RESEARCH PAPER

GEOSPATIAL DYNAMICS OF DENGUE FEVER DENSITY IN KUANTAN, MALAYSIA: GIS-BASED APPROACH

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ABSTRACT. Dengue fever (DF) presents a significant public health challenge, particularly in tropical regions like Kuantan, Malaysia. This study utilizes Geographic Information System (GIS) technology to analyze spatial and temporal patterns of DF cases from 2011 to 2020. The aim is to understand geographical distribution, identify high-density areas, and discern temporal trends to guide targeted interventions. Kuantan, a rapidly urbanizing city with a notable DF incidence, serves as the study area. Leveraging a decade of Ministry of Health data encompassing 11,330 confirmed cases, ArcGIS 10.6 software maps disease distribution and identifies high-density clusters. Statistical analyses, including Kernel Density Estimation (KDE) and Standard Deviational Ellipses (SDE), reveal directional spread with Kuala Kuantan as the epicenter. Collaboration with vector control units validates high-density areas, linking environmental conditions and infrastructure to DF incidence. Demographic and socioeconomic variables, urbanization, and transportation connections are identified as influential factors. The study underscores the importance of collaborative data sharing and validates GIS-based approaches for targeted interventions. Integration into an early warning system is proposed, enhancing public health strategies in Kuantan and similar regions. Overall, this research contributes to understanding DF transmission dynamics and offers proactive frameworks for mitigating its impact through advanced technologies and collaborative efforts.

KEYWORDS: dengue, risk, kernel density estimation, risk mapping

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INTRODUCTION

Dengue fever (DF), a viral illness transmitted by *Aedes spp* mosquitoes[1], poses a substantial global health threat. Its prevalence in tropical and subtropical regions, particularly in urban and semi-urban areas[2], has been exacerbated by rapid urbanization and climate change. Dengue is often underreported due to asymptomatic or mild cases that are self-treated[3], dengue affects a staggering number of people globally, with an estimated 390 million infections annually. The disease's impact is evident in the growing number of cases reported to the World Health Organization (WHO). Between 2000 and 2018, reported cases surged from 505,430 to 5.2 million, accompanied by a notable increase in reported deaths, predominantly among younger age groups. Although a decline in cases and deaths was observed between 2020 and 2021, the reliability of the data remains uncertain, potentially influenced by the ongoing COVID-19 pandemic.

Southeast Asia bears a disproportionate burden of DF, largely due to its tropical climate. High humidity and temperatures create an ideal breeding environment for Aedes mosquitoes, the primary vectors of the disease[4]. The region's rapid urbanization, high population density, and insufficient infrastructure have exacerbated the problem, leading to recurring epidemics that strains healthcare systems and impacts economic productivity[5,6]. The severity of the situation is evident in the dramatic increase in dengue cases, rising from 4.88 million in 1990 to 7.7 million in 2019 a staggering 72.95% increase[7]. Within the region, the Philippines, Malaysia, Lao People's Democratic Republic, and Cambodia face the highest age-standardized incidence rates[8]. The World Health Organization's South-East Asia Region (SEAR) encompasses ten dengue-endemic countries, where an estimated 1.3 billion people—approximately 52% of the global population at risk—reside. With the exception of North Korea, these countries experience frequent and cyclical epidemics, demonstrating an overall expansion of dengue's reach in recent decades[9] (Tsheten 2021). This trend underscores the urgent need for improved prevention and control strategies across Southeast Asia.

Malaysia exemplifies the increasing trend of dengue cases over recent decades, with rapid urban expansion and population growth creating more mosquito breeding sites and intensifying disease control challenges. Alongside neighbors like Thailand and Indonesia, Malaysia struggles with this persistent public health threat. The drivers of dengue in Malaysia are multifaceted, including viral virulence, human biological factors, climate conditions like high temperatures, relative humidity, increased rainfall, human movement and behavior, and economic and infrastructure development[10] (Ahmad et al., 2018). These factors can influence human susceptibility to infection, promote mosquito breeding, and increase interactions between viruses, vectors, and hosts. DF has become endemic in Malaysia, with the Malaysian Ministry of Health reporting over 123,133 cases and 100 deaths in 2023, a significant rise from 66,102 cases and 56 deaths in 2022, an 86.3% increase[11] (Abu Hassan, 2024). This surge imposes a heavy economic burden due to substantial healthcare costs and productivity losses

Within Malaysia, the state of Pahang has emerged as a significant hotspot for dengue outbreaks. Pahang's diverse topography, encompassing both urban and rural areas, provides varied environments for mosquito breeding. The state's healthcare system has been increasingly strained by the rising number of dengue cases, necessitating enhanced vector control and public health interventions. In recent years, specific districts in Pahang have reported alarming increases in dengue incidence, highlighting the urgent need for targeted strategies to combat the disease[12] (Sapuan et al., 2023). Kuantan, the capital city of Pahang, is a focal point for DF in the state[12,13] (Hanapi et al., 2021; Sapuan et al., 2023). The city's rapid urbanization, combined with its tropical climate, creates optimal conditions for *Aedes aegypti* and *Aedes albopictus* mosquitoes. The urban landscape, characterized by dense housing and inadequate waste management, provides abundant breeding sites for mosquitoes[14] (Tan et al., 2022). As a result, Kuantan has experienced recurrent dengue outbreaks, with significant morbidity and mortality rates.

The transmission dynamics in Kuantan are complex, with cases occurring throughout the year and peaking during the rainy seasons[14] (Tan et al., 2022). The burden of dengue in Kuantan not only affects public health but also places a considerable economic strain on the community. Efforts to control the spread of dengue have included community engagement, improved vector control measures, and public awareness campaigns[15,16] (Subramaniam et al., 2021; Rahman et al., 2022). However, the persistent challenge underscores the need for more effective and sustainable approaches. Dengue primarily spreads through *Aedes aegypti* mosquitoes[17], with *Aedes albopictus* acting as a secondary vector. Transmission occurs before and after symptomatic phases, highlighting the intricate dynamics of the disease. Given the influence of environmental and ecological factors on geographical and temporal patterns, Geographic Information System (GIS) becomes indispensable for depicting and modelling the spatial relationships between causes and disease.

