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## APPENDICES

### I. **Description of District locations**

Table1. The 170 Districts of Ghana as at 2010 PHC

| District code | District Name | Region |
|---|---|---|
| 1 | Jomoro | Western |
| 2 | Ellembelle | Western |
| 3 | Nzema East Municipal | Western |
| 4 | Ahanta West | Western |
| 5 | Sekondi- Takoradi Metro | Western |
| 6 | Shama | Western |
| 7 | Mpohor-Wassa East | Western |
| 8 | Tarkwa Nsueam Municipal | Western |
| 9 | Prestea Huni Valley | Western |
| 10 | Wassa Amenfi East | Western |
| 11 | Wassa Amenfi West | Western |
| 12 | Aowin -Suaman | Western |
| 13 | Sefwi Akontombra | Western |
| 14 | Sefwi Wiawso | Western |
| 15 | Sefwi Bibiani-Anhwiawso Bekwai | Western |
| 16 | Juabeso | Western |
| 17 | Bia | Western |
| 18 | Komenda-Edina-Eguafo-Abirem (KEEA) | Central |
| 19 | Cape Coast Metro | Central |
| 20 | Abura-Asebu-Kwamankese | Central |
| 21 | Mfantsiman Municipal | Central |
| 22 | Ajumako-Enyan-Essiam | Central |
| 23 | Gomoa West | Central |
| 24 | Effutu Municipal | Central |
| 25 | Gomoa East | Central |
| 26 | Awutu Senya | Central |
| 27 | Agona East | Central |
| 28 | Agona West Municipal | Central |
| 29 | Asikuma-Odoben- Brakwa | Central |
| 30 | Assin South | Central |
| 31 | Assin North Municipal | Central |
| 32 | Upper Denkyira East Municipal | Central |
| 33 | Upper Denkyira West | Central |
| 34 | Twifo-Hemang-Lower Denkyira | Central |
| 35 | Ga South Municipal | Greater Accra |

| | | |
|---|---|---|
| 36 | Ga West Municipal | Greater Accra |
| 37 | Ga East Municipal | Greater Accra |
| 38 | Accra Metropolis | Greater Accra |
| 39 | Adenta Municipal | Greater Accra |
| 40 | Ledzokuku/Krowor Municipal (LeKMA) | Greater Accra |
| 41 | Ashaiman Municipal | Greater Accra |
| 42 | Tema Municipal | Greater Accra |
| 43 | Dangme West/Shai Osudoku | Greater Accra |
| 44 | Dangme East | Greater Accra |
| 45 | South Tongu | Volta |
| 46 | Keta Municipal | Volta |
| 47 | Ketu South | Volta |
| 48 | Ketu North | Volta |
| 49 | Akatsi | Volta |
| 50 | South Dayi | Volta |
| 51 | Hohoe Municipal | Volta |
| 52 | Biakoye | Volta |
| 53 | Jasikan | Volta |
| 54 | Krachi East | Volta |
| 55 | Krachi West | Volta |
| 56 | Nkwanta South | Volta |
| 57 | Nkwanta North | Volta |
| 58 | North Tongu | Volta |
| 59 | Adaklu Anyigbe | Volta |
| 60 | North Dayi | Volta |
| 61 | Birim South | Eastern |
| 62 | Birim Central Municipal | Eastern |
| 63 | West Akim Municipal | Eastern |
| 64 | Suhum-Kraboa Coaltar | Eastern |
| 65 | Akwapem North | Eastern |
| 66 | New Juaben Municipal | Eastern |
| 67 | Yilo Krobo | Eastern |
| 68 | Lower Manya Krobo | Eastern |
| 69 | Asuogyaman | Eastern |
| 70 | Upper Manya Krobo | Eastern |
| 71 | Fanteakwa | Eastern |
| 72 | East Akim Municipal | Eastern |
| 73 | Kwaebibirem | Eastern |
| 74 | Akyemmansa | Eastern |
| 75 | Birim North | Eastern |
| 76 | Atiwa | Eastern |

