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Geoinformatics-Based Analysis of Seasonal Vegetation Dynamics and Mosquito-Borne Disease Patterns in Madurai District

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Abstract:
Vector-borne diseases continue to pose a major public health concern in tropical regions, where environmental factors play a crucial role in shaping transmission patterns. This study examines the spatial relationship between seasonal vegetation dynamics and the intensity of mosquito-borne diseases in Madurai District, Tamil Nadu, using geospatial approaches. Block-level morbidity data for the period 2023–24 were standardized using Z-score normalization for malaria, dengue, and chikungunya, and combined to create a composite Mosquito Burden Index. Pre-monsoon and monsoon Normalized Difference Vegetation Index (NDVI) values were obtained from satellite imagery and analyzed through zonal statistical techniques. The results indicate a moderate and statistically significant positive correlation between monsoon NDVI and the mosquito burden index, accounting for spatial variability across administrative blocks. The findings highlight the importance of spatial data analytics in enhancing public health planning and targeted vector control interventions.

Keywords — NDVI, Mosquito-borne diseases, Z-score standardization, Spatial analysis, Geoinformatics, Public health GIS

I. INTRODUCTION

Mosquito-borne diseases such as dengue, malaria, and chikungunya remain major public health challenges in tropical and subtropical regions [1]–[4]. Rapid urbanization, population growth, and environmental changes have accelerated the spread of these diseases globally [5]–[7]. In India, these diseases pose a significant burden, particularly in regions with favorable environmental conditions for mosquito breeding [8]–[10]. Environmental and climatic variables such as temperature, rainfall, humidity, and vegetation cover play a crucial role in influencing mosquito population dynamics and disease transmission [11]–[13]. Seasonal variations significantly affect the spatial and temporal distribution of vector-borne diseases [14]–[16]. Advancements in Geographic Information Systems (GIS) and remote sensing technologies have enhanced the understanding of environmental determinants of diseases. These tools allow integration of environmental and epidemiological datasets for spatial modeling and risk mapping [17]–[19]. Among various indicators, the Normalized Difference Vegetation Index (NDVI) is widely used to assess vegetation density and environmental suitability for mosquito habitats [20]–[21].

Higher NDVI values often correspond to increased moisture and shaded environments, which favor mosquito breeding [22]–[23]. Previous studies have demonstrated the effectiveness of geospatial techniques in identifying disease hotspots and understanding environmental influences on disease transmission [24]–[27]. Therefore, this study aims to examine the spatial relationship between vegetation dynamics and mosquito-borne disease burden in Madurai District.

II. OBJECTIVE

The primary objective of this study is to analyze the spatial association between seasonal vegetation patterns and mosquito-borne diseases in Madurai District.

III. STUDY AREA

Madurai District, located in Tamil Nadu, India, lies between 9°30′–10°50′ N latitude and 77°00′–78°30′ E longitude. The district covers an area of 3,741.73 sq. km and has a population of over 3 million. The region includes both urban and rural landscapes, making it suitable for analyzing environmental and health-related spatial patterns (Fig. 1).

