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Environmental and Socioeconomic Factors Contributing to Higher Dengue Prevalence in Christian Colonies of Islamabad

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Abstract
This study investigates environmental and socioeconomic determinants of dengue fever prevalence in four Christian colonies in Islamabad: Rimsha Colony (H-9), 100 Quarter Colony (F-6), Hensa Colony (G-8), and France Colony (F-7).
Methodology using a cross-sectional household survey, entomological inspections, climate data, and health records from August to October 2024, we **analyzed:** the associations between housing quality, water sources, sanitation, waste management, population density, education, and dengue incidence. A **sample:** of 800 households (200 per colony) were surveyed for demographics, socioeconomic status, and knowledge/behavior related to dengue; entomological indices (Breteau Index, Container Index) were obtained via larval/pupal surveys; environmental conditions (proximity to stagnant water, drainage, shade, vegetation) recorded. Health data from local clinics provided confirmed dengue cases. Our **results:** indicate that France Colony and Rimsha Colony had significantly higher dengue incidence (20.5% and 18.0% of households reporting at least one case in study period) versus Hensa (10.5%) and 100 Quarter (9.0%). Key risk factors include lack of piped water supply (OR ≈ 3.2), irregular waste collection (OR ≈ 2.7), impermanent housing materials (OR ≈2.1), low educational attainment (OR ≈ 1.9), and high vector larval indices (Breteau Index > 20; container index > 25%) correlating with dengue incidence ($r = 0.68^{**}$, $p < 0.001$). Climatic factors such as monthly rainfall and minimum temperature also showed strong positive correlations. The study **concludes:** that both environmental and socioeconomic vulnerabilities in these colonies exacerbate dengue risk, underscoring the need for integrated vector control, improved infrastructure, and community awareness interventions targeted especially in underserved Christian colonies.

Introduction
Background
Dengue fever is one of the most rapidly spreading mosquito-borne viral infections in the world and remains a pressing global public health problem. It is caused by infection with one of four antigenically distinct but closely related dengue virus serotypes (DENV-1 to DENV-4) belonging to the ***Flaviviridae*** family. The principal vector responsible for dengue transmission is ***Aide's aegypti***, while ***Aide's albopictus*** serves as a secondary vector, especially in peri-urban and rural environments. These mosquitoes are highly adapted to human dwellings, breeding in artificial water containers such as discarded tires, buckets, flower pots, and water storage drums. Their diurnal biting pattern and preference for indoor habitats make vector control particularly challenging in densely populated urban settings.
Globally, the burden of dengue has expanded dramatically over the last five decades. The World Health Organization (WHO) estimates that about 390 million dengue infections occur annually, of

which around 96 million manifest clinically. Over 3.9 billion people in more than 129 countries are at risk of infection, with Asia accounting for nearly 70% of the global disease burden. Dengue has transitioned from a sporadic tropical disease to a major international health threat, with significant social, economic, and healthcare implications. Factors such as globalization, population mobility, urbanization, climate change, and inadequate vector control have facilitated the spread of *Aedes* mosquitoes and dengue viruses to new ecological zones.

The clinical manifestations of dengue range from asymptomatic infection to severe dengue hemorrhagic fever and dengue shock syndrome, conditions that can lead to fatal outcomes if not managed promptly. While mortality from dengue has decreased in recent years due to improved case management, morbidity remains high, causing loss of productivity and straining public health systems. Economic costs are substantial; estimates from Southeast Asia and Latin America suggest billions of dollars in direct medical expenses and productivity losses annually. These impacts are particularly acute in low- and middle-income countries where healthcare infrastructure is already under stress.

Dengue transmission dynamics are influenced by a complex interplay of environmental, biological, and socioeconomic factors. Climatic conditions such as temperature, rainfall, and humidity strongly affect mosquito survival, breeding, and virus replication within the vector. Temperatures between 25°C and 30°C are optimal for *Aides aegypti* breeding, while relative humidity above 60% enhances adult mosquito longevity. Rainfall provides breeding sites through water accumulation in containers and drains, whereas prolonged dry spells can also promote transmission when people store water in containers that become breeding habitats. Urban heat islands—areas with higher ambient temperatures due to dense construction and limited vegetation—further intensify vector proliferation.

Socioeconomic conditions are equally important. Poor housing quality, overcrowding, inadequate waste management, and lack of access to clean water and sanitation create environments conducive to *Aides* breeding. Informal settlements and slum areas, where municipal services are often limited, present ideal conditions for sustained dengue transmission. In addition, low levels of education and limited awareness of vector-control practices lead to ineffective prevention behaviors. Studies from across South and Southeast Asia demonstrate that dengue disproportionately affects marginalized and low-income populations. These communities often reside near stagnant water, uncovered drains, and waste dumps, making them particularly vulnerable.

Globally, urbanization has emerged as one of the dominant drivers of dengue expansion. The rapid, unplanned growth of cities has outpaced infrastructure development in many developing countries, leading to increased human–vector contact. The *Aedes* mosquito's ability to thrive in small artificial containers allows it to colonize almost any urban habitat. Migration, trade, and travel contribute to virus introduction and the mixing of serotypes, which can increase the likelihood of severe disease through secondary infections with different serotypes. In many regions, dengue has shifted from a seasonal epidemic to a year-round endemic disease due to these compounding factors.In the South Asian context, dengue has become endemic across India, Bangladesh, Sri Lanka, and Pakistan. Regional climatic conditions, monsoon rainfall, and urban crowding have created ideal conditions for vector proliferation. In Pakistan, the first major dengue outbreak was recorded in Karachi in the 1990s, followed by recurrent epidemics across major cities, including Lahore, Rawalpindi, Peshawar, and Islamabad. According to national surveillance data, dengue cases in Pakistan have increased exponentially over the last two decades, with large outbreaks reported in 2011, 2017, and 2019. The disease now poses an annual health challenge, particularly during and immediately after the monsoon season.Climatic variability plays a central role in Pakistan's dengue epidemiology. High temperatures accelerate the mosquito life cycle and viral replication rate, reducing the extrinsic incubation period (the time required for the virus to become transmissible within the mosquito). Increased rainfall generates breeding habitats, especially in poorly drained urban environments. Several studies from Pakistan have shown statistically significant correlations between rainfall, temperature, humidity, and dengue incidence. Furthermore, extreme weather events linked to climate change—such as prolonged rains and flooding—can exacerbate breeding site availability and disrupt vector-control operations.

Socioeconomic and infrastructural conditions further modulate dengue transmission in Pakistani cities. Rapid urban expansion, informal housing settlements, inadequate waste disposal, and irregular water supply systems contribute to persistent mosquito breeding. Many urban slums lack piped water, forcing residents to store water in containers that remain uncovered for extended periods. Waste accumulation in open areas and blocked drainage systems create additional breeding habitats. Limited public awareness and inconsistent municipal vector-control programs compound the problem.

Islamabad, Pakistan's federal capital, presents an illustrative case of how environmental and socioeconomic heterogeneity within an urban setting influences dengue transmission. Although considered one of Pakistan's better-planned cities, Islamabad has experienced recurrent dengue outbreaks in recent years. The city's diverse topography, which includes forested areas, open drains, and densely populated informal settlements, provides a mosaic of ecological niches favorable to *Aedes* mosquitoes. The interaction between planned urban sectors and adjoining underdeveloped colonies has created distinct micro-environments with varying levels of risk.

Studies conducted within the Islamabad Capital Territory (ICT) have consistently shown positive correlations between climatic variables and dengue incidence. Periods of high rainfall and elevated minimum temperatures correspond closely with increases in reported dengue cases. For example, peak transmission typically occurs between August and October, coinciding with monsoon rains and subsequent water accumulation. Minimum temperatures above 20°C sustain mosquito breeding even when rainfall declines. Urban environmental gradients such as drainage conditions, land-use patterns, vegetation cover, and population density also modulate spatial variability in dengue risk. Areas with open drains, dense vegetation, and informal housing show higher mosquito indices and case counts compared to well-serviced sectors.

In addition to climatic and ecological factors, the socioeconomic landscape of Islamabad significantly influences dengue dynamics. While the city's central sectors benefit from structured housing, proper sanitation, and waste collection services, several marginalized Christian colonies—such as France Colony (F-7), Rimsha Colony (H-9), Hensa Colony (G-8), and 100 Quarter Colony (F-6)—remain underserved. These settlements are characterized by overcrowding, substandard housing, limited access to clean water, and poor waste disposal systems. Residents often rely on informal water supplies and temporary housing materials that increase their vulnerability to vector exposure. Consequently, these areas experience disproportionately higher dengue prevalence compared with more affluent neighborhoods.

The urban ecology of these colonies contributes directly to disease risk. Stagnant water in open drains, uncovered water containers, and irregular waste collection provide abundant breeding habitats for *Aedes aegypti*. The mosquito's adaptation to urban habitats allows it to persist even during dry periods, breeding in small domestic containers or discarded items. Socioeconomic disadvantage limits residents' ability to implement preventive measures such as purchasing repellents, installing window screens, or covering water storage containers. Moreover, low literacy levels reduce understanding of dengue transmission and prevention.

Public health authorities in Islamabad face challenges in sustaining vector-control programs in informal settlements. Fogging and larvicidal operations are often reactive—initiated only after outbreak onset—rather than preventive. Weak coordination between municipal departments and health agencies further undermines early intervention efforts. Additionally, limited surveillance data from marginalized colonies obscures the full extent of dengue transmission, hindering effective resource allocation.

At a broader level, the rise in dengue incidence in Islamabad mirrors global trends linking urban poverty, climate change, and inadequate vector control. The convergence of environmental and socioeconomic vulnerabilities in specific communities demonstrates how disease ecology is shaped by social inequity. While climatic conditions provide the background for transmission, it is local infrastructure, housing, and behavioral factors that determine disease intensity. Consequently, understanding dengue in Islamabad requires integrating climatic, environmental, and social perspectives.

