REVIEW ARTICLE

# Unveiling the Hidden Threat: Climatic, Environmental, and Socioeconomic Drivers of Dengue Transmission in the Middle East: A Systematic Review

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## ABSTRACT

**Background**: Dengue fever is an emerging public health concern in the Middle East, influenced by climatic, environmental, and socioeconomic factors. Traditionally linked to tropical regions, recent outbreaks in arid and semi-arid areas highlight increasing regional vulnerability. **Methods**: This systematic review (2000–2024) analyzed studies on climatic (temperature, humidity, rainfall), environmental (urbanization, land use), and socioeconomic (population density, household conditions) factors affecting dengue transmission. A total of seven studies were included in the final synthesis. The Newcastle-Ottawa Scale (NOS) was used to assess the methodological quality of included studies. Data synthesis was performed through a narrative review, categorizing findings into positive, negative, and non-significant associations with dengue incidence. **Results**: The findings highlight a strong correlation between climatic factors and dengue transmission, with temperature, humidity, and rainfall being the most significant predictors. While moderate rainfall provided breeding sites for Aedes mosquitoes, excessive rainfall disrupted larval development. Urbanization and poor neighborhood conditions were also positively associated with dengue incidence, particularly in high-density, lower-income communities with inadequate sanitation and water storage practices. Socioeconomic determinants such as age, gender, and occupation influenced exposure risk, with younger populations and outdoor workers being more susceptible. Methodologically, cross-sectional studies (42.8%) dominated the literature, followed by geospatial risk modeling (28.6%) and longitudinal studies (28.6%). **Conclusions**: The study highlights the urgent need for climate-adaptive dengue early warning systems, improved urban planning to mitigate vector breeding, and targeted interventions for high-risk populations.
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## INTRODUCTION

Dengue fever is an emerging public health concern in the Middle East, a region traditionally considered non-endemic for the disease [1]. However, urbanization, climate change, and increased travel connectivity have contributed to the growing incidence of dengue in countries such as Saudi Arabia, Sudan, and Yemen [2-3]. According to WHO, Sudan reported over 5,300 suspected dengue cases with 78 deaths in 2023, spanning 12 out of 18 states. In Saudi Arabia, local surveillance reports continue to document thousands of cases annually, particularly in coastal regions such as Jeddah and Mecca [4].

The Ae. aegypti and Ae. albopictus mosquito vectors, responsible for dengue virus transmission, have adapted to the urban landscapes and artificial water-holding containers in these regions, facilitating the spread of the disease [5]. While dengue remains a well-documented epidemic in Southeast Asia and Latin America, the Middle East presents unique challenges due to arid and semi-arid climatic conditions, which are generally considered less conducive to mosquito survival and breeding [6]. Despite this, localized outbreaks have been reported, particularly in Saudi Arabia's western coastal cities such as Jeddah and Mecca, where favorable environmental and socio-demographic factors facilitate transmission [7]. These coastal cities experience relatively higher humidity, moderate rainfall, and stable year-round temperatures, which create optimal conditions for Aedes mosquito breeding compared to inland cities like Riyadh or Sana'a, where arid climates and temperature extremes limit vector survival [8]. Despite the increasing burden of dengue in the Middle East, systematic reviews focusing on dengue epidemiology in this region remain limited. Most existing global reviews tend to focus on tropical and endemic regions, overlooking the distinct climatic and socio-environmental drivers of dengue transmission in Middle Eastern countries [9-10]. The lack of a region-specific systematic review has resulted in a gap in understanding the local determinants of dengue outbreaks, particularly the interplay between climate, urbanization, and socioeconomic status in shaping disease dynamics. Given that several studies have emerged in recent years investigating dengue transmission patterns in Saudi Arabia, Sudan, and neighboring countries, a comprehensive synthesis of findings is necessary to guide policy and research priorities [10-14].

Several local issues exacerbate dengue transmission risks in the Middle East. One of the primary concerns is rapid and unplanned urbanization, which has led to poor drainage systems, inadequate waste management, and the proliferation of artificial mosquito breeding habitats [15]. Additionally, water storage practices in water-scarce regions, particularly in Sudan and Yemen, have been identified as significant contributors to Aedes mosquito proliferation [16]. Climatic factors such as seasonal variations in temperature and humidity further complicate dengue epidemiology in the region, with hot and dry conditions potentially influencing mosquito behavior and virus transmission dynamics [17-20]. Ebi and Nealon (2016) said that Aedes mosquitoes thrive at temperatures between 22°C and 32°C, with relative humidity above 60% and moderate rainfall supporting breeding activity [21]. These climatic thresholds are increasingly crossed in arid and semi-arid regions due to climate change, expanding the geographic range and seasonal intensity of dengue outbreaks [22]. Furthermore, socioeconomic disparities and limited access to vector control programs disproportionately affect lower-income communities, increasing dengue vulnerability among these populations. The objective of this systematic review is to analyze the key climatic, environmental, and socioeconomic factors influencing dengue transmission in the Middle East. By addressing these objectives, this systematic review will provide evidence-based insights to improve dengue surveillance, vector control strategies, and public health preparedness in the region, ensuring a comprehensive and context-specific approach to mitigating dengue outbreaks in the Middle East.

