Received: 15 APR 2024 | Accepted: 10 MAR 2025 | Published Online: 23 APR 2025
Recoletos Multidisciplinary Research Journal Vol. 13 no. 1 (June 2025)
DOI: https://doi.org/10.32871/rmrj2513.01.03

Original Article

Spatio-Temporal Analysis of Dengue in the Philippines: The Case of South Cotabato

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Abstract

Background: *South Cotabato Province in the Philippines has experienced recurring dengue outbreaks, necessitating spatio-temporal analysis to guide effective prevention and control strategies.*

Methods: *This study analyzed 4,004 reported dengue cases from 2020 to 2022. Dengue incidence rates were computed per 10,000 population and adjusted for demographic differences. Spatial and temporal patterns were examined using Kulldorff's space-time scan statistic and Moran's I for cluster and hotspot detection. Quantum GIS and SaTScan were used to identify high-risk areas, while monthly trends assessed seasonal variations.*

Results: *The average dengue incidence was 22.6 per 10,000, peaking in 2021 at 27.3. Males and children aged 1–17 years showed higher incidence rates. Two significant spatio-temporal clusters were found: a large cluster (radius 30.30 km, RR = 1.78, p < 0.001) covering Polomolok, Koronadal City, and adjacent areas, and a smaller cluster (radius 4.88 km, RR = 1.14, p < 0.001) in Polomolok. Hotspots included Poblacion and Magsaysay in Polomolok, and Zones II and IV in Koronadal. Seasonal peaks occurred during the rainy season, with an unusual spike in May 2022.*

Conclusion: *Targeted interventions in hotspot barangays, strengthened real-time surveillance, and community-based vector control are essential. A multi-sectoral approach is vital for sustainable dengue prevention in South Cotabato.*

Keywords

spatiotemporal analysis, dengue, cluster analysis, hotspot analysis, South Cotabato Province

INTRODUCTION

Dengue fever, a viral disease transmitted by Aedes mosquitoes, poses a substantial public health challenge worldwide, especially in tropical and subtropical regions. The disease is caused by any of the four closely related dengue viruses (DENV-1 to DENV-4), and individuals can be infected multiple times throughout their lives (Centers for Disease Control and Prevention, 2024). The World Health Organization (2024) estimates that dengue affects millions yearly, making it one of the most widespread vector-borne diseases.

Globally, dengue infects approximately 400 million people annually, with around 100 million at risk of infection and 40,000 deaths due to severe complications (Centers for Disease Control and Prevention, 2024).

As of August 2022, the Philippines remains one of the hardest-hit countries, with over 2.5 million reported cases and more than 2,000 deaths (European Centre for Disease Prevention and Control, 2025). In the National Capital Region, studies, such as that by Pangilinan et al. (2017), have demonstrated the high burden of dengue, with significant variation in incidence across different areas. Similarly, the broader Asia-Pacific region, including the Philippines, has long been affected by dengue, as evidenced by Banu et al. (2014), who traced the dynamic spatiotemporal trends of dengue transmission across this region. In particular, Medina et al. (2023) highlighted the spatial and temporal distribution of dengue cases in Quezon City, Philippines, underscoring the variability in dengue hotspots and the need for localized interventions.

While the disease burden is clear, one of the key challenges in controlling dengue outbreaks is the ability to identify and monitor the geographic areas where cases are concentrated. Identifying dengue hotspots—areas where dengue transmission is most intense—is critical for designing targeted interventions to reduce transmission and prevent further outbreaks. However, despite the significant public health burden, there remains a gap in applying advanced spatiotemporal analysis techniques to dengue data at the provincial level in the Philippines, particularly in South Cotabato.

