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A systematic review of dengue epidemiology in Indonesia: Ten-year trends in case distribution and viral serotype dynamics

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ABSTRACT

Objective: To analyze the trends of dengue virus infection case distribution and dengue virus (DENV) serotype dynamics in Indonesia over the last decade through a spatio-temporal analysis and systematic literature review.

Methods: A mixed-methods approach was used, combining a descriptive spatio-temporal analysis of national dengue surveillance data from 2014-2023 and a systematic literature review of the DENV serotypes distribution in Indonesia. The national dengue surveillance data from 2014-2023 were analyzed through spatio-temporal analysis using QGIS 3.28.3 to visualize the distribution of dengue hemorrhagic fever cases and mortality. The articles for systematic literature review were retrieved from three databases (Scopus, PubMed, and Garuda) within the same period, and their quality was assessed using the Joanna Briggs Institute Critical Appraisal Checklist for cross-sectional and experimental studies.

Results: The highest number of cases occurred in 2016, and the lowest in 2018. The geographic spread of DENV transmission increased over time, reaching 484 affected districts in 2022. The highest case burden consistently occurred on Java Island (>10 000 cases per year). All four serotypes were detected across regions with varying dominance, and DENV-3 was identified as the predominant serotype during the study period. High population density and human mobility were key factors influencing regional differences in serotype distribution, while the strong transovarial transmission capability of DENV-3 may contribute to its persistence within mosquito populations.

Conclusions: Dengue virus infection in Indonesia demonstrates fluctuating trends with an expanding geographic distribution over the past decade. All four DENV serotypes continue to circulate nationwide, with DENV-3 remaining the predominant serotype. Variations in serotype dominance are likely influenced by population density, mobility, as well as the persistence of transovarial transmission within mosquito vectors. These findings highlight the importance of strengthening surveillance systems and implementing targeted control strategies to reduce dengue transmission in Indonesia.

KEYWORDS: DENV infection; Distribution; Indonesia; Serotype

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Summary

Question: How have dengue virus infection case trends and the distribution of dengue virus (DENV) serotypes changed in Indonesia over the past decade?

Findings: Spatio-temporal analysis from 2014 to 2023 revealed fluctuating dengue incidence across Indonesia, with cases reported in all regions and the highest burden consistently observed on Java Island (>10 000 cases annually). All four DENV serotypes circulated nationwide with varying dominance, with DENV-3 remaining the predominant serotype throughout the study period.

Meaning: These results emphasize the importance of enhanced surveillance and targeted control strategies to effectively reduce dengue transmission in Indonesia.

1. Introduction

Dengue virus infection (DVI) is an arboviral disease transmitted by *Aedes* (*Ae.*) *aegypti* and *Ae. albopictus* mosquitoes, involving four antigenically distinct serotypes (DENV-1, DENV-2, DENV-3, and DENV-4) that can cause a clinical spectrum ranging from mild fever to fatal dengue hemorrhagic fever (DHF)[1,2]. Asia bears the highest global burden of dengue, with tropical and subtropical regions experiencing dynamically shifting epidemiology driven by climatic factors, urbanization, and high population mobility[3,4].

Indonesia has faced complex dengue epidemiological challenges since the first cases were reported in Surabaya and Jakarta in 1968, with the disease subsequently spreading to 85.6% of cities across all provinces by 2018[5,6].

East Java Province reported the second-highest number of cases (8 449) with the highest national case fatality (84 deaths) and an incidence rate of 21.4 per 100 000 population[5]. The spatiotemporal heterogeneity of DVI cases in Indonesia is shaped by multifactorial interactions between climatic conditions (rainfall, temperature, humidity), demographics (population density), and socio-economic factors (housing conditions, healthcare access), creating variable transmission risks across regions[7].

Climatic factors influence the mosquito life cycle from egg to adult stage, with rainfall providing breeding sites, optimal temperatures accelerating viral replication and larval development, and humidity enhancing adult vector survival[8,9]. Urbanization creates ideal conditions for dengue transmission by increasing population density, proliferating artificial container habitats, and intensifying human-vector contact[10]. Socio-economic disparities exacerbate transmission risk, with low-income populations facing limited access to healthcare and environments conducive to vector proliferation[11,12].

DENV serotype surveillance in Indonesia remains fragmented and largely limited to sporadic regional studies. Research in Jember reported DENV-4 dominance[13], while a study in Bangkalan documented shifts in serotype dominance from DENV-1 to DENV-2 and back to DENV-1 during 2013-2014 across 17 positive samples[14]. Surabaya, a major metropolitan and endemic area, exhibits serotype dynamics that remain incompletely characterized[15]. A study in Semarang identified the circulation of two serotypes with persistent DENV-2 dominance throughout 2019[16].

The limited availability of national serotype data hampers comprehensive understanding of the spatiotemporal dynamics of DENV serotype distribution, which is critical for outbreak prediction, targeted surveillance strategies, and evidence-based interventions. This study aims to analyze the trends of DVI case distribution and DENV serotype dynamics in Indonesia over the last decade through a systematic literature review and secondary data analysis. The findings are expected to provide an evidence base for the development of a national serotype surveillance policy, spatial risk-based prevention strategies, and an adaptive dengue control framework aligned with Indonesia's evolving epidemiology.

2. Methods

2.1. Study design and setting

This study used a mixed-methods design combining a systematic literature review and descriptive spatial analysis. The study consisted of two main components: (1) a spatio-temporal analysis of national DHF case data from 2014 to 2023 (distribution and risk factor), and (2) a systematic literature review of DENV serotype distribution in Indonesia.

2.2. Spatio-temporal analysis

2.2.1. Population and sampling

The study population comprised all reported DHF cases in Indonesia from 2014 to 2023, obtained from the annual surveillance reports of the Ministry of Health of the Republic of Indonesia.

2.2.2. Data sources

Secondary data on DHF cases were obtained from the Indonesian Health Profile published by the Ministry of Health of the Republic of Indonesia, which is publicly accessible (https://kemkes.go.id/id/category-download/profil-kesehatan). Parameters collected included the number of DHF cases, morbidity ratio, mortality ratio, and geographic coverage of infection per province and district/city.

2.2.3. Data analysis

Spatial analysis was performed using QGIS 3.28.3 to visualize the distribution of DHF cases and mortality. Annual data on risk, mortality, and incidence rates were extracted and categorized into quintile-based groups according to the classification method proposed by Kaligis *et al.*[1]. Risk classification was stratified by quintiles according to annual case numbers: very low (0-1 000 cases), low (1 001-2 000), moderate (2 001-4 000), high (4 001-10 000), and very high (>10 000 cases) per year. Mortality was categorized as minimal (0-10), low (11-30), moderate (31-70), high (71-100), and extreme (>100 deaths) per region per year. Incidence rate trends were analyzed per 100 000 population: <20 (low), 20-49 (moderate), and >49 (high).

