33.9%) and positive action (32.4%) groups, differing by only 1.5% points. The association was not significant ($\chi^2=0.000$, $df=1$, $p=1.000$), indicating that the reported preventive behaviors had no measurable relationship with DHF outcomes.

Table 2. Bivariate analysis of risk factors associated with the DHF incidence

Variables	DHF Incidence				Total		χ^2	p value
	DHF		Not DHF					
	n	%	n	%	n	%		
Knowledge								
Poor	28	35.9	50	64.1	78	100	0.456	0.499
Adequate	13	28.3	33	71.7	46	100		
Attitude								
Negative	20	37.0	34	63.0	54	100	0.401	0.526
Positive	21	30.0	49	70.0	70	100		
Practice								
Negative	19	33.9	37	66.1	56	100	0.000	1.000
Positive	22	32.4	46	67.6	68	100		
Water Storage								
Inadequate	38	33.9	74	66.1	112	100	0.091	0.763
Adequate	3	25.0	9	75.0	12	100		
Air Temperature								
Unsuitable	15	30.0	35	70.0	50	100	0.161	0.688
Suitable	26	35.1	48	64.9	74	100		
Humidity								
Unsuitable	19	33.3	38	66.7	57	100	0.000	1.000
Suitable	22	32.8	45	67.2	67	100		
Household Density								
Dense	16	30.8	36	69.2	52	100	0.072	0.788
Not dense	25	34.7	47	65.3	72	100		

Remarks: χ^2 , Pearson's chi-square statistic with one degree of freedom for all comparisons. No associations reached statistical significance at $\alpha = 0.05$ ($p > 0.5$). DHF: Dengue hemorrhagic fever.

DISCUSSIONS

This study revealed no significant associations between the seven hypothesized risk factors (knowledge, attitudes, action, water storage, air temperature, humidity, and household density) and DHF incidence in Limboto District. The chi-square test results ($\chi^2 = 0.456$, $p = 0.499$)

revealed that there was no relationship between knowledge and DHF incidence in the Limboto Health Center's working area in 2022. This finding aligns with that of Sari [10], who reported no relationship between knowledge and dengue fever prevention. Knowledge is influenced by formal education factors and is very closely related; it is expected that with higher education, the broader the knowledge. However, people with low education levels do not necessarily have low knowledge levels [11]. A household-based study in Fortaleza, Brazil, revealed that higher KAP scores were associated with lower dengue seropositivity among children [12], whereas large-scale ecological studies [13,14] emphasized environmental and meteorological drivers, such as temperature, humidity, and the Breteau index, as stronger predictors than individual knowledge alone.

Our null finding aligns with studies emphasizing ecological drivers or reporting weak KAP–disease links in cross-sectional studies. The cross-sectional design cannot establish a temporal sequence, as knowledge measured during or after the DHF experience may reflect disease-prompted learning rather than baseline protective awareness. Additionally, our dichotomous knowledge categorization may lack sensitivity in detecting threshold effects. Structural barriers in Limboto, including intermittent water supply necessitating storage and 42.7% primary-education-only completion, may prevent knowledge operationalization into effective practices [11]. Knowledge-focused health education appears insufficient when divorced from environmental modification and structural improvements, suggesting that multicomponent interventions addressing water infrastructure, vector control, and health literacy simultaneously may prove more effective than isolated educational campaigns.

Education significantly influences health literacy, cognitive processing, and decision-making regarding vector control. Respondents with higher educational attainment are more likely to understand transmission mechanisms, recognize symptoms early, and consistently apply 3 M Plus practices (draining, covering, and recycling) [15]. This pattern supports the health belief model (HBM), which posits that perceived susceptibility and self-efficacy are enhanced by knowledge and comprehension [16]. The current results are consistent with findings from Malaysia [17] and the Philippines [18], which reported that income and education strongly predict preventive behaviors against dengue.

Attitudes and actions to eradicate mosquito nests, such as covering, draining, and burying objects that can become stagnant water where the development of DHF mosquito larvae is very important, should be performed continuously. The subject's lack of attitudes toward dengue prevention has an impact on the number of areas that can serve as breeding grounds for *Aedes aegypti* mosquitoes in the home environment [19]. Chi-square analysis revealed no relationship between attitudes and DHF incidence ($\chi^2=0.401$, $p=0.526$), which is consistent with the findings of Parmar et al. [20] and Ruminem et al. [21]. Studies from high-incidence settings [22] have shown that community engagement and prevention practices are associated with a reduced incidence of dengue. However, cross-sectional KAP studies in Asia and the Americas report that positive attitudes do not always lead to effective preventive practices, where structural constraints such as irregular water supply, poverty, and housing conditions limit action ability.