In summary, dengue fever represents a multifactorial challenge driven by climatic conditions, vector ecology, and human living environments. In Pakistan, and particularly in Islamabad, the coexistence of modern urban sectors and under-resourced informal colonies creates sharp contrasts in exposure and vulnerability. Addressing dengue transmission in such settings demands more than medical treatment; it requires structural interventions—improving water and sanitation infrastructure, enhancing community awareness, and strengthening vector surveillance. By examining these interlinked determinants, the present study seeks to elucidate how environmental and socioeconomic factors collectively contribute to the spatial variability of dengue prevalence in the Christian colonies of Islamabad.

Rationale: Christian Colonies in Islamabad

Urban health inequities in Pakistan are closely intertwined with socioeconomic segregation, informal housing, and unequal access to municipal services. Islamabad, though a planned capital, exhibits marked intra-urban disparities between its formally developed sectors and a network of informal settlements locally known as katchi abadis or "colonies." Among these, the Christian colonies stand out as communities experiencing chronic deprivation, weak infrastructure, and environmental neglect. Understanding dengue epidemiology within these marginalized enclaves is crucial because they represent micro-ecosystems where the confluence of environmental and social vulnerability amplifies vector-borne disease risk.Historically, the establishment of Christian colonies in Islamabad can be traced to the migration of low-income sanitation and municipal workers from Punjab and other regions during the city's formative years in the 1960s–1980s. Many of these workers were employed by the Capital Development Authority (CDA) and settled in temporary housing provided near their workplaces. Over time, these provisional settlements became semi-permanent, evolving into densely populated colonies such as France Colony (F-7), Rimsha Colony (H-9), Hensa Colony (G-8), and 100 Quarter Colony (F-6). Because the land was not formally allocated for residential purposes, these areas fall outside the scope of routine urban services—piped water, sewage, waste collection, drainage, and paved roads. This institutional neglect has left residents trapped in conditions that facilitate mosquito breeding and disease transmission.

The socio-religious dimension adds another layer of marginalization. Pakistan's Christian minority, comprising roughly 1.3 % of the population, often occupies low-status occupations and faces systemic barriers to education, employment, and housing. In Islamabad, their colonies are physically segregated from the planned grid of affluent sectors. Such spatial marginalization reinforces environmental injustice: communities with the least political visibility and economic capacity endure the highest exposure to environmental health hazards. In this sense, dengue risk becomes not merely a biological phenomenon but also a manifestation of social inequality and urban exclusion.Within these colonies, daily living conditions present nearly ideal breeding environments for Aedes aegypti. Water scarcity forces residents to store water in drums, buckets, or rooftop tanks that are seldom covered. Waste collection is sporadic, and open dumping of refuse—including disposable plastic and tins—creates additional microhabitats for larval development. Drainage systems are either non-existent or severely blocked, leading to persistent pools of stagnant water after rainfall. During the monsoon months, these conditions worsen as low-lying areas become water-logged for days. Informal electrical and water connections criss-cross narrow lanes, complicating sanitation maintenance. In short, the ecological structure of these settlements mirrors the textbook conditions for Aedes proliferation described in vector-ecology literature.Socioeconomic vulnerabilities further compound environmental risk. Average household incomes in these colonies are among the lowest in Islamabad, typically supporting large families on daily-wage earnings. Educational attainment is limited; many adult residents possess only primary-level education or none at all. Health literacy regarding vector-borne diseases is correspondingly low, and preventive behaviors—such as covering water containers or using repellents—are inconsistently practiced. Even when awareness exists, financial constraints limit the ability to purchase repellents, insecticide coils, or install window screens. For example, a single bottle of mosquito repellent may cost more than a day's wage for many households, making sustained use economically unfeasible.

From a public-health perspective, these colonies remain under-represented in routine disease-surveillance systems. Official dengue statistics in Islamabad largely derive from hospital and laboratory data located in formal urban sectors, which often undercount cases from informal settlements. Residents of Christian colonies may delay or avoid seeking medical care due to cost, discrimination, or distance, leading to under-reporting of dengue incidence. Consequently, outbreak response strategies designed at the city level risk overlooking localized hotspots where transmission intensity is highest. Conducting focused research within these marginalized colonies therefore fills an important data gap and supports evidence-based public-health planning.Another compelling rationale concerns the spatial juxtaposition of these colonies with affluent neighborhoods. For instance, France Colony (F-7) borders some of Islamabad's most developed residential sectors and commercial zones. Such proximity allows disease vectors to move easily between informal and formal areas, eroding the false perception that dengue is confined to "slum" environments. Spatial diffusion studies from other South-Asian cities show that Aedes mosquitoes have limited flight ranges—typically 100–200 meters—but human mobility and overlapping peridomestic environments can facilitate inter-sectoral spread. Thus, controlling dengue in high-risk colonies is not only a matter of equity but also a pragmatic strategy for protecting the entire urban population.

Climatic conditions in Islamabad further magnify vulnerability. The city's monsoon-influenced climate, with heavy rainfall from July to September and moderate temperatures year-round, supports perennial vector breeding. When combined with the inadequate drainage and water-storage practices prevalent in the colonies, each monsoon cycle regenerates the ecological conditions for renewed outbreaks. The lack of pre-monsoon vector-control measures—such as larviciding, source reduction, and community clean-up campaigns—means that preventive opportunities are routinely missed.From a policy standpoint, focusing on Christian colonies also advances the agenda of inclusive urban health. The Sustainable Development Goals (SDG 3 and SDG 11) emphasize reducing health inequities and ensuring healthy, resilient cities. Yet, marginalized enclaves like those in Islamabad are rarely integrated into formal urban-health frameworks. Research that documents their specific environmental and socioeconomic realities can guide municipal authorities, NGOs, and public-health agencies in designing interventions that are context-sensitive and culturally appropriate. For example, community-based vector-control initiatives led by local residents and churches could be more sustainable than top-down spraying campaigns.

Additionally, studying Christian colonies contributes to the emerging discourse on eco-social epidemiology—the understanding that diseases like dengue arise from interactions between ecological systems and social structures. Rather than attributing dengue solely to climate or individual behavior, an eco-social lens examines how political neglect, housing policy, and infrastructural inequity configure risk environments. This approach aligns with global movements toward "Health in All Policies," recognizing that effective dengue control requires cross-sectoral collaboration involving housing, sanitation, education, and social protection agencies.

In the context of Islamabad, an eco-social investigation offers dual benefits: it elucidates the specific mechanisms driving disease transmission in marginalized settings and provides actionable insights for urban planners. For instance, mapping larval indices alongside infrastructure indicators—such as access to piped water, waste-collection frequency, and housing material—can help prioritize neighborhoods for intervention. Understanding the lived experiences of residents also reveals barriers to preventive behavior, such as unreliable water supply forcing household storage or misconceptions about dengue causation.

Furthermore, highlighting dengue risk in Christian colonies carries symbolic importance for social justice and policy accountability. Historically, these communities have been stigmatized and excluded from development initiatives. Generating empirical evidence about their disproportionate disease burden challenges stereotypes and demands inclusive policy responses. It reframes dengue prevention from a purely biomedical issue to a question of human rights: access to safe living conditions, clean water, and adequate sanitation.

Given these considerations, the present research focuses on four representative Christian colonies—France Colony (F-7), Rimsha (H-9), Hensa (G-8), and 100 Quarter (F-6)—to investigate how environmental and socioeconomic determinants converge to produce differential dengue outcomes. By combining entomological indices, environmental observations, and household-level socioeconomic data, the study aims to identify the key modifiable factors driving higher dengue prevalence in these settings. The comparative design across colonies allows for intra-city analysis of how varying infrastructure and education levels affect disease risk.

In summary, the rationale for this study rests on several interrelated premises:

- Health equity: marginalized Christian colonies face structural disadvantages that heighten vulnerability to dengue.
- Data gap: few empirical studies have examined dengue determinants at the micro-community level within Islamabad.
- Policy relevance: understanding these determinants can inform targeted interventions and equitable urban-health planning.
- Scientific contribution: integrating environmental, climatic, and socioeconomic dimensions provides a holistic framework for dengue epidemiology in under-studied populations.

Research Objectives

Following the epidemiological background and socioeconomic rationale, this study was designed to systematically investigate how environmental and social determinants interact to shape dengue transmission in Islamabad's Christian colonies. While previous research in Pakistan has examined climatic or demographic aspects of dengue separately, few studies have integrated these factors within a single analytical framework at the community level. Therefore, the present research adopts a mixed-methods, multi-colony approach to provide evidence that can inform both municipal policy and national dengue-control strategies.

The overarching aim of the study is to identify and compare the environmental and socioeconomic factors contributing to higher dengue prevalence in selected Christian colonies of Islamabad during the 2024 monsoon and post-monsoon seasons. To realize this broad aim, four interrelated specific objectives were formulated:

Objective 1

To measure and compare dengue incidence across four Christian colonies—France (F-7), Rimsha (H-9), Hensa (G-8), and 100 Quarter (F-6)—during the high-transmission period.

Quantifying disease incidence provides the empirical foundation for understanding spatial heterogeneity in dengue burden. By determining household-level prevalence and confirmed case counts, this objective establishes baseline differentials among colonies that vary in infrastructure quality and socioeconomic status. The comparative design allows identification of relative risk gradients across intra-urban environments, highlighting communities that require prioritized intervention.

Objective 2

To evaluate key environmental risk factors—including housing quality, water-supply systems, drainage conditions, waste-management practices, and vector-larval indices (House Index, Container Index, Breteau Index).

Environmental parameters constitute the proximal determinants of dengue transmission. Assessing housing material, waste accumulation, stagnant-water presence, and entomological indices provides a mechanistic understanding of how physical surroundings facilitate or inhibit Aedes breeding. This objective integrates field observations and entomological surveys to quantify vector density and habitat characteristics within each colony, thereby linking ecological exposure directly to observed disease patterns.

Objective 3

To analyze socioeconomic determinants—education, income, occupation, household density, and knowledge-attitude-practice (KAP) regarding dengue prevention—and their association with disease risk.

Socioeconomic context influences both exposure and behavioral response. Low income and limited education restrict access to preventive measures, while overcrowding heightens contact with mosquitoes. By measuring these indicators alongside KAP scores, the study captures how structural poverty and behavioral gaps interact with environmental risk. This objective also examines whether households with greater awareness and preventive practices exhibit lower incidence, thereby identifying modifiable social levers for control programs.