2.3. Protocol and registration

The systematic review protocol of this study has followed the protocol of Randles and Finnegan[17]. The results of this study are reported based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. The protocol was registered with PROSPERO (No. CRD420251104809) prior to study initiation.

2.4. Population and sampling

The study population included all reported DHF cases in Indonesia from 2014 to 2023 and scientific publications on DENV serotypes in Indonesia during the same time period. The study sample included publications reporting laboratory-confirmed DENV serotype distribution in Indonesia, with sampling conducted between 2014 and 2023.

2.5. Systematic review search strategy

A literature search was conducted in the Scopus, PubMed, and Garuda Portal databases using a structured search strategy. Data on the distribution of DENV serotypes in Indonesia were obtained from the Scopus, PubMed, and Garuda databases. The data used were from the sampling period of 2014-2023, including locations and the number of cases for all four serotypes. To expand the scope of the study, the search was conducted in Indonesian (Garuda) and English (Scopus, PubMed). The search strategy used a combination of Medical Subject Headings (MeSH) and free-text terms: Scopus [All fields: “Dengue” OR “DENV” AND “Serotype” AND “Indonesia”], PubMed [All fields: “Dengue” OR “DENV” AND “Serotype” AND “Indonesia”], Garuda [Title/Abstract: “Dengue” OR “DENV” AND “Indonesia”]. Additional studies were identified through hand-searching the reference lists of all articles included as eligible in this study.

2.6. Inclusion and exclusion criteria

Inclusion criteria: (1) observational studies, case studies, cohort studies, prospective studies, and cross-sectional studies reporting the distribution of DENV serotypes in Indonesia from 2014 to 2023; (2) serotype confirmation using RT-PCR or enzyme-linked immunosorbent assay (ELISA) with monoclonal antibodies; (3) complete data on all four DENV serotypes; (4) publications in Indonesian or English. Exclusion criteria: (1) review articles, editorials, and commentaries; (2) studies that do not report specific geographic distribution; (3) studies using non-standard serotyping methodology; (4) duplication of data from the same publication.

2.7. Research procedures and data extraction

Article selection was conducted independently by two independent reviewers RK and FMP. Data extraction using a standardized form included: study characteristics [authors, year of publication, location, sampling period (month and year), and number of cases], serotyping methodology, sample size, and distribution of DENV-1 to DENV-4 serotypes.

2.8. Quality assessment

The quality of eligible studies was assessed using critical appraisal, specifically regarding study design and serotyping procedures. To reduce sample selection bias, critical appraisal was conducted to ensure serotyping was performed on blood samples (plasma, serum, and whole blood) collected from individuals with fever at several locations throughout Indonesia. Methodological quality was assessed using the Joanna Briggs Institute Critical Appraisal Checklist for cross-sectional and experimental studies. The evaluation included sample representativeness, validity of the serotyping methodology, and completeness of the data. Disagreements between reviewers were resolved through discussion or consultation with a third reviewer, NW.

2.9. Data analysis

The analysis of serotype distribution was performed descriptively by calculating the relative proportion of each serotype per region and period.

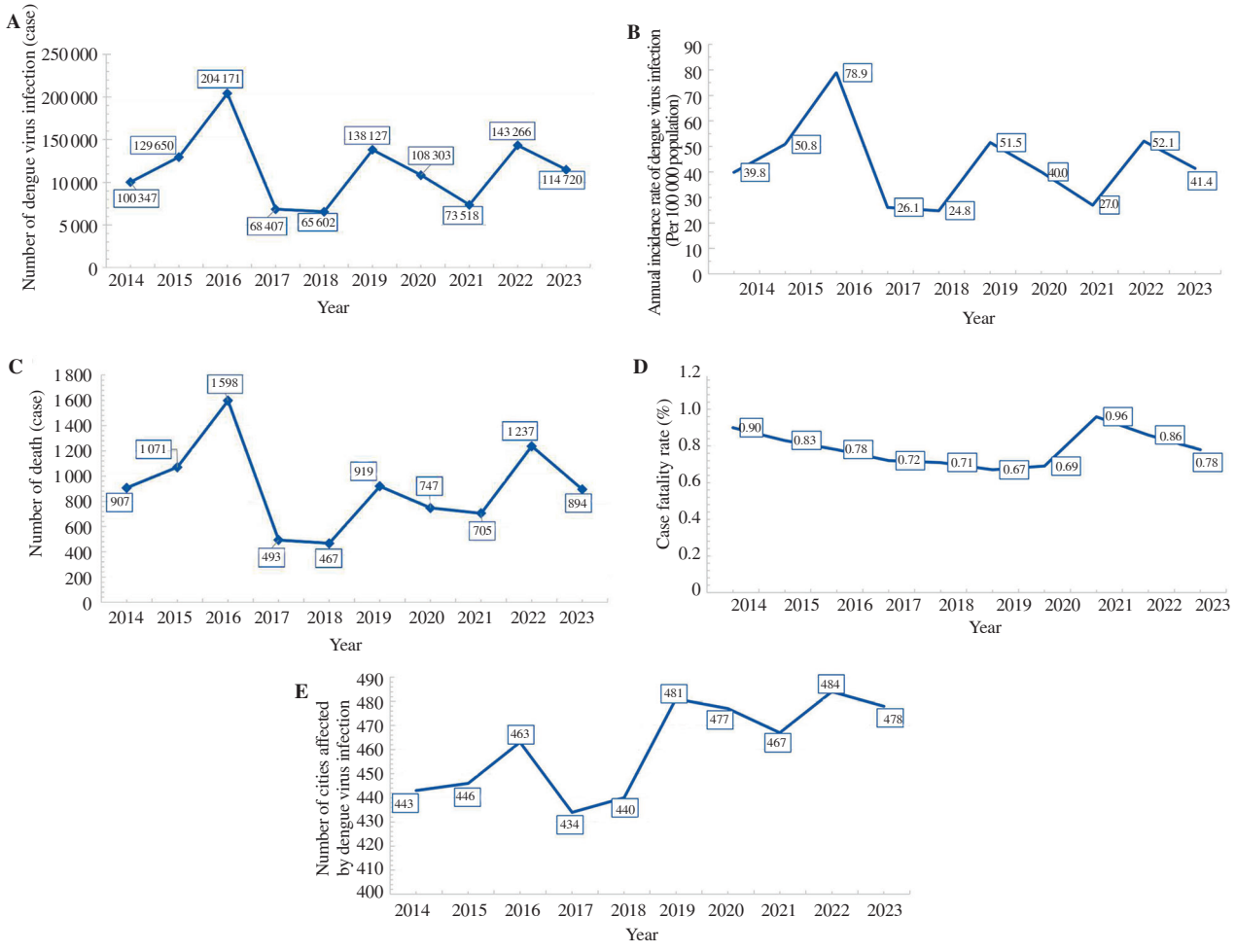

Figure 1. A. Annual trends in reported dengue virus infection cases in Indonesia between 2014 and 2023. B. Annual incidence rate of dengue virus infection in Indonesia during 2014-2023. C. Mortality trends of dengue virus infection in Indonesia from 2014 to 2023. D. Case fatality rate of dengue virus infection in Indonesia from 2014 to 2023. E. Number of cities affected by dengue virus infection in Indonesia from 2014 to 2023.