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|---|---|---|
| 77 | Kwahu West Municipal | Eastern |
| 78 | Kwahu South | Eastern |
| 79 | Kwahu East | Eastern |
| 80 | Kwahu North | Eastern |
| 81 | Akwapem South | Eastern |
| 82 | Atwima Mponua | Ashanti |
| 83 | Amansie West | Ashanti |
| 84 | Amansie Central | Ashanti |
| 85 | Adansi South | Ashanti |
| 86 | Obuasi Municipal | Ashanti |
| 87 | Adansi North | Ashanti |
| 88 | Bekwai Municipal | Ashanti |
| 89 | Bosome Freho | Ashanti |
| 90 | Asante Akim South | Ashanti |
| 91 | Ejisu Juaben Municipal | Ashanti |
| 92 | Bosumtwe | Ashanti |
| 93 | Atwima Kwanwoma | Ashanti |
| 94 | Kumasi Metropolis | Ashanti |
| 95 | Atwima Nwabiagya | Ashanti |
| 96 | Ahafo Ano South | Ashanti |
| 97 | Ahafo Ano North | Ashanti |
| 98 | Offinso Municipal | Ashanti |
| 99 | Afigya Kwabre | Ashanti |
| 100 | Kwabere (Kwabere East) | Ashanti |
| 101 | Afigya Sekyere (Sekyere South) | Ashanti |
| 102 | Asante Mampong Muni | Ashanti |
| 103 | Sekyere East | Ashanti |
| 104 | Sekyere Afram Plains | Ashanti |
| 105 | Sekyere Central | Ashanti |
| 106 | Ejura-Sekyedumase | Ashanti |
| 107 | Offinso North | Ashanti |
| 108 | Asante Akim North | Ashanti |
| 109 | Asunafo South | Brong Ahafo |
| 110 | Asunafo North Municipal | Brong Ahafo |
| 111 | Asutifi | Brong Ahafo |
| 112 | Dormaa Municipal | Brong Ahafo |
| 113 | Dormaa East | Brong Ahafo |
| 114 | Tano South | Brong Ahafo |
| 115 | Tano North | Brong Ahafo |
| 116 | Sunyani Municipal | Brong Ahafo |
| 117 | Sunyani West | Brong Ahafo |

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|---|---|---|
| 118 | Berekum Municipal | Brong Ahafo |
| 119 | Jaman South | Brong Ahafo |
| 120 | Jaman North | Brong Ahafo |
| 121 | Tain | Brong Ahafo |
| 122 | Wenchi Municipal | Brong Ahafo |
| 123 | Techiman Municipal | Brong Ahafo |
| 124 | Nkoranza South | Brong Ahafo |
| 125 | Nkoranza North | Brong Ahafo |
| 126 | Atebubu Amantin | Brong Ahafo |
| 127 | Sene | Brong Ahafo |
| 128 | Pru | Brong Ahafo |
| 129 | Kintampo South | Brong Ahafo |
| 130 | Kintampo North Municipal | Brong Ahafo |
| 131 | Bole | Northern |
| 132 | Sawla-Tuna-Kalba | Northern |
| 133 | West Gonja | Northern |
| 134 | Central Gonja | Northern |
| 135 | East Gonja | Northern |
| 136 | Kpandai | Northern |
| 137 | Nanumba South | Northern |
| 138 | Nanumba North | Northern |
| 139 | Zabzugu Tatale | Northern |
| 140 | Yendi Municipal | Northern |
| 141 | Tamale Metropolis | Northern |
| 142 | Kumbungu | Northern |
| 143 | Savelugu Nanton | Northern |
| 144 | Karaga | Northern |
| 145 | Gushiegu | Northern |
| 146 | Saboba | Northern |
| 147 | Chereponi | Northern |
| 148 | Bunkpurugu-Yunyoo | Northern |
| 149 | East Mamprusi | Northern |
| 150 | West Mamprusi | Northern |
| 151 | Builsa | Upper East |
| 152 | Bolgatanga Municipality | Upper East |
| 153 | Talensi Nabdam | Upper East |
| 154 | Bongo | Upper East |
| 155 | Bawku West | Upper East |
| 156 | Garu Tempane | Upper East |
| 157 | Bawku (East) Municipal | Upper East |
| 158 | Wa West | Upper West |

| | | |
|---|---|---|
| 159 | Wa Municipal | Upper West |
| 160 | Wa East | Upper West |
| 161 | Sissala East | Upper West |
| 162 | Nadowli | Upper West |
| 163 | Jirapa | Upper West |
| 164 | Sissala West | Upper West |
| 165 | Lambussie Karni | Upper West |
| 166 | Lawra | Upper West |
| 167 | Kasena Nankana East | Upper East |
| 168 | Kasena Nankana West | Upper East |
| 169 | Kadjebi | Volta |
| 170 | Ho Municipal | Volta |