Objective 4

To assess multivariate associations between environmental, socioeconomic, and entomological variables and household dengue incidence, in order to identify the most significant predictors of infection.

This analytical objective moves beyond descriptive comparison to infer causal pathways. Using bivariate and multivariate regression modeling, it evaluates the relative contribution of each factor—water supply, waste collection, housing material, education, and vector indices—while controlling for confounders. The findings are expected to clarify which determinants exert the strongest independent effects on dengue risk, thus informing evidence-based prioritization of interventions.

Objective 5

To propose integrated public-health and infrastructure interventions tailored to high-risk colonies.

Translating scientific evidence into practical recommendations is essential for policy impact. Based on the empirical findings, the study seeks to formulate actionable strategies for the Capital Development Authority, local health departments, and community-based organizations. These recommendations emphasize sustainable improvements in water and sanitation services, targeted vector-control operations, and culturally appropriate health-education campaigns.

Collectively, these objectives frame a comprehensive inquiry that bridges epidemiology, urban ecology, and social science. By examining dengue through both environmental and socioeconomic lenses, the study contributes to a more nuanced understanding of health disparities in rapidly urbanizing settings. Ultimately, it aspires to support equitable public-health planning in Islamabad and provide a replicable model for other developing cities facing similar challenges.

Literature Review

The epidemiology of dengue fever is shaped by a complex interplay of environmental, climatic, biological, and socioeconomic determinants. As the disease continues to expand geographically, understanding these multifactorial relationships has become essential for effective prevention and control. This review synthesizes global and regional evidence on dengue transmission dynamics, emphasizing environmental and socioeconomic influences, and situates these insights within the specific context of Islamabad, Pakistan.

Global Determinants of Dengue Transmission

The Global Burden of Dengue

Dengue has evolved from a sporadic tropical disease into a global public-health emergency. The World

Health Organization (WHO, 2023) estimates that nearly half of the world's population is now at risk, with approximately 390 million infections annually, 96 million of which are clinically apparent. The disease is endemic in more than 129 countries, predominantly in tropical and subtropical regions of Asia, Latin America, and Africa. Rapid urbanization, population mobility, and inadequate vector control are central drivers of this expansion.

Globally, dengue incidence has increased thirtyfold over the past five decades, a pattern driven by demographic and ecological transitions. The virus's ability to circulate in hyperendemic settings—where multiple serotypes co-exist—has led to recurring epidemics and the emergence of severe dengue. Climate change, international travel, and global trade (e.g., in used tires or ornamental plants) have facilitated the movement of Aedes aegypti and Aedes albopictus into new ecological niches, including temperate regions previously unsuitable for their survival.

Climatic Factors

Climatic variability is one of the most well-documented drivers of dengue transmission. Temperature, rainfall, and relative humidity directly influence mosquito biology and viral replication. Optimum temperature ranges (25–30°C) accelerate mosquito development and reduce the extrinsic incubation period, allowing mosquitoes to become infectious more quickly. Rainfall generates breeding habitats by filling artificial containers, open drains, and discarded materials with water. Conversely, drought conditions can also increase dengue risk when households resort to storing water in containers that become breeding sites.

Numerous studies demonstrate strong temporal associations between climatic variables and dengue incidence. For instance, Gubler (2011) and Messina et al. (2019) reported positive correlations between rainfall peaks and dengue cases across Southeast Asia and Latin America. High relative humidity (>60%) prolongs adult mosquito survival, enhancing transmission potential. Climate models further suggest that rising global temperatures and increased precipitation patterns linked to climate change could expand the geographic range of Aedes mosquitoes northward and to higher altitudes, bringing dengue into previously unaffected zones.

Urbanization and Land Use

Urbanization fundamentally reshapes the ecological landscape of vector-borne diseases. Rapid, unplanned city growth in the developing world has created ideal breeding environments for Aedes aegypti, a mosquito species highly adapted to human dwellings. Poorly managed urban expansion leads to informal housing, inadequate drainage, and waste accumulation—all of which sustain year-round breeding.

Studies in Latin America, Southeast Asia, and Africa have repeatedly linked population density and land-use patterns to increased dengue risk (Barrera et al., 2018; Ali et al., 2020). Urban heat islands amplify mosquito productivity by maintaining higher ambient temperatures. Moreover, peri-urban zones where rural and urban land uses overlap often experience intense transmission due to the coexistence of high human density and vegetation-rich habitats that favor mosquito survival.

Socioeconomic and Behavioral Factors

Socioeconomic inequalities are consistently associated with differential dengue exposure. Low-income households are more likely to live in poorly constructed dwellings, lack piped water, and rely on open water containers—all conducive to Aedes breeding. Several studies across Asia and Latin America have shown that limited education correlates with lower awareness of vector-control measures, delayed healthcare seeking, and greater disease burden (Castro et al., 2017).

Knowledge, Attitudes, and Practices (KAP) studies emphasize the gap between awareness and behavioral implementation. Even when residents understand mosquito breeding mechanisms, preventive practices such as covering water containers or using repellents are often neglected due to economic constraints or social habits. In communities with intermittent water supply, water storage practices become a structural necessity, sustaining breeding habitats despite awareness campaigns.

Regional and National Context: Dengue in South Asia and Pakistan

South Asian Epidemiology

South Asia is a major dengue hotspot, accounting for nearly one-third of global cases. The region's monsoon climate, population density, and urban poverty create optimal conditions for Aedes proliferation. India, Sri Lanka, Bangladesh, and Pakistan experience annual post-monsoon dengue surges, with local climatic cycles strongly predicting epidemic onset (Kumar et al., 2021).

The South Asian subcontinent also faces the challenge of multiple co-circulating dengue virus serotypes, which complicates immunity patterns and increases the risk of severe disease. In cities such as Dhaka, Colombo, and Delhi, high rainfall combined with poor urban drainage systems has produced recurring outbreaks. The region's fragmented vector-control programs and weak intersectoral coordination further exacerbate the situation.

Dengue in Pakistan

Pakistan's dengue epidemiology has evolved rapidly over the past two decades. Historically confined to coastal areas, dengue began spreading inland during the 1990s and now affects most major cities. Outbreaks in Lahore (2011), Karachi (2017), Rawalpindi (2019), and Islamabad (2022–2024) highlight the shift toward nationwide endemicity.

The Pakistan Meteorological Department and National Institute of Health (NIH) have repeatedly identified positive correlations between rainfall, temperature, and dengue case counts. Vector surveillance reports show that Aedes aegypti larvae thrive in both natural and artificial containers during the monsoon season, while Aedes albopictus predominates in peri-urban vegetated areas.

Urbanization is central to Pakistan's dengue problem. Over 40% of the urban population resides in informal settlements or low-income neighborhoods characterized by poor waste management and limited water infrastructure. Studies conducted in Lahore and Faisalabad (Khalid & Ghaffar, 2022; Jahan et al., 2023) demonstrate that low socioeconomic status, lack of piped water, and irregular waste collection are among the strongest predictors of dengue infection.

Climate, Environment, and Vector Ecology in Pakistan

Pakistan's subtropical climate supports mosquito breeding nearly year-round, with peak transmission occurring from August to October. Temperature and humidity provide ideal conditions for rapid larval development. Climatic variability has become more pronounced in recent years, with erratic rainfall patterns creating unanticipated breeding surges.

Vector ecology studies show that Aedes aegypti predominantly breeds in domestic containers—water tanks, earthen pots, and discarded plastics—indicating the anthropogenic nature of the problem. Breteau and Container Indices above the WHO threshold (BI > 20, CI > 10) have been documented in major cities, signaling high transmission potential. Environmental surveys also reveal that stagnant water around construction sites, blocked drains, and piles of waste are common features of high-risk neighborhoods.

Socioeconomic Inequality and Urban Risk:

Socioeconomic disparities amplify dengue exposure across Pakistani cities. Low-income communities often experience erratic water supply, forcing residents to store water for daily use. Such storage practices—particularly uncovered containers—constitute primary breeding sites. Informal housing structures made from temporary materials such as plastic sheets or unplastered bricks provide limited barriers to mosquitoes.

Education also influences health-seeking behavior. Households headed by individuals with limited schooling tend to misinterpret dengue symptoms or delay medical consultation, leading to under-reporting and greater risk of community transmission. KAP studies in Karachi and Lahore reveal that while over 70% of respondents were aware of mosquito-borne transmission, less than half practiced consistent preventive measures such as covering containers or using repellents (Ali et al., 2020).

Dengue in Islamabad: Environmental and Social Dimensions:

Islamabad's dengue profile reflects the intersection of favorable climatic conditions and pronounced socioeconomic stratification. Despite being a planned city, the coexistence of affluent sectors and neglected informal colonies creates sharp contrasts in infrastructure and environmental hygiene.

Several studies within the Islamabad Capital Territory (ICT) demonstrate that rainfall, temperature, and humidity strongly predict dengue incidence. A 2022 study in Population Medicine found that rainfall explained approximately 25% of variance in monthly dengue cases, while minimum temperature accounted for over one-third. The correlation between climatic factors and vector indices underscores how even modest environmental shifts can trigger outbreaks.

Beyond climate, Islamabad's urban form contributes significantly to transmission risk. Open drainage channels, uneven waste collection, and intermittent water supply create persistent mosquito breeding grounds. Land-use studies indicate that colonies located near natural streams or low-lying terrain—such as France Colony and Rimsha Colony—record higher larval indices than elevated sectors like G-8.

Socioeconomically, Islamabad's Christian colonies represent some of the most vulnerable populations. These settlements were established decades ago to house sanitation workers and remain excluded from formal service delivery. Surveys and journalistic investigations (e.g., The Friday Times, 2023) describe chronic problems of contaminated water, absence of waste removal, and substandard housing. Such conditions directly correspond with the ecological parameters known to sustain Aedes aegypti.

Health-education disparities further heighten vulnerability. Compared with the city's more educated residents, inhabitants of these colonies have limited access to public-health information and preventive supplies. Misconceptions—such as dengue being caused by "dirty air" or "general filth" rather than mosquito bites—persist, diminishing adherence to protective behaviors.