Kernel Density Estimation (KDE), a technique for incident location estimation, has proven crucial in identifying areas with a high density of dengue cases[18,19]. Urbanization, a significant driver behind increased mosquito density, is creating favorable conditions for disease transmission, especially in unplanned urban settings and peri-urban areas[20,21]. Understanding the epidemiologic patterns of dengue in these contexts is essential for effective prevention and control. While dengue is a significant public health concern in Malaysia, there is a notable lack of comprehensive spatial data on dengue cases specifically in Kuantan, a rapidly urbanizing city in Pahang. This gap in knowledge limits our understanding of the local transmission patterns and hinders the development of targeted prevention and control strategies. Our study aims to address this deficiency by providing detailed spatial-temporal analysis of dengue cases in Kuantan. Through this analysis, the research not only calculates incidence rates but also elucidates clustering patterns of dengue transmission. The findings contribute to the understanding of dengue in urban and peri-urban settings and advocate for the increased use of GIS technology in public health applications, thereby enhancing the efficiency of dengue surveillance programs and providing crucial information for more effective dengue management in this rapidly urbanizing area.

METHODS

Study area

Kuantan, positioned 250 kilometers east of Kuala Lumpur (3.816667N, 103.333333E), stands as an expanding city on the east coast of Peninsular Malaysia. This city, divided into six sub-districts (refer to Fig. 1), has undergone rapid industrialization and urbanization over the past decade, resulting in significant economic growth and a surge in both population and vehicular

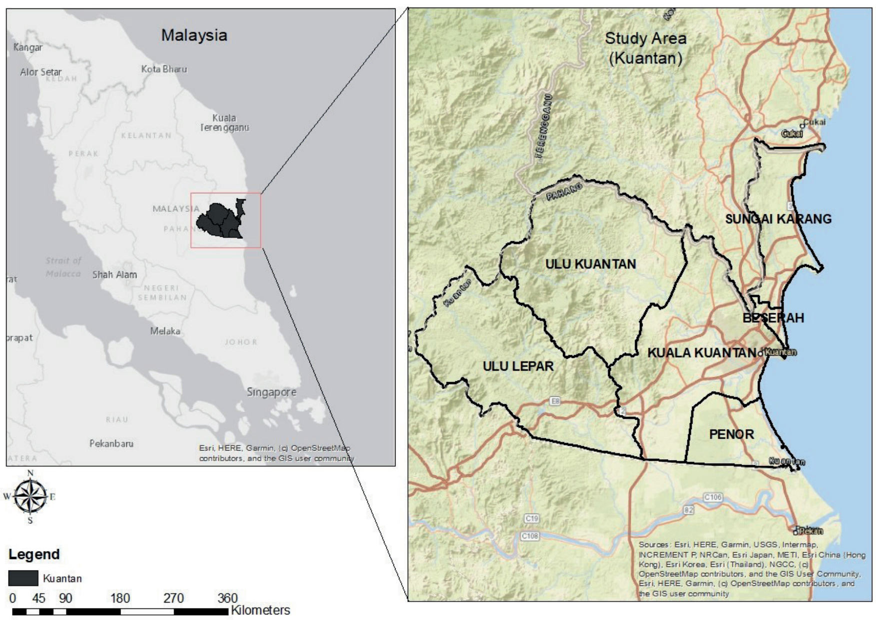

Fig. 1. Location of the study area of Kuantan, Pahang is a rising city on the east coast of Peninsular Malaysia

density. Boasting a populace of approximately 608,000 individuals, Kuantan holds the distinction of being Malaysia's ninth-largest city. The diverse land uses within Kuantan, spanning traffic, industry, enterprise, residential areas, gardens, and tourism, mirror various activity patterns, population movements, and potential mosquito breeding grounds.

Kuantan was chosen as the focal point for this study due to a dearth of recent research in the area, offering an opportunity to provide valuable insights. Additionally, Kuantan has registered the highest number of DF incidences in the state of Pahang. These unique characteristics position the study to effectively identify and analyse the spatial and temporal distribution of high-density areas for DF within the city.

Dengue fever cases data

A comprehensive compilation of DF cases was precisely conducted using the official DF website of the Malaysian government (http://edenguev2.moh.gov.my/). The dataset was carefully curated from the registered entries at the Kuantan District Health Office, spanning 2011 to 2020. This meticulous process resulted in a total of 11,330 confirmed dengue cases within Kuantan during this timeframe, forming the foundational basis for subsequent analysis.

Geographic Information System (GIS)

To visually and spatially analyze the distribution of DF cases, x and y coordinates corresponding to each patient's location were extracted from the dataset. The spatial mapping process was carried out using ArcGIS version 10.6 (ESRI, Redlands, CA, USA). This geospatial analysis facilitated the generation of a detailed map that highlights the geographical spread of DF incidences across Kuantan.

Statistical Analysis

To comprehensively assess the spatial distribution of DF cases and identify contributing factors, various statistical analysis tools within ArcGIS v10.6 were employed.

Geographic Distribution Pattern Assessment: The spatial pattern of dengue density was evaluated using essential metrics, including spatial mean center, directional distribution, and standard distance. These measurements provided valuable insights into the dispersion of dengue cases across the geography of Kuantan.