## MATERIAL AND METHOD

### Study Design

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, ensuring transparency, reproducibility, and methodological rigor [23]. Although this systematic review followed PRISMA guidelines to ensure methodological rigor and transparency, it was not registered in PROSPERO or any other systematic review registry. A preliminary search conducted in PROSPERO did not identify any reviews with a similar focus, confirming the novelty of this topic within the Middle Eastern context. The review aimed to synthesize existing evidence on the climatic, environmental, and socioeconomic determinants influencing dengue transmission in the Middle East, focusing primarily on Saudi Arabia, Sudan, and neighboring countries. Given the increasing burden of dengue in the region, understanding the interplay between climate variability, urbanization, and socioeconomic disparities is critical for developing effective vector control measures, risk assessment models, and public health interventions (Fig. 1).

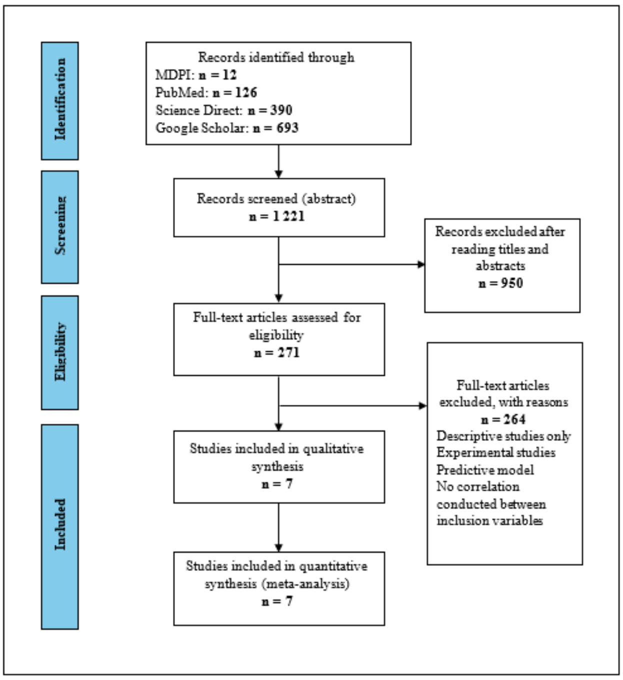


**Fig. 1: Flow chart of articles selection using PRISMA guidelines**

A structured systematic literature search and study selection process was employed to ensure that only relevant, high-quality research was included. The methodological approach involved identifying studies, extracting key data, and synthesizing the findings to examine the relationship between climatic conditions (temperature, humidity, rainfall), environmental changes (land use, urbanization), and socioeconomic factors (population density, occupation, household characteristics) in relation to dengue incidence. The Newcastle-Ottawa Scale (NOS) for observational studies was applied to evaluate the quality of included studies, minimizing bias, confounding factors, and methodological inconsistencies. Additionally, a PRISMA flow diagram was used to document the study selection process, ensuring transparency and replicability.

**Eligibility Criteria**
Studies were selected based on well-defined inclusion and exclusion criteria to maintain relevance, methodological rigor, and applicability to the Middle Eastern context. The inclusion criteria focused on studies conducted in Middle Eastern countries, particularly Saudi Arabia and Sudan, where dengue transmission has been reported. Studies were included if they examined climatic factors (temperature, humidity, rainfall), environmental determinants (land cover, urbanization), and socioeconomic variables (population density, household characteristics, occupation) in relation to dengue incidence. Only quantitative epidemiological studies, such as time-series analysis, geospatial mapping, risk modeling, and case-control studies, were considered. Furthermore, articles published in peer-reviewed journals between 2000 and 2024 in English or Arabic were included to ensure coverage of both historical trends and recent advancements in dengue research.

Conversely, studies that focused primarily on clinical, virological, or immunological aspects of dengue, such as vaccine trials, molecular research, or host immune response studies, were excluded, as they did not align with the review's focus on transmission dynamics. Non-peer-reviewed sources, including conference abstracts, editorials, commentaries, and opinion pieces, were also excluded to maintain scientific credibility and reproducibility. Additionally, studies with insufficient data on the correlation between dengue incidence and climatic, environmental, or socioeconomic factors were omitted. Research lacking quantitative epidemiological analysis, appropriate statistical associations, or detailed methodological descriptions was considered methodologically weak and therefore excluded.

The inclusion and exclusion criteria were carefully designed to ensure that the review provides high-quality, region-specific insights into the factors driving dengue transmission in the Middle East. By prioritizing peer-reviewed, methodologically robust studies, the review ensures the reliability and validity of findings, which can be used to guide public health policies, vector control strategies, and future research. The exclusion of non-quantitative and low-quality studies further strengthens the credibility and reproducibility of this systematic review, aligning it with the standards of high-ranking scientific journals.

**Search Strategy**
A comprehensive and systematic literature search was conducted across multiple academic databases, including MDPI, PubMed, Science Direct, and Google Scholar to identify relevant studies examining the climatic, environmental, and socioeconomic determinants of dengue transmission in the Middle East. The search covered all peer-reviewed articles published until March 2024, ensuring the inclusion of both historical trends and the most recent advancements in dengue research. A combination of Medical Subject Headings (MeSH) terms and relevant keywords was used to optimize the search process, allowing for a broad yet targeted retrieval of studies. Boolean operators (AND, OR) were applied to refine the search queries and capture relevant studies addressing dengue transmission in the Middle East.