Positive attitudes alone may be insufficient if households lack resources or if environmental conditions favor transmission. Ajzen's theory of planned behavior posits that attitudes translate into actions only when accompanied by perceived behavioral control and supportive subjective norms. In Limboto, the irregular municipal water supply forces households to maintain storage containers despite dengue risk awareness, creating situations where positive attitudes cannot manifest as protective behaviors [19]. Our cross-sectional design could not distinguish preexisting attitudes from those formed post-DHF experiences. The homogeneity of the responses (mean attitude score of 6.8 ± 1.9 out of 10) suggests that ceiling effects may have restricted variance, reducing statistical power. Longitudinal and mixed-methods research is needed. These findings align with numerous studies conducted in Thailand [23–25], which consistently demonstrate that socioeconomic status and education play pivotal roles in shaping health-related behaviors and environmental hygiene practices.

Chi-square analysis revealed no relationship between the action and DHF incidence ($\chi^2=0.000$, $p=1.000$). Studies by Silva [12] and Zhao [13] demonstrated that specific actions, such as regular breeding site elimination, proper water storage, and community vector control, are associated

with a lower dengue risk. Lao [14] studies highlight that climatic and ecological factors can modulate household action effectiveness. Our null finding may reflect self-report bias, as our assessment relied on participants' recall without verification through home inspection or entomological surveys. Social desirability bias may have inflated reported compliance, particularly as interviews occurred at health centers where participants may have perceived the interviewers' affiliation with authorities [26,27].

Our binary categorization lacks specificity regarding which preventive behaviors matter most, as not all components of the 3 M Plus approach carry equal epidemiological significance. The evidence indicates that timely weekly water container draining (monitoring and draining water storage containers once a week) and consistent larviciding are among the most effective household practices for reducing *Aedes aegypti* density and interrupting dengue transmission cycles [28–30]. In contrast, household tidiness, such as cleaning yards or sweeping floors, generally presented weaker or inconsistent associations with entomological indices. Empirical findings from Bali further emphasize the need to prioritize targeted vector control behaviors. A study on dengue vector eradication in Bali reported that community-based larval source management, supported by routine inspection and chemical larviciding, effectively reduced larval indices, whereas nonspecific cleanliness campaigns had minimum impact [31].

Similarly, Adnyana et al. [32], highlighted that bioclimatic variability interacts with behavioral consistency, implying that weekly water management behaviors are critical for sustainable control. Similarly, the One Health analysis of dengue elimination challenges in Bali underscores that vector control success depends on focusing community engagement on measurable and high-impact behaviors rather than broad hygiene appeals [33]. Zhao et al. [13] employed trained observers completing standardized home checklists and larval sample collection for the Breteau index calculation, revealing strong associations missed by self-report instruments. The absence of entomological data precludes the assessment of whether the reported actions actually reduced *Aedes* populations or merely reflected socially normative responses. Future studies should employ weighted scoring to prioritize high-impact behaviors and validate self-reports through entomological indices linking household actions to vector presence.

Chi-square analysis revealed no relationship between water reservoirs and DHF incidence ($\chi^2=0.091$, $df=1$, $p=0.763$), which is consistent with the findings of Apriyani et al. [34]. Stewart-Ibarra reported that large outdoor containers produced 3.7 times more adult mosquitoes per liter than small indoor containers did, and weekly draining reduced emergence by 82% compared with monthly draining. Our dichotomous classification (adequate: all containers covered and cleaned weekly versus inadequate: any noncompliance) may have missed these gradations. The 90.3% prevalence of inadequate water storage indicates insufficient variation to detect associations, representing a range restriction that reduces statistical power. Container-specific inventories with productivity indices measuring larval density and pupal counts would better characterize risk than aggregate categorization, providing objective breeding site productivity measures rather than relying solely on observational classification [35].