Recent studies have demonstrated the potential of spatiotemporal analysis to improve outbreak detection and response for tropical diseases like dengue (Akter et al., 2019; Ceballos, 2021; Queiroz & Medronho, 2022; Singh & Chaturvedi, 2021). Techniques such as spatial and temporal analysis and time series analysis allow for identifying clusters of high-risk areas, providing a more nuanced understanding of the disease's geographic spread. However, the application of these methods at the provincial level remains underexplored, particularly in the context of South Cotabato. Rejuso et al. (2024) highlighted that while spatiotemporal analysis has been widely applied in urban settings like Cebu City, there is a lack of studies focusing on provincial-level data, especially in areas with unique environmental and socio-economic conditions. Similarly, Pasaribu et al. (2021) emphasized the need for further research on the use of Kulldorff's space-time scan statistic in identifying dengue clusters in regions with limited healthcare infrastructure, such as South Cotabato, where interventions may be more challenging to implement.

This study aims to fill this gap by utilizing spatiotemporal analysis to identify dengue hotspots within South Cotabato Province, offering a novel approach to disease surveillance at the provincial level. This study's originality and scientific merit lie in its application of these advanced analytical tools to dengue data, which has not been extensively done in the region. By applying Kulldorff's space-time scan statistic and Moran's Index for hotspot detection, this research will provide detailed insights into the spatiotemporal distribution of dengue cases, enabling public health authorities to target their interventions better. The findings of this study are expected to inform policy decisions, enhance early warning systems, and contribute to developing more effective strategies for controlling dengue outbreaks in the region.

METHODS

Study Design, Setting, and Population

The study uses a retrospective ecological study with a spatio-temporal analysis approach. South Cotabato Province is situated in the southern Philippines (see Figure 1) and spans an area of 3,793.90 km^2. The province experiences a tropical rainforest climate with an average annual rainfall of 1,220 mm and temperatures ranging from 22°C to 32°C. It comprises 10 municipalities and one city, with a population of 975,476 based on the 2020 census. The study utilized barangay-level (community-level) data to ensure precise spatial analyses.

Study Variables, Data Source, Data Collection

Dengue cases for the years 2020 to 2022 are considered in this study. These are sourced from the Department of Health, Region 12. Key variables considered are the hospital admission date, patient sex, age, and residential address. Records are directly sourced from health authorities to ensure that only confirmed dengue cases are included in the analysis. Using the Google Maps API, residential addresses were geocoded to latitude and longitude coordinates, which allowed the mapping of the geographical distribution of dengue cases. A thorough screening process and review are applied to ensure the inclusion of only valid, confirmed cases.

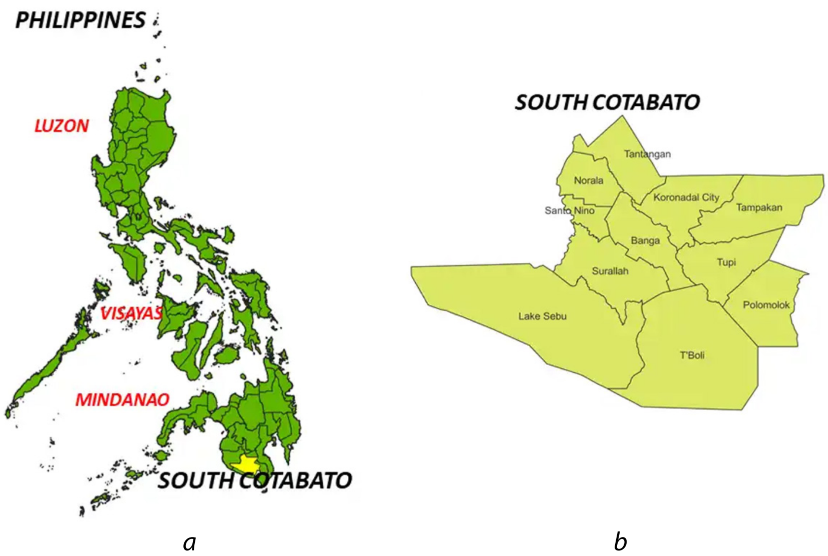

Figure 1. *Map of the Philippines (a) and South Cotabato Province (b) generated from QGIS*

Data Analysis

The dengue incidence rate is calculated monthly, reflecting the number of reported cases per 10,000 population to standardize comparisons over time and across regions. Dengue incidence rate is analyzed across different demographic categories, including age and sex. The monthly variation in dengue incidence rates over the study period (2020–2022) is analyzed.