The search strategy was structured around three key thematic areas. First, dengue-specific search terms such as ("Dengue" OR "Dengue Fever") AND ("Middle East" OR "Saudi Arabia" OR "Sudan") were used to identify research articles explicitly investigating dengue epidemiology in the region. Search terms prioritized countries with reported dengue activity. Other Middle Eastern countries were not excluded but yielded no eligible studies during screening. Second, studies exploring climatic influences on dengue transmission were retrieved using search terms such as ("Climate Change" OR "Temperature" OR "Rainfall" OR "Humidity") AND ("Dengue Transmission"), which focused on understanding how meteorological variables impact mosquito population dynamics and viral transmission cycles. Lastly, the socioeconomic and urbanization aspects of dengue were addressed through search terms like ("Socioeconomic Factors" OR "Urbanization" OR "Population Density") AND ("Dengue Risk"), aiming to capture studies that assessed the role of housing conditions, occupation, population density, and sanitation practices in shaping dengue transmission patterns.

In addition to retrieving articles from scientific databases, a manual search of gray literature, national health reports, and WHO regional publications was performed to include government reports, unpublished research, and policy documents relevant to dengue transmission in the Middle East. This additional search ensured that epidemiological surveillance data and localized health reports that may not be indexed in major databases were incorporated into the review. Furthermore, the reference lists of key identified articles were manually screened using a snowballing technique, allowing for the inclusion of additional studies that met the eligibility criteria but were not captured in the initial database search.

To enhance reproducibility and minimize selection bias, two independent reviewers cross-verified the retrieved studies, ensuring that only relevant literature meeting the inclusion criteria was selected. Any discrepancies in study selection were resolved through consensus discussions or consultation with a third reviewer. This rigorous multi-database search strategy, combined with gray literature screening and manual reference checking, ensured that the systematic review captured a comprehensive body of high-quality evidence on the climatic, environmental, and socioeconomic determinants of dengue transmission in the Middle East.

**Study Selection and Data Extraction**

The selection of studies for this systematic review followed a structured and rigorous process to ensure that only high-quality, relevant research was included. Two independent reviewers conducted a comprehensive screening of all retrieved studies at three levels: title screening, abstract screening, and full-text review. Initially, duplicates were removed, and studies that were clearly irrelevant based on their titles were excluded. Following this, abstracts were reviewed to assess their relevance to the climatic, environmental, and socioeconomic determinants of dengue transmission in the Middle East. Studies that met the preliminary inclusion criteria were then subjected to full-text evaluation, ensuring they aligned with the study's objectives.

Any discrepancies in the selection process were resolved through consensus discussions between the two reviewers. In cases where disagreements persisted, a third reviewer was consulted to provide arbitration. This multi-reviewer approach ensured objectivity, consistency, and methodological rigor throughout the selection process. After the final selection of eligible studies, data extraction was performed using a standardized data extraction form. This form was designed to capture all relevant study characteristics, exposure variables, outcome measures, and key findings in a structured manner. Extracted information included the title of the study, author(s), year of publication, country of focus, and sample size, providing a contextual overview of the research.

Key exposure variables were also documented, particularly climatic factors (temperature, humidity, rainfall), environmental determinants (land cover, urbanization), and socioeconomic variables (population density, occupation, household conditions). These factors were assessed to determine their potential associations with dengue incidence and mosquito abundance in different settings. The primary outcome variables included reported dengue incidence, mosquito density, and findings from risk modeling approaches, allowing for a comprehensive synthesis of disease patterns and contributing factors.

Furthermore, statistical findings from each study were systematically recorded, including odds ratios (ORs), regression coefficients, p-values, and confidence intervals, where applicable. These data points provided quantitative insights into the strength of associations between dengue transmission and various risk factors. Methodological details, such as study design, data sources, and analytical techniques, were also extracted to assess the robustness and validity of each study's conclusions. By implementing this systematic, multi-step selection and data extraction process, this review ensures that findings are scientifically rigorous, evidence-based, and methodologically sound, thereby providing a comprehensive synthesis of dengue research in the Middle East.

**Quality Assessment**

The methodological quality of the included studies was assessed using the Newcastle-Ottawa Scale (NOS), a widely recognized tool for evaluating observational studies in systematic reviews and meta-analyses [24]. This assessment focused on three key domains: selection, comparability, and outcome, scoring each study on a 9-point scale to determine its methodological robustness. The selection domain examined the representativeness of the study population, adequacy of case definition, selection of controls, and ascertainment of exposure to ensure that the studies provided reliable data on dengue transmission. The comparability domain evaluated whether the studies effectively controlled for potential confounding variables, such as age, socioeconomic status, and environmental conditions, which could influence the relationship between exposure variables and dengue incidence. The outcome domain assessed the definition of outcomes, appropriateness of statistical analyses, and follow-up duration, ensuring that results were interpreted with statistical and epidemiological rigor. Based on NOS scores, studies were classified as high-quality (8–9), moderate-quality (6–7), or low-quality (<5). This quality assessment ensured that only methodologically sound and well-executed studies contributed to the final synthesis, thereby minimizing bias and enhancing the reliability of the systematic review's findings.

**Data Synthesis and Analysis**

A narrative synthesis was conducted to summarize the key findings on dengue transmission in the Middle East, given the heterogeneity in study designs, statistical models, and exposure variables among the included studies. A quantitative meta-analysis was not performed due to variations in methodological approaches, outcome measures, and data collection techniques across studies. Instead, data were systematically categorized into three main themes: climatic determinants (temperature, humidity, rainfall), environmental factors (urbanization, land cover, water storage practices), and socioeconomic influences (population density, household characteristics, occupational exposure). This approach allowed for a comprehensive interpretation of trends and associations, highlighting positive, negative, and non-significant correlations with dengue incidence. The synthesis also identified gaps in research, inconsistencies in findings, and areas requiring further investigation, providing a foundation for future studies on dengue epidemiology in the region.