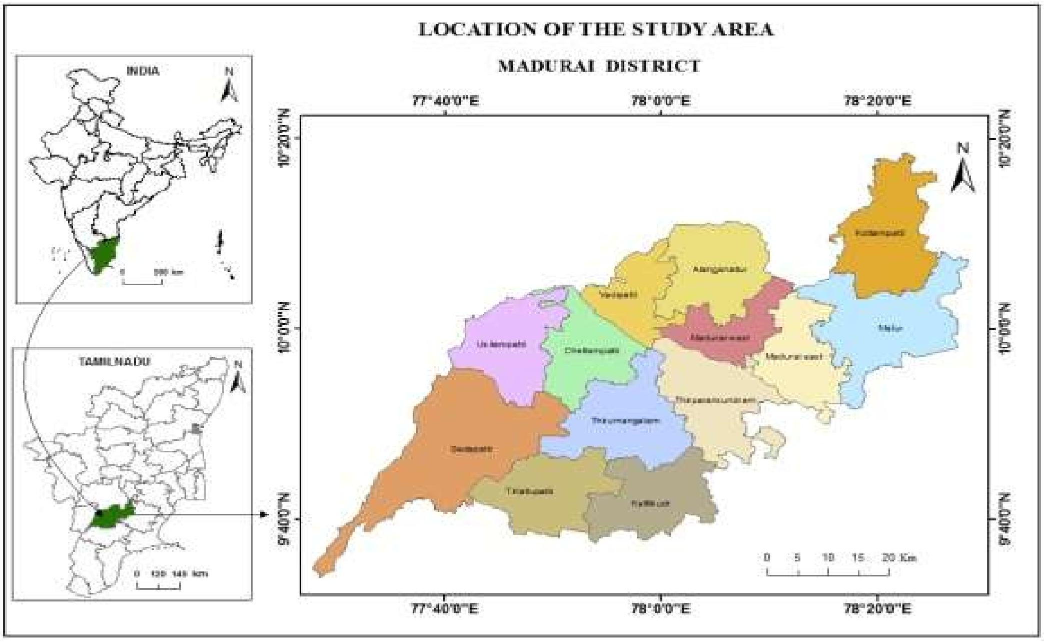

Fig. 1 Location of Study area

IV. METHODOLOGY

A. Data Sources

The study is based on both primary and secondary data:
Primary Data:

- MODIS satellite data (2023)
- Field survey using stratified random sampling (260 samples)
- Block-wise mosquito-borne disease data

Secondary Data:

- Census data (2011)

B. Techniques Used

The study employs the following techniques:

- Google Earth Engine for NDVI extraction
- Z-score normalization for disease standardization
- GIS-based cartographic analysis
- Linear regression analysis using R

Z-score formula:

$$z = \frac{x - \mu}{\sigma}$$

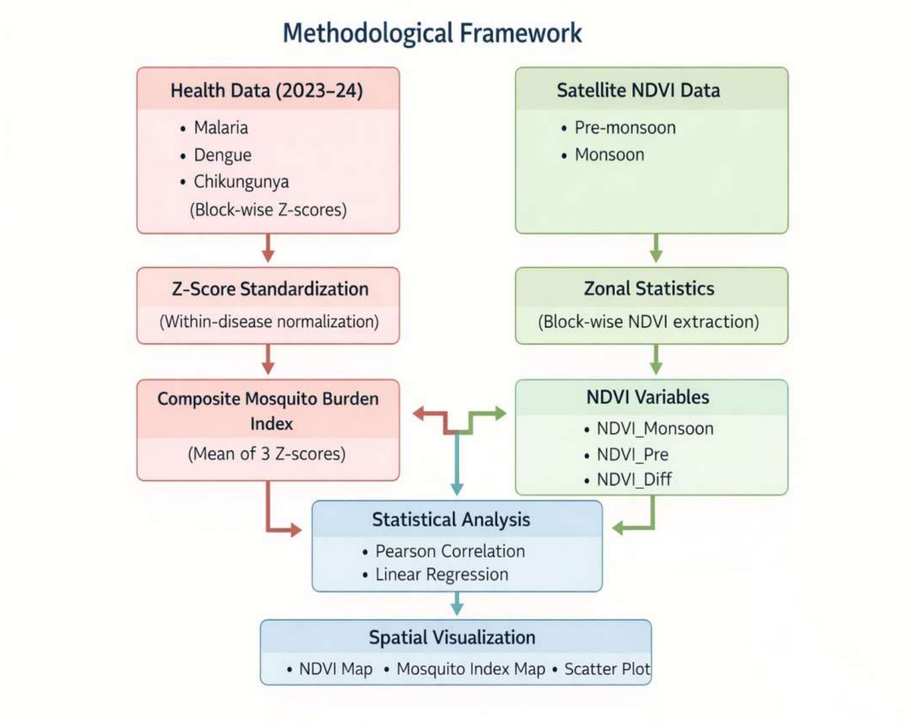

Fig. 2 Methodology Flow chart

V. RESULTS AND DISCUSSION

A. Primary Health Care Centres Distribution

Madurai District has a total of 53 Primary Health Centres (PHCs) that provide essential primary health care services to the population. For the purpose of this study, 13 PHCs were selected, representing one PHC from each administrative block in the district (Fig. 3). The selection was carried out using a stratified random sampling procedure to ensure spatial representation and minimize sampling bias across the district. This approach enabled the study to capture variations in health conditions and disease occurrence across different geographic locations.

