Spatio-Temporal Generalized Linear Modeling of Climatic Influences on Malaria Incidence in Ghana

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Background

Introduction

Malaria is a Vector-borne disease caused by *Plasmodium* via **female *Anopheles*** mosquitoes. (CDCP): It can be transmit- ted through blood transfusions, organ transplants, infective syringes & needles. WHO: **Over 2.2 billion cases and 12.7 million** deaths averted since 2000 worldwide. (2023): **177 million cases prevented and 1 million deaths, of which 80% cases and 94%** of deaths in Africa. Yet, **251 million cases (95% of global cases) & 579,414 malaria deaths (97% of global deaths)** in Africa. **76% of deaths were children < 5**. Ghana: **5.2M cases, 151 deaths**; prevalence declined from **14.1% (2019) to 8.6%.** National Elimination goal: Reduce Malaria prevalence by **50% (2021- 2028).**

Ayo (2018): Negative Binomial outperformed Poisson (Uganda). Diao et al. (2023): Poisson outperformed NB (Senegal). Kleinschmidt et al. (2001): Poisson GLMs found positive association (South Africa). Klutse et al. (2014): Negative association between high temp and malaria (Ghana). Amadi and Erandi (2024): High rainfall reduced malaria incidence (Nigeria).

2. Problem statement

Climatic conditions directly influence malaria transmission dynamics: Temperature, rainfall, and humidity are key determinants of vector lifecycle and parasite development. Existing GLM studies produce mixed results due to variations in models and covariates. Many models underperform due to limited covariate use and neglect of spatial dependence. This study introduces new variables such as apparent temperature, solar radiation, UV index, dew point, and sea level pressure. A Negative Binomial approach addresses overdispersion in count data and underfitting and a Bayesian framework is adopted to incorporate spatial and temporal structure.

Current Work

1. Objectives

The main of objective is to model malaria incidence using generalized linear and spatio-temporal frameworks incorporating climatic variables in Ghana. The specific objectives:

1. **Identify appropriate GLMs for malaria incidence.**
2. **Evaluate significance of diverse climatic factors.**
3. **Conduct spatial mapping of malaria hotspots.**

2. Methodology

DATA SOURCE:

Malaria Incidence : Ghana Health Service (GHS), Monthly aggregated cases per region , Time: Jan 2020 to Dec 2024, Spatial resolution: 16 administrative regions .

Climatic Variables : Visual Crossing Historical Climate API , Frequency: Daily data aggregated monthly, Variables: Temp, rainfall, humidity, apparent temp, dew point, sea level pressure, solar energy, radiation, UV index.

MODEL FORMULATION:

Generalized Linear Models (GLMs):

Poisson: $\boldsymbol{\psi_i \sim poisson\ (\mu_i)}$, $\log(\mu_i) = \xi_i^T \beta$; Estimation via MLE Newton-Raphson Algorithm**.**

Negative Binomial: $Var(\psi_i) = \mu_i + \delta\mu_i^2$ accounts for over-dispersion.

Model Evaluation: Pearson Chi-Square, Deviance and Pseudo R-Squared**.**

Bayesian Framework: Spatio-Temporal Bayesian Modeling

$\log(\pi_{ij}) = \mu + u_i + v_i + \gamma_j + \delta_{ij} + \xi_{ij}^T\beta$, u_i spatial structured effect, v_i spatial heterogeneity, γ_j temporal effect and, δ_{ij} space-time interaction

- Captures nonlinear climate trends, lagged effects.

Hotspot Analysis: Estimation via the Local Moran's I

Significance: via random permutation pseudo p-values

Hotspots: High-High clusters; Cold spots: Low-Low clusters

Conclusion & Expectations

This study seeks to model malaria incidence in Ghana using climatic variables through generalized linear and Bayesian spatio-temporal models. The approach addresses overdispersion and spatial heterogeneity in disease data.

Expected outcomes include:

- **I**dentifying significant environmental predictors, selecting optimal statistical models.
- Detecting high-risk Regions and producing spatial risk maps.
- Findings are anticipated to support targeted malaria interventions and guide data-driven public health policies.

References & Acknowledgment

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