## RESULTS

### Overview of Study Selection and Exclusion Reasons

A total of 1,221 records were identified through database searches. Following the removal of 54 duplicate records, 1,167 titles and abstracts were screened. Of these, 950 articles were excluded. The primary reasons for exclusion at this stage included studies unrelated to dengue transmission (n = 270), articles focused on clinical, virological, or immunological aspects rather than environmental or socioeconomic determinants (n = 402), and non-peer-reviewed materials such as editorials, conference papers, and commentaries (n = 278).

At the full-text screening stage, 264 studies were excluded for the following reasons: 104 were descriptive studies without analytical correlation between exposure and outcome; 65 lacked methodological detail or used inappropriate study designs; 48 did not assess relevant variables related to climate, environment, or socioeconomic factors; and 47 were predictive or laboratory-based studies outside the scope of this review. As a result, only seven studies met all inclusion criteria and were included in the final synthesis.

### Methodological Quality Assessment of Included Studies

The methodological quality assessment of the seven included studies, evaluated using the Newcastle-Ottawa Scale (NOS), revealed distinct patterns in design rigor and adherence to methodological standards (Table I). All studies demonstrated robust performance in the Selection domain (Q1–Q4), with full marks achieved across criteria such as population representativeness, adequacy of selection methods, control group definition, and exposure ascertainment. For instance, Al-Neffate et al. and Khormi et al. utilized geographically diverse cohorts and age- and sex-matched controls, respectively, while Ahmed et al. minimized selection bias through randomized sampling [7, 25-26]. These practices underscored strong internal validity and consistency in recruitment strategies. Similarly, in the Comparability domain (Q5–Q6), all studies exhibited rigorous control for confounding variables, adjusting for key factors such as age, sex, and socioeconomic status and addressing context-specific confounders [27-28]. This systematic adjustment strengthened the reliability of reported associations. Variability emerged in the Outcome domain (Q7–Q9): while all studies clearly defined outcomes using standardized criteria and employed appropriate statistical methods, differences in follow-up duration influenced quality categorization. Ahmed et al. [26], scoring highest (9/9), demonstrated exemplary follow-up (>5 years), whereas moderate-quality studies had shorter observation periods (<2 years), limiting long-term inference.

High-quality studies (scores 8–9), including Al-Neffate et al. and Khormi et al. [7, 25], provided robust evidence for causal inference despite minor follow-up limitations, while moderate-quality studies (6–7) retained strengths in confounder control but lacked longitudinal depth. Overall, the findings highlight a critical gap in follow-up protocols, emphasizing the need for extended observation periods in future research to enhance outcome validity. Systematic reporting of follow-up duration and justification for its adequacy should be prioritized to align with NOS criteria, ensuring methodological transparency and reproducibility in longitudinal designs. This synthesis underscores the importance of balancing confounder adjustment with comprehensive outcome assessment to advance evidence quality in observational research.

**Table I: Methodological Quality Assessment of Included Studies Using the Newcastle-Ottawa Scale (NOS)**

| | Al-Nefaie et al. (2022) [18] | Kholedi, et al. (2012) [23] | Seidahmed, et al. (2012) [24] | Khormi, et al. (2013) [19] | Alkhaldy, & Basu, (2022) [21] | Yasin, (2015) [22] | Ahmed, et al. (2019) [20] |
|---|---|---|---|---|---|---|---|
| **Q1:** Is the Study Population Representative? | √ | √ | √ | √ | √ | √ | √ |
| **Q2:** Was the Selection Method Adequate? | √ | √ | √ | √ | √ | √ | √ |
| **Q3:** Were Controls Defined Appropriately? | √ | √ | √ | √ | √ | √ | √ |
| **Q4:** Was the Ascertainment of Exposure Adequate? | √ | √ | √ | √ | | | √ |
| **Q5:** Did the Study Control for Key Confounders? | √ | √ | √ | √ | √ | √ | √ |
| **Q6:** Did the Study Control for Additional Confounders? | √ | | √ | √ | | | √ |
| **Q7:** Was the Outcome Well-Defined? | √ | √ | √ | √ | √ | √ | √ |
| **Q8:** Were Statistical Methods Appropriate? | √ | | √ | √ | √ | √ | √ |
| **Q9:** Was Follow-up Long Enough? | | | | | | | √ |
| **Total** | **8** | **6** | **8** | **8** | **6** | **6** | **9** |

**Note:** The methodological quality of the included studies was assessed using the Newcastle-Ottawa Scale (NOS). Domains include: (I) Selection (Q1–Q4): Representativeness of the study population, adequacy of selection methods, control group definition, and exposure ascertainment; (II) Comparability (Q5–Q6): Control for key and additional confounders and (III) Outcome (Q7–Q9): Definition of outcomes, appropriateness of statistical methods, and follow-up duration. Total scores categorize studies as *high quality* (8–9), *moderate quality* (6–7), or *low quality* (<5).

