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(Review Article)

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Spatial analysis in epidemiological studies of dengue: A systematic review and meta-analysis

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Abstract

Background: Dengue is a serious tropical disease caused by the mosquito-borne dengue virus (DENV). Over the last 50 years, the incidence of dengue fever (DF) and dengue fever and dengue hemorrhagic fever (DHF) worldwide has increased by 50-fold and 2.5 billion people currently live in dengue-endemic regions. This study reports a systematic review and meta-analysis of different types of applications offered by spatial analysis in epidemiological studies of dengue.

Materials and methods: A comprehensive literature search of Web of Science, SCOPUS, Google Scholar, and PubMed were conducted up to December 2023. A total of three sub-sections, namely spatial analysis of points, spatial analysis of area data, and software programs used for spatial analysis of dengue cases, will be presented in this review.

Results: It was found that spatial analysis can effectively support the study of dengue fever and dengue hemorrhagic fever such as to investigate spatial patterns, hotspot, spatial clustering, the spread, transmission of dengue fever and dengue hemorrhagic fever and it's affecting factors.

Conclusion: applications of spatial analysis can provide important information and contribute to development of effective measurements to control and prevent the dengue fever and dengue hemorrhagic fever transmission. Finding in this study provide an insight into how to use different techniques in the study of dengue fever and dengue hemorrhagic fever.

Keywords: Spatial analysis; Epidemiological studies; Dengue fever; Systematic review; Meta-analysis**.**

1. Introduction

Dengue is a mosquito-borne viral disease caused by infection with any of four dengue virus (DENV) serotypes (DENV-1 to DENV-4) (1). With an estimated 390 million annual infections in 2010, of which 96 million are with clinical manifestations, dengue is a major public health burden, notably in tropical and sub-tropical regions of the world (2,3). Dengue, encompassing both dengue fever and dengue hemorrhagic fever, is the virus that spreads most quickly through mosquito bites and is becoming a bigger global public health concern (4). The incidence of dengue has tripled over the last 50 years, coinciding with an increase in the spatial shift from urban to rural areas (5,6). Current estimates place the number of people at risk in tropical and subtropical regions at 2.5 billion, with at least 100 nations having dengue endemicity and an annual incidence of roughly 50 million cases of the disease (4). Due to its disruption and quick spread over national borders, dengue was listed as a disease that may qualify as a public health emergency of international concern under the 2005 revisions to the International Health Regulations. This could have an impact on health security (7). Due to reports linking the risk of dengue to seasonal variations in climate, there is growing public

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concern about the effects of global warming on human health, particularly with regard to vector-borne diseases (5,6,8,9), and mosquito larval indices (10–12). Dengue virus (DENV) is estimated to be the cause of 105 million infections annually in the world, the most of which are asymptomatic (13). DENV results in serious economic harm (14). Acute febrile illness ranging from mild and self-limiting to severe organ dysfunction and shock can be the symptom of DENV infection (15).

Most people across the world are constantly at danger of major health complications due to vector-borne diseases, which are the most prevalent health concern globally (16). Of these, dengue fever is the most widespread, spreading over most tropical and desert regions of the world. There are two types of the disease that are spread to humans by Aedes mosquitoes: the conventional dengue fever, known as dengue fever (DF), and the potentially fatal dengue hemorrhagic fever (DHF), which can develop into dengue shock syndrome (DSS) (17). Dengue infection occurs due to the bite of the mosquito Aedes aegypti, that is infected with one of the four dengue virus serotypes (18). Previously limited to urban and semi-urban settings, the virus is now also present in rural areas (19). It is therefore, the applications of mordenr methods in dengue studies play an important role in the fight of dengue hemorrhagic fever.

People, place and time are the basic elements of epidemiological investigations. According to (20), the development of spatial analysis in Geographic Information System (GIS) has, over the last twenty years, boosted the development of the analysis of spatial patterns and processes in public health. A general interest in spatial data analysis has developed rapidly over the last few decades, mainly because of the need for better public health tools. Greater interest and the subsequent improvements made have enabled researchers to tackle new urban diseases such as the dengue fever. Geographical factors and information from different sources and formats can be spatially combined by GIS, both in epidemiology and public health - as, for example, in the studies of (21–23). With the growing number of studies such as these in public health research, new methods of geospatial analysis have been developed specifically for applications in epidemiological studies and have been incorporated in different analytical software packages around the world. Moreover, currently, it is possible to access several innovative geospatial analysis tools via Internet (24). Thus, alots of studies have successfully applied spatial analysis in GIS in the study of dengue hemorrhagic fever.