Kernel Density Estimation (KDE) and Standard Deviational Ellipses (SDE): KDE and SDE played crucial roles in delineating distributions within uncertain areas. KDE, in particular, facilitated the identification of problematic dengue areas characterized by high-density incidence. SDE added a valuable dimension by establishing ellipses that highlighted the standard deviations of the distribution, aiding in the interpretation of spatial patterns.

Spatiotemporal Distribution Analysis

Transformation of DF Cases: DF cases underwent transformation into weighted data points on a map using ArcGIS v10.6. Each data point, characterized by X and Y centroid coordinates, represented a distinct number of cases. This transformation enabled a nuanced depiction of the spatiotemporal distribution of DF cases.

Analysis of Emerging Spatial and Temporal Density: A strategy was developed to analyze emerging spatial and temporal density based on the geographical locations of dengue cases in the Kuantan district. The KDE method played a pivotal role in simulating density analysis and mapping the spreading pattern of the epidemic. The study incorporated specific bandwidths in accordance with a defined formula, with the aim of identifying the distribution pattern of DF density through a comprehensive density map, as formulated below.

$$\lambda(s) = \sum_{i-11\tau}^{n} \frac{1}{2} k\left(\frac{(s - s_i)}{\tau}\right) \quad (1)$$

Where *λ(s)* is the estimated infected value by dengue per area; *τ* is the smoothing factor; *k* () is the kernel weighting function; *s* is the center of the area and s_i is the location of the point.

Standard Deviational Ellipses (SDE): function as a robust tool for characterizing the properties of geographical spaces, encompassing central tendency, dispersion, and trend direction[22]. Traditionally, trends within a geographic area are measured by applying standards to compute distances independently along the x and y axes. The resulting elliptical distribution characteristics are defined in both measurements, yielding ellipses with specific orientations and elongated features. The term "standard deviation ellipses" is derived from the method of calculating the standard deviation of the x and y coordinates of the center axis. Central tendency and dispersion are pivotal aspects in epidemiological studies, prompting the use of ellipses to model the geographical distribution of diseases. In this study, geographical statistical analyses were conducted using ArcGIS 10.5 to employ SDE, providing insights into the spatial characteristics of DF distribution in Kuantan, as depicted below.

$$SDEx = \sqrt{\frac{\sum_{i=1}^{n}\left(x - \bar{X}\right)^2}{n}} \quad (2a)$$

$$SDEy = \sqrt{\frac{\sum_{i=1}^{n}\left(y - \bar{Y}\right)^2}{n}} \quad (2b)$$

where x_i and y_i are the coordinates for feature *i*, $\{\bar{X}, \bar{Y}\}$ shows mean center, and n is the total number of features. The SDE generated a new feature class that comprised centered ellipse polygons on mean center for all attributes (or for cases when values were defined). The attributes of the ellipse polygon comprised standard distance (long and short axis) and ellipse orientation. The orientation represented the rotation of the long axis clockwise from noon. In this study, SDE was used to quantitatively examine the direction of DF cases to determine the extent to which these dengue outbreaks may have spread.

Apart from that, it also indicated the number of standard deviations. When characteristics have a normal spatial distribution; i.e., highest density in the center that decreases towards the edges; one standard deviation can account for up to 68% of all centroid input data while two standard deviations can account for up to 95% of all features and three can account for up to 99% of all centroid features.

Validation and Expert Input

To enhance the credibility of our findings and gain expert insights into the causes of high-density DF occurrences, we proactively collaborated with the head of vector control units. This proactive engagement involved soliciting responses to three pivotal questions as shown in Table 1

RESULTS

Spatiotemporal distribution of dengue fever cases in Kuantan.

In 2011, the study revealed a scattering of DF cases concentrated primarily in the Kuala Kuantan sub-district. However, a significant shift unfolded over the subsequent nine

Table 1. Overview of key questions and the rationale for DF high-density analysis

Indicator	Question	Rationale
Correlation with Dengue Problems	Does the observed high-density correspond to areas where dengue problems are prevalent?	To evaluate the alignment between our identified high-density areas and those recognized by on-the-ground experts, we sought confirmation on the spatial congruence of our findings with the practical experiences of the vector control units
Factors Facilitating High Density:	What factors might facilitate the occurrence of high-density dengue fever cases?	Understanding the local factors contributing to high-density areas is crucial for contextualizing our spatial analysis. Insights from the vector control units help elucidate environmental, ecological, or demographic determinants influencing dengue fever prevalence
Surveillance and Control Measures	What surveillance and control measures can be implemented in high-density areas?	Expert recommendations on effective surveillance and control strategies provide practical implications for public health interventions. By incorporating these suggestions, our study aims to contribute not only to the understanding of high-density occurrences but also to the development of targeted and efficient control measures