Maps were generated using Quantum Geographic Information System (QGIS) 3.26.2 to visualize the spatial distribution of dengue incidence rates. These maps allowed the identification of spatial patterns and trends in dengue incidence across South Cotabato Province. Kulldorff's space-time scan statistic was employed to detect spatiotemporal clusters of dengue incidence. This method was selected because it identifies clusters in both time and space, determining whether geographic clustering is due to random variation or represents statistically significant concentrations of dengue cases.

The analysis followed the guidelines and settings outlined by Pasaribu et al. (2021) and other relevant studies to ensure methodological consistency. Specifically, the Space-time Poisson Probability Distribution Model was used, as it is a robust model for cluster detection, providing more accurate results compared to other models such as the space-time continuous uniform model and the space-time permutation model (Bokhari, 2020). This model accounts for varying disease rates across space and time, making it ideal for analyzing the dynamic nature of dengue transmission.

The spatial clustering of dengue cases was assessed using SatScan software, an open-source tool widely used for geographic disease surveillance. SatScan allows the identification of statistically significant clusters based on the likelihood of spatial or temporal aggregation, helping to distinguish actual outbreaks from random variations. In addition, hotspot analysis was performed using Moran's Index, a measure of spatial autocorrelation, to assess whether there were significant spatial patterns in dengue incidence across South Cotabato. Moran's Index was computed using GeoDa software, which provides comprehensive tools for exploratory spatial data analysis (Leitner & Brech, 2007).

Ethical Considerations

The data used in this study was requested from the Department of Health Region 12. The data is made available to the public, and personal information like the patients' names is not included. Thus, consent was not needed. Further, the authors uphold the requested data in complete confidentiality.

RESULTS

Incidence of Dengue

Table 1 shows the dengue incidence from 2020 to 2022 based on age and sex per 10,000 inhabitants. Analysis of the demographic data revealed that most patients fell within the 1–17 age bracket, consistent across all three years. Table 1 also presents the dengue incidence rate for males and females from 2020 to 2022. Males consistently exhibited higher incidence rates than females throughout the study period, with the highest rates observed in 2020. Interestingly, males exhibited a consistently higher risk, while the incidence rate decreased for both sexes from 2020 to 2022.

Table 1. *Dengue Incidence per 10,000 based on Age and Sex*

Demographics	2020	2021	2022
Sex			
Male	17	27	28
Female	16	21	23
Age			
Below 1 year old	2.5	1.4	1.8
1 - 17 years old	18	29	27
18-35 years old	13	18	16
36 - 55 years old	7.6	8.2	9
56 years and older	1.5	0.8	0.4

Temporal Patterns of Dengue Incidence

The annual dengue incidence rate in South Cotabato Province is shown in Figure 2. The Philippines experiences two distinct seasons: the wet season from June to January and the dry or hot season from February to May (PAG-ASA, 2020.). Results reveal that the dengue incidence rate peaked in January, corresponding to the wet season, and then showed a declining trend through April, the height of the dry season. A slight increase in incidence was noted during the initial two months and the final month of the wet season. However, the trend in 2022 deviated from previous years, with the highest incidence rate recorded in May, the last month of the dry season, followed by an increase in June, the first month of the wet season. Despite this variation, the dengue incidence remained generally higher during the wet season, particularly in January, across all three years analyzed.

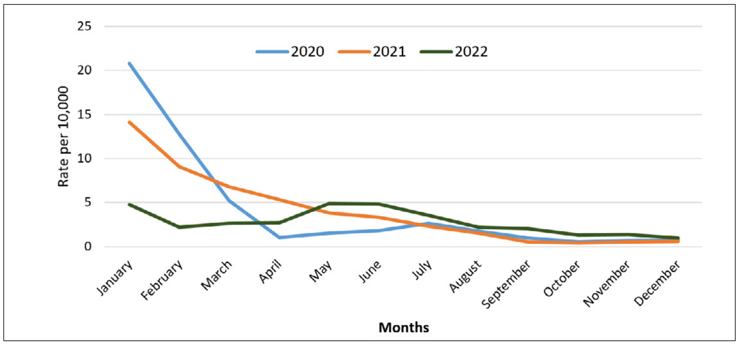

Figure 2. *Monthly Dengue Incidence Rate of South Cotabato Province*

Spatial Distribution of Dengue Incidence

Figures 3(a), 3(b), and 3(c) illustrate the spatial distribution of dengue incidence rates across South Cotabato province over the three-year study period. In 2020, as depicted in Figure 3(a), the barangays of New