II. **Modeling spatial relationship**

**a. Summary of model estimations**

i. Ordinary Least Squares (OLS) model

Number of observation: 170 Degree of freedom: 165

Mean dependent variable : 18742.1 Number of parameter estimates: 5

S.D. dependent variable : 9445.01 S.E of regression : 8515.63

Table 2. Ordinary Least Squares (OLS) model parameter estimations

| Variable | Coefficient | Std. Error | t-Statistic | P-value |
|---|---|---|---|---|
| Constant | 48113.79 | 11235.93 | 4.2821 | 0.00003* |
| Sex ratio | -250.0656 | 115.3896 | -2.1671 | 0.03166 * |
| Basic education | -25755.49 | 4827.879 | -5.3347 | 0.00000* |
| Urbanisation level | 13262.02 | 3013.719 | 4.4005 | 0.00002 * |
| Inter-migration | 4678.116 | 1972.485 | 2.3717 | 0.01886 * |

ii. Spatial Lag model

Number of observation: 170 Degree of freedom: 164

Number of parameter estimates: 6 Mean dependent variable : 18209.2

S.D. dependent variable : 5989.4 S.E of regression : 4157.8

Table 3. Spatial Lag model-maximum likelihood parameter estimations

| Variable | Coefficient | Std. Error | z-value | P-value |
|---|---|---|---|---|
| Lag coeff. (Rho) | 0.713833 | 0.0573 | 12.4540 | 0.00000* |
| Constant | 3385.134 | 5536.44 | 0.6114 | 0.54092 |
| Sex ratio | 22.9913 | 56.4371 | 0.4074 | 0.68373 |
| Basic education | -2391.13 | 2367.834 | -1.0099 | 0.31257 |
| Urbanisation level | 384.0142 | 963.1658 | 0.3987 | 0.69011 |
| Inter-migration | 1407.215 | 1477.828 | 0.9522 | 0.34099 |

iii. Spatial Error model

Number of observation: 170 Degree of freedom: 165

Number of parameter estimates: 5 Mean dependent variable : 18742.052

S.D. dependent variable : 9445.0078 S.E of regression : 8285.79

Table 4. Spatial Error model-maximum likelihood parameter estimations

| Variable | Coefficient | Std. Error | z-value | P-value |
|---|---|---|---|---|
| Lag coeff. (Lambda) | 0.185317 | 0.1070157 | 1.7317 | 0.08333 |
| Constant | 48507.49 | 11891.22 | 4.0793 | 0.00005* |
| Sex ratio | -256.1356 | 122.8256 | -2.0854 | 0.03704* |
| Basic education | -24712.86 | 5080.963 | -4.8638 | 0.00000* |
| Inter-migration | 3843.55 | 1901.16 | 2.021687 | 0.04321* |
| Urbanisation level | 12848.4 | 3166.587 | 4.057491 | 0.00005* |

**b. Spatial Regression Model Diagnosis**

i. OLS model diagnostics

Table 5 Diagnosis of OLS model

| Model diagnostic measure | Value | P-value | Model assessment |
|---|---|---|---|
| $R^2$ | 0.211024 | - | Performance |
| Adjusted-$R^2$ | 0.191897 | 0.0000* | Performance |

| | | | |
|---|---|---|---|
| Corrected Akaike info criterion, AICc | 3564.25 | - | Performance |
| Log likelihood | -1777.12 | - | Performance |
| Moran's I (error) | 2.1049 | 0.03530* | Spatial dependence |
| Jarque-Bera (df = 2) | 107.7229 | 0.0000* | normality of errors (model bias) |
| Breusch-Pagan test (df = 4) | 3.8145 | 0.43169 | Heteroskedasticity (non-stationary of predictors) |
| Moran's I on residuals | 0.0878 | 0.05604 | Misspecification |

ii. Spatial Lag model diagnostics

Table 6. Diagnosis of Spatial Lag model

| Model diagnostic measure | Value | P-value | Model assessment |
|---|---|---|---|
| $R^2$ (pseudo) | 0.518094 | | Performance |
| Adjusted - $R^2$ | - | | Performance |
| Corrected Akaike info criterion, AICc | 3352.05 | - | Performance |
| Log likelihood | -1670.03 | - | Performance |
| Likelihood Ratio Test (df = 1) | 83.481 | 0.00000* | Spatial dependence |
| Breusch-Pagan test (df = 4) | 8.6989 | 0.06908 | Heteroskedasticity (non-stationary of predictors) |
| Moran's I on residuals | -0.1009 | 0.0377* | Misspecification and bias |

iii. Spatial Error model diagnostics

Table 7. Diagnosis of Spatial Error model

| Model diagnostic measure | Value | P-value | Model assessment |
|---|---|---|---|
| $R^2$ (pseudo) | 0.230403 | - | Performance |
| Adjusted - $R^2$ | - | - | Performance |
| Corrected Akaike info criterion, AICc | 3561.28 | - | Performance |
| Log likelihood | -1775.64 | - | Performance |
| Likelihood Ratio Test (df = 1) | 2.9676 | 0.08495 | Spatial dependence |
| Breusch-Pagan test (df = 4) | 4.7826 | 0.31034 | Heteroskedasticity (non-stationary of predictors) |
| Moran's I on residuals | -0.0140 | 0.8695 | Misspecification and model biasness |