3. Results

3.1. Trends and incidence rate dynamics of dengue virus infection cases in Indonesia, 2014–2023

Since the first dengue infection cases were reported in Jakarta and Surabaya in 1968, the number of DVI cases in Indonesia has shown fluctuating trends over time. Our analysis of data from the past decade indicates that the highest incidence occurred in 2016, whereas the lowest was recorded in 2018 (Figure 1A).

When examining the provincial-level trend dynamics of DVI cases in Indonesia, several provinces in Java, Sumatra, and Kalimantan continue to report very high case numbers (>10 000 cases per year). In contrast, low to very low case counts are more commonly observed in the eastern regions of Indonesia (Figure 2).

The incidence rate (IR) is one of the key indicators for monitoring and controlling DVI. Over the past decade, the IR of DVI cases in Indonesia has remained markedly high compared to the national target of <10 cases per 100 000 population. The highest incidence rate in the last decade was recorded in 2016, at 78.9 cases per 100 000 population, while the lowest was observed in 2018, at 24.8 cases per 100 000 population (Figure 1B).

3.2. Dynamics of mortality and case fatality rate of dengue virus infection in Indonesia, 2014–2023

The number of DVI-related deaths in Indonesia has shown fluctuating patterns over the past decade, closely mirroring the overall case trends. The highest mortality was recorded in 2016, with 1 598 deaths out of 204 171 DVI cases, whereas the lowest

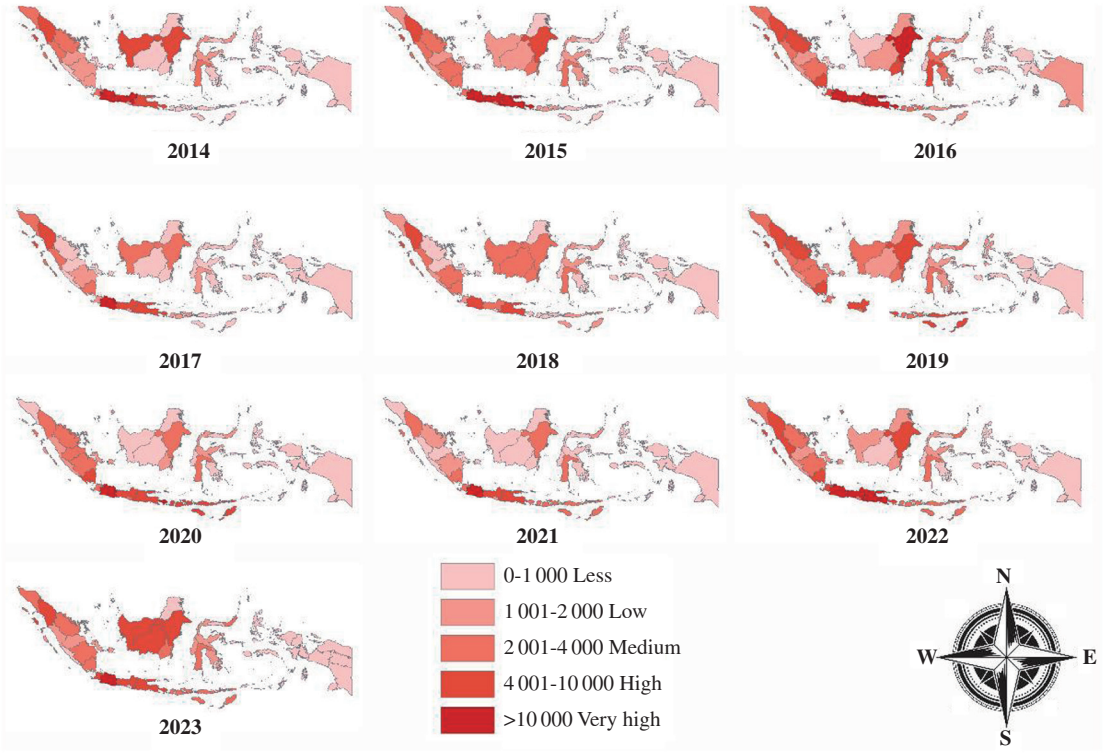

Figure 2. Spatiotemporal dynamics of dengue virus infection across provinces in Indonesia, 2014-2023. The reported mortality represents the total number of dengue-related deaths within one year in each respective region.

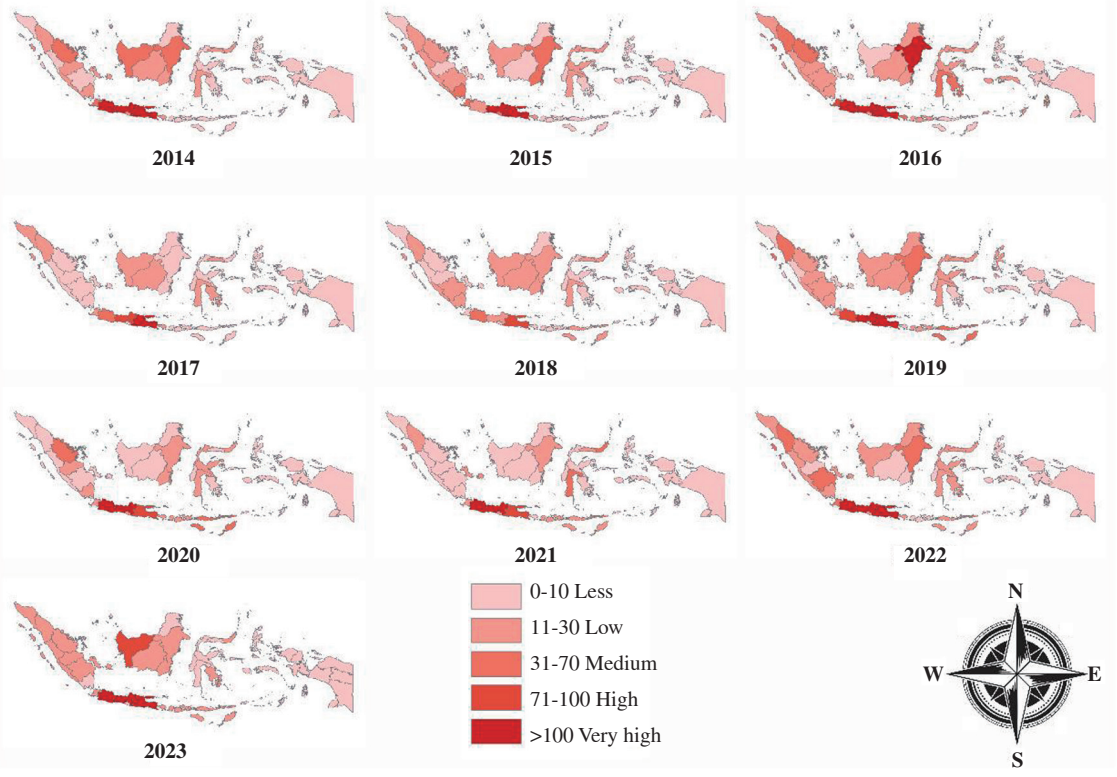

Figure 3. Spatiotemporal dynamics of dengue virus infection mortality in Indonesia from 2014 to 2023. The reported mortality represents the total number of dengue-related deaths within one year in each respective region.