Iloilo in Tantangan and Benitez in Banga experienced the highest dengue incidence rates, ranging from 82 to 102 per 10,000 inhabitants, which indicates that these areas were major hotspots for dengue transmission in that year.

In 2021, shown in Figure 3(b), the spatial distribution of dengue incidence shifted, with only Barangay Buenavista in Surallah falling into the highest incidence category, with a rate between 72 and 90. This change may reflect a reduction in transmission intensity in other areas, possibly due to environmental factors or improved vector control measures. However, other factors, such as mobility restrictions during the COVID-19 pandemic (Khan et al., 2022), may have influenced the observed pattern.

By 2022, as shown in Figure 3(c), the trend continued, with Barangay Buenavista remaining the only area in South Cotabato with the highest incidence rate, ranging from 64 to 80 per 10,000 inhabitants, which indicates that despite efforts to control dengue transmission, certain areas continued to experience higher transmission intensity, suggesting the persistence of favorable environmental conditions or insufficient control measures. The concentration of cases in Buenavista highlights the importance of localized surveillance and targeted interventions in areas identified as high-risk hotspots.

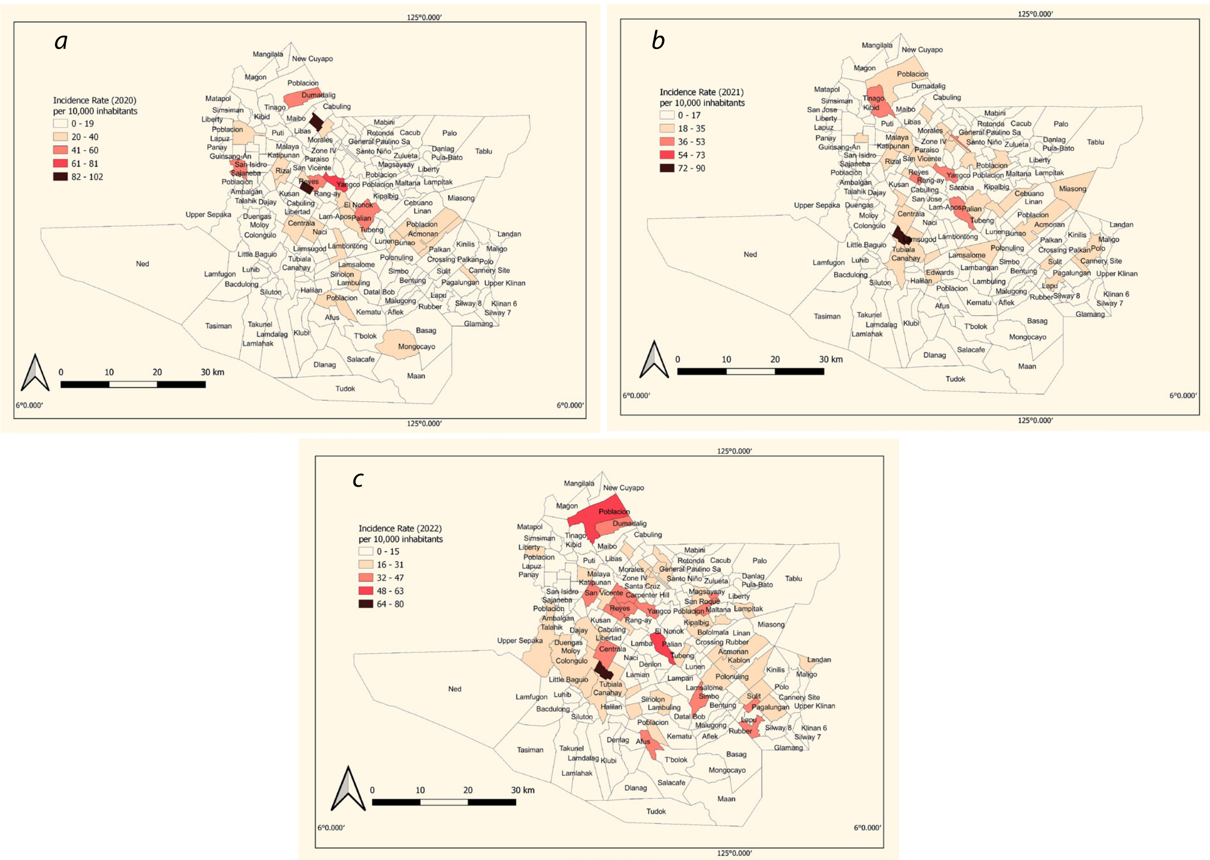

Figure 3. *Spatial Distribution of Dengue Incidence 2020 (a), 2021(b) and 2022 (c)*

Space-time Clusters

The results of the space-time cluster analysis from 2020 to 2022 revealed two significant dengue clusters in South Cotabato. The first, larger cluster encompassed 147 barangays within a radius of 30.30 km, covering the entire municipalities of Banga, Tupi, and Koronadal City, along with parts of Surallah, Polomolok, Norala, Tampakan, Tantangan, T'boli, Sto. Niño, and Lake Sebu (Figure 4; Table 2). Individuals residing in barangays within this large cluster had a 78% higher likelihood of dengue infection than those living outside this area (RR=1.78, p<0.001). This cluster corresponds to areas with high population density, as many of the barangays are among the most populated in the province (List of Most Populated Barangays of South Cotabato, 2020), which could influence both the spread of the disease and the accessibility of vector control measures.

The second, smaller cluster was identified within the Municipality of Polomolok, encompassing the barangays of Silway 8, Magsaysay, Silway 7, Glamang, Rubber, and Klinan 6. This cluster had a smaller radius of 4.88 km and a relative risk of 1.14 (p<0.001), indicating a 14% higher likelihood of dengue infection for residents of these areas than those outside the cluster.