The selected PHCs served as the primary data collection points for analyzing mosquito-borne diseases and associated environmental factors. By distributing the sample across all blocks, the study ensured that the spatial patterns of disease burden and environmental indicators could be effectively examined at the block level, allowing for a more comprehensive understanding of the geographical distribution of mosquito-borne diseases in Madurai District.

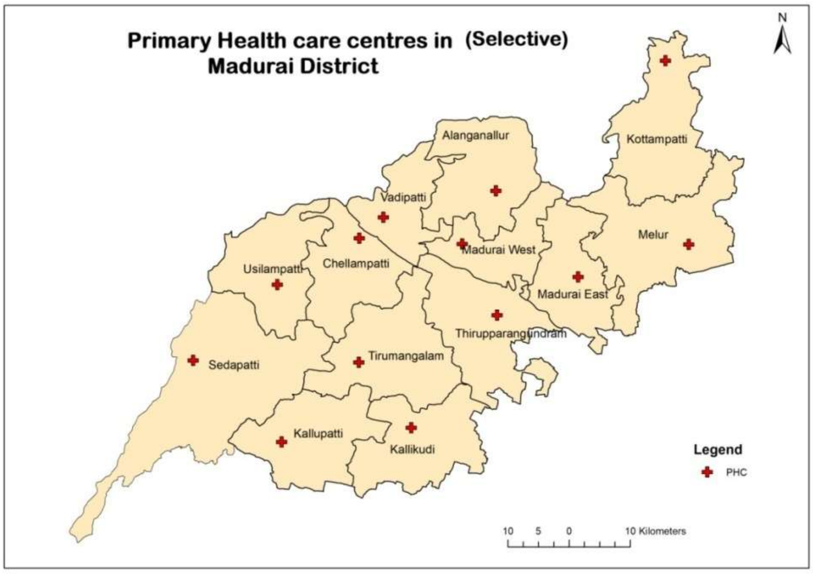

Fig. 3 Primary health care centre location (Selective)

B. Geo-spatial Perspective of Mosquito-Borne Diseases in Madurai District

The analysis of mosquito-borne diseases in Madurai District indicates that dengue, malaria, and chikungunya are the most commonly reported vector-borne diseases affecting the population. These diseases are transmitted primarily through mosquito vectors and are strongly influenced by environmental conditions such as temperature, rainfall, and vegetation cover. In recent years, mosquito-borne diseases have emerged as a growing public health concern in many tropical regions, including southern India. The spatial distribution of these diseases shows considerable variation across different blocks of the district, reflecting differences in ecological conditions, urbanization patterns, and human settlement characteristics. Areas with favorable breeding conditions, such as stagnant water bodies, dense vegetation, and humid climatic conditions, tend to experience higher disease prevalence. The increasing incidence of these diseases highlights the need for improved surveillance systems and spatial monitoring to identify vulnerable areas and implement targeted vector control measures.

C. Spatial Distribution of Mosquito-Borne Diseases in Madurai District

The spatial distribution of mosquito-borne diseases in Madurai District reveals clear geographical variations in disease burden across different administrative blocks. Based on the composite Mosquito Burden Index, the district can be categorized into four levels of disease risk: very low, low, high, and very high (Table 1). Blocks such as Sedapatti, Kallupatti, and Thirupparankundram fall under the very low category, indicating relatively lower disease incidence and minimal mosquito breeding conditions (Fig. 4). Chellampatti, Tirumangalam, Kalligudi, and Melur exhibit low mosquito burden, suggesting moderate levels of disease risk. In contrast, Usilampatti, Kottampatti, and Madurai West show high mosquito burden, indicating increased vulnerability to mosquito-borne diseases. The highest burden is observed in Alanganallur, Vadipatti, and Madurai East, which fall into the very high-risk category. These areas are characterized by environmental conditions that favor mosquito breeding, including dense vegetation, water stagnation, and higher population density.

