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Predicting the Spread of Dengue (Break-Bone Fever) Using the Susceptible-Exposed-Infected-Recovered-Susceptible (SEIRS) Model

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RESEARCH ARTICLE INFORMATION	ABSTRACT

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Dengue fever is a recurring public health concern in tropical countries like the Philippines. This study focused on predicting future dengue fever incidence in a particular municipality in the Philippines from 2025 to 2030, since it is a persistent public health challenge in the country. The Susceptible-Exposed-Infected-Recovered-Susceptible (SEIRS) model was utilized for the prediction. The model was built using historical dengue case data (2019–2024), which considered seasonal variations from Manuel A. Roxas District Hospital and population data from the local government. Complementary quantitative analyses, including Welch's T-test, ANOVA, and Tukey's HSD Test, were conducted to validate seasonal variability and parameter trends at the municipal level. The resulting predictions would inform and improve public health strategies for mitigating future dengue outbreaks. The study confirms that dengue cases are significantly higher during the wet season. Statistical analysis revealed significant variations in dengue spread across both years and seasons, with the two factors interacting in a meaningful way. The SEIRS model forecasts a stable pattern, driven by natural immunity, from 2026 to 2030, reflecting a model-based behavior of below 20 monthly cases. This forecast provides crucial, actionable insights for hospitals, clinics, and the Local Government Unit (LGU), enabling them to strategically plan and optimize resource allocation for timely and targeted public health actions.

Keywords: *dengue fever, SEIRS Model, epidemiological modeling, disease forecasting, public health*

Introduction

Dengue fever remains a significant global health threat, particularly in tropical and subtropical regions like the Philippines, where mosquito-borne transmission is prevalent (WHO, 2024). According to Lim et al. (2025), approximately 5.66 billion people live in areas where dengue and other arboviruses can easily spread. This highlights the significant threat posed by dengue, especially in urban environments where Aedes aegypti and Aedes albopictus mosquitoes thrive. The vast spread, coupled with potential underreporting, poses a significant challenge to health systems and governments, hindering effective control and prevention efforts.

To address these challenges, the World Health Organization's "Global Strategy for Dengue Prevention and Control 2012-2020" emphasizes that reducing dengue morbidity relies on improved outbreak prediction and detection through coordinated epidemiological and entomological surveillance. In the Philippines, where dengue remains a significant public health concern, these strategies are particularly relevant.

According to Villanueva (2024), there were 340,860 dengue cases and 881 deaths in the Philippines from January 2024 to November 2024. Within the country, certain regions are particularly vulnerable to dengue outbreaks, including Roxas, Isabela, which declared a state of calamity in 2019 due to the surge of dengue incidence in the town with 135 cases from January to August (Edale Jr., 2019). Thus, the need for locally focused forecasting is equally essential. Bardiago et al. (2024) and Bergantiños and Gallena (2024) emphasized the importance of municipality-level public health analytics.

In the municipality of Roxas, epidemics have occasionally occurred due to ideal environmental circumstances for mosquito development. Urbanization and climate change have been linked to a rise in dengue cases in rural municipalities.

Understanding these epidemiological patterns is crucial for predicting future outbreaks and implementing effective control measures. Forecasting is a method of predicting future events by analyzing patterns and uncovering trends in previous and current data, and is often associated with predictive analytics. (Seposo et al., 2024; Stryker & Caballar, 2025) To this end, mathematical models like the Susceptible-Exposed-Infected-Recovered-Susceptible (SEIRS) model can provide valuable insights.

Since the emergence of the outbreak of COVID-19, SIR model-related models for the analysis of the prediction of epidemic courses and the impact of interventions are commonly employed. The SEIRS model plays critical roles in predicting outbreaks, evaluating the impact of interventions, and informing public health interventions. The predictive power of mathematical and computational models makes the SEIRS model highly applicable in studying diseases like dengue and COVID-19, where immunity is not guaranteed and reinfection is a possibility (Bjørnstad et al.,2020; Syafruddin et al. 2019).