This paper aims to give an overview of different types of applications offered by spatial analysis in epidemiological studies of dengue. The content is presented under three sub-sections; namely spatial analysis of points, spatial analysis of area data, and software programs used for spatial analysis of dengue cases.

2. Materials and methods

2.1. Materials

In this study, a total of 57 scientific papers colected from Web of Science, SCOPUS, Google scholar and PubMed databases was used. These were mostly high impact and were mainly published in recent years after the COVID-19 outbreak.

2.2. Methods

In order to yield the largest number of articles utilizing spatial analysis, searches using the Web of Science (https://mjl.clarivate.com/), SCOPUS (https://www.scopus.com), Google scholar (https://scholar.google.com), PubMed (http://www.ncbi.nim.nih.gov/pubmed) databases were conducted using, in the first search, the keyword 'spatial analysis'. In the following searches, the keywords: 'spatial association + dengue', 'spatial clustering dengue', 'hotspot analysis + dengue' and 'spatial clustering + dengue' were used because they had appeared in the articles found in the first search. In addition, Web of Science, Google Scholar, PubMed, and SCOPUS databases were also queried with different combinations of keywords including 'applications', 'Spatial analysis', 'GIS' or 'Geographic Information System', 'Kernel density estimation', 'Knox method' or 'Ripley's K statistic', 'Bayes smoothing' or 'Kulldorff's space-time scan statistics', 'Exploratory Spatio-Temporal Data Analysis', 'Standard deviational ellipse' or 'Generalized additive model', and 'Maxent algorithm', 'Angular wavelet analysis', 'Local K-function', 'Fourier analysis', 'Global Moran's I statistic', 'LISA', 'Kulldorff's space-time scan', 'Getis-Ord Gi*', 'Getis-Ord index', 'Getis-Ord General G analysis', 'Arc/Info', 'ArcGIS', 'GeoDa', 'TerraView', 'MapInfo', 'Satscan', 'PPA', and 'S-PLUS'. Three different sub-topics was then identified based on applications of spatial analysis in in epidemiological studies of dengue including spatial analysis of points, spatial analysis of area data, and software programs used for spatial analysis of dengue cases.

3. Results and discussions

3.1. Spatial analysis of points

Data from Table 1 summarises applications of spatial analysis of points in dengue studies. The Space-Time Kernel Density Estimation (STKDE) is one of the commonly used method for dengue studies. in a parallel computational framework to account for the computational complexity involved. A spatial and temporal extension of the kernel density estimation algorithm was applied to map space-time clusters of dengue fever in Cali, Colombia for the year of 2010 (25). Also using kernel conditional density estimation, the method was applied to predicting dengue fever and influenza and compare to a seasonal autoregressive integrated moving average model and HHH4, a previously published extension to the generalized linear model framework developed for infectious disease incidence (26). Spatial statistical tools were used to show spatial correlation of dengue cases and kernel density was implemented to identify dengue hotspot localities in a dengue outbreak in Seksyen 7, Shah Alam, Malaysia (Figure 1) (27). Also in Malaysia, Kernel density estimation was applied in this study to locate 'hot spot' for dengue incidence: a case study in Putrajaya (28).

Table 1 Summary of spatial analysis of points in dengue studies.

Methods	Purposes of study	Study area	Study
Kernel density estimation	Mapping space-time clusters of dengue fever	Cali, Colombia	(25)
	Predicting dengue fever and influenza	USA	(26)
	Identifying dengue hotspot localities in a dengue outbreak	Malaysia	(27)
	Identifying 'hot spot' for dengue incidence: a case study in Putrajaya	Putrajaya, Malaysia	(28)
Knox method	Spatiotemporal pattern of an epidemic dengue	Northeast of Brazil	(29)
	Investigating the important temporal intervals in the pattern of dengue virus transmission,	Thailand	(30)
Ripley's K statistic	Analysis of spatial dimensions of dengue virus transmission across interepidemic and epidemic periods	Iquitos, Peru	(31)
Bayes smoothing	Spatiotemporal mapping of relative dengue disease risk	Bandung, Indonesia	(32)
Kulldorff's space-time scan statistics	Identify spatial clusters and to provide the relative risk of arboviruses	Pernambuco, Brazil	(33)
Exploratory Spatio-Temporal Data Analysis	Spatiotemporal patterns of dengue and its association with climatic, environmental, and sociodemographic factors	Punjab, India	(34)
Standard deviational ellipse	Study the distribution of dengue fever disease	Banjar City, Indonesia	(35)
The generalized additive model	Investigating the association between climate factors and dengue fever	Asuncion, Paraguay	(36)
The Maxent algorithm	Identifying a high probability of the presence of Aedes aegypti under current and future (2050) climatic conditions	Ecuador	(37)
Angular wavelet analysis	Analysis of the relationship between rainfall occurrence and dengue incidences reported from 2007 to 2015	Paraíba State, Brazil	(38)
Local K-function	the impact of IRS and spatial autocorrelation in the odds of weekly dengue infection	Cairns, Australia	(39)
Fourier analysis	Characterising the seasonal patterns of dengue hospitalisation per state	Brazil	(40)