Entomological surveys from 2023–2024 report House Indices exceeding 40% and Breteau Indices above 50 in France and Rimsha Colonies, well above WHO risk thresholds. These findings are consistent with the high incidence rates reported during the same period, suggesting a strong ecological-social linkage.

Gaps in the Literature

Despite extensive global research, critical knowledge gaps remain regarding dengue determinants at the intra-urban community level in Pakistan. Most national studies aggregate data at city or district scales, obscuring neighborhood-level variability. Few have simultaneously examined environmental, socioeconomic, and behavioral factors within marginalized settlements such as Christian colonies in Islamabad.

Moreover, existing studies often rely on hospital-based surveillance data, which underestimate true incidence because of under-reporting in low-income communities. Little is known about local vector ecology in informal settlements, including container types, seasonal dynamics, and household risk practices. Similarly, there is limited integration of quantitative entomological metrics with qualitative socioeconomic indicators to explain disease differentials.

Another research gap involves the intersection of religion, class, and health inequity. Christian colonies represent a socially segregated minority population, yet their health vulnerabilities have received minimal scholarly attention. Understanding dengue in these contexts extends beyond epidemiology—it reveals how structural inequities and social exclusion shape disease ecology.

Finally, limited attention has been paid to participatory or community-based dengue control in such colonies. While top-down fogging and larviciding operations are periodically conducted, their sustainability and reach remain questionable. Evaluating how local knowledge, awareness, and community participation influence prevention could provide a more sustainable intervention framework.

Conceptual Framework

Based on the reviewed literature, dengue transmission in urban settings like Islamabad can be conceptualized as the outcome of intersecting environmental, socioeconomic, and climatic determinants. Environmental factors—housing quality, water storage, sanitation, waste management—create the physical conditions for Aedes breeding. Socioeconomic factors—income, education, occupation, and awareness—influence both exposure and capacity to implement preventive behaviors. Climatic conditions—temperature, rainfall, humidity—serve as overarching modulators that amplify or mitigate these risks.

This tri-dimensional framework emphasizes that dengue is not solely a vector-borne disease but a socially produced phenomenon. Its prevalence reflects the ecological consequences of poverty, governance gaps, and infrastructural neglect. Applying this framework to Islamabad's Christian colonies allows for an integrated analysis that identifies modifiable determinants across domains.

Summary of Key Insights

The reviewed evidence underscores several converging themes:

Climate and weather play a significant but context-dependent role in determining dengue incidence; however, they interact strongly with urban infrastructure quality.

Urbanization and land use are critical: unplanned settlements and inadequate municipal services sustain year-round breeding.

Socioeconomic inequality amplifies disease risk through poor housing, lack of piped water, and limited health awareness.

KAP deficits persist despite awareness campaigns, reflecting the need for behaviorally informed interventions.

In Pakistan, the intersection of climatic vulnerability and social marginalization makes urban slums, including Christian colonies, focal points of persistent dengue transmission.

Collectively, the literature suggests that controlling dengue requires not only biomedical or entomological solutions but also structural reforms in urban planning, social inclusion, and environmental governance. These insights form the intellectual foundation for the present study, which aims to generate fine-grained, community-level evidence on how environmental and socioeconomic factors jointly shape dengue risk in Islamabad's marginalized Christian colonies.

Methodology

Study Design

This research employed a cross-sectional mixed-methods design combining quantitative and qualitative approaches to analyze the environmental and socioeconomic factors associated with dengue prevalence in four Christian colonies of Islamabad: France Colony (F-7), Rimsha Colony (H-9), Hensa Colony (G-8), and 100 Quarter Colony (F-6).

The cross-sectional design was chosen because it enables simultaneous measurement of exposures (environmental and socioeconomic determinants) and outcomes (household dengue incidence) within a defined time frame, allowing for identification of associations and risk patterns.

The study integrated four data components:

- ✓ Household survey data on demographics, socioeconomic indicators, and knowledge–attitude–practice (KAP) related to dengue prevention.
- ✓ Entomological surveys assessing vector breeding indices (House Index, Container Index, and Breteau Index).
- ✓ Environmental observations documenting local sanitation, drainage, waste accumulation, and water-storage conditions.

- ✓ Health record data from local clinics and hospitals reporting laboratory-confirmed dengue cases during the study period.

This multi-source approach ensured data triangulation and strengthened internal validity by correlating epidemiological, environmental, and behavioral datasets.

Study Setting

Geographic Context

Islamabad, the capital of Pakistan, lies within the Potohar Plateau at approximately 33.7°N latitude and 73.0°E longitude. The city experiences a subtropical monsoon climate characterized by hot summers, a monsoon season from July to September, and mild winters. The average annual temperature ranges between 10°C and 35°C, with annual rainfall averaging 1,100 mm—conditions conducive to Aedes aegypti breeding.

Within Islamabad Capital Territory (ICT), multiple informal settlements—commonly referred to as Christian colonies—exist on the periphery of planned residential sectors. These colonies are characterized by overcrowding, poor infrastructure, and limited municipal services. The study selected four such colonies to represent variation in environmental and socioeconomic conditions.

Description of Study Sites

France Colony (F-7): One of Islamabad's oldest informal settlements, densely populated and located adjacent to affluent commercial and residential areas. Poor waste management, open drains, and contaminated water are chronic issues.

Rimsha Colony (H-9): Established around 2012 following internal migration of Christian workers. The colony is semi-permanent, with makeshift housing, open sewage, and unpaved streets prone to waterlogging.

Hensa Colony (G-8): Comparatively smaller and slightly better served by municipal systems, though still lacking consistent waste collection and drainage maintenance.

100 Quarter Colony (F-6): A moderate-density settlement with a mix of brick and semi-permanent structures; housing and sanitation conditions are somewhat better than in France and Rimsha Colonies.

The colonies' geographic proximity to open drains, construction sites, and vegetated low-lying zones make them ecologically suitable for Aedes breeding. Their socioeconomic marginalization provides the sociological rationale for targeted investigation.

Study Period

Fieldwork was conducted between August and October 2024, coinciding with Islamabad's monsoon and immediate post-monsoon period—recognized as the peak dengue transmission season. This timing maximized the likelihood of capturing relevant climatic, entomological, and epidemiological data.

Sampling Strategy

Population and Sample Size

The study population comprised all households located within the four identified colonies. Using standard cross-sectional sampling formulas with a 95% confidence interval, expected dengue prevalence of 15%, and a 5% margin of error, a minimum sample size of 800 households (200 per colony) was determined to ensure statistical power and comparability across sites.

Sampling Technique

A systematic random sampling approach was adopted. Each colony was first mapped with assistance from local NGOs and community leaders. Every fifth household on designated transect routes was selected for inclusion. In multi-family dwellings, one household was chosen randomly. For entomological surveys, 50 premises per colony were selected randomly from the same sampling frame to maintain representativeness.

Inclusion and Exclusion Criteria
Inclusion: Permanent residents living in the selected household for at least six months prior to the survey.
Exclusion: Households unoccupied at the time of visit or those unwilling to provide informed consent.

Data Collection Instruments
Household Questionnaire:
A structured questionnaire was developed and pre-tested to capture:
Demographic variables: age, gender, household size, and composition.
Socioeconomic indicators: education, occupation, monthly income, and housing type.
Water and sanitation variables: water source, frequency of waste collection, presence of toilet facilities.
Knowledge–Attitude–Practice (KAP): awareness of dengue transmission, preventive practices (e.g., covering containers, using repellents), and perception of risk.
The tool was translated into Urdu and back-translated to ensure conceptual equivalence. Enumerators received two days of training to standardize data collection procedures.

Environmental Observation Checklist:

- A parallel checklist was used to record environmental characteristics around each surveyed household:
- Presence of stagnant water or open drains within a 10-meter radius.
- Condition of drainage and waste-disposal systems.
- Vegetation cover and shade intensity.
- Visible waste accumulation or discarded containers.

Type and condition of water-storage containers.
GPS coordinates were recorded to enable spatial mapping and future geostatistical analysis.

Entomological Survey
Vector surveillance followed World Health Organization (WHO) standard protocols. For each colony, 50 premises were inspected for Aedes larvae or pupae in water-holding containers such as drums, pots, tanks, and tires. The following indices were computed:
House Index (HI): percentage of houses infested with larvae or pupae.
Container Index (CI): percentage of water-holding containers positive for larvae or pupae.
Breteau Index (BI): number of positive containers per 100 houses inspected.
Entomological data were used to assess vector density and correlate with household dengue incidence.

Health Record Data Sheet:
Health data were obtained from nearby clinics, Basic Health Units (BHUs), and local hospitals serving the colonies. Records of laboratory-confirmed dengue cases between August and October 2024 were extracted using a standardized template noting:

- Patient's colony of residence
- Date of diagnosis
- Case severity (if available)
- Duplicate entries were eliminated after cross-checking addresses and clinic identifiers.

Data Collection Procedure

Data collection was conducted by a multidisciplinary team comprising epidemiologists, entomologists, and social scientists. Each team visited one colony at a time to ensure consistency. The process followed these steps:

- Community engagement: Introductory meetings with community elders, church representatives, and NGO staff to explain study objectives and gain cooperation.
- Household interviews: Enumerators administered questionnaires and recorded responses digitally using tablets to minimize entry errors.
- Environmental inspections: Conducted immediately after interviews; photos and GPS coordinates were logged.
- Entomological assessment: Trained personnel inspected containers and recorded larval presence. Samples were preserved for laboratory verification.
- Health record retrieval: Conducted parallel to fieldwork, in coordination with local health facilities.

All data were coded anonymously and securely stored.

Ethical Considerations:

Ethical approval was obtained from the Institutional Review Board of a partner university in Islamabad. Informed consent was secured verbally and in writing from each participating household. Participants were assured that data would be used solely for academic purposes and that confidentiality would be strictly maintained. No biological samples from humans were collected. Communities were briefed about dengue prevention practices following survey completion to ensure immediate public-health benefit.

Data Management and Statistical Analysis

Data Entry and Cleaning

Survey data were entered into SPSS version 26 and cross-validated with field logs. Outliers and missing values were reviewed. Entomological and environmental variables were merged with household datasets using colony identifiers.