While these studies demonstrate the SEIRS model's potential and its effectiveness in forecasting dengue cases, there is limited actual data to confirm this. Hence, a significant gap remains in research specifically addressing and predicting dengue outbreaks in locales like Roxas, Isabela. Existing studies usually focus on the global, national, and regional forecasting and do not include municipal-level predictions.

Locally grounded predictions are crucial as the spread of dengue may have town-to-town differences due to geographical and industrial factors.

This study aimed to develop a forecasting model using the Susceptible-Exposed-Infected-Recovered-Susceptible (SEIRS) model to accurately predict the spread of dengue in local settings, specifically in Roxas, Isabela. By doing so, it seeks to enhance existing knowledge and support critical decisions in improving control and prevention measures, enabling timely interventions, and enhancing the evaluation of program effectiveness, particularly in high-burden areas and during periods of unstable transmission.

This study focused on predicting the spread of dengue (break-bone fever) in Roxas, Isabela, using the Susceptible-Exposed-Infected-Recovered-Susceptible (SEIRS) model. Specifically, it determined the seasonal frequency of dengue fever in Roxas, Isabela, from 2019 to 2024, in terms of wet and dry season; identified if there is a significant difference in the spread of dengue disease each year; determined if there is a significant difference in the spread of dengue disease in relation to the season; determined if there is a significant interaction effect between year and season on the spread of dengue disease; and predicted the spread of dengue disease from 2026 to 2030.

Methods

Research Design

The study used mathematical modeling and simulation with quantitative statistical analysis to predict the future transmission of dengue fever in Roxas, Isabela. Mathematical modeling involves utilizing mathematical concepts to clarify systems, functions, and events (Oksana Kurakova, 2023). A deterministic Susceptible-Exposed-Infected-Recovered-Susceptible (SEIRS) model was employed to simulate the transmission dynamics of dengue fever. This research design enabled the researchers to investigate the complex dynamics of infectious disease spread and to produce forecasts of future patterns based on a specific set of assumptions and limitations (Yadav & Akhter, 2021). Quantitative analysis using ANOVA, T-tests, and Tukey's HSD test was employed as supporting analyses to observe historical trends and validate seasonal variations.

Locale of the Study

This study was conducted in the municipality of Roxas in Isabela, where dengue fever remains a prevalent public health concern.

Model Description

The Susceptible-Exposed-Infected-Recovered-Susceptible (SEIRS) model has been extensively applied and adapted to analyze dengue fever dynamics in Roxas, Isabela. This model expands upon the simpler Susceptible-Infected-Recovered (SIR) (pioneered by Kermack & McKendrick in 1927) framework by including an Exposed € compartment to account for a latency period in the disease's progression (Phaijoo et al., 2025). A month-of-year varying transmission rate was incorporated into the Subido SEIRS model as it captures strong seasonal patterns in dengue outbreaks, which are influenced by climatic factors. M-o-Y has been integrated into studies across the Philippines to improve the accuracy of dengue epidemic modeling (Herriman et al., 2018; Salami et al., 2020). Meanwhile, the Susceptible-Exposed-Infected-Recovered-Susceptible (SEIRS) model performed in this study utilized the human population only.

It does not include the dynamics of the mosquito vector and of antibody-dependent enhancement (ADE) for simplification. The study relied on the seasonally varying transmission only since entomological data were not available at the municipality. The SEIRS model's four main compartments are as follows:

1. Susceptible (S): These are individuals who are at risk of dengue infection (Chen et al., 2022). In this study, the initial number of susceptible individuals was set to the total population of Roxas at the start of the study period.
2. Exposed (E): These individuals have been infected but are not yet infectious (Bjørnstad et al., 2020). They cannot transmit the disease to others, but will progress to the infected state.
3. Infected (I): These are individuals currently infected with dengue and are capable of transmitting the disease to susceptible individuals (Chen et al., 2022). Historical data on reported dengue cases in Roxas over the past six years were used to represent the infected population.
4. Recovered (R): These are individuals who have recovered from dengue (Chen et al., 2022). They are temporarily assumed to have immunity, but they can lose this immunity and return to the susceptible state.