Table 1: Descriptive Summary (Summary Statistics)

Variable	Min	Max	Mean	SD (approx)
Mosquito Index	-0.947	0.997	-0.001	~0.53
Monsoon NDVI	0.513	0.667	~0.566	~0.05
Pre-monsoon NDVI	0.409	0.608	~0.506	~0.06
NDVI Difference	0.010	0.113	0.057	~0.03

The spatial pattern highlights the importance of identifying localized disease hotspots for implementing targeted public health interventions.

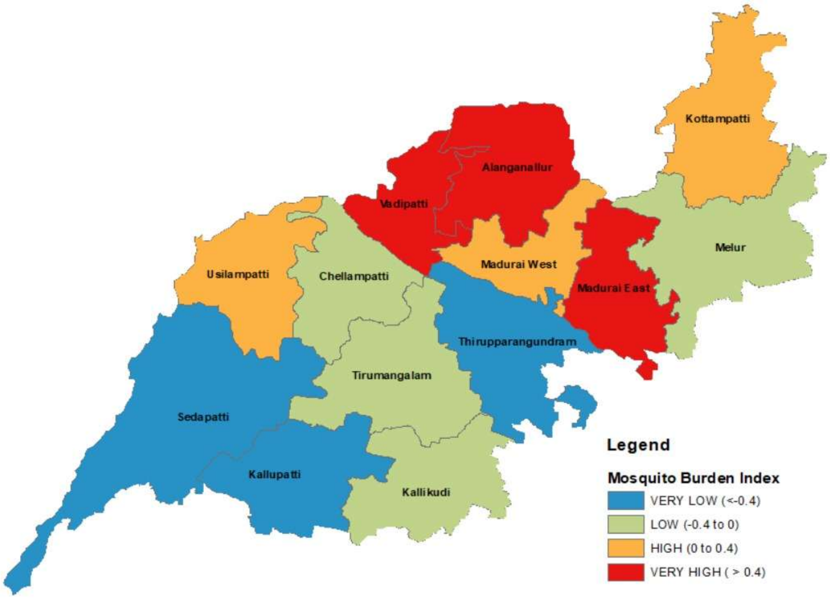

Fig. 4 Normalised Differential Vegetation Index (NDVI) - Monsoon

D. Normalised Differential Vegetation Index (NDVI) – Monsoon

The Normalized Difference Vegetation Index (NDVI) map for the monsoon season illustrates the spatial distribution of vegetation density across Madurai District. Higher NDVI values, represented by blue and green shades, indicate dense vegetation and are predominantly observed in the western and north-western rural regions of the district (Table 2). These areas are characterized by agricultural activities, irrigated lands, and natural vegetation cover (Fig. 5). Moderate NDVI values, shown in yellow and light green, dominate most parts of the district, reflecting mixed land use patterns including cultivated land and scattered vegetation. In contrast, low NDVI values, represented by orange and red shades, are concentrated around Madurai city and other urbanized areas where built-up surfaces and infrastructure limit vegetation growth. The spatial pattern suggests that vegetation density generally increases from the urban core toward the rural periphery during the monsoon season. This vegetation growth during the monsoon period creates favorable micro-environmental conditions such as increased humidity and shaded habitats that can support mosquito breeding and survival.