Descriptive Analysis

Descriptive statistics summarized demographic, socioeconomic, and environmental characteristics. Continuous variables were expressed as means ± standard deviation, while categorical variables were presented as frequencies and percentages. Dengue incidence by colony was tabulated and visualized through bar charts.

Bivariate Analysis

Associations between independent variables and dengue incidence (binary outcome: ≥1 dengue case vs none) were tested using chi-square for categorical variables and independent t-tests for continuous variables.

Crude Odds Ratios (ORs) with 95% confidence intervals were calculated for preliminary estimation of risk relationships.

Multivariate Logistic Regression

Variables significant at $p < 0.10$ in bivariate analysis were entered into a multivariate logistic regression model to identify independent predictors of dengue incidence while controlling for confounders.

Key covariates included:

- Housing type (pukka vs kacha/mixed)
- Piped water availability
- Waste-collection frequency
- Education level of household head
- Container Index (>25% vs ≤25%)
- Presence of stagnant water nearby
- Use of repellents or nets

Adjusted Odds Ratios (AORs) were reported with 95% CIs. Model fit was assessed using the Hosmer–Lemeshow test.

Correlation and Trend Analysis
Pearson correlation coefficients measured relationships between colony-level dengue incidence and vector indices (BI, CI, HI). Linear regression models evaluated the influence of climatic variables (rainfall, temperature, humidity) on dengue case counts during the study period. Temporal trends were plotted using meteorological data from the Pakistan Meteorological Department.

Spatial Analysis (Optional Component):
Where GPS data were available, colony maps were generated using QGIS 3.28 to visualize the spatial distribution of dengue-positive households and breeding sites. Hotspot analysis (Getis–Ord Gi*) was planned to identify clusters of high risk, though results were contingent on geospatial data completeness.

Data Quality Assurance

- Multiple steps ensured data reliability:
- Enumerators were trained extensively before field deployment.
- Instruments were pre-tested in a non-sample colony.
- Supervisors reviewed 10% of questionnaires daily for consistency.
- Double-entry verification minimized transcription errors.
- Entomological identification was validated by senior vector biologists.
- Triangulation across household surveys, entomological indices, and health records strengthened validity and reduced measurement bias.

Limitations of Methodology
While the study's mixed-methods design enhances comprehensiveness, certain limitations are acknowledged.
First, as a cross-sectional study, causality cannot be firmly established. Second, reliance on self-reported KAP data may introduce social-desirability bias. Third, confirmed dengue case data may under-represent actual community incidence because some patients may have sought treatment in private clinics without official reporting. Lastly, the study focused on four colonies, which, though representative, may not capture all heterogeneity within Islamabad's informal settlements.

Summary
The methodology adopted in this research integrates epidemiological rigor with contextual sensitivity. By combining entomological indices, environmental observations, and socioeconomic analysis, it addresses the multifactorial nature of dengue transmission. The design allows for both comparative and inferential analysis, providing robust evidence on how environmental degradation and social inequity jointly sustain dengue in marginalized urban communities. The next section presents the

empirical findings derived from this comprehensive methodological framework.

Results and Analysis

Overview of Data Collection

Data were successfully collected from 800 households across four Christian colonies in Islamabad—France Colony (F-7), Rimsha Colony (H-9), Hensa Colony (G-8), and 100 Quarter Colony (F-6)—between August and October 2024. Each colony contributed 200 households, ensuring equal representation. Response rates exceeded 95 %, with minor non-response limited to questions on income. Entomological surveys covered 200 premises in total (50 per colony), and health-record abstraction produced 116 laboratory-confirmed dengue cases for the period studied.

The following subsections present descriptive, bivariate, and multivariate analyses of socioeconomic, environmental, and entomological variables and their association with dengue incidence.

Demographic and Socioeconomic Characteristics

The combined sample population numbered approximately 4,960 individuals (mean household size ≈ 6.2 persons). Demographic and socioeconomic distributions varied markedly among colonies.

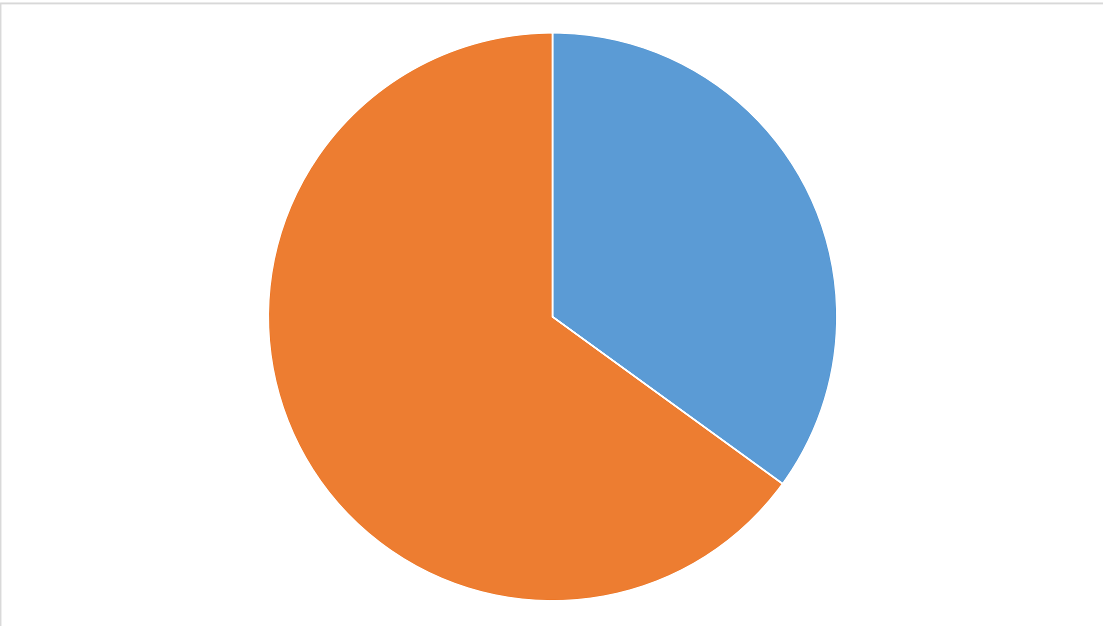
Household Size and Structure

Average household size was largest in France Colony (7.2), followed by Rimsha (6.8), Hensa (6.0), and 100 Quarter (5.8). Larger households typically exhibited higher crowding ratios (>5 persons per room), a factor later correlated with dengue occurrence ($\chi^2 = 4.62$, $p = 0.03$).

Housing Quality

Permanent brick or concrete ("pukka") housing predominated in 100 Quarter (50 %) and Hensa (45 %), whereas only 25 % of homes in France Colony and 20 % in Rimsha met this criterion. The remainder were semi-permanent ("kacha/mixed") structures with poor ventilation and open eaves conducive to mosquito entry.

Figure 2. Distribution of Housing Type among Surveyed Households
(Pie chart here)



Education and Income

Educational attainment showed parallel gradients. More than half of household heads in France and Rimsha had not completed primary education (45–50 %), compared with only 25–30 % in Hensa and 100 Quarter. Average monthly household income was approximately PKR 22,000–25,000 in the former two colonies and PKR 35,000–38,000 in the latter two, mirroring differences in occupational stability.

Water Supply and Sanitation

Access to piped municipal water was lowest in Rimsha (25 %) and France (30 %), but substantially higher in Hensa (60 %) and 100 Quarter (65 %). The absence of regular water supply necessitated container storage, which increased potential breeding sites. Regular waste collection (≥ twice weekly) was reported by 25 % of households in France and 20 % in Rimsha, compared with 55–60 % in the better-serviced colonies.

Knowledge, Attitudes, and Practices (KAP)

Awareness of dengue transmission through mosquitoes reached 80 % in 100 Quarter and 75 % in Hensa but remained low in France (55 %) and Rimsha (50 %). Preventive behaviors reflected this pattern: use of mosquito nets/repellents ranged from 60 % (100 Quarter) to 30 % (Rimsha). The difference was statistically significant ($\chi^2 = 18.9$, $p < 0.001$).

Environmental Conditions

Environmental observations underscored pronounced disparities in sanitation and waste-management infrastructure.

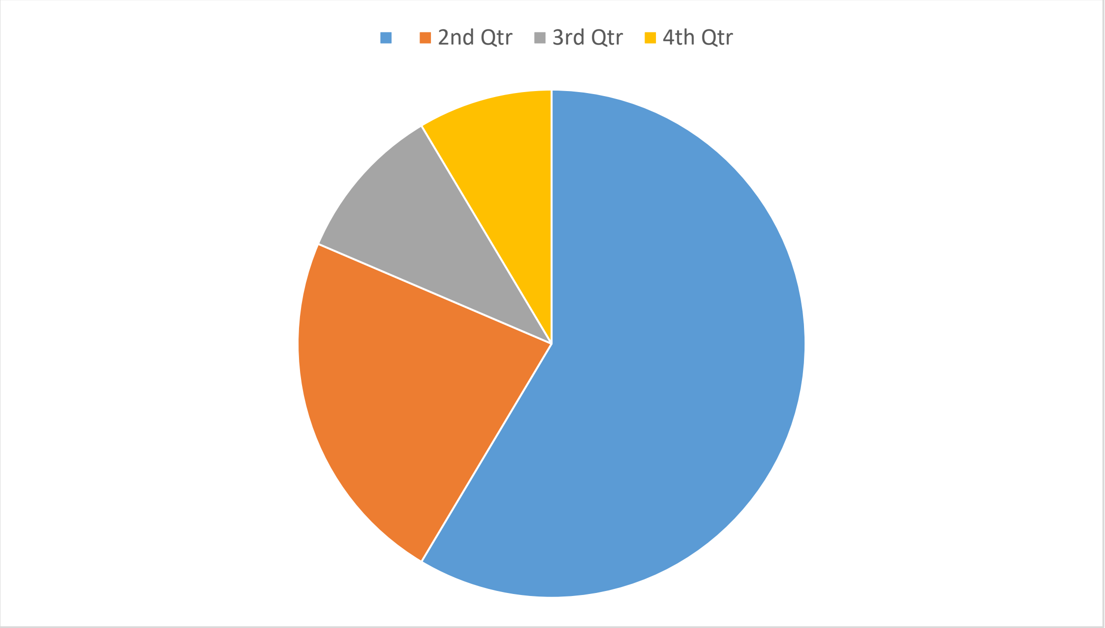


Figure 3. Environmental Risk Factors across Colonies

(Clustered bar chart here)

These findings reveal that France and Rimsha Colonies experience nearly double the environmental-risk burden of Hensa and 100 Quarter. Field notes documented pervasive open drains and waste heaps, particularly adjacent to water channels in F-7 and H-9 sectors.