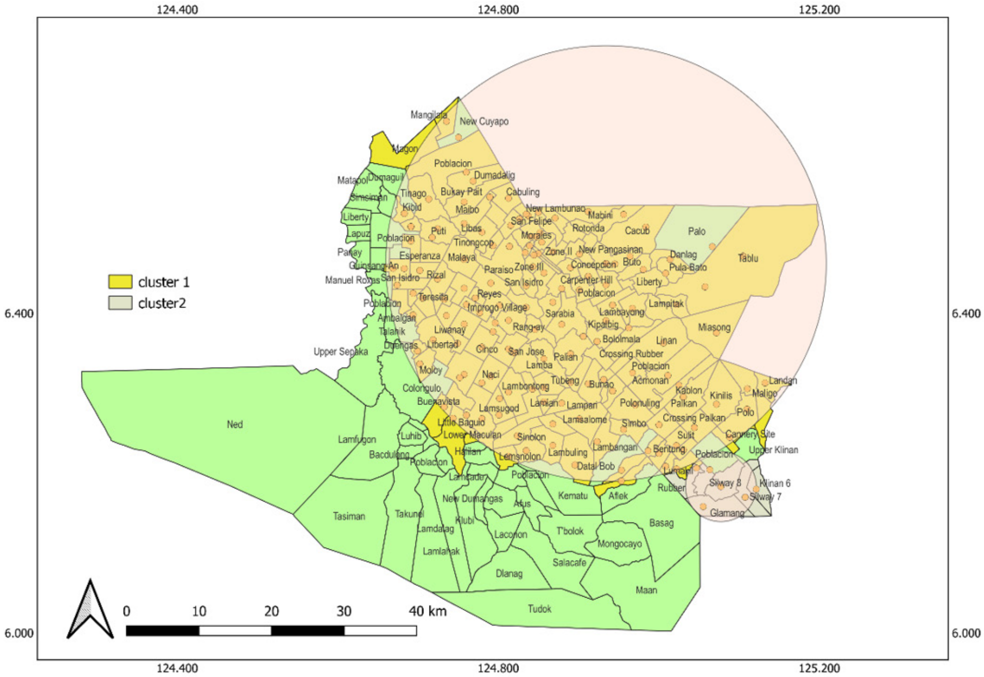

Figure 4. *Spatial Clustering of Dengue Cases in South Cotabato*

Table 2. *Significant Space-time Clusters of Dengue Incidence*

Cluster	No. of Barangay	Radius (km)	Observed Cases	Expected Cases	Relative Risk	LLR	p-value
1	147	30.30	332	185	78.19	8232.63	p < 0.001
2	6	4.88	158	11	14.36	271.40	p < 0.001

Note: LLR - Log Likelihood Ratio

Hotspot Identification

Hotspot Analysis using Local Moran's I revealed distinct spatial clusters indicating areas of high dengue incidence. As illustrated in Figure 5, the high-high cluster in red was composed of four barangays: Poblacion and Magsaysay in Polomolok and Zone II and Zone IV in Koronadal City. A common factor among these hotspots is high population density, intensifying human-mosquito interactions and elevating the risk of dengue transmission.

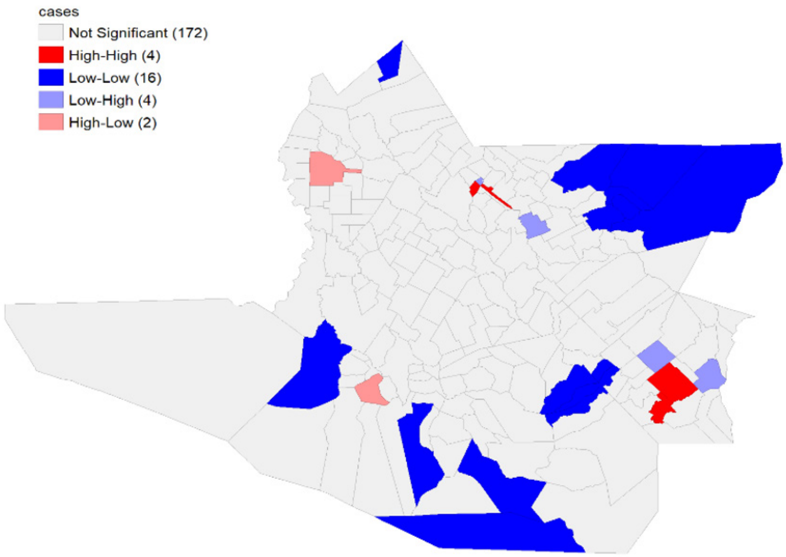

Figure 5. *Hotspot Analysis of Dengue Incidence*

DISCUSSION

The findings of this study reveal that dengue incidence in South Cotabato was highest among children and adolescents under 18 years old. This trend is consistent with previous studies, such as Kumar et al. (2020) in India, where school-aged children (7–18 years old) exhibited the highest rates of dengue infection. The increased vulnerability of younger age groups can be attributed to greater outdoor exposure, as children frequently engage in activities in open spaces where Aedes mosquitoes thrive. Similarly, Save the Children (2019) reported that children aged 5–9 years accounted for nearly half of all dengue-related fatalities during an outbreak in the Philippines, highlighting their heightened risk. A comparable pattern was observed in Zamboanga City's 2022 dengue outbreak, where the 0–9 and 10–19 age groups had the highest incidence rates (Garcia, 2022).

Dengue incidence was consistently higher among males than females, a trend supported by studies such as those by Anker and Arima (2011) and Harwiati et al. (2022). One possible explanation is that males are more likely to engage in outdoor activities, increasing their exposure to mosquito bites. Kumar et al. (2020) also noted that men, particularly those working in agriculture, construction, and outdoor labor, are at greater risk of mosquito bites due to prolonged exposure in endemic areas.