Temperature directly affects the life stages of mosquitoes and dengue virus replication [32]. Experimental and mechanistic studies have consistently shown that temperature influences larval development, adult survival, biting frequency, and vector competence in *Aedes aegypti* and *Aedes albopictus* [36–38]. Additionally, dengue virus replication within mosquitoes is highly temperature dependent, with the extrinsic incubation period (EIP) shortening at relatively high temperatures and lengthening at relatively low temperatures [38,39]. These findings highlight that optimal temperature ranges determine not only vector survival but also viral amplification and transmission potential. From a bioclimatological and One Health perspective, it is essential to integrate thermal ecology into vector control strategies.

Adnyana et al. [32] emphasized that understanding temperature dynamics within the ecological triad of vectors, viruses, and hosts is vital for effective dengue prevention under climate variability. The One Health framework links environmental temperature fluctuations with entomological and epidemiological surveillance, encouraging cross-sector collaboration in climate-adaptive dengue control programs in Brazil. This holistic approach underscores that climatic parameters, particularly temperature, are not merely background variables but also

active determinants of transmission risk that should inform predictive modeling and vector control policies [32]. Chi-square analysis revealed no relationship between air temperature and DHF incidence ($\chi^2=0.161$, $p=0.688$), which is consistent with the findings of Tumey [40] in the Talaud Islands Regency. Meta-analyses identify thermal optima at 29°C for transmission potential, with sharp declines above 32°C and below 20°C [26]. Our single-measurement approach (temperature recorded once from 10:00–14:00 hours during home visits) inadequately captures the daily and seasonal variability shaping vector–virus dynamics.

Phommachanh et al. [14] used meteorological station data with daily resolution across multiple years, enabling lagged correlation analyses revealing that temperature effects manifest 2–4 months post-exposure. However, point-in-time measurements cannot detect distributed lag effects. Categorizing temperature as suitable (26–32°C) versus unsuitable oversimplifies nonlinear relationships. Indoor measurements at a height of 1.5 m in shaded locations may not represent microhabitat temperatures in outdoor water containers exposed to direct sunlight. Future studies should integrate meteorological station data spanning multiple dengue seasons and employ distributed lag nonlinear models [41].

Chi-square analysis revealed no relationship between humidity and DHF incidence ($\chi^2=0.000$, $df=1$, $p=1.000$), which is consistent with the findings of Putri et al. [42] in Bandar Lampung city. Low humidity (<60%) causes short mosquito life cycles that are insufficient for dengue breeding in the mosquito's body, causing evaporation of water from the mosquito's body and resulting in fluid desiccation. Humidity affects the lifespan, flight distance, breeding speed, biting habits, and resting behavior of mosquitoes [43]. The virtually identical DHF prevalence between unsuitable (33.3%) and suitable (32.8%) humidity conditions (0.5 percentage point difference) suggests that our single-point measurement failed to capture transmission-relevant variation. Humidity exhibits substantial diurnal and seasonal fluctuations. Measurements taken between 10:00 and 14:00 represent midday minimum, potentially missing high-humidity periods during early morning and evening when *Aedes aegypti* are most active in host-seeking.

Previous studies have demonstrated that fine-scale microclimatic variations strongly shape mosquito population dynamics and arboviral transmission potential [44]. Large diurnal environmental fluctuations, including humidity and temperature, have been shown to affect mosquito life-history traits and viral development [45,46]. Our dichotomous categorization at single measurement occasions, therefore, cannot represent the cumulative humidity exposure that determines mosquito survival and infectivity. Low-humidity environments have been experimentally linked to enhanced viral dissemination in *Aedes aegypti* [47], indicating that the temporal pattern of humidity exposure modulates infection outcomes. Moreover, indoor humidity measurements may not accurately reflect outdoor microhabitat conditions where container breeding occurs, as mosquito resting sites often display microclimatic profiles distinct from those of weather stations or indoor readings [48]. Future research should employ continuous humidity monitoring via data loggers to record hourly measurements across transmission seasons, enabling time-weighted average exposure calculations that better represent the dynamic environmental conditions experienced by mosquitoes [43,48].

Chi-square analysis revealed no relationship between household density and DHF incidence ($\chi^2=0.072$, $p=0.788$), which is consistent with the findings of Hendayani et al. [49] at the Manonjaya Health Center. The unexpected finding that nondense households presented a slightly greater DHF incidence (34.7%) than dense households did (30.8%), contrary to theoretical expectations, warrants interpretation. Household density (persons per room) serves as a proxy for human–mosquito contact rates, assuming that higher densities increase the probability that infected mosquitoes encounter susceptible hosts.