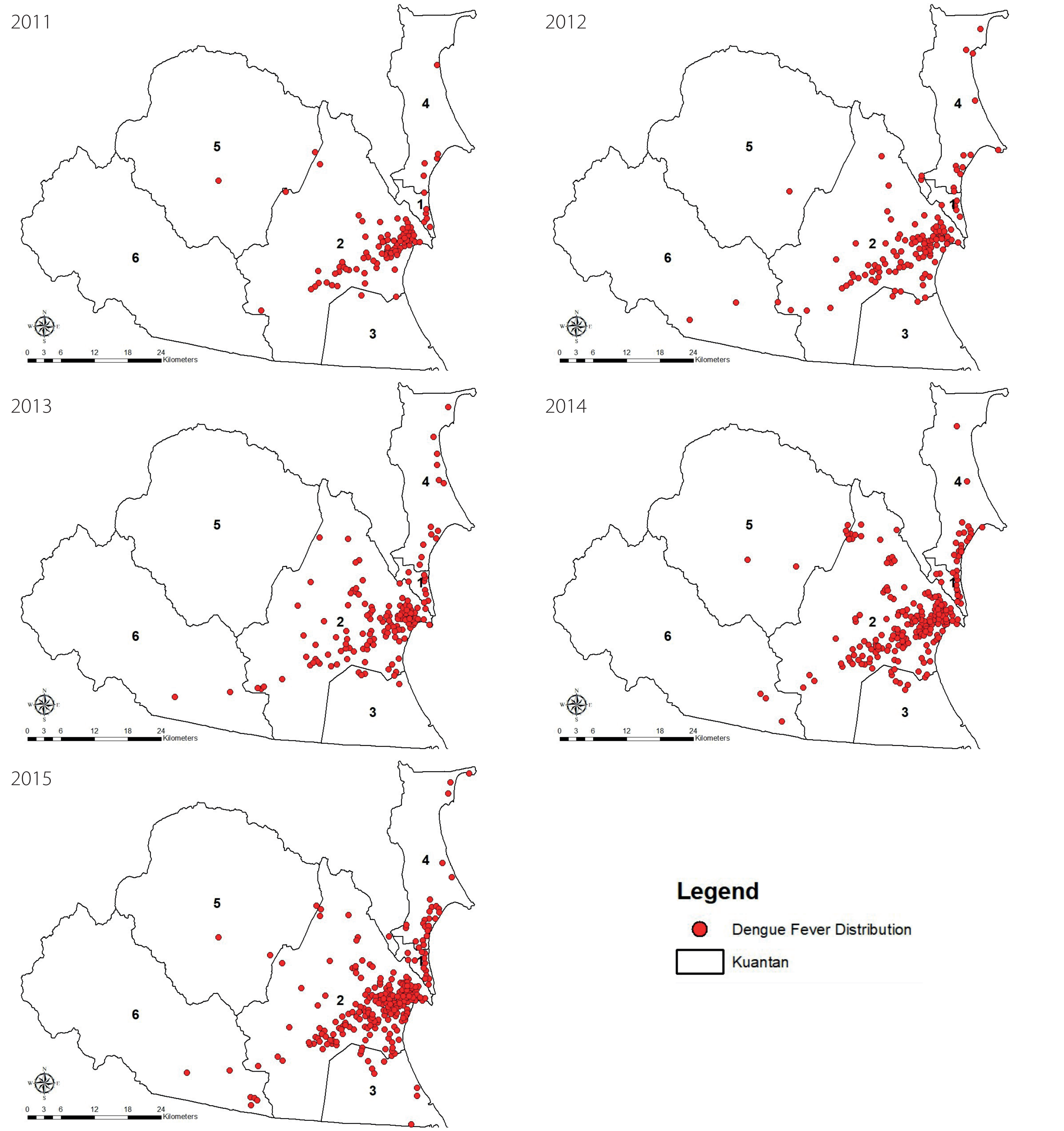

Fig. 2. Density mapping of DF cases in Kuantan, Malaysia from January 2011 to December 2020. (1) Beserah, (2) Kuala Kuantan, (3) Penor, (4) Sungai Karang, (5) Ulu Kuantan and (6) Ulu Lepar