Model Parameters

The SEIRS model is ruled by the following differential equations:

(1) $\frac{dS}{dt} = -\frac{\beta SI}{N} + \xi R$

(2) $\frac{dE}{dt} = \frac{\beta SI}{N} - \sigma E$

(3) $\frac{dI}{dt} = \sigma E - \gamma I$

(4) $\frac{dR}{dt} = \gamma I - \xi R$

Where:

N – the total population size (S + E + I + R), assumed to be constant
S(t) – the number of susceptible individuals at time t
E(t) – the number of exposed individuals at time t
I(t) – the number of infected individuals at time t
R(t) – the number of recovered individuals at time t
β (t) – the transmission rate
γ (gamma) – the recovery rate
σ (sigma) – the incubation rate
ξ (xi) – the waning immunity rates

For the municipal-level prediction, the parameters of the SEIRS model, namely, transmission rate (β), incubation rate (σ), recovery rate (γ), and loss of immunity rate (ξ), were quantified using both local hospital-based data and literature-based values with no optimization. Due to a data-limited locale, the incubation rate (σ) and loss of immunity rate (§) were adopted from previous estimates (Harshit & Harjule, 2024). The recovery rate (γ) was specified using the locally available data from the MARDH, while the transmission rate (β) was derived from the seasonal incidence.

Furthermore, the following assumptions for the SEIRS Model were assumed (Harshit & Harjule, 2024).

1. *Homogeneous mixing:* Every individual in the entire population has an equal chance of contact with any other individual.
2. *Isolated population:* Factors such as migration, births, and deaths are not considered in the core model, meaning the total population N remains constant.
3. *Temporary immunity:* Individuals who recovered from the disease are presumed to be immune for a finite period, after which they lose immunity and return to the susceptible state (R —> S).
4. *Constant rates:* Progression rate Σ, recovery rate γ, and loss of immunity rate ξ are considered to be constant during the conduct of the study. However, to get the seasonal trends of dengue spread, the transmission rate β (t) was permitted to have monthly variation.
5. *No detailed modeling of the vector population:* The model does not explicitly include the impact of environmental factors or the dynamics of the mosquito population (the vector for dengue). The transmission process is modeled only through the human population compartments.
6. *Single serotype assumption:* The model presumes that there is only one circulating serotype of dengue within the population, meaning recovered individuals are only temporarily immune to that specific serotype before losing immunity.

Data Collection Procedure

This study utilized historical dengue case data from January 2019 to December 2024, obtained from the Manuel A. Roxas District Hospital (MARDH). These data consisted of 72 monthly counts of dengue patients, specifically the number of admissions and recoveries. All records from the six years were taken with no missing data; thus, imputation measures were not performed. Also, extreme values were still included in the analysis as they reflect significant epidemiological happenings. Population data for Roxas were sourced from the Office of the Municipal Planning and Development (MPDO) at the Local Government Unit (LGU) of Roxas. Data entry, organization, and initial graphing were performed in Microsoft Excel. Quantitative analyses (ANOVA and post-hoc tests) were performed using Jamovi (version 2.4.11). The SEIRS model simulation was implemented in Python (version 3.13) using the SciPy, NumPy, Matplotlib, and Statsmodels libraries.

Analysis of Data

The data gathered underwent thorough statistical analysis to meet the research objectives.

1. T-test (Welch's) – the t-test was utilized in determining the significant difference of dengue spread in terms of season.
2. ANOVA – analysis of variance was used to determine the significant differences across the years and the combined effects of year and season on the spread of dengue fever. Specifically, it tested whether the impact of season on dengue fever varied across different years.

3. Post-hoc Tests (Tukey's HSD) – this test was conducted to determine the seasonal differences within each year, and yearly differences within each season.
4. Effect Size Estimation – Cohen's d, ω^2, and $\eta^2 p$ were reported to support the quantitative analyses (T-test, ANOVA) to present the practical differences of the variables.
5. SEIRS Model – the Susceptible-Exposed-Infected-Recovered-Susceptible model was utilized to predict the spread of dengue fever from 2026-2030 in Roxas, Isabela.