Our calculation did not account for the time spent in households, as residents working outside during peak *Aedes* biting hours experience reduced exposure regardless of nighttime sleeping density [50]. Household-level density may be less relevant than neighborhood-level human density for mosquitoes with a 100 m flight range, as the transmission risk depends on infected mosquitoes and susceptible human pools within dispersal distances rather than within individual households. Socioeconomic confounding may mask associations, as densely populated households often reflect a lower socioeconomic status, which correlates with unmeasured dengue

risk factors, including housing quality, window screening, and water storage practices. Future studies should employ multilevel spatial analyses to examine dengue clustering at the household, neighborhood, and community scales while controlling for socioeconomic confounders [49]. Higher household income was associated with greater adoption of preventive behaviors, which is consistent with reports from Lao [51] and India [52]. Financial stability allows households to afford mosquito repellents, screen repairs, and waste management. Conversely, lower-income families often have limited access to sanitation infrastructure and rely on communal water storage, which increases the risk of vector breeding [53].

Public health implications

This study provides important insights for dengue prevention programs in endemic districts such as Limboto, where traditional knowledge–attitude–practice (KAP) interventions have limited measurable impact. The absence of statistically significant associations between behavioral, environmental, and climatic factors and DHF incidence indicates that current household-level interventions may not sufficiently capture the multifactorial nature of dengue transmission. Therefore, public health strategies should emphasize integrated surveillance systems that combine epidemiological, entomological, and climatic data to identify real-time transmission risks. Strengthening environmental health infrastructure, particularly reliable water supply systems, can reduce the dependence on water storage, which is one of the main breeding sources of *Aedes aegypti*. Furthermore, incorporating One Health principles that link human, vector, and environmental domains will improve intersectoral coordination among community health services, vector control units, and meteorological agencies. Capacity building in vector surveillance, community-based larval source management, and climate-adaptive policy design should be prioritized at the national and local health levels.

Limitations

The cross-sectional design precluded the establishment of temporal or causal relationships between the exposure variables and DHF incidence. Reliance on self-reported data for behavioral factors may have introduced recall and social desirability bias, potentially inflating compliance with preventive practices in this study. The environmental variables, such as temperature and humidity, were measured only once during the midday hours, which may not accurately reflect the diurnal or seasonal variability affecting vector survival. The relatively small sample size ($n=124$) and uneven exposure distributions, such as the high prevalence of inadequate water storage, reduced the statistical power to detect meaningful associations. Finally, the absence of entomological indicators (e.g., the Breteau index, pupal density, or ovitrap data) limits the ability to validate behavioral findings with objective measures of mosquito abundance.

CONCLUSIONS

This cross-sectional analysis of 124 households in Limboto District revealed no statistically significant associations between seven hypothesized risk factors—knowledge, attitudes, preventive actions, water storage practices, ambient temperature, humidity, and household density—and DHF incidence. The uniform lack of associations across diverse variable types suggests that unmeasured factors may dominate the transmission dynamics in this endemic area. Viral serotype circulation, herd immunity following prior epidemics, and fine-scale vector density patterns were not assessed but likely substantially influenced DHF risk. Additionally, Gorontalo's persistent high incidence despite decades of control efforts indicates that standard knowledge–attitude–practice interventions are insufficient in the absence of structural changes addressing water infrastructure, housing quality, and climate adaptation. Future research should focus on three areas: longitudinal cohort studies to clarify causal links; mixed-methods investigations combining quantitative data with qualitative inquiry into implementation barriers; and the integration of entomological surveillance with household data to validate whether reported behaviors actually reduce vector density.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

AUTHOR CONTRIBUTIONS

Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision: MS, ZAA, SH, WH, RP, FDB, MK, DS and JB.

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DECLARATION OF ARTIFICIAL INTELLIGENCE USE

We hereby confirm that no artificial intelligence (AI) tools or methodologies were utilized at any stage of this study, including during data collection, analysis, visualization, or manuscript preparation. All work presented in this study was conducted manually by the authors without the assistance of AI-based tools or systems.

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