To investigate the spatiotemporal pattern of an epidemic dengue occurred at a medium-sized city in the Northeast Region of Brazil in 2009, an ecological study of the notified dengue cases georeferenced according to epidemiological week and home address was conducted using the Knox method (29). Also based on Knox method, to reveals important temporal intervals in the pattern of dengue virus transmission, a novel method was successfully used to determine the temporal intervals between cases at which spatial clustering occurred (30). To study spatial dimensions of dengue virus transmission across interepidemic and epidemic periods in Iquitos, Peru (1999-2003), global patterns of dengue seroconversions were analyzed within each trimester using a case-control Ripley's K statistic (31). Bayesian spatiotemporal mapping of relative dengue disease risk was carried out in Bandung, Indonesia where a Bayesian spatiotemporal random effects (pure) model of relative dengue disease risk estimated by integrated nested Laplace approximation was presented (32). With the aim of describing, through spatial analysis, the cases of arboviruses (dengue and chikungunya), including deaths, during the first epidemic after the circulation of the chikungunya virus in the state of Pernambuco, Northeastern Brazil, Kulldorff's space-time scan statistics method was successfully adopted to identify spatial clusters and to provide the relative risk (33).

To understand spatiotemporal patterns of dengue and its association with climatic, environmental, and sociodemographic factors in Punjab, India. Exploratory Spatio-Temporal Data Analysis was used to estimate dengue incidence rates, time series features and correlation coefficients up to the sub-district level (34). Another study has carried out a study to obtain information regarding the area of dengue fever disease distribution in Banjar City, Kabupaten Ciamis, Indonesia, by utilizing the Standard Deviational Ellipse (SDE) mode with dengue fever cases from the period of 2007-2013 (35). A Generalized Additive Model was successfully used to investigate the association between climate factors and dengue fever in Asuncion, Paraguay using cumulative dengue cases from January 2014 to December 2020 (36). When identifying the most important factors influencing the risk of dengue virus infection in Ecuador, the maximum entropy algorithm (MaxEnt) was successfully used to determine the areas with a high probability of the presence of Aedes aegypti under current and future (2050) climatic conditions, using the location of reported dengue cases and potential environmental factors (37). A recent study has shown that weather is considered to be a key factor in the temporal and spatial distribution of vector-transmitted diseases. Thus, the relationship between rainfall occurrence and dengue incidences reported from 2007 to 2015 in João Pessoa city, Paraíba State, Brazil, was analyzed by means of wavelet transform, when a frequency analysis of both rainfall and dengue incidence signals was performed (38). Spatial (local K-function, angular wavelets) and space-time (Knox test) analyses quantified the intensity and directionality of clustering of dengue cases, whereas a semi-parametric Bayesian space-time regression assessed the impact of IRS and spatial autocorrelation in the odds of weekly dengue infection in Australian city of Cairns (39). In Brazil, Fourier analyses were also successfully used to characterise the seasonal patterns of dengue hospitalisation per state (40). In addition,