The Welch's t-test and the ANOVA were performed to justify the inclusion of the seasonally changing transmission rate in the SEIRS model.

Ethical Considerations

The researchers sought permission from Manuel A. Roxas District Hospital (MARDH) and the Office of Municipal Planning and Development (MPDO) of Roxas, Isabela, to gather the needed data.

Results and Discussion

Seasonal Frequency of Dengue Fever in Roxas, Isabela (2019-2024)

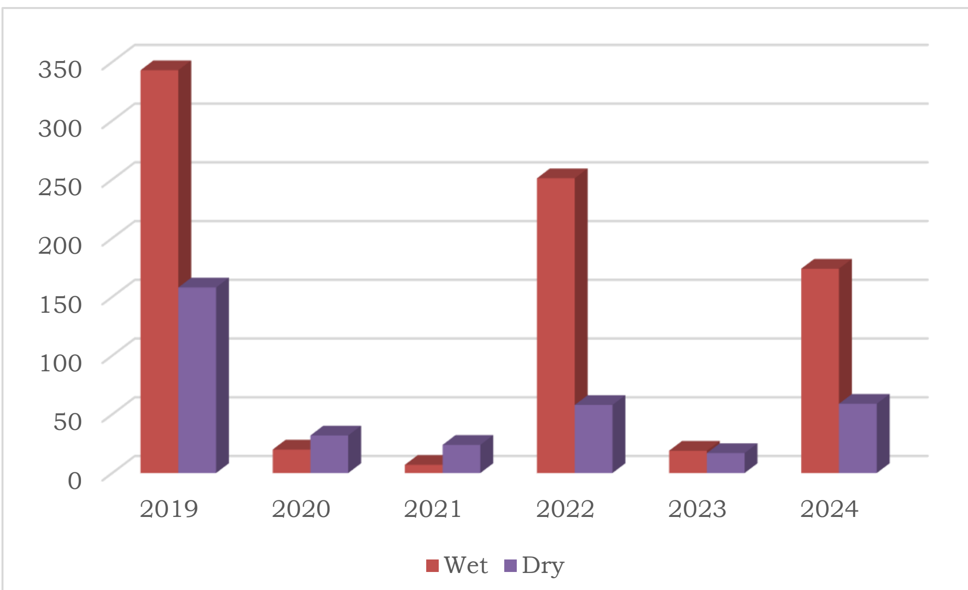

Figure 1. *Seasonal Frequency of Dengue Fever*

Figure 1 illustrates the seasonal frequency of dengue fever in Roxas, Isabela, from 2019 to 2024. It reveals that both the wet and dry seasons in 2019 had the highest recorded dengue fever cases, with a frequency of 343 and 158, respectively. As reported by Edale Jr. (2019) in his article Roxas town under State of Calamity due to dengue, the municipality declared a state of calamity because dengue cases had been steadily rising from the first quarter to the middle of the third quarter of 2019. On the other hand, the lowest frequency in the wet season was noted in 2021 with only seven (7) cases, and the lowest number of cases in the dry season was documented in 2023 with 17 cases.

The graph depicts an unstable pattern of dengue fever counts in Roxas. Specifically, it has a notable decline in 2020 and 2021. During these years, the COVID-19 pandemic significantly affected the number of documented dengue fever cases in the Philippines (Interior et al., 2024). However, as the pandemic transitioned to its post-pandemic phase, dengue fever in Roxas spiked again in 2022 and 2024. It is also stated by Herriman (2024) that the Philippines reported an increase in the number of dengue cases in 2024. These data highlight dengue fever as a major public health concern in Roxas and across the country.

Differences in Dengue Spread in Terms of Season

Table 1. Welch's T-test for Season

Independent Samples T-Test

		Statistic	**df**	**p**		**Effect Size**
Cases	Welch's t	-2.61	49.1	0.012	Cohen's d	-0.615

Note: H_a $\mu_{Dry} \neq \mu_{Wet}$

The comparison of dengue cases between the dry and wet seasons in the town of Roxas is shown in Table 1. The Welch's T-test was employed to compare the seasonal difference of dengue spread at the municipal level.