Dengue transmission in South Cotabato exhibits a strong seasonal trend, with cases peaking during the rainy season, particularly in January. The province's tropical climate, with an average temperature of 27.22°C and humidity level of 84.61%, creates an environment conducive to Aedes mosquito breeding. These findings from South Cotabato correspond with studies conducted in other parts of the Philippines, such as Pangilinan et al. (2017), which identified similar trends in the National Capital Region. The study found that areas with higher humidity levels and warmer temperatures tend to have increased mosquito populations and, consequently, a higher risk of dengue outbreaks. Therefore, the climate conditions observed in South Cotabato and its seasonal fluctuations likely contribute to the temporal variations in dengue incidence, with peak incidences observed during the wet season when rainfall and humidity are elevated.

Environmental factors such as temperature, rainfall, and humidity are known to play a significant role in the transmission dynamics of dengue. Edillo et al. (2024) found that in areas with higher humidity and rainfall, there was a marked increase in the density of Aedes mosquitoes, the primary vectors for dengue virus transmission. In line with this, the high humidity levels (84.61%) and the seasonal rainfall patterns in

South Cotabato may contribute to the observed fluctuations in dengue incidence, with the wet season fostering conditions conducive to mosquito breeding. Additionally, temperature plays a critical role in the development of the virus within the mosquito, with higher temperatures accelerating the virus's replication, which can lead to more infectious mosquitoes. These ecological drivers of dengue transmission are consistent with the trends observed in the study, where higher dengue incidences were generally reported during the wet season, particularly in January, when rainfall and humidity levels peaked.

It is important to acknowledge the potential influence of the COVID-19 pandemic, including lockdowns and mobility restrictions, on dengue incidence during the study period. In 2020 and 2021, measures implemented to control the spread of COVID-19 may have contributed to decreased mobility and altered behavior, potentially reducing the spread of dengue. The restrictions on travel, public gatherings, and outdoor activities could have exposed fewer people to areas with high mosquito breeding sites. Khan et al. (2022) discussed how COVID-19-related restrictions may have affected the reporting and surveillance of dengue cases, potentially leading to underreporting during the pandemic. This reduction in dengue case reporting might have been compounded by health systems focusing primarily on managing COVID-19, further hindering accurate surveillance. Conversely, the loosening of restrictions in 2022 facilitated higher rates of human mobility, increasing exposure to dengue transmission hotspots. Thus, the observed shift in dengue incidence patterns, especially the peak in May 2022, could reflect not only climatic factors but also the indirect effects of the pandemic on human activities, vector control efforts, and disease surveillance practices.

During the analysis, we considered potential biases, particularly those related to underreporting during the COVID-19 pandemic (2020-2021), when public health measures such as lockdowns and school closures may have impacted disease reporting and transmission dynamics. These factors were considered to provide a more accurate representation of the trends in dengue incidence during these years.

Dengue transmission in South Cotabato is spatially heterogeneous, with cases concentrated in specific geographical areas rather than uniformly distributed across the province. These findings align with studies in the Philippines (Rejuso et al., 2024), emphasizing the importance of localized hotspots in dengue transmission. The identification of these clusters suggests that dengue risk is influenced by urbanization, population density, and environmental conditions. Urban centers like Koronadal City experience higher dengue incidence due to inadequate drainage systems, water storage practices, and human-mosquito interactions.

Population growth, inter-regional migration, and environmental factors such as temperature and humidity may increase dengue cases in these areas. Studies such as those by Edillo et al. (2024) and Pangilinan et al. (2017) have demonstrated that environmental conditions—particularly temperature and rainfall—are key factors in shaping the spatial distribution of dengue cases in the Philippines. In this context, the warm and humid conditions observed in South Cotabato may create an environment conducive to breeding Aedes mosquitoes, further contributing to clustering cases in high-risk areas. Moreover, migration patterns and population density may exacerbate the risk of dengue transmission, as higher population concentrations can lead to more opportunities for human-mosquito contact and, consequently, higher rates of disease spread, which is similar to findings in studies conducted in other regions of the Philippines, where densely populated urban centers were shown to have higher dengue incidence rates due to both environmental and demographic factors (Medina et al., 2023; Undurraga et al., 2017).