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**Overview of Study Characteristics**

The studies summarized in the Table II highlight the complex interplay between meteorological, environmental, and socioeconomic factors in driving dengue transmission across various regions, particularly in Saudi Arabia and Sudan. Several studies demonstrated a strong correlation between climate variables such as temperature, humidity, and rainfall with dengue incidence. For instance, Al-Nefate et al. found that these factors significantly influenced dengue cases ($p<0.05$) [7], while Alkhaldy reported that hot, dry conditions substantially increased dengue risk ($p<0.01$) [21]. Similarly, Seidahmed et al. analyzed dengue transmission across different neighborhoods and seasons, revealing that lower- and middle-class neighborhoods experienced a higher burden of cases, likely due to inadequate sanitation and water storage practices [30].

Beyond meteorological influences, socioeconomic and urbanization factors were also found to be key determinants of dengue transmission. Kholedi et al. identified significant differences in dengue spread among households with varying socioeconomic characteristics, such as occupation and urbanization levels (chi-square test) [29]. Khormi et al. further demonstrated that population density and neighborhood quality were strong predictors of dengue cases, with their geographically weighted regression model yielding an R of 0.80 [25]. These findings suggest that densely populated urban areas with poor living conditions may serve as hotspots for dengue transmission.

In addition to human population dynamics, studies investigating Aedes mosquito abundance confirmed the critical role of environmental conditions in vector proliferation. Yasin et al. (2015) found that temperature, rainfall, and humidity significantly influenced larval and adult mosquito density ($p<0.05$), reinforcing the importance of meteorological monitoring in vector control programs [28]. Ahmed et al. further demonstrated that rainfall positively correlated with Ae. aegypti density, while humidity influenced adult mosquito survival, highlighting the necessity for climate-responsive vector control interventions [26]. The collective findings from these studies underscore the need for an integrated approach in dengue surveillance and control, incorporating environmental and socioeconomic factors. Developing climate-based early warning systems could enhance outbreak prediction, while urban planning policies should prioritize improved waste disposal, water storage, and drainage systems to minimize mosquito breeding grounds. Furthermore, targeted community-based interventions in lower-income neighborhoods could significantly reduce dengue transmission risks. In conclusion, the evidence suggests that dengue control efforts must extend beyond conventional vector management strategies, integrating spatial epidemiology, climate modeling, and socioeconomic assessments to develop more effective, sustainable interventions. Future research should focus on machine learning approaches for predictive modeling and longitudinal studies to assess the long-term impacts of climate change on dengue epidemiology.

**Table II: Summary of Studies on Environmental and Socioeconomic Factors Influencing Dengue Transmission in the Middle East and North Africa**

| ID | Title & Author(s) | Population | Exposure | Comparison | Outcome |
|---|---|---|---|---|---|
| **[1]** | Al-Nefate et al. (2022) [18] | 1,458 confirmed/suspected dengue cases in Jeddah, Saudi Arabia (Jan–Dec 2020). | Temperature, humidity, land cover, rainfall, socioeconomic factors (age, gender, area, occupation). | Association between demographic/environmental variables and dengue incidence (logistic regression). | Age, gender, occupation, and area were significantly associated with dengue cases ($p < 0.05$). |
| **[2]** | Kholedi et al. (2012) [23] | 650 suspected dengue cases in Jeddah Governorate, Saudi Arabia (2007). | Socioeconomic factors (occupation, age, household characteristics), urbanization, meteorological factors. | Differences in dengue spread between households with varying socioeconomic/urbanization traits (chi-square). | Environmental and demographic factors were statistically significant determinants of dengue transmission. |
| **[3]** | Seidahmed et al. (2012) [24] | 2,825 households, 4,640 water containers, and 791 blood samples in Port Sudan City (2008–2009). | Meteorological factors (temperature, rainfall, humidity), neighborhood socioeconomic status, water storage practices. | Dengue transmission patterns across neighborhoods (upper vs. middle vs. lower class) and seasons (ANOVA). | Lower- and middle-class neighborhoods had higher entomological indices; temporal peaks linked to rainfall. |
| **[4]** | Khormi et al. (2013) [19] | 111 districts in Jeddah, Saudi Arabia (2006–2010). | Population density, neighborhood quality, mosquito counts, meteorological factors. | District-level dengue risk modeled via socioeconomic/environmental variables (geographically weighted regression). | Strong association between dengue cases and population density/neighborhood quality ($R$ = 0.80). |
| **[5]** | Alkhaldy (2022) [21] | Dengue cases in Jeddah City, Saudi Arabia (2006–2009). | Climate variables (temperature, humidity). | Lag effects of hot/dry vs. humid conditions on dengue incidence (distributed lag non-linear model). | Hot, dry conditions significantly increased dengue risk ($p < 0.01$). |
| **[6]** | Yasin (2015) [22] | 31,041 mosquito larvae and 2,036 adult mosquitoes in Eastern Province, Saudi Arabia (2014). | Environmental factors (temperature, rainfall, humidity). | Correlation between climatic variables and mosquito abundance (bivariate/multivariate analyses). | Temperature, rainfall, and humidity correlated with larval and adult mosquito density ($p < 0.05$). |
| **[7]** | Ahmed et al. (2019) [20] | 20 households per cluster in Kassala City, Sudan (2014–2015). | Rainfall, humidity, temperature. | Seasonal variations in *Aedes aegypti* density (Ryan-Einot-Gabriel-Welsch multiple range test). | Rainfall positively correlated with adult mosquitoes; humidity linked to larval/pupal abundance ($p < 0.05$). |

**Profile of dengue transmission research in the Middle East**

The findings of this study provide a comprehensive profile of dengue transmission research in the Middle East, highlighting the geographical distribution, key research objectives, environmental and socioeconomic factors, and study design methodologies (Fig. 2). The research is predominantly focused on Saudi Arabia (71.4%), with a smaller but notable proportion in Sudan (28.6%). This suggests that dengue transmission in arid and semi-arid climates is an emerging public health concern, reinforcing the need for climate-adaptive surveillance and vector control strategies tailored to Middle Eastern environmental conditions.