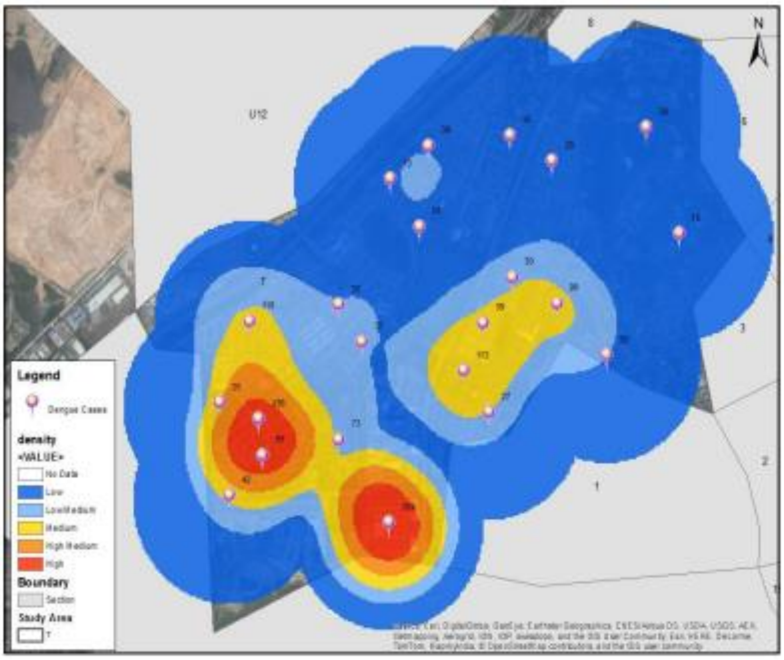

Figure 1 Hotspot locations of dengue cases in Seksyen 7, Shah Alam Malaysia.

3.2. Spatial analysis of area data

Applications of spatial analysis of area data in dengue studies were summarised in Table 2. Local indicators of spatial association (LISA) has been a commonly used method for analyzing polygon data. Another widely applied methods were the global, local Moran and Getis and Ord Gi* statistic. A study has analyzed the dengue fever epidemic in 2002 and the socio-demographic context of the State of Rio de Janeiro, Brazil, using spatial analysis and statistical modeling. Associations between incidence and socio-demographic variables and spatial autocorrelation using the Moran Global Index were analyzed, which showed spatial dependence for both the outcome and the independent variables. A multivariate linear regression model was used (41). Later, also in 2009, the dengue fever epidemic in 2002 and the socio-demographic context of the State of Rio de Janeiro, Brazil was studied using spatial analysis and statistical modeling whereas associations between incidence and socio-demographic variables and spatial autocorrelation was analyzed using the Moran Global Index, which showed spatial dependence for both the outcome and the independent variables (42). In addition, the multiple linear regression model and the conditional auto-regression spatial model were also used to analyze the relationship between dengue and socioeconomic context (42). In Thailand, a spatial autocorrelation statistic was applied to determine the degree of association between variables of points or blocks and their adjacent points or blocks. Using the enumeration district block level and the Global Moran's I statistic, this study looked at the incidence of dengue fever and dengue haemorrhagic fever within the Songkhla municipality in Thailand (43).

Spatial analysis is used to analyze the correlation between endemic dengue areas (geographical location) and DHF incidence in Java-Bali, Indonesia,. The measure of the correlation is determined using spatial autocorrelation, global index, and Moran's index (Moran's I). Moran's index is a global index used to determine the absence/ presence of spatial autocorrelation in disease transmission. However, it does not provide information on spatial patterns in certain areas (it merely globally represents spatial autocorrelation). For that reason, local indicator of spatial association (LISA) is required to determine the mapping of DHF and distribution patterns of DHF cases in Java and Bali (44). In China, to understand the spatial temporal distribution of dengue fever epidemics in the mainland of China during 2005-2013. Methods Geographic information database was established by using the incidence data of dengue fever and demographic data reported in 27 provinces and 4 municipalities in China from 2005 to 2013, Global indication of spatial autocorrelation (GISA), local indication of spatial autocorrelation (LISA), and spatial-temporal clustering analysis were conducted with software GeoDa 1.2.0 and SaTScan 9.3 to determine high risk areas of dengue fever (45). In Ecuador, to analyze the spatial distribution of reported cases of dengue fever in the city of Guayaquil (Ecuador) during the period from 2005 to 2009, techniques of spatial statistics and GIS-Analysis including LISA are applied to characterize the geographical distribution of dengue incidence (46).

Table 2 Summary of spatial analysis of area data in dengue studies.