Table 1. DENV serotype distribution in Indonesia, 2014-2023.

Year	Location	Number of dengue infection cases	Serotype, *n* (%)				Predominant serotype	Ref.
			DENV-1	DENV-2	DENV-3	DENV-4		
2014	Banjarmasin	37	3 (8.0)	14 (38.0)	11 (30.0)	9 (24.0)	DENV-2	[18]
2014	Indonesia	126	34 (27.0)	23 (18.2)	37 (29.4)	3 (2.4)	DENV-3	[19]
2014	Indonesia	776	101 (13.1)	131 (16.9)	104 (13.5)	32 (4.1)	DENV-2	[20]
2014-2015	Jambi	94	62 (66.0)	23 (24.5)	2 (2.1)	5 (5.3)	DENV-1	[21]
2015	Indonesia	150	31 (20.7)	25 (16.7)	71 (47.3)	4 (2.7)	DENV-3	[19]
2015	Aceh	29	11 (40.7)	7 (25.9)	7 (25.9)	0 (0.0)	DENV-1	[22]
2015	Jawa Tengah	47	11 (23.4)	5 (10.6)	26 (55.3)	4 (8.5)	DENV-3	[23]
2015	Denpasar	99	14 (32.6)	12 (46.2)	41 (55.4)	6 (10.0)	DENV-3	[24]
2015	Gianyar	106	29 (67.4)	14 (53.8)	33 (44.6)	0 (0.0)	DENV-3	[24]
2015-2016	Balikpapan	51	23 (45.0)	2 (3.9)	26 (50.9)	0 (0.0)	DENV-3	[25]
2015-2016	Samarinda	81	12 (14.8)	12 (14.8)	55 (67.9)	2 (3.9)	DENV-3	[25]
2015-2017	Bali	133	11 (9.2)	58 (48.7)	43 (36.1)	4 (3.4)	DENV-2	[26]
2016	Banjarmasin	52	8 (15.0)	15 (29.0)	11 (21.0)	18 (35.0)	DENV-4	[18]
2016	Indonesia	151	21 (14.0)	33 (21.8)	64 (42.4)	11 (7.3)	DENV-3	[19]
2016	Jambi	27	2 (10.5)	11 (57.9)	5 (26.3)	1 (5.2)	DENV-2	[22]
2016	Surabaya	46	8 (17.4)	8 (17.4)	29 (63.0)	0 (0.0)	DENV-3	[27]
2016-2017	Yogyakarta	197	87 (44.2)	10 (5.1)	88 (44.7)	12 (6.1)	DENV-3	[28]
2017-2019	Batam	100	34 (34.0)	33 (33.0)	9 (9.0)	24 (24.0)	DENV-1	[29]
2017-2019	Banjarmasin	102	23 (22.6)	9 (8.8)	56 (54.9)	9 (8.8)	DENV-3	[29]
2017-2019	Ambon	27	20 (74.1)	5 (18.5)	0 (0.0)	1 (3.7)	DENV-1	[29]
2018	Banjarmasin	56	5 (9.0)	13 (23.0)	22 (39.0)	16 (29.0)	DENV-3	[18]
2018-2019	Malinau	162	32 (19.8)	64 (39.5)	35 (21.6)	22 (13.6)	DENV-2	[30]
2018-2019	Tarakan	108	30 (27.8)	33 (30.5)	31 (28.7)	11 (10.2)	DENV-2	[30]
2019	Manado	79	10 (12.7)	5 (6.3)	60 (75.9)	4 (5.1)	DENV-3	[31]
2019-2020	Jember	62	3 (4.9)	3 (4.9)	12 (19.7)	43 (70.5)	DENV-4	[13]
2019-2020	Jember	61	3 (4.9)	3 (4.9)	12 (19.7)	43 (70.5)	DENV-4	[32]
2020	Maumere	71	2 (2.8)	2 (2.8)	62 (87.3)	5 (7.0)	DENV-3	[33]
2021	Lampung	37	3 (8.1)	17 (45.9)	12 (32.4)	1 (2.7)	DENV-2	[34]
2022	Bali	48	5 (10.4)	14 (29.2)	28 (58.3)	0 (0.0)	DENV-3	[35]
2022	Sulawesi Utara	10	7 (70.0)	2 (20.0)	0 (0.0)	1 (10.0)	DENV-1	[36]
2023	Jember	67	13 (13.4)	13 (13.4)	23 (34.3)	4 (6.0)	DENV-3	[37]

mortality occurred in 2018, with 467 deaths out of 65 602 DVI cases (Figure 1C).

When examining the mortality trends of DVI in Indonesia, Java Island consistently accounts for very high mortality (>100 deaths per year). Additionally, a notable peak in mortality was also recorded in East Kalimantan Province in 2016 (Figure 3).

The case fatality rate (CFR) is one of the key indicators for monitoring and controlling DVI. Over the past decade, the annual CFR consistently exceeded the 0.7% threshold set by Indonesia's National Dengue Control Strategy. Nationally, the CFR of DVI cases in Indonesia from 2014 to 2023 remained relatively low, as it was below 1% (Figure 1D). However, at the provincial level, several provinces exhibited high CFR values (>1%).

3.3. Number of districts/cities affected by DVI in Indonesia

As a tropical country, nearly all regions of Indonesia are endemic for dengue virus (DENV). Annual fluctuations are observed in the number of reported cases and deaths, accompanied by year-to-year variation in the number of districts/cities affected by DVI. Over the past decade, the geographic spread of DENV infection has expanded, as reflected by the increasing number of affected districts/cities (Figure 1E).