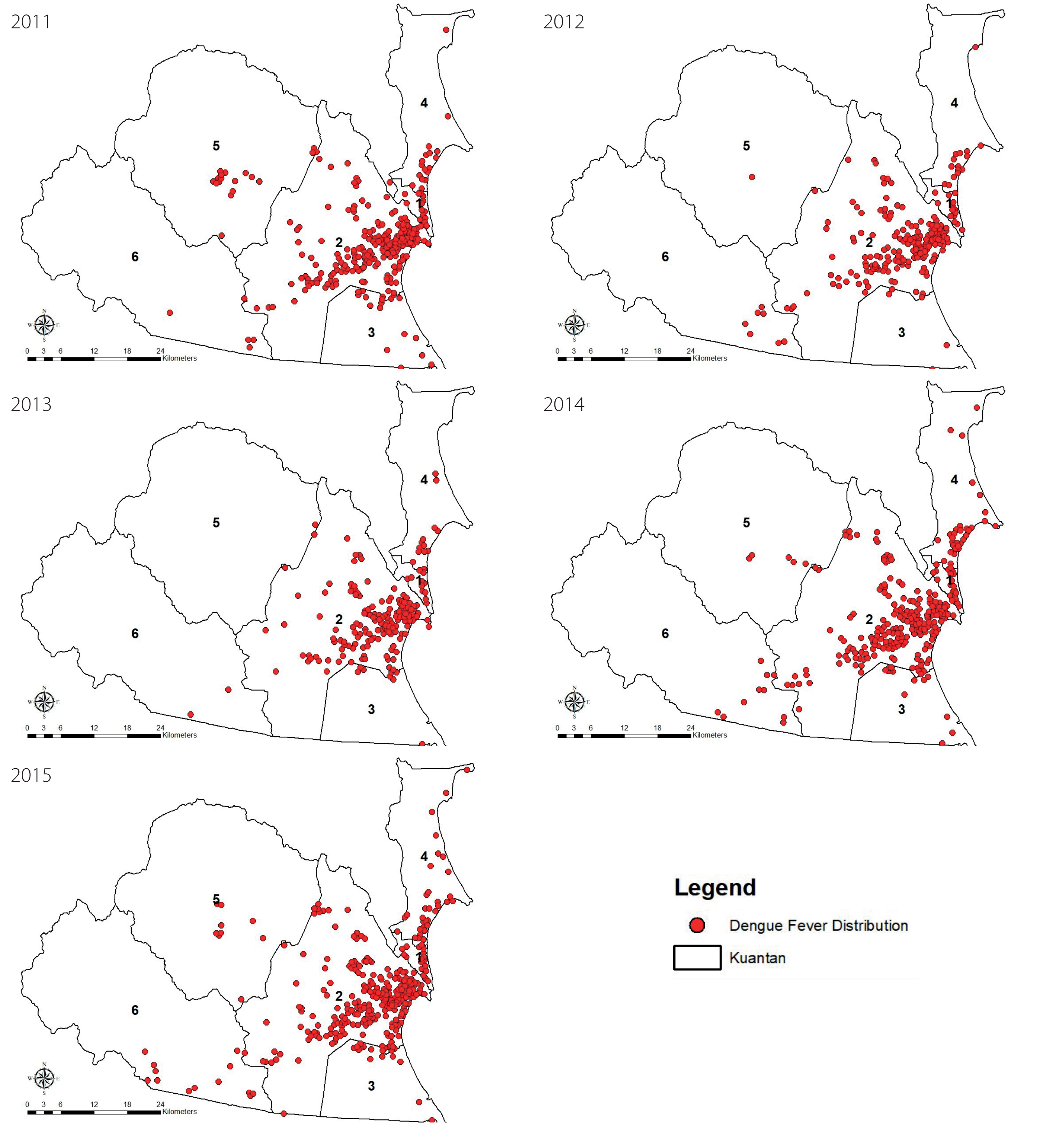

Fig. 2. Continued

years, spanning from 2012 to 2020. During this period, there was a marked escalation in the frequency of DF cases, indicating a consistent upward trend in disease incidence. Simultaneously, the spatial distribution underwent a notable transformation, extending beyond the initial hotspot in Kuala Kuantan to encompass neighboring sub-districts, notably Beserah and Sungai Karang. The persistent increase in the density of DF incidents from 2012 to 2020 underscores an enduring and expanding public health challenge in Kuantan.

Spatial density of dengue fever in Kuantan

The study covering DF cases from 2011 to 2020 focused on identifying high-density areas, a task accomplished through the utilization of KDE maps (refer to Fig. 3). These maps vividly illustrate the spatial distribution of DF occurrences, distinguishing high-density zones represented by red points, denoting an elevated frequency of cases, and low-density areas indicated by green-tinted points, signifying a lower incidence of DF. Notably, a discernible spatial pattern of DF emerged, with the Kuantan sub-district serving as the epicenter of this public health concern. The Kuala Kuantan sub-district exhibited the highest density of DF occurrences, closely followed by Sungai Karang and Penor sub-districts. Over the nine-year period, the high-density area consistently expanded, underscoring a growing density pattern in Kuantan. In the year 2020 alone, this expansion manifested in 22 additional high-density localities. Further granularity in the analysis revealed that 82% of these localities were concentrated in Kuala Kuantan, while Penor accounted for 9%, and both Ulu Kuantan and Sungai Karang sub-districts contributed 9% collectively. These findings not only provide insights into the temporal evolution and distribution of high-density areas but also inform the development of targeted public health strategies for effective DF control in Kuantan.