The key research objectives in Middle Eastern dengue studies are multidisciplinary, covering environmental and climatic influences (28.6%), socioeconomic and urbanization factors (28.6%), dengue risk modeling and spatial analysis (28.6%), and mosquito abundance and seasonal variation (14.2%). The equal distribution among the first three categories indicates an increasing shift towards data-driven dengue forecasting, integrating epidemiology, climate science, and urban planning. However, the relatively low percentage of studies on mosquito abundance (14.2%) suggests that dengue research in the region prioritizes macro-level transmission dynamics rather than traditional entomological surveillance.

Dengue transmission in Saudi Arabia and Sudan is strongly associated with climatic and environmental variables, reflecting the unique ecological challenges of dengue control in arid regions. The research highlights climate variables (temperature, humidity, and rainfall) as the most studied factor (42.8%), demonstrating a strong correlation between seasonal weather fluctuations and vector activity. Additionally, urbanization changes (14.3%), population density and neighborhood quality (14.3%), and water storage practices (28.6%) are identified as key environmental contributors to dengue spread. The latter is particularly relevant in Middle Eastern regions, where water scarcity leads to extensive water storage practices, inadvertently creating Aedes breeding habitats. These findings reinforce the need for vector control strategies tailored to water management behaviors in the region.

Beyond climate, socioeconomic conditions play a pivotal role in dengue transmission across Middle Eastern studies. Demographic factors (40%), including age, gender, and occupation, shape the population's vulnerability to dengue, while household conditions (20%), neighborhood socioeconomic status (20%), and urbanization/population density (20%) influence transmission risk. These findings emphasize that dengue is not only an environmental issue but also a social and economic challenge, particularly in rapidly urbanizing areas such as Riyadh, Jeddah, and Khartoum. The research suggests that Middle Eastern dengue prevention programs should integrate public health education, urban planning, and economic policies alongside traditional vector control efforts to achieve sustainable results.

Dengue research in the Middle East is dominated by cross-sectional studies (42.8%), which provide important epidemiological snapshots but are limited in assessing long-term disease trends. The increasing use of geospatial and risk modeling approaches (28.6%) demonstrates the region's growing reliance on machine learning, GIS, and predictive analytics for dengue forecasting. However, longitudinal studies (28.6%) remain underrepresented, indicating a gap in long-term surveillance and intervention effectiveness evaluation. This suggests a need for cohort-based studies that track dengue dynamics over multiple seasons to inform regional dengue control policies.

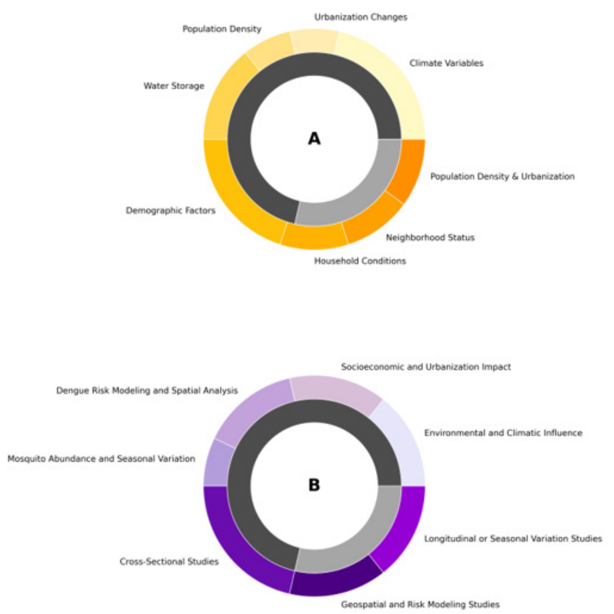


**Fig 2: The distribution factors influencing dengue transmission in Middle East; (A) represents environmental and socioeconomic factors, with the outer ring categorizing environmental influences in lighter yellow tones and socioeconomic influences in darker yellow tones. The inner ring indicates the proportion of studies conducted in Saudi Arabia and Sudan. Chart (B) visualizes key research objectives and study designs, where lighter purple tones represent key objectives, while darker purple tones indicate study designs. The inner ring remains consistent, showing the distribution of studies by country.**

**The Role of Climatic, Environmental, and Socioeconomic Determinants in Risk Assessment and Control Strategies**

Table III presents an analysis of the correlation between climatic, environmental, and socioeconomic factors with dengue incidence, highlighting both significant and non-significant associations. The findings provide critical insights into how various factors influence dengue transmission dynamics, which is essential for improving surveillance, risk modeling, and vector control strategies.

Among the climatic and environmental factors, temperature showed a positive correlation across multiple studies, indicating that higher temperatures enhance mosquito breeding and virus replication. However, one study found no significant association, suggesting that regional differences, seasonal variations, or study design factors may influence outcomes. Similarly, relative humidity was positively correlated in most studies, reinforcing the role of humidity in increasing Aedes mosquito survival and dengue transmission. However, one study reported a negative correlation, possibly due to excessive humidity altering mosquito host-seeking behavior. Rainfall had mixed effects, with some studies showing a positive correlation due to increased breeding sites, while others reported no significant association, likely because heavy rainfall can wash away mosquito larvae. Land cover changes, particularly urbanization, were not significantly correlated with dengue incidence, yet they remain an important indirect factor influencing mosquito habitat availability.