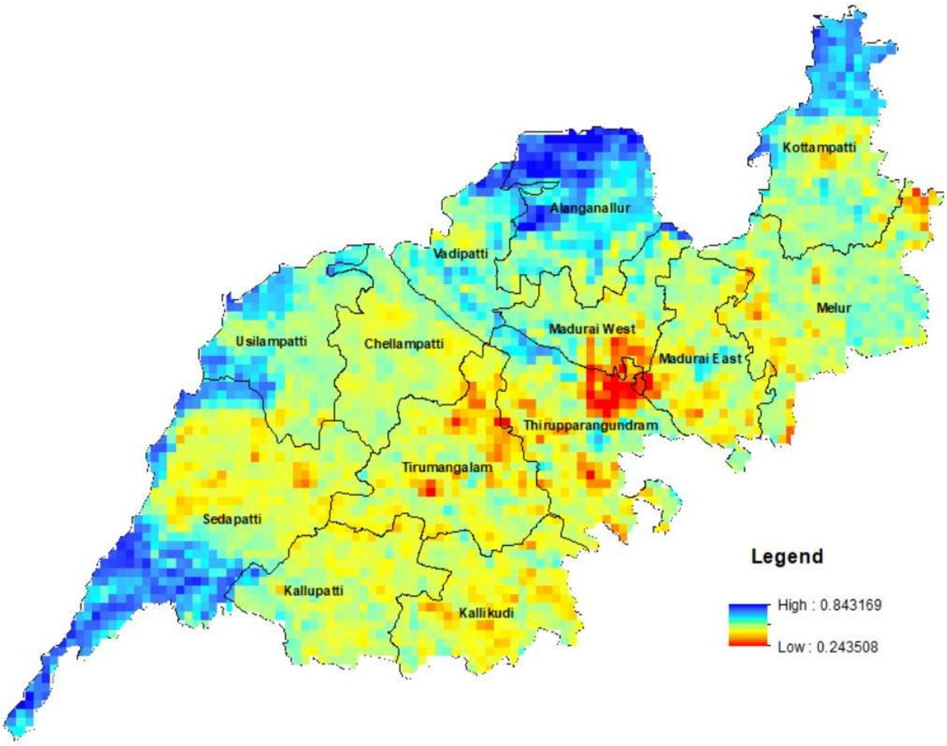

Fig. 5 Normalised Differential Vegetation Index (NDVI) – Monsoon

Table 2: Correlation Results
Correlation between NDVI and Mosquito Index

NDVI Variable	r (Pearson)	p-value	Interpretation
Monsoon NDVI	0.636	0.019	Significant (+)
Pre-monsoon NDVI	0.633	0.020	Significant (+)
NDVI Difference	-0.285	0.345	Not Significant

E. Normalised Differential Vegetation Index (NDVI) – Pre-Monsoon

The NDVI Fig. 6 for the pre-monsoon season shows the spatial variation of vegetation cover in Madurai District before the onset of monsoon rainfall. Compared to the monsoon period, overall vegetation density is relatively lower due to dry climatic conditions and limited soil moisture availability. Higher NDVI values, represented by blue and green colors, are mainly observed in the northern and western parts of the district, where irrigated agricultural fields and small forest patches help maintain vegetation cover even during dry periods. Moderate NDVI values dominate most parts of the district, indicating areas with seasonal vegetation and cultivated land. Low NDVI values, shown in orange and red shades, are concentrated in the central and southern regions, particularly around Madurai city and other urban centers. These areas are characterized by sparse vegetation, dry land surfaces, and extensive built-up areas. The pre-monsoon NDVI pattern highlights the reduced vegetation activity across the district before the arrival of monsoon rainfall, which subsequently influences environmental conditions associated with mosquito breeding habitats.