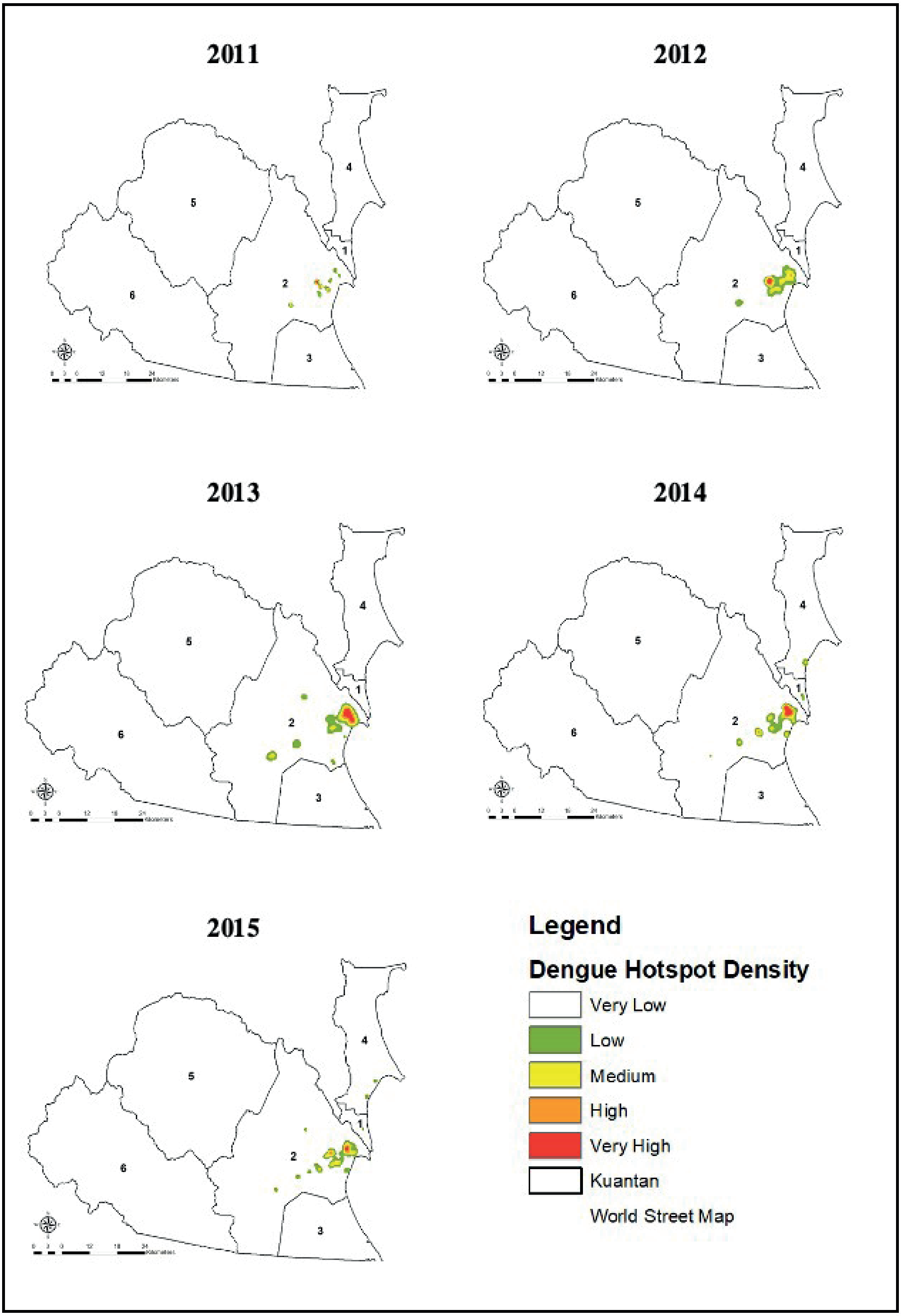

Fig. 3. High density detection of DF incidence in Kuantan based on Kernel Density Estimation statistic from 2011 – 2020. (1) Beserah, (2) Kuala Kuantan, (3) Penor, (4) Sungai Karang, (5) Ulu Kuantan and (6) Ulu Lepar

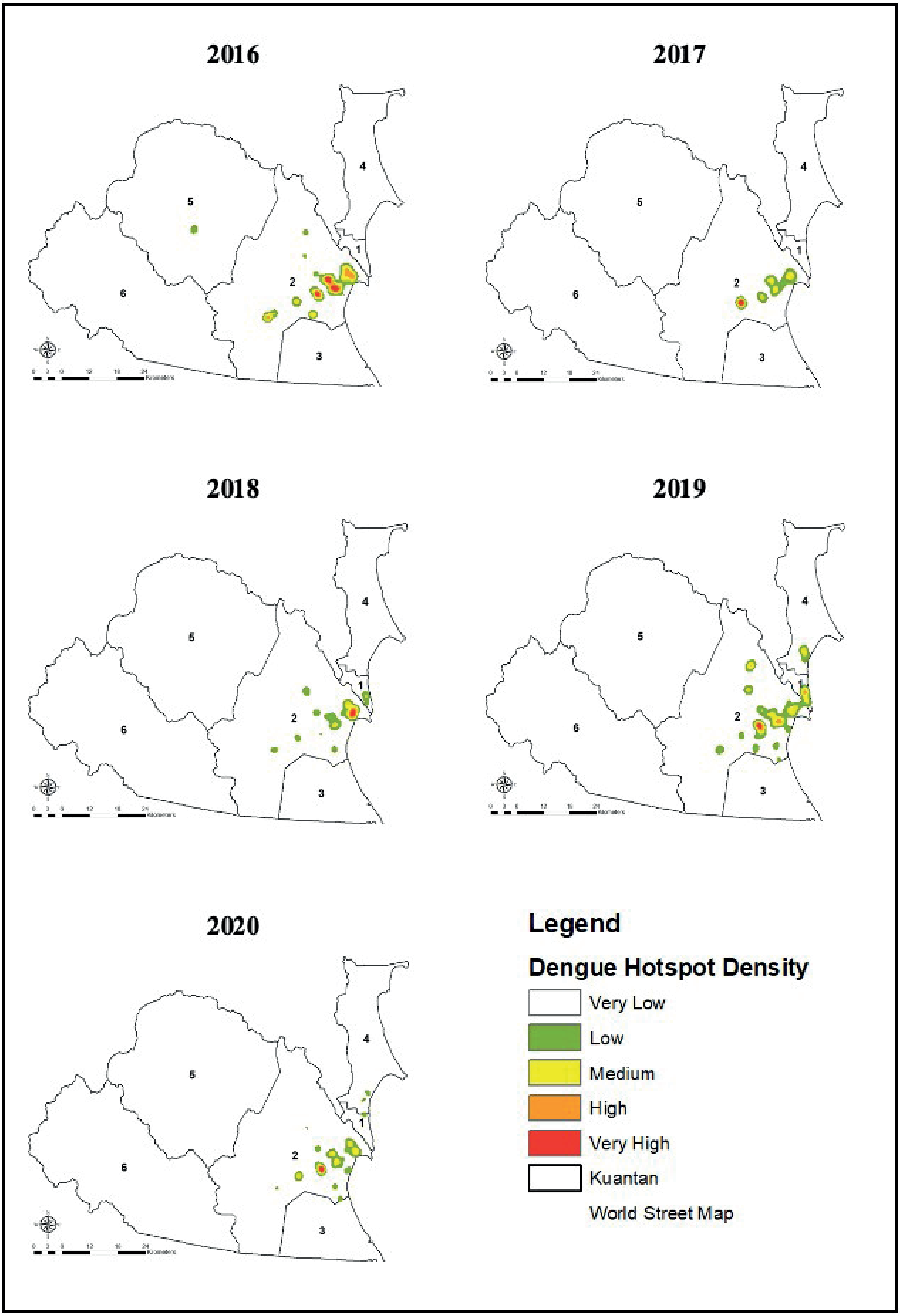

Fig. 3. Continued

The collaboration with the head of the vector control units yielded valuable insights, indicating a high agreement between the identified high-density areas and those historically contributing the most DF cases in sub-districts within Kuantan. This alignment reinforces the reliability of our spatial analyses and holds significant implications for subsequent research, surveillance, and control measures concerning DF outbreaks in the region.

The findings from this collaborative assessment underscore critical environmental and social factors as root problems in high-density areas, as elucidated by the head of vector control. Table 2 outlines these identified factors, emphasizing the need for a holistic approach to address the root causes of dengue incidence. Environmental conditions, including poorly built and improperly managed drainage systems, as well as inadequacies in solid waste management, emerged as pivotal contributors to the heightened density of DF cases. Additionally, social factors play a role, emphasizing the interconnectedness of urban planning, infrastructure, and public health outcomes. This comprehensive assessment not only strengthens the understanding of the spatial distribution of dengue cases but also guides the formulation of targeted interventions. The identified root problems serve as a foundation for further research endeavors and the development of strategic surveillance and control measures aimed at mitigating the impact of DF outbreaks in Kuantan.