***** Statistically significant at p-value < 0.05

-: Not applicable/Available

**c. Predicted maps of the selected model (Spatial Lag model)**

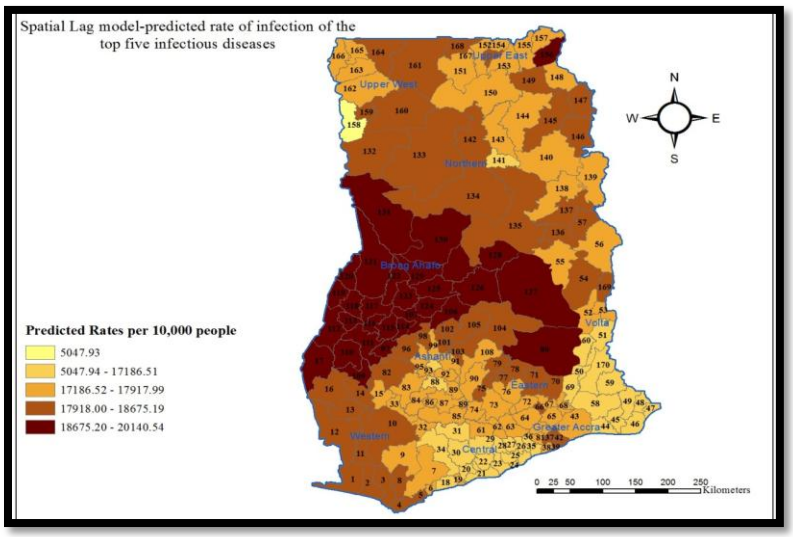


Fig 1 Predicted incidence from Spatial Lag model

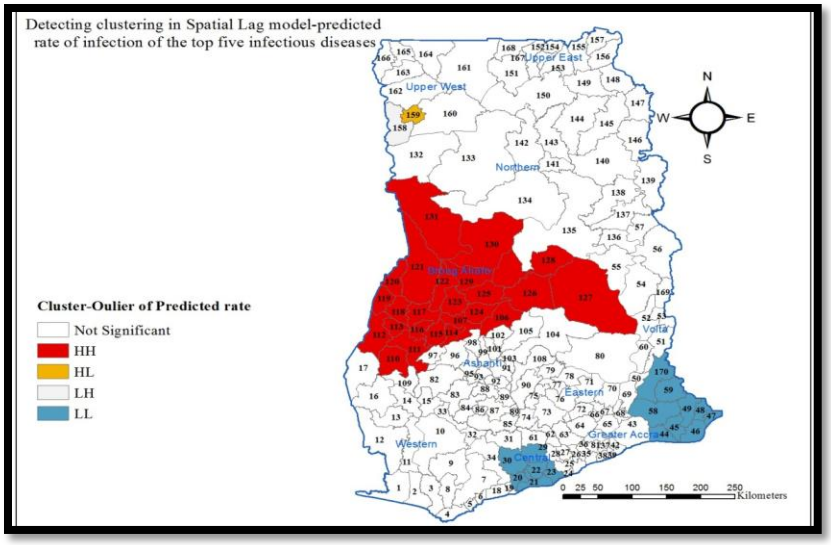


Fig 2: Cluster-Outlier detection in Spatial Lag model-predicted incidence

**d. Spatial Regression Modeling Equations**

i. *Ordinary Least Squares regression*

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \varepsilon$$

Y = dependent variable (to be predicted or understood)

X = value of the explanatory/ independent variables (predictors)

β = coefficients computed by the regression tool (representing the strength and type of relationship between X and Y

ε = random error term/ residuals

n = number of exploratory variables

ii. *Spatial Lag Model*

$$y = (\rho) W_y + \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \varepsilon$$

Y = dependent variable

Wy = spatially lagged dependent variable for connectivity weights matrix $W_{ij}$

$W_{ij}$= the element in the spatial weight matrix corresponding to the observation pair of districts i, j to define the spatial interaction among the districts in the study area by wi·yi with the connectivity vector wi· The W connectivity matrices are row-standardized such that each row sums to 1 (Σwij = 1) if districts i and j share a common boundary; otherwise wij = 0, for non-neighbouring districts.

X = matrix of observations on the explanatory variable

ε = vector of error terms

ρ(rho) and β(beta) are estimated parameters

NB: Spatial lag variable averages the neighboring values of a location

y is dependent on its neighbors through the weights matrix

Weights matrix accounts for the autocorrelation in the model

*iii. Spatial Error Model*

This also include spatial autoregressive error term to accounts for autocorrelation in the error

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \lambda(W)\varepsilon + \mu$$

Y = dependent variable

X = matrix of observations on the explanatory variables

W= spatial weights matrix

ε = is a vector of spatially autocorrelated error terms

u = is a vector of i.i.d. (independent identically distributed) errors

λ (lambda) and β are estimated parameters