Methods	Purposes of study	Study area	Study
The global Moran's I statistic	Assess the relationship between the DF epidemic in 2002 and the socio-demographic context	Rio de Janeiro, Brazil	(41)
	Association between points or blocks and the incidence of DF/DHF	Songkhla, Thailand	(43)
	Associations between incidence and socio-demographic variables and spatial autocorrelation	Rio de Janeiro, Brazil	(42)
LISA	Mapping of DHF and distribution patterns of DHF cases	Java-Bali, Indonesia	(44)
GISA nad LISA	Study the spatial temporal distribution of dengue fever epidemics	Mainland of China	(45)
LISA	Characterizing the geographical distribution of dengue incidence	Guayaquil, Ecuador	(46)
Kulldorff's space-time scan, Getis-Ord Gi*, LISA	Assessment spatio-temporal patterns of dengue incidence	North Sumatera, Indonesia	(47)
Getis-Ord, Kulldorff's scan statistics	Space and space-time distributions of dengue in a hyper-endemic urban space	Girardot, Colombia	(48)

Global Moran's I and Getis-Ord General G analysis	Analysí the temporal-spatial distribution of overseas imported dengue fever in dengue fever outbreak areas	China	(49)
Getis-Ord Gi*	Cluster analysis of dengue using self organizing maps	Pradesh, India	(50)

With the aim of characterizing the epidemiology and spatio-temporal patterns of dengue in Medan City, Indonesia using data on dengue incidence were obtained from January 2016 to December 2019, the Getis-Ord Gi* and Anselin Local Moran's I statistics were successfully used for further characterisation of dengue hotspots and cold spots (47). Also using spatial statistics, Kulldorff's space-time scan statistics were used to assess the concentration of dengue cases, whereas Getis-Ord indices (both global and local) were used to assess the aggregation of data within a dataset and a local measure to evaluate the location of the clustered data Girardot, Colombia (48). When investigating epidemiological characteristics and temporal-spatial analysis of overseas imported dengue fever cases in outbreak provinces of China during 2005-2019, Based on spatial autocorrelation analysis of ArcGIS 10.5 and temporal-spatial scanning analysis of SaTScan 9.5, the temporal-spatial distribution of overseas imported dengue fever in dengue fever outbreak areas was analyzed in the mainland of China. In India, Getis-Ord Gi* was successfully applied to identify hot spots and cold spots of dengue disease in Andhra Pradesh, India, 2011–2013 (50).