3.4. Distribution of DENV serotypes in Indonesia

Data on DENV serotypes in Indonesia were systematically collected from full-text published articles identified through literature searches in three major databases: Scopus, PubMed, and Garuda. The results of study selection process are presented following PRISMA reporting guidelines, as shown in Figure 4. A total of 366 articles were initially identified from the databases. After removing 217 duplicate articles, 149 articles were screened based on their titles and abstracts. Subsequently, 36 full-text articles were assessed for eligibility, resulting in 21 studies that met the inclusion criteria and were included in the final analysis. The distribution of DENV serotypes reported in the included studies is presented in Table 1. Overall, DENV-3 was identified as the predominant serotype

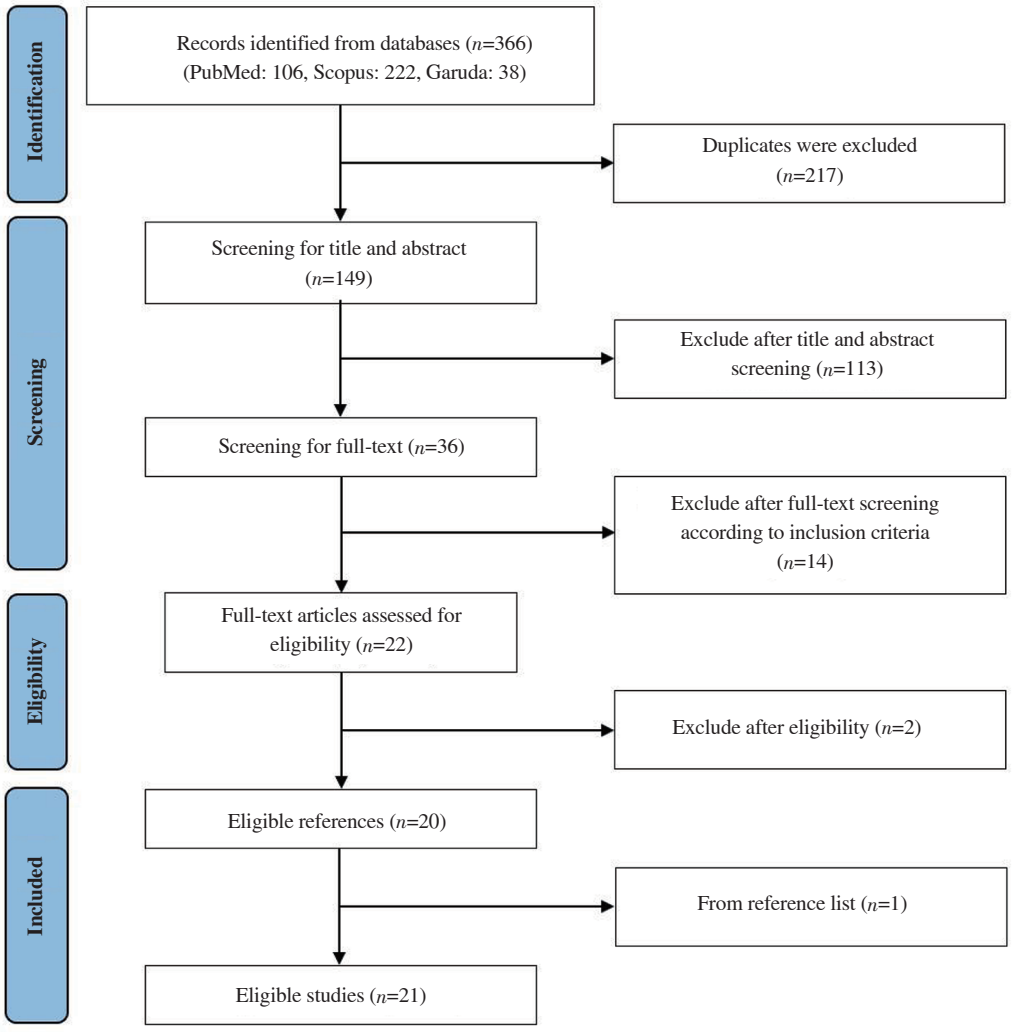

Figure 4. PRISMA flow diagram showing the selection and inclusion process of studies in the systematic review.

(39.2%), followed by DENV-1 (25.4%), DENV-2 (23.9%), and DENV-4 (11.4%), indicating that DENV-3 was the most frequently reported serotype circulating in Indonesia during the study period.

4. Discussion

DVI is endemic in more than 100 tropical and subtropical countries. DVI is widely distributed worldwide and frequently causes outbreaks. Most dengue cases occur in tropical and subtropical regions. In recent years, not only has the number of cases increased, but the geographic range has also expanded beyond traditional tropical and subtropical regions, such as in the United States and Europe[38,39]. Climate change driven by global warming contributes to the spread of dengue beyond its traditional regions. Rainfall, humidity, and ambient temperature directly affect the mosquito life cycle at all stages and can indirectly influence dengue transmission[40–42].

For more than 50 years, DVI cases in Indonesia have shown a sharp annual increase, rising from only 0.05 cases per 100 000 population in 1968 to 77.96 cases per 100 000 population in 2016. The incidence rate of DVI in Indonesia exhibits a unique cyclical pattern, with case peaks occurring approximately every 6-8 years. Major peaks were recorded in 1973, 1988, 1998, 2009, and 2016[43]. The Government of Indonesia, through the Ministry of Health, publishes the annual "Profil Kesehatan Indonesia," which reports nationwide health statistics, including DVI. This report serves as an important tool for evaluating disease trends and guiding policy development to address public health challenges. For dengue virus infection, the reported data include the annual number of cases, incidence rate, and CFR for each province.

4.1. Dynamics of case distribution and incidence rate of dengue virus infection in Indonesia

In Indonesia, DVI cases are monitored through the annual "Indonesia Health Profile" published by the Ministry of Health. Case data are presented as the number of reported cases and the incidence rate. The incidence rate is a fundamental concept in infectious disease epidemiology, representing the frequency of new infections per population unit over a specified time[44]. According to the Indonesia Health Profile, DVI in Indonesia has shown fluctuating distribution dynamics over the past decade, with dengue cases reported in all provinces. DVI cases have been reported in every Indonesian province since 1994[45]. This pattern reflects the nationwide endemicity of dengue virus, with year-round transmission and seasonal peaks occurring during the rainy season[33,46]. The highest number of cases was recorded in 2016, with 204 171 cases. Provinces with very high case counts (>10 000 cases/year) were consistently dominated by several provinces in Java over the last decade, while some provinces in Sumatra and Kalimantan also reported very high case counts.

The dominance of DVI incidence in Java is closely linked to its large population. Java is the most densely populated island in Indonesia, accounting for approximately 51% of the total population, or 151.59 million people[47]. Moreover, Java is the administrative and economic center of the country, with major metropolitan cities such as Jakarta and Surabaya. High population mobility in these areas contributes to increased dengue transmission risk[48,49]. Regions with dense populations and closely spaced housing facilitate more efficient person-to-person dengue virus transmission *via* mosquito vectors, leading to higher case numbers compared to sparsely populated areas. This pattern also relates to the flight range and vertical transmission of the mosquito vector. *Aedes* mosquitoes have limited flight capacity, typically traveling no more than 100 meters from their breeding sites[50]. Furthermore, vertical transmission allows DENV to persist within mosquito populations across multiple generations without requiring human infection, enabling the virus to survive even during periods of low case numbers[51,52].