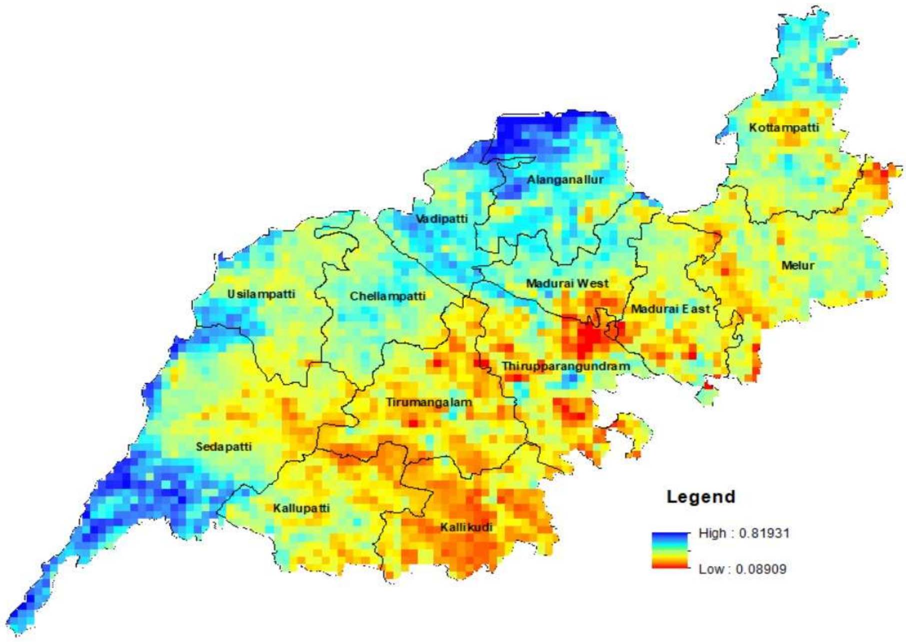

Fig. 6 NDVI – Pre-Monsoon

F. Mosquito Burden Index and NDVI – Linear Regression Analysis

The relationship between vegetation density and mosquito-borne disease burden was further examined using linear regression analysis between the Mosquito Burden Index and NDVI values. The scatter plot (Fig. 7) results indicate a moderate positive relationship between the two variables, with a correlation coefficient of 0.64. This suggests that areas with higher vegetation density tend to experience higher mosquito burden levels. The coefficient of determination (R^2) indicates that approximately 40 percent of the variation in mosquito burden across different blocks can be explained by NDVI values. This finding highlights the significant role of vegetation and environmental conditions in influencing mosquito breeding habitats and disease transmission patterns. Dense vegetation areas often provide favorable microclimatic conditions such as shade, moisture retention, and water accumulation, which support mosquito population growth. Therefore, the results emphasize the importance of integrating environmental monitoring with public health surveillance to identify high-risk zones and implement targeted vector control strategies.

Table 3: Regression Results

Parameter	**Estimate**	**p-value**
Intercept	-4.464	0.0197
NDVI_Monsoon	7.883	0.0194

Linear Regression (Monsoon NDVI) Model: Mosquito_Index = -4.464 + 7.883 × NDVI_Monsoon

• $R^2 = 0.405$, Adjusted $R^2 = 0.351$, $p = 0.019$

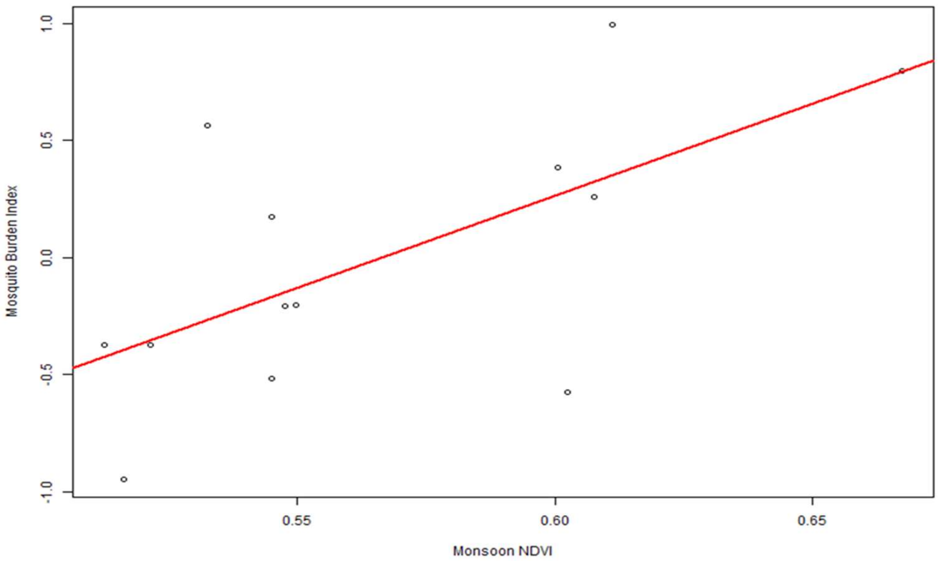

Fig. 7 Mosquito Burden Index and NDVI – Linear Regression Analysis

r = 0.64, p = 0.019, R^2 = 0.40 Moderate positive association observed.
Monsoon NDVI shows a statistically significant moderate positive correlation (r = 0.64), explaining approximately 40% of the spatial variation in mosquito burden across blocks (Table 3).

VI. CONCLUSION

The study highlights that vegetation density significantly influences mosquito-borne disease distribution in Madurai District. Areas with dense vegetation during the monsoon season exhibit higher disease burden. Geospatial techniques such as GIS and remote sensing provide effective tools for identifying high-risk zones and supporting targeted interventions. Integrated approaches combining environmental monitoring and public health strategies are essential for effective disease control.

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