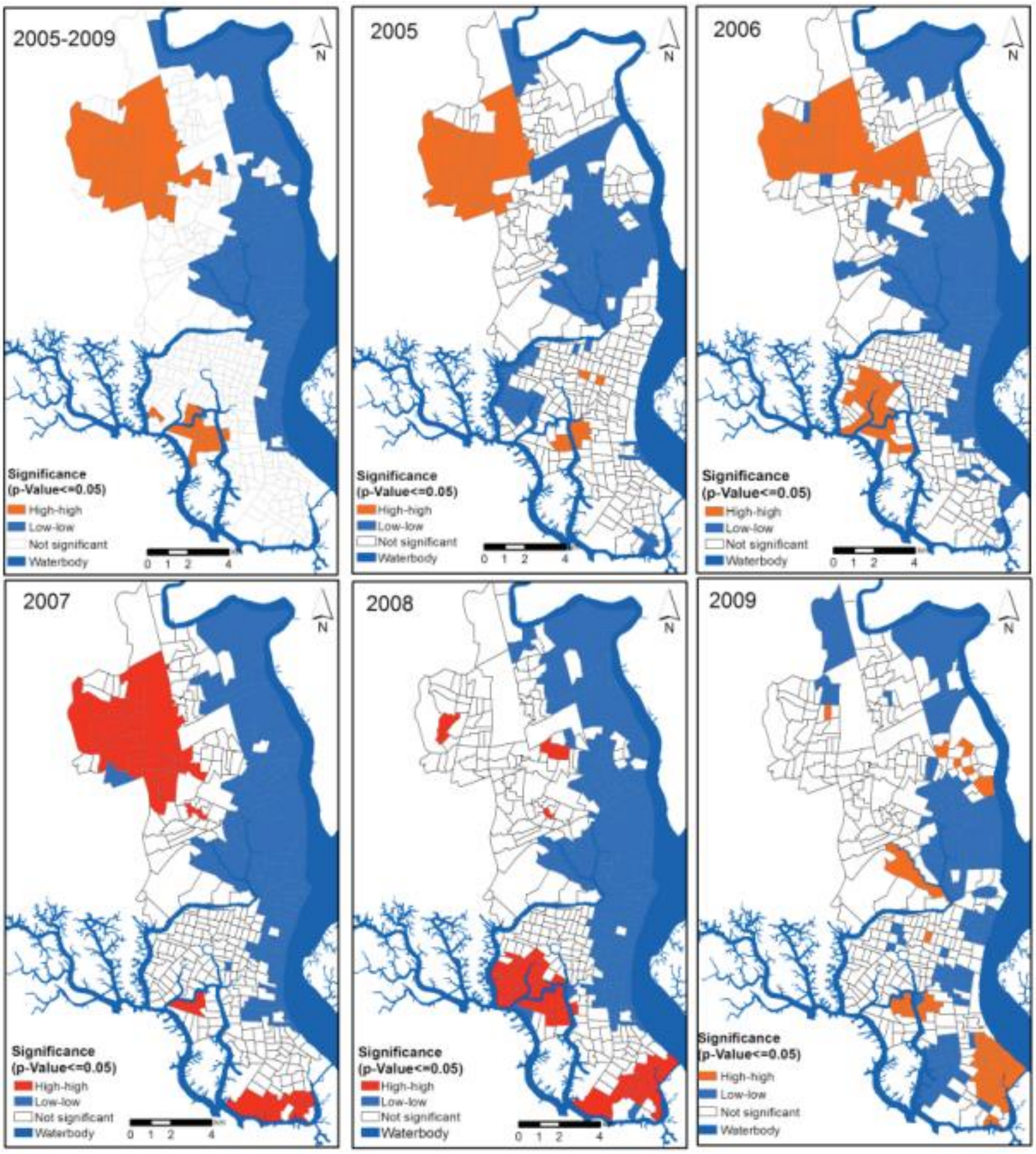

Figure 2 LISA local clusters of dengue incidence during 2005-2009 in Guayaquil, Ecuador (46).

3.3. Software programs used for spatial analysis of dengue cases

In certain articles, the software used to conduct the spatial analysis of the data was not reported. Further, in some cases, the method of spatial analysis was not referenced; instead, the focus was on the set of operations utilized. For example, it was clear in every article that different software had been used; in some cases, one software program was used to create the geographical coordinates (latitude and longitude), and another specifically to perform the spatial analysis (24). Data from Table 3 demonstrate summary of The commonly used software programs were ArcGIS (51), GeoDa (52), TerraView (53) and MapInfo (54). Several other software programs - for example, Satscan (55), Arc/Info (34), PPA (56), S-PLUS (57), and other customized ones - were used, but not as often.

Table 3 Summary of software programs used for spatial analysis of dengue cases.

Methods	Purposes of study	Study area	Study
Arc/Info	Exploratory space-time analysis of reported dengue cases	Florida	(34)
ArcGIS	Risk analysis for dengue suitability	Africa	(51)
GeoDa	patiotemporal analysis of dengue feve	Nepal	(52)
TerraView	Space-time description of dengue outbreaks	São Paulo, Brazil	(53)
MapInfo	Mapping the geographical distribution and seasonal variation of dengue and chikungunya vector mosquitoes	India	(54)
Satscan	Spatiotemporal-based clusters as a method for dengue surveillance	São Paulo, Brazil	(55)
PPA	Detecting Dengue Virus NS1 Antigen, and Anti-Dengue Virus IgM and IgG Antibodies	Vientiane, Laos	(56)
S-PLUS	Investigating effects of the El Niño-Southern Oscillation on dengue epidemics	Thailand	(57)

Additionally, these softwares can be used to visualize and describe the spatial distribution of dengue reported cases and to identify demographic and environmental risk factors that contribute to the development of dengue fever and dengue hemorrhagic fever.

4. Conclusions

This study reports a systematic review and meta-analysis of different types of applications offered by spatial analysis in epidemiological studies of dengue. A comprehensive literature search of Web of Science, SCOPUS, Google Scholar, and PubMed were conducted up to December 2023. A total of three sub-sections, namely spatial analysis of points, spatial analysis of area data, and software programs used for spatial analysis of dengue cases, will be presented in this review. It was found that spatial analysis can effectively support the study of dengue fever and dengue hemorrhagic fever such as to investigate spatial patterns, hotspot, spatial clustering, the spread, transmission of dengue fever and dengue hemorrhagic fever and affecting factors. It can be concluded that applications of spatial analysis can provide important information and contribute to development of effective measurements to control and prevent the dengue fever and dengue hemorrhagic fever transmission. Particularly, the application of geographic information systems and spatial analysis for the detection of areas of greater transmission of DENV is of vital importance for the prevention and control of vector-borne diseases such as dengue. Finding in this study provide an insight into how to use spatial analyis and GIS techniques in the study of dengue fever and dengue hemorrhagic fever.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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