Moran's I analysis revealed that Barangays Poblacion and Magsaysay in Polomolok and Zone II and Zone IV in Koronadal City were identified as dengue hotspots. Similar findings by Osano (2022) underscored the historical significance of Koronadal City and Polomolok as recurrent dengue hotspots. The concentration of cases in these areas underscores the importance of targeted interventions in high-risk barangays with the highest transmission rates. This detailed clustering information is crucial for improving vector control programs, as it allows health authorities to concentrate efforts—such as targeted fogging, larviciding, and community education—in specific, high-risk barangays. Given that these barangays are identified as high-risk areas, intervention strategies, particularly educational awareness campaigns, should be prioritized in these localities. Studies have shown that public knowledge and awareness are key in mitigating dengue transmission. For example, Hossain et al. (2021) demonstrated that education levels significantly influence public awareness and dengue prevention practices, underscoring the importance of enhancing local understanding of dengue transmission dynamics and prevention strategies.

Educational programs targeting communities in these hotspot areas can significantly improve awareness of the disease's risk factors and promote preventive measures, such as proper waste management, eliminating mosquito breeding sites, and using mosquito nets or repellents. Similarly, as suggested by previous research in the Philippines (Rejuso et al., 2024; Medina et al., 2023), combining education with other interventions, such as vector control programs and timely surveillance, can substantially reduce dengue incidence in identified hotspots.

To effectively mitigate dengue transmission, school-based and community-driven interventions should be strengthened. Schools play a critical role in dengue prevention by implementing awareness campaigns, environmental sanitation programs, and insecticide-treated uniforms to reduce mosquito exposure. Additionally, targeted prevention strategies—including parental education and active community participation in mosquito control—should be prioritized to protect children, who are among the most vulnerable to dengue. Gender-sensitive interventions must also be incorporated into public health campaigns, emphasizing the use of insect repellent and protective clothing, particularly for individuals who spend long hours outdoors. Furthermore, workplace-based mosquito control programs should be introduced to minimize transmission among high-risk occupational groups.

Dengue prevention efforts must be intensified before and during the rainy season through proactive vector control measures, such as larviciding and source reduction. Integrating epidemiological surveillance with real-time environmental monitoring is essential for predicting and preventing unexpected outbreaks. Urban centers like Koronadal City, where inadequate drainage systems, poor water storage practices, and high human-mosquito interaction contribute to increased dengue incidence, require enhanced vector control efforts. High-risk municipalities should implement intensified surveillance, foster community engagement, and adopt targeted vector control strategies to prevent recurring outbreaks and reduce the overall burden of dengue.

CONCLUSION

Analyzing dengue incidence's spatial and temporal patterns provides valuable insights into the disease's distribution and risk factors. Future research should explore additional factors influencing dengue transmission dynamics, such as environmental conditions (e.g., temperature, humidity), community settings, sanitation, and socio-economic status. Furthermore, investigating the economic impact of dengue, particularly the costs associated with treatment, would provide valuable information for governmental agencies in allocating resources for prevention and treatment programs. A multi-sectoral approach involving local governments, healthcare providers, and communities is crucial for developing the province's sustainable and long-term dengue prevention strategies.

Author Contributions

Ygonia: Conceptualization, Methodology, Software, Formal analysis, Writing – Original draft; **Deligero:** Supervision, Validation, Writing – Review & Editing; **Ceballos:** Conceptualization, Methodology, Writing – Review & Editing.

Funding

This research received no funding.

Ethical Approval

Not Applicable.

Competing interest

The authors declare no conflicts of interest.

Data Availability

Data will be made available by the corresponding author on request.

Declaration of Artificial Intelligence Use

Not Applicable.

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How to cite this article:
Ygoña, J., Deligero, E., & Ceballos, R. (2025). Spatio-Temporal Analysis of Dengue in the Philippines: The Case of South Cotabato. Recoletos Multidisciplinary Research Journal 13(1), 33-43. https://doi.org/10.32871/rmrj2513.01.03