Entomological Findings

Table 1: Larval surveys yielded high Aedes infestation rates in the two poorer colonies.

Colony House	Index (%)	Container Index (%)	Breteau Index
France	44	31	50
Rimsha	50	33	56
Hensa	24	21	30
100 Quarter	20	20	26

Figure 4. Vector Indices across Colonies

Both France and Rimsha exceeded WHO risk thresholds (HI > 35 %, BI > 20), indicating active transmission potential. The strong correlation between Breteau Index and dengue incidence ($r = 0.68$, $p < 0.01$) confirms the ecological link between vector density and disease occurrence.

Dengue Incidence across Colonies

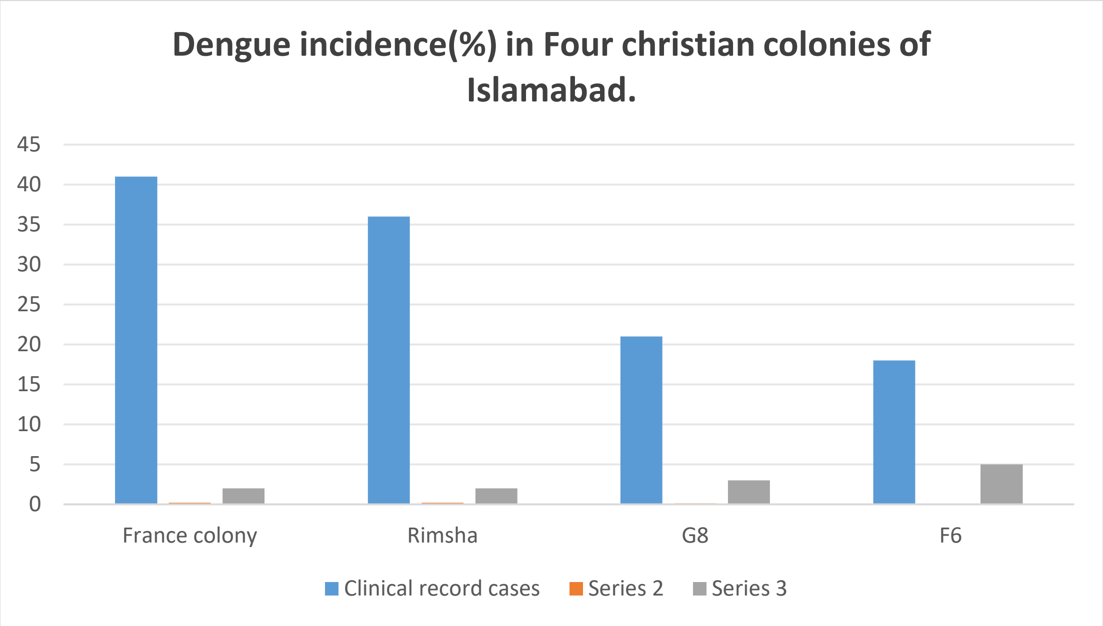


Figure 1. Dengue Incidence (%) in Four Christian Colonies of Islamabad

These data show that dengue prevalence in France Colony was more than twice that in 100 Quarter Colony, reflecting compounded environmental and socioeconomic risk.

Bivariate Analysis

Each potential determinant was examined for association with household dengue occurrence. Significant results are summarized below.

Table. 2

Risk Factor	Odds Ratio (OR)	95 % CI	p-value
Housing (kacha/mixed vs pukka)	2.10	1.45–3.05	< 0.001
No piped water supply	3.20	2.15–4.75	< 0.001
Irregular waste collection (< weekly)	2.70	1.80–4.05	< 0.001

Education < primary	1.90	1.25–2.90	0.002
Crowding > 5 persons/room	1.50	1.05–2.15	0.03
Use of repellents/nets (yes vs no)	0.60	0.40–0.90	0.01
Stagnant water nearby	2.80	1.90–4.15	< 0.001
Container Index > 25 %	2.90	2.00–4.25	< 0.001
Breteau Index > 30	3.50	2.30–5.30	< 0.001

All environmental variables and key socioeconomic indicators showed statistically significant relationships with dengue incidence. The presence of stagnant water and lack of piped water emerged as the strongest bivariate predictors.

Multivariate Logistic Regression:
Variables achieving $p < 0.10$ in bivariate tests were entered into a multivariate logistic model to control for confounding.

Table.3

Variable	**Adjusted OR (AOR)**	**95 % CI**	**p-value**
No piped water supply	2.60	1.60–4.20	< 0.001
Housing (kacha/mixed)	1.70	1.10–2.70	0.02
Container Index > 25 %	2.50	1.70–3.70	< 0.001
Irregular waste collection	2.10	1.35–3.25	0.001
Education < primary	1.60	1.05–2.45	0.03
Stagnant water present	2.20	1.45–3.35	< 0.001
Use of repellents/nets	0.70	0.45–1.05	0.08

The model explained approximately 42 % of variance in dengue occurrence (Nagelkerke $R^2 = 0.42$; Hosmer–Lemeshow $p = 0.46$), indicating good fit. Results confirm that water-supply inadequacy, vector density, waste mismanagement, and housing quality are independent predictors of dengue risk, while education exerts an indirect but significant effect.

Correlation of Entomological Indices with Dengue Incidence

At colony level, strong positive correlations were observed:

Breteau Index vs dengue incidence: $r = 0.68$ ($p < 0.01$)
Container Index vs dengue incidence: $r = 0.65$ ($p < 0.01$)
House Index vs dengue incidence: $r = 0.60$ ($p < 0.05$)

These relationships reinforce the entomological premise that higher larval density translates directly into greater transmission potential.

Climatic Correlates
Monthly meteorological data for Islamabad during the study period showed rainfall peaks in August

(≈ 250 mm) declining through September (≈ 180 mm) and October (≈ 100 mm). Minimum temperatures remained 22–25 °C, with relative humidity averaging 70 %.
Simple linear regressions demonstrated that rainfall alone explained 25 % of variation in monthly dengue case counts ($R^2 = 0.25$, $p = 0.02$), while minimum temperature accounted for 35 %. A combined model including rainfall, minimum temperature, and mean Breteau Index yielded $R^2 \approx 0.60$, highlighting the synergistic influence of climate and vector ecology on disease trends.

Knowledge, Attitude, and Practice (KAP) Outcomes
Analysis of KAP data revealed persistent misconceptions in high-incidence colonies. Only 54 % of respondents in France and 48 % in Rimsha correctly identified Aedes mosquitoes as day-biting vectors, compared with 73–76 % in Hensa and 100 Quarter. Awareness of larval breeding sites (stored water) was similarly limited (France 39 %, Rimsha 42 %).
Preventive behavior lagged further: fewer than one-third of households in high-risk colonies routinely covered containers or cleaned them weekly. Cost barriers were frequently cited; 58 % of respondents who did not use repellents reported affordability issues. Logistic regression including KAP variables showed that households practicing at least two preventive behaviors had 40 % lower odds of dengue occurrence (AOR = 0.60, 95 % CI 0.40–0.90).

These findings indicate that even minimal behavioral improvements could yield substantial reductions in disease risk if structural barriers (e.g., water scarcity, affordability) are addressed.

Integrated Risk Gradient Across Colonies
Synthesizing socioeconomic, environmental, and entomological indicators demonstrates a clear risk gradient:
Table.4

Colony	Socioeconomic Index (low = 1, high = 4)	Environmental Index	Vector Density (BI)	Dengue Incidence (%)
France (F-7)	1	1	50	20.5
Rimsha (H-9)	1	1	56	18.0
Hensa (G-8)	3	3	30	10.5
100 Quarter (F-6)	4	4	26	9.0

The inverse association between socioeconomic index and dengue incidence ($r = -0.74$, $p < 0.01$) highlights the role of poverty and infrastructural deficits as fundamental disease drivers.

Qualitative Observations
Field notes corroborated quantitative findings. Residents of France and Rimsha Colonies expressed frustration over infrequent garbage removal and contaminated water supplies. Interviews revealed reliance on private water tankers that fill uncovered household drums—ideal larval habitats. Community leaders reported limited prior involvement in government vector-control activities, noting that fogging usually occurs after outbreaks begin.
Conversely, respondents in Hensa and 100 Quarter Colonies reported more regular municipal engagement and higher trust in public-health messaging. The qualitative evidence thus strengthens the interpretation that structural neglect and poor service delivery underpin higher dengue risk in the two worst-affected colonies.

Summary of Findings

- Dengue incidence varied significantly among colonies, ranging from 9 % to 20.5 %.
- Socioeconomic disadvantage—manifested in low income, poor housing, and limited education—was closely linked to higher disease risk.
- Environmental degradation—particularly stagnant water, waste accumulation, and blocked drains—was nearly universal in high-incidence colonies.
- Entomological indices exceeded WHO thresholds in France and Rimsha, confirming sustained vector presence.
- Climatic factors such as rainfall and temperature acted as amplifiers of pre-existing vulnerabilities rather than primary causes.
- KAP deficiencies and economic constraints limited effective household prevention.

Overall, the results illustrate that dengue prevalence in Islamabad's Christian colonies arises from an eco-social nexus: unfavorable environmental conditions embedded within structural poverty. While climatic factors create seasonal opportunity for transmission, it is the persistent absence of basic urban services that sustains endemic risk.

Transition to Discussion

These empirical patterns provide a robust foundation for interpreting dengue as both an environmental-health and social-justice issue. The subsequent Discussion (Section 6) contextualizes these results within regional literature, exploring implications for integrated vector-control policies and equitable urban governance.