Regarding socioeconomic and demographic factors, age showed a positive correlation in multiple studies, suggesting that younger populations may face higher exposure risks due to increased mobility and outdoor activities. Gender was positively correlated in one study, indicating that males may be more exposed to mosquito bites due to occupational and behavioral factors. Occupational exposure was identified as a key risk factor, with outdoor workers being particularly vulnerable to mosquito bites, reinforcing the need for workplace-based vector control measures. Household conditions, such as poor housing infrastructure and inadequate sanitation, were positively correlated with dengue incidence, emphasizing that socioeconomic disparities contribute to increased disease burden. Urbanization and population density were also significant predictors, with studies indicating that densely populated, low-income areas are more susceptible to sustained dengue transmission due to limited access to vector control measures.

The study findings have several critical policy and research implications. Climate-based early warning systems should be integrated into dengue surveillance, given the strong correlations between temperature, humidity, and rainfall with dengue transmission. Targeted vector control measures should focus on urban and high-risk neighborhoods, particularly in low-income and densely populated areas where mosquito breeding is more prevalent. Additionally, workplace-specific prevention strategies are needed to protect outdoor laborers from dengue exposure. Improving housing and sanitation infrastructure can significantly reduce mosquito breeding sites, while public health campaigns should be tailored to specific age and gender groups to enhance dengue prevention efforts.

The table provides strong empirical evidence that dengue transmission is influenced by a combination of climatic, environmental, and socioeconomic factors. The dominance of temperature, humidity, rainfall, and population density as key predictors underscores the critical role of climate variability and urbanization in disease transmission. Furthermore, socioeconomic conditions such as household quality, occupational exposure, and neighborhood status significantly contribute to dengue risk. These findings highlight the need for climate-sensitive health policies, improved urban planning, and targeted vector control programs to mitigate the impact of dengue. Future research should focus on longitudinal data collection, predictive modeling, and climate change projections to develop sustainable dengue prevention strategies. By implementing these evidence-based approaches, dengue control programs can be more effective in reducing disease burden and preventing future outbreaks.

**Table III: Determining the correlation between climatic, environmental, and socioeconomic factors with dengue incidence**

| Factors | Positive correlation | Negative correlation | Non-significant correlation | Explanation |
|---|---|---|---|---|
| **Climatic & Environmental Factors** | | | | |
| ▪ Temperature | 2, 3, 4, 5, 6, 7 | - | 1 | Higher temperatures increase mosquito breeding and virus replication. |
| ▪ Relative Humidity | 2, 3, 4, 6, 7 | 5 | 1 | Increased humidity promotes Aedes mosquito survival and dengue transmission. |
| ▪ Rainfall | 2,6,7 | - | 1,3 | Excessive rainfall creates breeding sites, but heavy floods can wash away larvae. |
| ▪ Land Cover | - | - | 1 | Urbanization affects mosquito breeding habitats. |
| **Socioeconomic & Demographic Factors** | | | | |
| ▪ Age | 1,2 | - | - | Younger populations may have higher exposure risks due to mobility. |
| ▪ Gender | 1 | - | - | Males may be more exposed to mosquito bites due to work environments. |
| ▪ Occupation | 1,2 | - | - | Outdoor workers are at greater risk of exposure. |
| ▪ Household characteristics | 2 | - | - | Poor housing conditions increase breeding site availability. |
| ▪ Urbanization | 2 | - | - | Dense urban areas promote stagnant water collection. |
| ▪ Neighborhood status | 1,3,4 | - | - | Lower-income neighborhoods may have limited vector control measures. |
| ▪ Population density | 4 | - | - | Higher density increases human-vector interactions. |

**Note:** This table presents the associations between climatic, environmental, and socioeconomic variables with dengue cases, highlighting significant positive and negative correlations, as well as non-significant findings. Key environmental factors such as temperature, humidity, rainfall, and land cover are evaluated alongside socioeconomic determinants including age, occupation, urbanization, and neighborhood status. Study IDs (1,2,3, etc) correspond to referenced literature correspond to Table 1, supporting the interpretation of observed correlations.

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## DISCUSSION

Dengue fever remains a significant public health challenge in the Middle East, particularly in Saudi Arabia and Sudan, where the majority of studies have been conducted. The systematic review highlights the complex interplay of climatic, environmental, and socioeconomic factors in shaping dengue transmission in this region. Unlike endemic dengue zones in Southeast Asia and Latin America, the Middle East presents a unique epidemiological profile characterized by arid and semi-arid climatic conditions, rapid urbanization, and increasing population density, which collectively contribute to dengue emergence and outbreaks. The systematic review underscores the strong influence of temperature, humidity, and rainfall on dengue transmission dynamics in the Middle East. Studies such as Al-Nefate et al. and Alkhaldy demonstrate that high temperatures and dry conditions significantly increase dengue risk, likely due to enhanced mosquito vector survival and viral replication rates [7,27]. This finding is consistent with global research that highlights optimal temperature ranges for Aedes mosquito proliferation [19]. However, excessive heat and arid conditions may also limit vector activity, explaining inconsistencies in temperature-related dengue incidence across different studies [31-32].