Directional distribution of dengue fever cases

Fig. 4 illuminates the directional distribution of DF cases over a decade, providing a comprehensive overview of the spatial dynamics within the entire sub-district of Kuala Kuantan. Remarkably, the directional patterns exhibited notable consistency over the ten-year period, following

Table 2. High density analysis agreement with locations indicated as vulnerable for DF transmission[23]

Sub-district	Does the high-density area match with areas you identify as problematic (yes, partially, no)?	What local conditions determine the occurrence of high density (ecological, environmental, infrastructure, social, or other determinants)?	What surveillance or control activities could you implement in your city considering the presence of high-density area?
Kuala Kuantan	Yes: most problematic area coincides with density analysis	Sociodemographic: regions with a high population density and varying levels of education. Ecological: high frequency of infested dwellings with a variety of breeding place during the rainy season, mostly by plastic containers that people amass and are difficult to remove.	Surveillance: improved surveillance using ovitraps and active case detection. Control: preventative vector control (health education, source and reduction), as well as response employing truck-mounted ultra-low volume and interior space spraying. Other enhancements include housing and public infrastructure upgrades.
Beserah	Partially: The regions are not issue zones, although places on the outside of the sub-district contribute to many cases.	Sociodemographic: regions with a medium population density and varying levels of education. Environmental: premises with big and planted (shady) patios, new vs. old low-middle-class dwellings. Other: include a lack of community participation in the removal and control of larval habitats.	Control: integrated vector management (IVM), which includes larval control, residual pesticide applications, monthly spatial spraying, and impact evaluation on a regular basis.
Penor	No	Not associate	Monitoring: increased surveillance using ovitraps, as well as an aggressive active case detection (ACD). Control: immediate larval control, followed by high coverage indoor residual spraying and ultra-low volume spraying once cases are detected.
Sungai Karang	Partially: The regions are not issue zones, although places on the outside of the sub-district contribute to many cases.	Environmental: premises with big and planted (shady) patios, new vs. old low-middle-class dwellings. Sociodemographic: regions with a medium population density and varying levels of education.	Surveillance: improved surveillance using ovitraps and active case detection. Control: include preventative vector control before to transmission season (information campaigns, source reduction, and indoor residual spraying).
Ulu Kuantan	Partially: The regions are not issue zones, although places on the outside of the sub-district contributed to many cases.	Ecological: Small plastic containers are the most common in terms of environmental impact, followed by large tanks.	Control: immediate larval control, followed by high coverage indoor residual spraying and ultra-low volume spraying once cases are detected.
Ulu Lepar	No	Not associate	Monitoring: increased surveillance using ovitraps, as well as an aggressive active case detection (ACD). Control: immediate larval control, followed by high coverage indoor residual spraying and ultra-low volume spraying once cases are detected.

a trajectory from the northeast to the southwest. The representation of these patterns through ellipse polygons offers a nuanced understanding of temporal changes. In 2011, the directional distribution was characterized by an ellipse polygon with a rotation of 51.046° on the long axis. Subsequent years witnessed variations, including expansions, contractions, and shifts in rotation angles. Noteworthy changes include the enlargement and southwestward extension in 2012, a reduction in size in 2015, and a wider, longer configuration in 2016. The year 2020 marked the occurrence of the outermost, largest, and longest ellipse polygon. These variations, while subtle, hint at evolving spatial dynamics in DF cases over time. The persistent directionality from northeast to southwest underscores the enduring spatial pattern, providing crucial information for the strategic planning of public health interventions tailored to the evolving spatial trends in Kuala Kuantan.

DISCUSSIONS

The integration of epidemiology with computational information management proves crucial for effective health-based surveillance and control[24], a principle exemplified by our statistical analysis of geographical data in this study. The concentration of DF cases within specific areas from the south to the west of Kuantan, covering nearly half of the study area, suggests these regions as high-density areas and preferred breeding sites for dengue vectors. This spatial pattern becomes more pronounced with the saturation of Kuantan's urban development. The rise in DF cases from 2011 to 2016, followed by a subsequent decrease in 2017 and a resurgence in 2018, underscores the dynamic nature of dengue transmission. This study's identification of high-density areas within Kuantan from 2011 to 2020 reveals distinct temporal and spatial patterns, influenced by demographic and socioeconomic factors.

Demographic variables, including urban population density, residence income, and single-story homes, play significant roles in shaping the frequency and spread of DF[25]. Dengue's adaptability to urban environments, facilitated by the Aedes aegypti mosquito vector, contributes to its prevalence in urban and suburban settings[26]. Notably, high a few studies revealed that population density, proximity to transportation arteries, and urban development correlate with increased DF incidence[27,28,29]. The impact of urbanization, characterized by high-rise buildings and modifications for development, is evident in its influence on land surface temperature and DF incidences[30].

Collaboration with the Kuantan district health officer corroborates the susceptibility for DF transmission in high-density areas identified through KDE and SDE analyses. The expansion of suburban regions in Kuala Kuantan's sub-districts contributes to the rise in mosquito population and DF transmission. Poor environmental hygiene further promotes conducive breeding sites in urban areas[31], aligning with research showing higher potential breeding sites in urban compared to suburban and rural areas[32]. The study emphasizes the need for additional data on the primary mosquito vector and breeding site control methods to enhance our understanding of DF transmission dynamics.