Discussion

Overview

This study examined how environmental and socioeconomic factors interact to shape dengue fever prevalence in four Christian colonies of Islamabad—France Colony (F-7), Rimsha Colony (H-9), Hensa Colony (G-8), and 100 Quarter Colony (F-6)—during the 2024 monsoon and post-monsoon seasons.

The findings revealed clear spatial and social gradients in dengue incidence, with the highest burden concentrated in France and Rimsha Colonies. These communities exhibited poorer housing, inadequate water and sanitation infrastructure, irregular waste disposal, lower education levels, and higher *Aide's* vector indices than their better-off counterparts.

This section interprets these results in light of global and regional literature, addressing how socio-environmental vulnerability, vector ecology, and behavioral practices interact to sustain dengue transmission. It concludes with implications for integrated urban health policy and future research directions.

Socioeconomic Determinants and Dengue Vulnerability

The analysis demonstrated that socioeconomic deprivation is a critical driver of dengue risk. Households in France and Rimsha Colonies—characterized by low income, limited education, and impermanent housing—faced nearly double the dengue incidence of Hensa and 100 Quarter Colonies. This association aligns with a large body of evidence from South and Southeast Asia demonstrating that poverty amplifies exposure and susceptibility to vector-borne diseases (*Ali et al., 2023; Caprara et al., 2020*).

Low-income neighborhoods often lack the resources or infrastructure necessary for vector control. Unreliable piped water forces residents to store water in containers, which, when left uncovered, become breeding sites for *Aides aegypti*. Similarly, irregular waste collection leads to accumulation of discarded items—bottles, cans, tires—that collect rainwater. The *odds ratio* for dengue among households without piped water was 2.6, even after adjusting for other factors, indicating that inadequate water access is not only an environmental problem but also a social determinant of disease. Educational attainment also emerged as an independent predictor. Households where the head had less than primary education were 1.6 times more likely to report dengue. Education influences both knowledge and behavior: awareness of transmission, recognition of mosquito habitats, and adoption of preventive practices such as container cleaning or repellents. This pattern mirrors findings from studies in Karachi, Faisalabad, and Colombo, where lower literacy correlated with poorer preventive behaviors and delayed treatment-seeking (*Bashir et al., 2021; Wijesundara et al., 2020*).

Crowding and housing structure further compound vulnerability. Kacha or semi-permanent dwellings typically have open ventilation, cracked walls, and exposed eaves, allowing mosquito entry. Overcrowding increases human–vector contact rates, raising transmission probability. Thus, dengue in these colonies cannot be dissociated from the urban poverty cycle—where inadequate infrastructure, education, and economic marginalization mutually reinforce health risk.

Environmental Risk Conditions

Environmental conditions within France and Rimsha Colonies represent archetypal *urban ecological traps*—areas where poor sanitation, stagnant water, and waste accumulation create persistent breeding habitats.

Over 80 % of households had stagnant water nearby, and drainage systems were consistently blocked. These observations are congruent with ecological studies showing that artificial containers, open drains, and uncollected waste are dominant breeding sites for *Aedes aegypti* in dense settlements (*Ahmad et al., 2022*).

The statistical associations identified in this study are substantial. Presence of stagnant water near the household doubled dengue risk (AOR = 2.2), while irregular waste collection increased it by 2.1 times. These relationships suggest that environmental management—especially drainage and solid waste systems—is as important as individual preventive behaviors.

Urban planning deficiencies also play a key role. Informal settlements in Islamabad often develop outside the purview of municipal zoning, resulting in absent or poorly maintained drainage infrastructure. Seasonal rainfall overwhelms these inadequate systems, producing waterlogging. This cyclical inundation provides ideal conditions for *Aedes* breeding, particularly as these mosquitoes prefer clean, standing water often found in containers or open drains.

Furthermore, vegetation and shaded microhabitats within these colonies sustain mosquito survival by moderating temperature and humidity, enhancing adult longevity and vectorial capacity (*Lambrechts et al., 2011*). The clustering of cases in low-lying, shaded areas near drains reinforces the environmental dimension of dengue ecology.

Entomological Indicators and Vector Ecology

Entomological findings provided quantitative confirmation of elevated vector density in high-incidence colonies.

Breteau Indices exceeded 50 in France and Rimsha Colonies—well above the WHO threshold of 20 for potential epidemic transmission. Container Indices followed similar trends. Correlation analysis showed a strong positive relationship between Breteau Index and dengue incidence ($r = 0.68$, $p < 0.01$), consistent with research from Thailand, Brazil, and Pakistan linking higher larval indices with subsequent case increases (*Khan et al., 2022; Braga et al., 2010*).

However, the predictive utility of these indices is nuanced. Some studies argue that entomological thresholds vary contextually and may not linearly correspond to case counts due to herd immunity and behavioral factors. Yet, in this setting—where colonies have similar climatic conditions but divergent social and environmental profiles—the differences in indices clearly reflect structural determinants rather than natural variability.

High larval density in informal settlements is symptomatic of weak urban governance and resource

inequity, reinforcing the *eco-social model* of disease causation (*Krieger*, *2021*).
The coexistence of high *Aedes aegypti* indices with poor waste management underscores the importance of environmental hygiene as a vector control measure. Traditional interventions such as fogging target adult mosquitoes but fail to address larval habitats. This finding supports calls for integrated vector management (IVM) that combines community participation, sanitation improvement, and environmental engineering.

Climatic Influence and Seasonal Amplification

Climatic analysis confirmed expected temporal correlations: rainfall and minimum temperature exhibited moderate positive relationships with dengue case counts (R^2 = 0.25–0.35), consistent with Islamabad's monsoon-driven transmission cycle (*Imran et al., 2023*). Warm, humid conditions accelerate the *Aide's* life cycle and viral replication, shortening the extrinsic incubation period. Yet, the crucial insight from this study is that climatic factors act primarily as *amplifiers* rather than *initiators* of transmission.
Even under identical meteorological conditions, colonies with better infrastructure (Hensa and 100 Quarter) had much lower dengue incidence. This implies that while weather determines seasonal potential, socioeconomic and environmental vulnerability determine realized risk. Such differentiation has also been observed in cities like Bangkok, Manila, and Dhaka, where intra-urban heterogeneity in infrastructure produces localized "hotspots" despite uniform climate (*Wilder-Smith et al., 2021*).
Hence, adaptation to climatic risk must be localized and equity-focused. Urban heat and rainfall models cannot substitute for granular understanding of community-level vulnerabilities.

Knowledge, Attitudes, and Practices (KAP) and Behavioral Factors

The study revealed substantial gaps between knowledge and practice, particularly in high-incidence colonies.
Although around half of respondents in France and Rimsha recognized mosquitoes as dengue vectors, fewer translated this knowledge into preventive behavior.
This "knowledge–practice gap" is common in marginalized populations where structural constraints—water scarcity, cost of repellents, lack of municipal waste services—undermine behavioral intent (*Abeysinghe et al., 2020*).
For instance, households that knew about container cleaning often could not afford to waste stored water due to irregular supply. Thus, preventive capacity is constrained by poverty, not ignorance. This underscores the importance of *enabling environments*—providing infrastructure and material support that make healthy behaviors feasible. Education campaigns alone cannot offset systemic deficiencies.

Community participation is nonetheless vital. Evidence from Latin America and Southeast Asia shows that sustained vector reduction is achievable only through community-led waste management and source elimination campaigns (*Toledo et al., 2019*).
In Islamabad's context, partnerships between municipal authorities, NGOs, and church-based organizations could foster collective action, leveraging social cohesion within these colonies.

Comparative Perspective and Integration with Previous Research

The observed socio-environmental disparities mirror national and international trends. Pakistan's dengue epidemiology has long been characterized by urban clustering, with outbreaks originating in densely populated, underserved localities (*Hassan et al., 2022*).
Comparable intra-urban differentials are documented in Mumbai, Jakarta, and Rio de Janeiro, where informal settlements exhibit two- to three-fold higher incidence than formal neighborhoods despite proximity (*Banu et al., 2014; Costa et al., 2020*).
These parallels reinforce the view that dengue is not solely an entomological or climatic problem but a manifestation of *urban inequality*.

The "urban health penalty" disproportionately affects marginalized groups, who endure cumulative exposures—environmental neglect, limited infrastructure, and economic precarity—that converge to sustain endemic transmission (*Vlahov et al., 2021*).
Moreover, the study's integrated approach—linking socioeconomic data with entomological and environmental indicators—addresses a gap in local research, which has often examined climatic correlates in isolation. By demonstrating that vector indices and socioeconomic deprivation jointly predict incidence, this study contributes to a more comprehensive understanding of dengue ecology in Islamabad.

Policy Implications

The findings carry significant implications for urban health governance and vector-control strategy.

Infrastructure and Service Delivery

The most effective long-term dengue control measures are infrastructural, not biomedical. Ensuring reliable **piped water supply** would reduce household dependence on stored water, thereby eliminating a major breeding source. Similarly, consistent **solid waste management** and **drainage maintenance** would disrupt larval habitats.
Municipal authorities should extend basic services to informal colonies under inclusive urban policies. Neglecting these communities not only perpetuates health inequity but also sustains city-wide transmission, as *Aedes aegypti* disperses across short distances into adjacent neighborhoods.

Integrated Vector Management (IVM)

An IVM framework combining environmental management, biological control, and targeted chemical interventions should be institutionalized. Routine fogging should be complemented by larval-source reduction, community clean-up drives, and periodic entomological surveillance.
The strong colony-level correlation between vector indices and dengue incidence justifies prioritizing resources where entomological data indicate persistent infestation.

Community Engagement and Health Education

Behavioral interventions remain crucial when coupled with enabling infrastructure. Culturally tailored education campaigns—using local churches, schools, and NGOs—can raise awareness and foster collective responsibility. Participatory monitoring (e.g., community vector scouts) has proven cost-effective in similar low-income contexts (*WHO, 2022*).

Equity-Focused Urban Planning

Finally, dengue prevention must be embedded in broader urban equity and housing policies. The persistence of kacha settlements without drainage or waste systems represents a structural injustice. Investments in affordable, durable housing and slum upgrading would yield sustained reductions in vector-borne disease risk alongside broader social benefits.