Rainfall patterns also play a crucial role, as observed in Yasin (2015) and Ahmed et al., where increased precipitation correlated with higher Ae. aegypti densities [26,28]. The presence of water storage practices in urban and peri-urban communities, often necessitated by water scarcity, contributes to artificial breeding sites, which sustain mosquito populations even in dry regions [33]. However, excessive rainfall and flooding can disrupt breeding sites, reducing mosquito density in certain locations [20]. This variability underscores the need for localized climate-adaptive vector control programs. Land cover changes, particularly urbanization and neighborhood characteristics, were also explored. Khormi et al. demonstrated that population density and poor neighborhood conditions were significant predictors of dengue cases, with their geographically weighted regression model achieving a high predictive accuracy (R = 0.80) [25]. These findings align with global research, where rapid, unplanned urbanization leads to increased waste accumulation, inadequate drainage, and artificial water-holding containers, all of which provide ideal conditions for Aedes breeding [34]. However, the lack of direct correlations between land cover and dengue cases in some studies suggests that mosquito adaptation to human-modified landscapes requires further investigation.

Beyond meteorological influences, socioeconomic disparities and demographic characteristics significantly shape dengue transmission risks in the Middle East. Studies such as Seidahmed et al. and Kholedi et al. highlight how lower-income communities and densely populated neighborhoods experience a higher burden of dengue cases, likely due to poor sanitation, limited vector control measures, and inadequate healthcare access [29-30]. These findings reinforce the well-established link between poverty and vector-borne disease burden, where communities with substandard housing, improper waste management, and stagnant water sources serve as persistent mosquito breeding sites. Demographic variables such as age, gender, and occupation were also found to influence dengue risk. Al-Nefate et al. and Kholedi et al. found a positive correlation between age and dengue incidence, suggesting that younger populations are more susceptible due to increased mobility and outdoor exposure [7,29]. Similarly, gender-based differences in exposure were reported, with males exhibiting a higher dengue risk due to occupational factors that increase contact with mosquito habitats. These findings suggest that targeted interventions for high-risk demographic groups should be prioritized in dengue prevention strategies. The urbanization-dengue transmission relationship is particularly relevant in Saudi Arabia, where large-scale infrastructure projects, migration, and urban expansion have transformed city landscapes. Studies such as Khormi et al. and Alkhaldy suggest that dengue is increasingly becoming an urban disease in the Middle East, as seen in Jeddah, Riyadh, and other rapidly growing metropolitan areas [25,27]. High population density, combined with construction-related water accumulation and waste mismanagement, has created new vector breeding grounds, necessitating integrated urban planning and vector control approaches [36-38].

The included studies predominantly utilized cross-sectional designs (42.8%), followed by geospatial and risk modeling studies (28.6%) and longitudinal studies (28.6%). While cross-sectional studies provide valuable snapshot data on dengue epidemiology, their limited temporal scope hinders the ability to assess long-term trends and intervention effectiveness. Geospatial and predictive modeling approaches, such as those employed by Khormi et al. and Seidahmed et al., demonstrate the potential for advanced surveillance and risk forecasting, particularly in identifying high-risk transmission zones [25,30]. However, a notable gap in longitudinal studies was observed, limiting our understanding of how climatic variability and urbanization patterns influence dengue transmission over time. Future research should focus on long-term cohort studies, climate change projections, and machine learning-driven predictive models, which could significantly enhance early warning systems and targeted intervention planning.

The findings of this systematic review emphasize the urgent need for integrated, region-specific dengue control strategies in the Middle East. The strong influence of climate variables suggests that meteorological monitoring and early warning systems should be incorporated into dengue surveillance. Real-time climate data, combined with geospatial mapping of high-risk areas, could enable proactive intervention strategies, such as targeted insecticide spraying and larval source reduction programs. Additionally, the socioeconomic disparities in dengue burden highlight the necessity for community-based interventions. Governments should prioritize vector control measures in lower-income neighborhoods, ensuring that adequate sanitation, proper waste disposal, and effective water storage practices are implemented. Educational campaigns tailored to high-risk groups (outdoor workers, school-aged children, and densely populated communities) could further reduce exposure risks. Given the growing role of urbanization in dengue emergence, urban planning policies should integrate vector control measures. This includes improving drainage systems, implementing stricter building regulations to prevent water stagnation, and enhancing waste management in high-density areas. Additionally, workplace-based vector control strategies could protect occupational groups most vulnerable to mosquito exposure.

This review has several limitations. The number of included studies was relatively small, which may affect the generalizability of the findings. Only studies published in English and Arabic were considered, potentially introducing language bias. In addition, a formal meta-analysis was not feasible due to heterogeneity in study designs, outcomes, and analytical approaches.

## CONCLUSION

Dengue epidemiology in the Middle East is influenced by a combination of climatic, environmental, and socioeconomic factors, necessitating multidisciplinary approaches to vector control and disease prevention. The strong correlation between climate variables and dengue incidence underscores the need for climate-adaptive surveillance strategies, while socioeconomic and urbanization factors highlight the importance of targeted interventions in high-risk communities. Future research should emphasize longitudinal studies, machine learning-driven risk modeling, and climate change projections to develop sustainable and effective dengue prevention strategies. By integrating environmental monitoring, public health policies, and urban planning initiatives, the Middle East can enhance its dengue control efforts and mitigate the long-term impact of vector-borne diseases.

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