It reveals that the dry and wet season has a significant difference with a p-value of 0.012 and have a moderate practical difference (Cohen's d = -0.615). Moreover, the negative t-statistic (-2.61) suggests that the mean of the dry season is lower than the mean of the wet season. It implies that dengue fever cases are higher during the wet season in Roxas, Isabela.

It is also stated in the study of Subido and Aniversario (2022) that dengue fever cases mostly occur during the rainy season. However, dengue can still be a threat during the dry season as human activity can impact the production of mosquitoes (VietnamPlus, 2025). While this confirms that seasonal patterns are evident at the municipality level, the explanatory ability is limited by the dependence on hospital-based data.

Significant Differences in Dengue Spread in terms of Year

Table 2. Analysis of Variance for Year

ANOVA - Dengue Fever Cases

	Sum of Squares	**df**	**Mean Square**	**F**	**p**	**ω^2**
Year	15058	5	3012	10.5	< .001	0.396
Residuals	19003	66	288			

Table 2 compares dengue incidence in Roxas across the years 2019-2024. The main purpose of employing ANOVA is to explore the interannual variation of dengue spread in the locale as a supporting tool in the SEIRS model.

The analysis shows that dengue fever incidence varied significantly across the years (F=10.5, p<.001), with a very large effect size at 0.396. This infers that the reported dengue fever cases in Roxas, Isabela, change from year to year and that 40% of the variance is attributed to the years.

Also, as documented by the World Health Organization (2025), the fluctuations of dengue cases were also explained by several factors, such as climate change.

Significant Influence of Season and Year Interaction on Dengue Spread

Table 3. Analysis of Variance for Season and Year Interaction

ANOVA - Dengue Fever Cases

	Sum of Squares	df	Mean Square	F	p	$\eta^2 p$
Season ✻ Year	4079	5	816	4.11	0.003	0.255
Residuals	11908	60	198			

Table 3 presents the significant effect of season and year interaction on dengue spread in Roxas. The analysis shows a statistically significant interaction effect between season and year in the spread of dengue (F=4.11, p = 0.003), with a very large effect size ($\eta^2 p$ = 0.255). This implies that the influence of the season on dengue spread is dependent upon the year, or conversely, the influence of the year on dengue spread is dependent upon the season.

A large outbreak in 2019 led the municipal government to declare a state of calamity after cases far exceeded normal thresholds. The declaration allowed local authorities to use disaster funds for fogging, insecticides, and other control measures (Marquez, 2019). According to PAGASA, the relationship between seasons and years is characterized by recurring weather patterns influenced by the Philippines' proximity to the equator.

Furthermore, the results indicate that the difference between the dry and wet seasons lacks consistency from the years 2019 to 2024. The changes in seasonal patterns over the years may be an effect of climate change. According to Taye et al. (2024) in their research, there were irregular variations between dry and wet years.

Table 4 shows the Tukey Post-hoc comparisons of dengue spread across different seasons and years. The table reveals that the wet season in 2019 is significantly higher than all dry seasons except 2024. Non-significant comparisons have been omitted for conciseness.

Table 4. Tukey Post-hoc Raw Data Comparisons of Dengue Cases by Year and Season

Season	Year		Season	Year	Mean Difference (higher/lower dengue incidence)	SE	df	t	p_{tukey}
Dry	2019	-	Wet	2019	-30.833	8.13	60	-3.7908	0.017
	2020	-	Wet	2019	-51.833	8.13	60	-6.3726	< .001
		-	Wet	2022	-36.5	8.13	60	-4.4875	0.002
	2021	-	Wet	2019	-53.167	8.13	60	-6.5366	< .001
		-	Wet	2022	-37.833	8.13	60	-4.6514	0.001
	2022	-	Wet	2019	-47.5	8.13	60	-5.8399	< .001
		-	Wet	2022	-32.167	8.13	60	-3.9547	0.01
	2023	-	Wet	2019	-54.333	8.13	60	-6.68	< .001
		-	Wet	2022	-39	8.13	60	-4.7949	< .001
	2024	-	Wet	2019	-47.333	8.13	60	-5.8194	< .001
		-	Wet	2022	-32	8.13	60	-3.9342	0.011
Wet	2019	-	Wet	2020	53.833	8.13	60	6.6185	< .001
		-	Wet	2021	56	8.13	60	6.8849	< .001
		-	Wet	2023	54	8.13	60	6.639	< .001
		-	Wet	2024	28.167	8.13	60	3.4629	0.042
	2020	-	Wet	2022	-38.5	8.13	60	-4.7334	< .001
	2021	-	Wet	2022	-40.667	8.13	60	-4.9998	< .001
		-	Wet	2024	-27.833	8.13	60	-3.422	0.047
	2022	-	Wet	2023	38.667	8.13	60	4.7539	< .001