By 2022, nearly all provinces in Kalimantan reported very high numbers of DVI cases, similar to those observed on Java Island. However, all provinces in Kalimantan recorded fewer DVI-related deaths compared to those in Java. Several factors may explain this pattern. Surveillance system limitations remain a major challenge in dengue epidemiology. The lower number of reported DVI deaths in Kalimantan may be attributable to passive surveillance practices, which can underestimate the true burden of cases and deaths due to underreporting[53]. Household environmental conditions, such as house layout, inter-house distance, and ambient temperature, indirectly influence dengue transmission and recovery outcomes. According to Ridha *et al.*[54], dengue incidence in a specific area can be influenced by surrounding areas with active transmission. In Java, houses are generally located closer to each other, while in Kalimantan, houses tend to be spaced further apart. This spacing may create a healthier environment for individuals recovering from dengue. Socio-demographic behaviors and lifestyle factors may also contribute to regional differences in DVI mortality. Differences in living conditions, cultural practices, and community habits between Kalimantan and Java likely influence the observed disparities in case outcomes[55].

Eastern Indonesia, particularly the provinces of Papua Island, tends to report low case numbers. A study by Agustiningsih *et al.*[56] documented the first laboratory-confirmed dengue cases in Papua in 2012, identified in Mimika, Papua Province. This study analyzed 13 serum samples from suspected dengue patients, all of which were identified as dengue virus serotype 3 (DENV-3). The low reported case numbers in Papua are likely due to underreporting and undiagnosed infections. Furthermore, since malaria and HIV are considered the primary public health concerns in Papua, dengue is not regarded as a priority disease. Local hospital confirmation of dengue infection is often limited to clinical assessment and platelet count (thrombocytopenia), which may overlap with other viral infections and lead to misdiagnosis.

4.2. Dynamics of mortality and case fatality rate of dengue virus infection in Indonesia

The mortality of DVI in Indonesia has exhibited fluctuating patterns over the past decade. The highest mortality was recorded in 2016, with 1 598 deaths. Provinces with very high mortality (>100 deaths/year) were consistently dominated by several provinces in Java during this period. Meanwhile, the CFR of DVI in Indonesia has shown a gradual decline over the last decade, although intermittent fluctuations occurred in certain years. The DVI CFR decreased by more than 20% compared to the 1960s, reaching 0.78% in 2016[7]. This decline indicates the success of improved clinical management and preventive strategies, as increasing reported case numbers were accompanied by a lower proportion of deaths[57]. Dengue preventive programs in Indonesia include surveillance systems, case management, vector control, and community behavior change initiatives. Vector control efforts are integrated with behavioral interventions through the "3M Plus" surveillance approach, which encourages communities to routinely eliminate mosquito breeding sites[58].

The CFR curve sharply increased to 0.96% in 2021, coinciding with the COVID-19 pandemic in Indonesia. During this period, the DVI CFR rose 1.5-fold. This increase may be attributed to the simultaneous circulation of arbovirus and coronavirus, which

facilitated human-to-human transmission chains[59–61]. Khurram *et al.*[62] reported that patients with concurrent dengue and COVID-19 infection have a higher mortality rate than those with COVID-19 alone, contributing to an increased global health burden[63]. Ideally, the CFR of dengue infection should remain below 1%[57]. In 2021, 13 provinces recorded high CFR values (>1%), exceeding the 0.7% threshold set by the National Dengue Control Strategy[64]. Central Java, Gorontalo, and North Sulawesi were the three provinces with the highest CFRs, at 2.71, 2.69, and 2.68, respectively[65].

A study by Muna *et al.*[66] identified several factors contributing to the high CFR in Central Java. Low educational background, poor nutritional status, and inadequate mosquito eradication practices were the three most significant factors associated with DVI cases in this province. In addition, densely packed residential areas and favorable environmental conditions supported mosquito proliferation as DENV vectors. Conversely, education level was not a significant factor for DVI incidence in Gorontalo Province[67]. An Average Nearest Neighbor analysis by Hambali *et al.*[68] demonstrated that densely clustered residential areas were the primary factor driving DENV spread in Gorontalo. This was further supported by environmental conditions, such as annual rainfall, elevation, and humidity, which created optimal mosquito breeding conditions[69]. Rainfall was also a key driver of high DVI incidence in North Sulawesi, where high population density and human mobility further contributed to disease transmission[70–72].

The highest number of dengue-related deaths was recorded in West Java Province, with 212 deaths in 2021 out of 23 959 reported DVI cases[65]. Furthermore, dengue-related deaths in Java between 2014 and 2023 remained consistently high (>100 deaths). High population density and mobility are the main factors underlying the elevated mortality in Java. Dense populations facilitate dengue transmission through increased contact between infected mosquitoes and human hosts[73–75], while human mobility accelerates the spatial spread of DENV[76]. Dengue-related deaths are predominantly observed in elderly patients, severe dengue cases, and those with secondary infections[77]. This aligns with the findings of Mahmood *et al.*[78], which demonstrated that patients over 45 years old, leukocytosis, and acute kidney injury were significant risk factors for dengue mortality. Other studies have also revealed an association between age, delayed treatment, the occurrence of dengue shock syndrome, and mortality in dengue patients[79].

4.3. Expansion of dengue virus infection areas in Indonesia

The expansion of DENV infection areas in Indonesia can be observed through the increasing number of affected cities. Over the past decade, the number of cities reporting DENV infections has fluctuated, with the highest number recorded in 2022, totaling 484 cities. This number represents an increase compared to previous years, followed by a slight decline to 478 cities in 2023. According to Irawan and Hayati[80], this geographic expansion is primarily driven by population mobility and increasing population density. High human mobility facilitates the spatial spread of DENV infections. In addition, population movement is closely related to the dominance of different DENV serotypes between regions. Human mobility represents a critical yet often underestimated risk factor in dengue epidemiology. Studies have shown that individuals traveling between their homes, workplaces, and public areas contribute to local dengue transmission at the community scale. Moreover, long-term migration also affects transmission dynamics: migrants moving from rural or low-transmission areas to urban centers may be more susceptible to infection[81].

On the other hand, increasing population density also contributes to the rising number of DVI cases in certain regions. High population density has been associated with an increase in dengue incidence, as reported in several population clusters in Sri Lanka and Bangladesh[82]. Dense urban environments facilitate frequent interactions between humans and vectors such as *Ae. aegypti* and *Ae. albopictus*, thereby increasing the likelihood of viral transmission[83]. Furthermore, high-density areas often face environmental management challenges, such as water stagnation and waste accumulation, which provide ideal mosquito breeding sites. These conditions sustain more intense dengue transmission cycles and enhance the risk of expanding dengue-endemic areas[84].

Environmental conditions are key risk factors for the expansion of DENV infection areas. Indonesia's tropical climate, with high temperature and humidity, is highly favorable for mosquito breeding[85,86]. Annual rainfall also contributes to the availability of mosquito habitats. During the rainy season, mosquito populations increase as eggs hatch upon the flooding of breeding sites. This scenario leads to a higher vector population and increased risk of dengue virus transmission and geographic spread[8]. In addition, deforestation indirectly influences the environmental conditions by disrupting natural ecosystems, forcing mosquitoes to move closer to human settlements[87].