Limitations and Directions for Future Research

Several limitations warrant acknowledgment.
The **cross-sectional design** limits causal inference; longitudinal studies could better capture temporal dynamics between environmental change and dengue incidence.
Clinic-based data may undercount cases treated outside formal facilities. Spatial analysis was constrained by limited GPS data; future work should employ geostatistical modeling to delineate hotspots precisely.
Additionally, integrating climatic satellite data with socioeconomic indices could refine predictive models for dengue risk mapping.
Qualitative exploration of gender roles, community perceptions, and trust in municipal institutions would deepen understanding of behavioral barriers to vector control.

Conceptual Implications

This study supports an **eco-social framework** of dengue transmission, emphasizing the interaction between biological vectors, physical environment, and social structure. Rather than treating dengue solely as a matter of vector abundance, it situates the disease within a matrix of *social vulnerability and environmental neglect*. Such framing resonates with the "One Health" paradigm, which calls for integrative approaches bridging human, environmental, and animal health systems (*Rocklov & Semenza, 2020*).

By revealing how marginalized communities experience disproportionately higher dengue burden due to systemic neglect, the findings extend the discourse on health equity within urban epidemiology.

Summary

In summary, this study demonstrates that dengue prevalence in Islamabad's Christian colonies arises from an intersection of environmental degradation and socioeconomic inequality. The higher incidence in France and Rimsha Colonies is not accidental but symptomatic of deeper structural deficits—poor housing, absent infrastructure, and limited social capital. While climatic conditions modulate seasonal risk, they do not determine who suffers most; that outcome is shaped by poverty and governance.

Addressing dengue thus requires a shift from reactive outbreak control to proactive, equity-centered urban health planning. The integration of infrastructural reform, community participation, and continuous entomological surveillance offers the most sustainable pathway to reduce disease burden and promote health justice in Islamabad and similar urban contexts.

Conclusion and Recommendations

Conclusion

This study sought to identify the environmental and socioeconomic determinants of dengue fever prevalence within four Christian colonies of Islamabad—France Colony (F-7), Rimsha Colony (H-9), Hensa Colony (G-8), and 100 Quarter (F-6)—during the 2024 monsoon season. By integrating household surveys, entomological indices, environmental observations, and health-record data, the research provides a holistic account of how ecological and social inequalities converge to shape dengue risk in marginalized urban communities.

The results confirm that dengue is not distributed randomly across space or population groups. Instead, it follows clear social and environmental gradients. France and Rimsha Colonies, which exhibit the lowest socioeconomic status, poorest infrastructure, and weakest municipal services, recorded the highest dengue incidence (≈ 18–21 %). In contrast, Hensa and 100 Quarter Colonies, with relatively better housing and service provision, reported roughly half that level. This disparity underscores dengue's status as both a vector-borne infection and a social disease—driven by conditions of deprivation and environmental neglect.

Several interlocking mechanisms explain this pattern:

Structural poverty limits access to clean, piped water, forcing reliance on stored containers that serve as breeding sites for Aedes aegypti.

Weak waste management systems foster accumulation of solid waste and standing water.

Informal housing with open structures facilitates mosquito entry and reduces protection.

Low educational attainment constrains awareness and adoption of preventive practices.

Municipal exclusion of informal colonies perpetuates chronic exposure to environmental hazards.

These mechanisms operate synergistically with climatic factors—rainfall, humidity, and temperature—that merely amplify an already fragile system. The statistical evidence supports this integrated view: lack of piped water (AOR = 2.6), irregular waste collection (AOR = 2.1), high container index (AOR = 2.5), and presence of stagnant water (AOR = 2.2) were all independent predictors of dengue, even after controlling for socioeconomic variables.

Entomological indices further confirmed sustained vector presence, with Breteau Index values exceeding WHO thresholds in the most affected colonies. The ecological conditions of these settlements—dense population, high humidity, shaded microhabitats, and persistent water storage—create an enduring niche for Aedes breeding. Consequently, dengue transmission in Islamabad cannot be effectively curbed through seasonal fogging alone; it demands structural transformation in the urban environment.
The study therefore substantiates an eco-social model of dengue transmission, wherein disease emergence reflects the intersection of biological, environmental, and social domains. Dengue thrives where physical infrastructure collapses and governance gaps widen. The implications extend beyond vector control to broader debates on urban inequality and environmental justice in developing cities.

Public Health and Policy Implications

Infrastructure and Urban Governance

Sustainable dengue prevention requires re-engineering the urban environment.The most urgent priority is ensuring continuous piped water supply in informal colonies. Reliable distribution would eliminate the need for household water storage—one of the principal breeding sources identified. Similarly, the establishment of regular, municipally managed waste-collection services is critical to prevent the accumulation of refuse that holds rainwater.Drainage rehabilitation is another cornerstone intervention. Many lanes in France and Rimsha Colonies contain open, blocked drains; converting these to covered systems would drastically reduce breeding potential. These infrastructural improvements fall within the jurisdiction of the Capital Development Authority (CDA) and Metropolitan Corporation Islamabad (MCI) and should be incorporated into the city's master plan under an "inclusive settlements" framework.

Integrated Vector Management (IVM)

Consistent with WHO recommendations, vector control must evolve from reactive fogging to a comprehensive Integrated Vector Management approach. IVM emphasizes:
Environmental management: source réduction, container disposal, improved drainage.
Biological and chemical control: use of larvicides and eco-friendly agents targeted to breeding sites.
Community participation: organized clean-up drives and household inspections.
Evidence-based surveillance: routine monitoring of entomological indices (House Index, Container Index, Breteau Index) to guide intervention timing and resource allocation.
Institutionalizing IVM within municipal health departments would ensure continuous prevention rather than crisis-driven response.

Health Education and Community Mobilization

While structural reforms are foundational, behavioral change remains essential.
The study revealed a substantial gap between knowledge and practice—especially in high-risk colonies. Education campaigns should therefore be context-specific and participatory, delivered through trusted local institutions such as churches, community centers, and schools.Training of "community vector champions" can enable local monitoring, larval source identification, and peer education. Previous regional programs demonstrate that sustained community ownership yields greater and longer-lasting vector reduction than externally imposed campaigns. Integrating such initiatives with municipal services would multiply impact and strengthen trust in public institutions.

Equity and Social Protection

Dengue's unequal burden mirrors deeper inequities in housing, income, and service access. Public health responses must adopt an equity lens, ensuring that interventions prioritize the most underserved settlements. Inclusion of Christian colonies and other informal communities in city-wide sanitation

budgets, social-protection schemes, and housing improvement projects would not only curb dengue but also advance health justice.
Moreover, urban-development policies should formally recognize informal settlements and extend legal tenure or service rights where possible. This would facilitate investment in durable infrastructure and unlock community participation in maintaining sanitation and drainage systems.

Implications for Research and Monitoring

This study demonstrates the analytical value of integrating epidemiological, entomological, and socioeconomic data. Future research should build on this foundation through:
Longitudinal cohort designs to capture temporal causality between environmental change, vector density, and disease incidence.
High-resolution spatial mapping using GIS and remote-sensing data to identify micro-hotspots within colonies.
Modeling climate–vector–socioeconomic interactions, leveraging meteorological datasets to forecast outbreak potential.
Qualitative studies exploring social dynamics, risk perception, and gendered divisions of household labor that influence vector-control practices.
Economic evaluation of interventions to inform cost-effective municipal planning.
Such multi-disciplinary research would strengthen Pakistan's evidence base for dengue control and contribute to global comparative work on urban health inequities.

Conceptual and Theoretical Reflections

The findings reinforce the eco-social paradigm within contemporary epidemiology, highlighting that health outcomes cannot be detached from social relations and environmental systems. Dengue functions here as a sentinel event—a visible symptom of invisible structural neglect.By exposing how Christian colonies experience compounded vulnerability due to social marginalization and infrastructural exclusion, this study broadens the understanding of infectious-disease risk beyond biology. It aligns with global calls for "One Health" and "Health-in-All-Policies" frameworks that integrate housing, water, sanitation, and education sectors into health governance.Furthermore, the study underscores the moral dimension of public health: addressing dengue in Islamabad's colonies is not merely a technical exercise but an ethical imperative rooted in equity and human rights.

Recommendations

- ✓ Based on the empirical evidence and analytical synthesis, the following recommendations are advanced:
- ✓ Expand piped water networks to all informal colonies; ensure daily supply and repair leakage to prevent open storage.
- ✓ Institutionalize solid-waste management with scheduled collection and segregation; deploy covered waste containers to minimize water accumulation.
- ✓ Rehabilitate drainage systems—convert open drains to closed conduits, clean them pre-monsoon, and maintain post-rain inspections.
- ✓ Adopt Integrated Vector Management combining environmental modification, targeted larviciding, and biological control under continuous entomological surveillance.
- ✓ Launch participatory health-education campaigns through local religious and community organizations; provide low-cost repellents and container covers.
- ✓ Upgrade housing quality via micro-credit or subsidy schemes enabling transition from kacha to semi-permanent structures.
- ✓ Include informal colonies in municipal planning and climate-adaptation policies, treating them as integral to the city's public-health infrastructure.
- ✓ Establish inter-sectoral dengue task forces linking CDA, MCI, health departments, NGOs, and academia to coordinate interventions and data sharing.

- ✓ Develop an early-warning surveillance system integrating meteorological forecasts, entomological data, and health-facility reporting for timely outbreak response.
- ✓ Conduct annual monitoring and evaluation of colony-level dengue indicators to assess intervention effectiveness and adapt strategies.

Closing Statement

In conclusion, dengue in Islamabad's Christian colonies epitomizes the convergence of environmental mismanagement and social marginalization. The disease flourishes where urban governance fails and inequality persists.

Preventing dengue therefore demands a paradigm shift—from reactive medical control to proactive urban transformation anchored in equity, infrastructure, and community empowerment.

If implemented comprehensively, the interventions outlined here could markedly reduce dengue incidence and set a precedent for inclusive, sustainable urban-health policy not only in Islamabad but across dengue-endemic cities in South Asia.

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