Note: Comparisons are based on estimated marginal means.

Figure 2 displays the visual comparison of dengue cases in terms of year and season in Roxas, Isabela. The illustration reveals that 2019 and 2022 show a significant seasonal difference. In particular, the wet season of 2019 shows more variability compared to its dry season.

Similarly, 2022 exhibits a comparable trend, although with less intensity. These findings correspond with the observation that dengue incidence significantly increases during the rainy season (World Health Organization, 2024), but the degree of this effect fluctuates from year to year.

On the other hand, minimal differences between the seasons were reported in 2020, 2021, and 2023. The documented dengue fever cases in these years are low in both dry and wet seasons, generally. This implies that aside from seasonality, there are other factors that contribute to the occurrence of dengue fever during these years. This can be explained by the surge of the COVID-19 pandemic (Interior et al., 2024), particularly in 2020 and 2021.

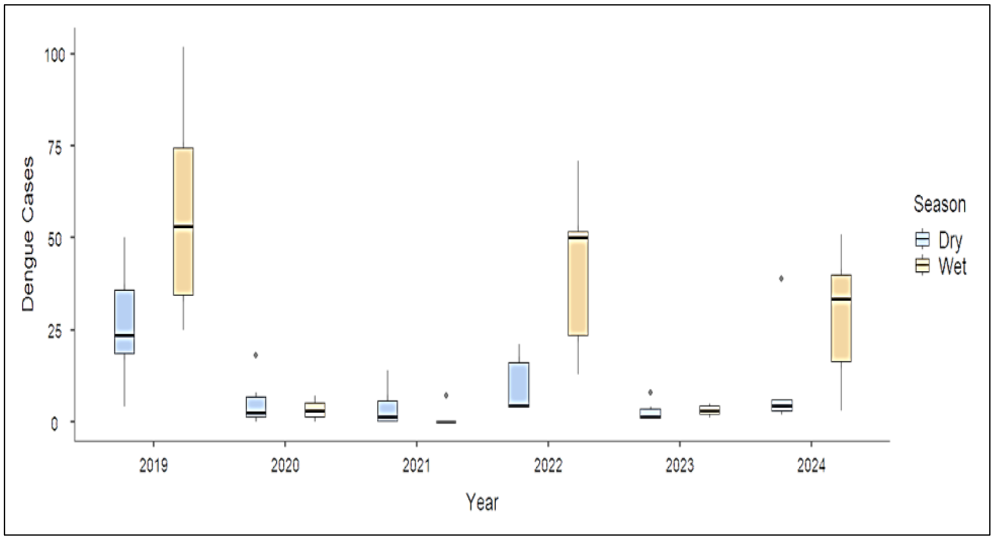

Figure 2. *Tukey Post-hoc Visual Comparisons of Dengue Cases by Year and Season*

Furthermore, the boxplot evidently shows that there is a significant difference in the spread of dengue fever between the dry and wet seasons in Roxas from 2019 to 2024. The fluctuation highlights the complex interactions of elements that influence the spread of dengue fever in Roxas, Isabela. The annual dengue incidence can change not only due to seasonal trends but also because of additional factors (Polwiang, 2020).