4.4. Dynamics of DENV serotype distribution in Indonesia

The first dengue cases in Indonesia were reported in Surabaya and Jakarta in 1968, with a notably high CFR of 41.38%. Since then, dengue has become a persistent global health challenge[6,88]. DENV infection has been reported in all Indonesian provinces since 2014, and by 2019, dengue cases were detected in 481 out of 514 cities. Over the last five decades, dengue incidence has increased

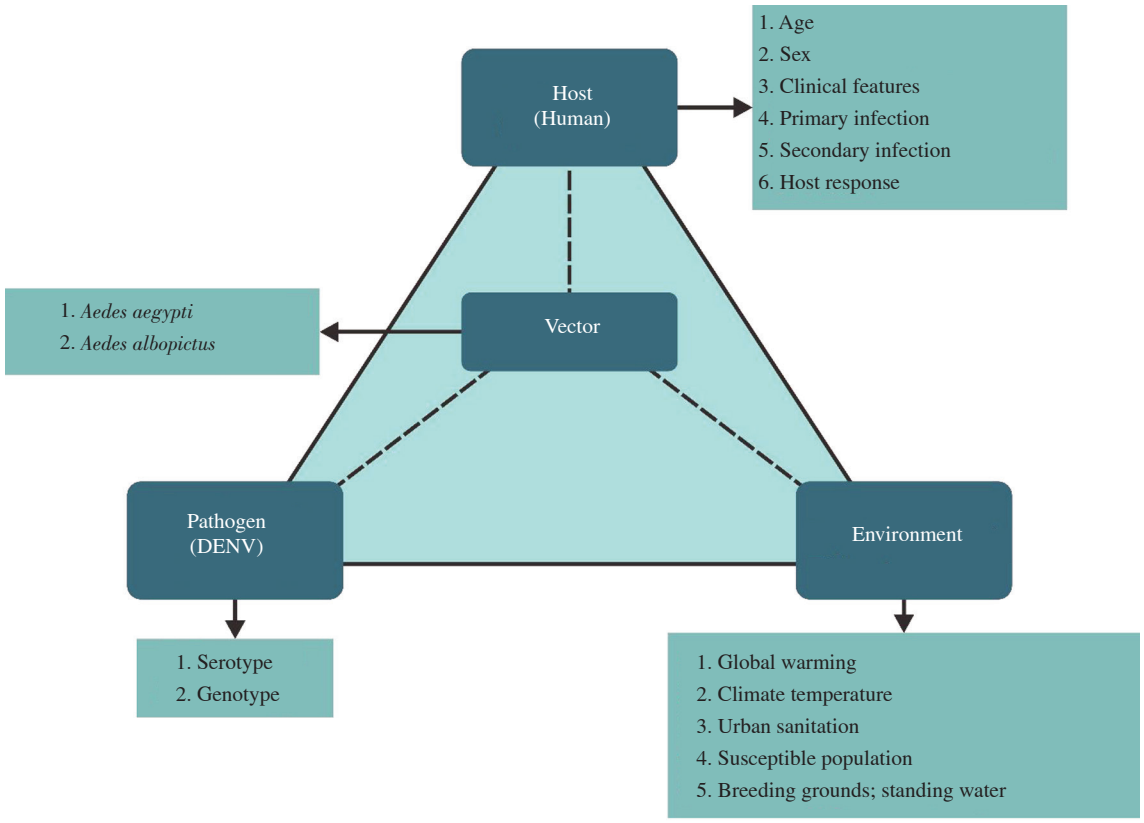

Figure 5. Epidemiological triad of dengue virus infection based on Firdous *et al*[119] and Rao *et al*[120].

substantially, with the highest peaks recorded in 2009 and 2016[7]. All four DENV serotypes have been documented to circulate widely across Indonesia[29,33,37]. Serotype dominance varies across regions and over time. Several studies have demonstrated that shifts in circulating serotypes are associated with outbreak surges, highlighting the importance of population immunity in dengue epidemic dynamics[89,90].

This study utilized 21 eligible and credible sources to analyze the dynamics of DENV serotype distribution in Indonesia. All studies reported spatiotemporal variations in serotype dominance. Our systematic literature review indicated that serotype shifts have occurred in Indonesia over the last decade. Overall, DENV-3 was the most dominant serotype in this period, followed by DENV-1, DENV-2, and DENV-4. In 2014, DENV-2 and DENV-3 were the most prevalent serotypes, in contrast to Singapore, where DENV-1 predominated throughout the same year[91]. Historically, DENV-2 has circulated in Southeast Asia since 1944, first reported in Papua New Guinea and Indonesia, followed by Malaysia and Thailand in the early 1960s, China, India, and Singapore in the 1970s, and Central America in the 1980s. DENV-3 has been globally widespread since its first report in Southeast Asia in 1953, with sporadic cases documented in Africa since that same year[92].

DENV-2 has been a major contributor to severe dengue in Cuba, Thailand, and Malaysia, with several studies linking DENV-2 to fatal dengue, particularly in children[93,94]. In Indonesia, DENV-3 is the predominant serotype associated with severe dengue[92,95]. Multiple studies suggest that infections caused by DENV-2 and DENV-3 are correlated with more severe clinical manifestations compared to other serotypes[96]. DENV-2 infection displays a wide clinical spectrum, including dengue hemorrhagic fever, symptomatic dengue fever, and severe dengue shock syndrome[97], while DENV-3 can cause hemorrhagic manifestations even in primary infections[98]. Lovera *et al.*[96] reported that abdominal pain is more often associated with DENV-2 infection, whereas myalgia and headache are commonly linked to DENV-3. Narvaez *et al.*[99] further highlighted that DENV-3 is associated with the highest severity in both primary and secondary infections, whereas DENV-2 is frequently linked to DHF and DSS in secondary cases. These serotype shifts are epidemiologically significant because both DENV-2 and DENV-3 have been implicated in major DHF outbreaks[100].

DENV-1 and DENV-4 have also demonstrated transient regional dominance. Serological surveys indicate that DENV-1 was the

dominant serotype in the late 1980s, alongside DENV-2, before being replaced by DENV-3[101]. DENV-1 re-emerged as the dominant circulating serotype in Indonesia from 2009 to 2012, after which all serotypes began alternating in dominance across different areas[31]. Furthermore, DENV-1 and DENV-2 remain the most prevalent serotypes across Southeast Asia[102]. Additional studies have shown DENV-1 dominance in Singapore and Pakistan, while DENV-2 predominates in Singapore, Thailand, Sri Lanka, and China[103]. DENV-4 consistently demonstrates the lowest prevalence in Indonesia according to multiple epidemiological studies[35,103]. However, DENV-4 has been the primary serotype responsible for most dengue cases in specific local outbreaks, such as Banjarmasin in 2016[18] and Jember during 2019-2020[13,32]. Its low prevalence in Indonesia may be related to pre-existing heterologous antibodies in secondary infections that cross-neutralize this serotype. Moreover, DENV-4 is hypothesized to share substantial antigenic similarity with other serotypes, particularly DENV-2, enabling partial recognition by cross-reactive neutralizing antibodies[35].