The study also revealed the role of urban livestock as a potential source of disease transmission. While valuable for food and revenue, urban livestock may increase the risk of vector-borne diseases, including DF[33,34]. Addressing this requires a balance between the benefits of urban livestock and the potential health risks. Additionally, raising public awareness of DF and its prevention techniques, especially in peri-urban areas, plays a pivotal role in disease control. Considering the broader context, climate variability, environmental issues, and land use warrant further investigation at the sub-scale to micro-scale level. Such a comprehensive understanding is essential for the

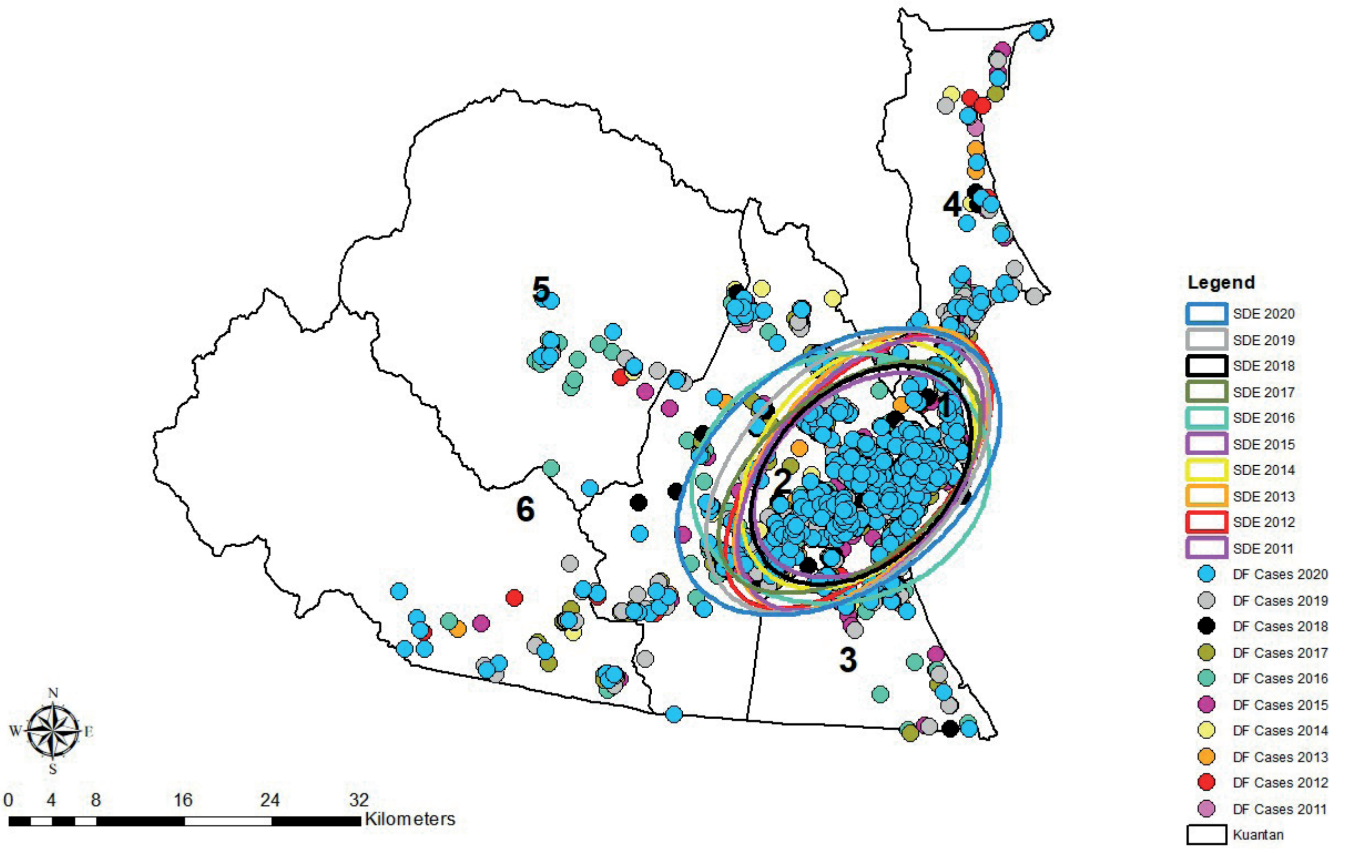

Fig. 4. Standard deviational ellipses of dengue cases in Kuantan from 2011 to 2020. (1) Beserah, (2) Kuala Kuantan, (3) Penor, (4) Sungai Karang, (5) Ulu Kuantan and (6) Ulu Lepar

development of effective dengue control strategies, taking into account the intricate interplay of climatic factors, human-mosquito interactions, and the urban landscape.

CONCLUSIONS

This study provides valuable insights into the spatiotemporal dynamics of DF in Kuantan, Malaysia from 2011 to 2020, revealing distinct patterns in the distribution and density of DF cases with significant implications for public health strategies. Our analysis identified specific high-density areas for DF, primarily concentrated in the Kuala Kuantan sub-district and expanding to neighboring areas over time. The temporal trends and consistent northeast to southwest directional pattern of DF cases provides critical information for predicting the future spread and planning preventive measures.

Our findings, corroborated by local health officials, highlight the role of urbanization, population density, and environmental conditions in facilitating DF transmission. The successful application of spatial analysis techniques demonstrates the potential for developing an early warning system for dengue outbreaks. The integration of diverse datasets, including meteorological, environmental, and entomological information, could further refine our understanding of DF transmission dynamics.

This study underscores the value of a multidimensional, data-driven approach to dengue control, leveraging advanced spatial analysis techniques and collaborative data sharing across agencies. We recommend the implementation of targeted interventions in identified hotspots, the development of an interactive dengue surveillance system, and increased collaboration between urban planners and public health officials. Such an approach has the potential to significantly improve prevention and management strategies, not only in Kuantan but also in other regions facing similar challenges with dengue and other vector-borne diseases.

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