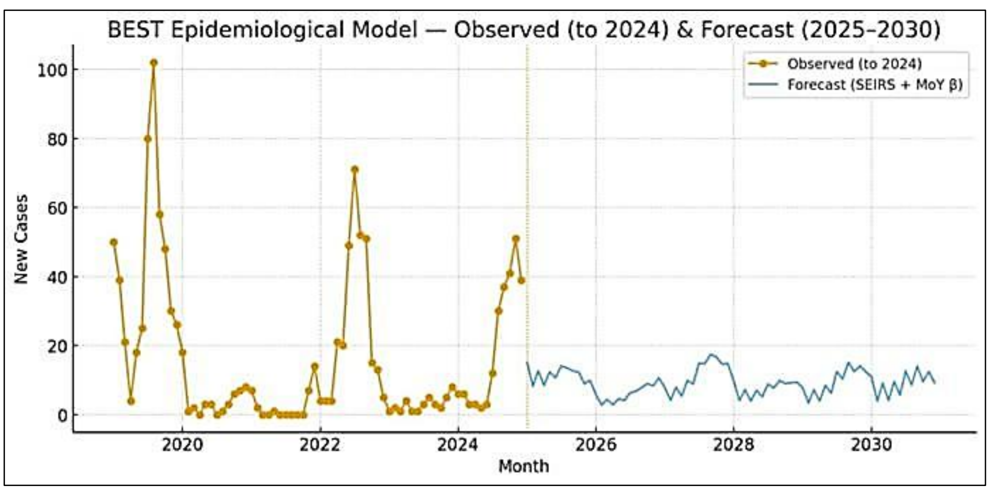

Figure 3. *Comparison of Observed and Predicted Number of Dengue Cases*

The level to which the model reflects general seasonal patterns is shown in Figure 3. It explicitly shows the comparison of observed number of dengue cases and predicted number of dengue cases using the SEIRS model framework with month-of-year varying transmission rates (MoY β). The highest dengue incidence in July 2019 had over 100 cases, while the model calibrated that July 2019 had over 90 cases, according to the model's assumptions, which is slightly lower than the actual cases. While the SEIRS model is effective in simulating seasonality and frequency in predicting the spread of dengue (Bjørnstad et al., 2020), the above figure shows disagreements between the predicted and observed data in 2022. The data spiked up to cases of at least 50, while the model calibrated only up to 40 cases, and September 2024 had over 50 cases, while the model calibrated below 20.

The 2022 peak and 2024 resurgence underestimation of the model may be influenced by the 2019 huge outbreak. The current model overlooked the sudden resurgence as the pattern stabilizes for the succeeding years due to the COVID-19 pandemic. This suggests that the model mostly reflects long-term seasonal and recovery dynamics. Moreover, the sensitivity of the model to abrupt changes may be lessened due to the simplified SEIRS used in this study.