Serotype dominance in specific locations and time periods is strongly associated with human activity and mobility[104]. Vazquez-Prokopec *et al.*[105] emphasized that the complexity of dengue transmission patterns is largely driven by human movement. Population mobility facilitates the introduction of DENV into previously non-infected areas[106]. Furthermore, alternating serotype dominance is also influenced by the persistence of dengue virus within vector populations before human transmission occurs. Viral persistence through vertical transmission (transovarial transmission) allows the virus to survive across mosquito generations, serving as a natural environmental reservoir[107,108]. Previous studies demonstrated that DENV-1 can persist until the first mosquito generation, DENV-2 until the fifth, DENV-3 until the seventh, and DENV-4 until the third generation, allowing sustained circulation even in the absence of human hosts[109].

4.5. Risk factors for dengue virus transmission in Indonesia

The risk factors for dengue virus (DENV) transmission are closely related to the concept of the epidemiological triad. The epidemiological triad theory explains that the occurrence of a disease is influenced by the interaction of three essential components: the agent (pathogen), the host, and the environment, which are typically illustrated as a triangular model (Figure 5). Based on this concept, dengue virus infection occurs when there is an imbalance among host factors (human susceptibility), the causal agent (DENV), and environmental conditions that facilitate transmission.

Environmental factors facilitate contact with the agent, encompassing physical, social, and biological environments. Physical environmental factors influencing dengue virus (DENV) infection cases include household layout, type of water storage containers, frequency of container cleaning, availability of container lids, altitude, and climate[110]. Indonesia's tropical climate, characterized by year-round rainfall and warm temperatures, represents an important environmental factor in dengue virus transmission. High-intensity rainfall throughout the year increases water accumulation, providing breeding sites for *Ae. aegypti* and *Ae. albopictus*, the primary vectors of dengue virus. Optimal environmental temperatures (approximately 25-30 ℃) accelerate the gonotrophic cycle of mosquitoes and viral replication within the vector, thereby enhancing transmission capacity[8,111,112]. Studies by Mamenun *et al.*[7] and Xu *et al.*[9] demonstrated that increases in temperature and humidity are positively correlated with the incidence of dengue in Indonesia. This phenomenon explains the rise in case numbers coinciding with the rainy season in most DENV-endemic regions.

Areas with high population density also increase the risk of dengue transmission. High-density populations facilitate more frequent contact between humans and vector mosquitoes, thereby increasing the likelihood of viral transmission[83]. In urban areas, the accumulation of garbage, clogged drainage systems, and the use of open water containers create potential mosquito habitats. A spatial analysis by Norjanah and Ridha[82] demonstrated a positive correlation between population density and dengue incidence in South Kalimantan. Unplanned urbanization without proper environmental management can expand dengue endemic areas into peri-urban and suburban regions. However, low-density areas remain at risk if human activity and mobility are high[113].

Human activity, as the host factor, also influences dengue virus transmission. A study by Sofia *et al.*[114] showed that individuals with low physical activity levels (longer sedentary durations) had a 3.3-fold higher likelihood of getting mosquito bites than more active individuals. Another study by Ismail *et al.*[115] found that the habit of sleeping in the morning (5:00-11:00) increased the risk of mosquito bites by 6.97-fold, corresponding to the peak activity of *Ae. aegypti*, which occurs a few hours after sunrise or before sunset. Deforestation also contributes to DENV transmission risk by disrupting natural ecosystems and forcing mosquitoes to seek alternative habitats closer to human settlements[87]. High human mobility into and out of urban areas is closely associated with the dominance of DENV serotypes in one region that differ from those in other regions[80]. Furthermore, host-related factors are strongly linked to socioeconomic and behavioral aspects. Socioeconomic disparities, such as unequal access to clean water, poor sanitation, and limited access to healthcare, contribute to more severe dengue outcomes[116]. Additionally, education level, knowledge, and income are directly correlated with dengue preventive behaviors[117]. The role of socioeconomic factors is increasingly recognized as critical in local DENV risk, where worsening socioeconomic conditions and

a lack of public knowledge substantially increase the risk of dengue infection[118].

This study highlights the dynamics of DENV incidence rates and mortality patterns in Indonesia, along with the distribution and predominance of DENV serotypes and associated risk factors. However, several limitations should be considered when interpreting these findings. First, the literature search was limited to three databases (Scopus, PubMed, and Garuda), which may have resulted in the exclusion of relevant studies indexed in other databases. In addition, variations in study design, sampling strategies, and diagnostic methods among the included articles may have introduced heterogeneity in the reported results. Therefore, the findings of this review should be interpreted with caution. Future studies incorporating broader data sources and more standardized methodologies are recommended to provide a more comprehensive understanding of DENV serotype circulation in Indonesia.

5. Conclusions

Over the past decade, the epidemiology of dengue in Indonesia has exhibited a dynamic pattern, characterized by fluctuations in case numbers and shifts in the dominant dengue virus serotypes across different regions. Case distribution tends to increase in densely populated areas and in environments conducive to the proliferation of *Ae. aegypti* and *Ae. albopictus* vectors. Shifts in serotype dominance, particularly among DENV-1, DENV-2, and DENV-3, may influence transmission patterns and disease severity, posing a risk of recurrent outbreaks. These findings highlight the importance of strengthening serotype-based surveillance, environmental management, and health system preparedness in addressing the dynamic epidemiology of dengue in Indonesia. Moving forward, we recommend that dengue control efforts focus on enhancing integrated surveillance, including continuous serotype monitoring for the early detection of shifts in serotype dominance. Community-based vector control programs should also be reinforced through health education promoting clean and healthy living behaviors, environmental management, and the adoption of innovative mosquito control technologies. Furthermore, multisectoral collaboration involving the health, education, environmental, and governmental sectors is essential to establish comprehensive prevention policies and strategies.

Conflict of interest statement

The authors declare that they have no conflict of interest.

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Authors' contributions

All contributors participated actively in the preparation of this manuscript and approved the final version. NW was primarily responsible for the conceptualization and design of the study, defining the intellectual content, conducting the literature review, performing data acquisition and analysis, and drafting the initial manuscript. RK and FMP contributed to the literature search, data collection, and data analysis, as well as manuscript editing. FS assisted in data acquisition, data analysis, and manuscript preparation. THS supported the literature search, data analysis, and critical manuscript editing. IMDMA contributed to manuscript editing and critical review to improve the scientific quality and clarity of the manuscript. DH contributed to the study concepts and design, critically reviewed the manuscript, and served as the guarantor of the work, taking responsibility for the overall integrity and accuracy of the content.

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