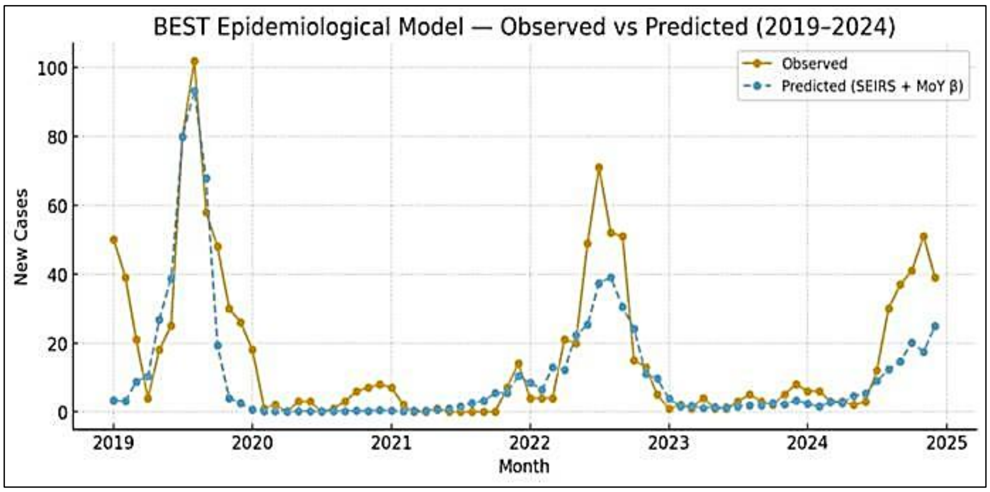

Figure 4. *Observed and Predicted Dengue Cases*

Figure 4 displays the observed historical dengue cases and future forecasted cases using the SEIRS Model. Historical data from 2019 to 2024 indicate a fluctuation with reported cases not exceeding a few hundred individuals. From an increase in 2024, the model's prediction from 2025-2030 forecasts relatively stable and lower dengue cases, with dengue cases projected to not exceed 20 infections per month under current conditions. Under the model's assumptions, with cases not exceeding 20, the peak month of future dengue incidences will occur in 2027 or 2028, followed by 2029. This also indicates that future transmission dynamics may be more controlled in Roxas, Isabela. In addition, the stabilized prediction may be attributed to the model assumptions, which place a huge number of infected individuals from previous outbreaks in the recovered group, thus assuming temporary immunity and never getting infected right away for the next five years. However, this trend and outcome might shift with vector resistance, new serotypes, or changing rainfall.

In contrast to this finding, Wang et al. (2024) reported that there is a possibility of an increase in dengue transmission across Southeast Asian Nations from the 2030s to 2090s, including the Philippines. This contradiction was due to the previous study's inclusion of environmental variables, while the current study does not explicitly use the dynamics of the mosquito vector and environmental factors. While past studies focused on climate-driven factors, the present study uses the locally available hospital-based data in Roxas, Isabela.

Conclusion and Future Works

This study shows the importance of localized modeling as a significant tool in understanding the dynamics of dengue in Roxas, Isabela. Using the town's historical data in the SEIRS Model to forecast the spread of dengue provides insights into planning public health care and action at the municipality level.

The higher incidence during the wet season underscores the need for intensified surveillance and community sanitation before the onset of rains. The local authorities may use these findings to strengthen preventive measures such as vector control interventions, early warning systems, community and school-based awareness campaigns, or collaborative clean-up drives.

For the healthcare institutions in the municipality, the results may also give insights into the future healthcare demand. Although the model prediction is stable for the next five years, these findings may still be updated using new available data for clinical preparedness protocols and flexible hospital resource scaling.

In general, the results in this study may be a helpful support tool for both the local government unit and healthcare providers to manage the resources efficiently for dengue prevention in Roxas, Isabela. It emphasizes the value of locally grounded forecasting for the effective coordination of authorities in preventing possible dengue outbreaks.

While this study provides valuable insight for the municipality of Roxas, the current model may be refined by incorporating the vector dynamics and environmental variables. Based on these critical findings and the current model's simplifying assumptions, there is a need to enhance the predictive power and policy relevance of the model. To further improve this study, future researchers can include Seasonal Weather Data. Since the analysis clearly showed that the wet season presents a significantly higher risk, future models should stop assuming constant rates.

Moreover, the current model excludes the impact and dynamics of the mosquito vector. Hence, it is recommended for future studies to adopt a Host-Vector model (like SEIR-SEI). This means adding equations for the mosquito population to account for environmental factors and the mosquito's own incubation period, making the model a better tool for a vector-borne disease like dengue.

And since dengue has four serotypes, the single serotype assumption is a simplification. Future models should explore a multi-strain model to account for the risk of secondary infections and the associated severe forms of dengue.

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Conflict of Interest

The author declares that there are no conflicts of interest regarding the publication of this paper.

Artificial Intelligence (AI) Declaration Statement

The author declares that Artificial Intelligence tools, specifically Grammarly and ChatGPT, were utilized for the completion of this study. To assist with grammar correction, organization of ideas, paraphrasing, and language improvement, the AI was primarily employed. No critical interpretation, data analysis, or generative material is provided by AI alone. The authors' own work, insight, and understanding are the source of all intellectual contributions, analyses, and conclusions in this study. Strict adherence to ethical academic norms ensured that the research's originality and integrity were preserved.