Central European Journal of Geography and Sustainable Development 2020, Volume 2, Issue 2, Pages: 5-14
ISSN 2668-4322, ISSN-L 2668-4322 https://doi.org/10.47246/CEJGSD.2020.2.2.1

A Geo-Statistical Analysis for Prediction Modeling of Filariasis (Elephantiasis) Transmission Risk in Bangladesh Using Geographic Information Systems

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Received: 16 July 2020; Revised: 12 September 2020; Accepted: 15 September 2020;
Published online: 23 September 2020

Abstract: Various socio-economic and environmental factors play a vital role in the transmission of many infectious diseases of which some are among the most important cause of mortality and morbidity in the developing countries. Filariasis is the disease of the poor people and has been neglected for more than 50 years in Bangladesh and it is endemic in 23 out of 64 districts of Bangladesh so far. The affected people are generally the poorest and most vulnerable segment of the country. This research article has been made to analyze the prediction of filariasis disease. It discusses how GIS technology can be utilized as an array of several databases and as an effective tool for integrating different sectoral and information of various significant decision-making processes. It utilizes the kriging and cokriging methods of ArcGIS Geostatistical Analyst to predict filariasis occurrences using various socio-economic and environmental parameters and comparing the predicted models for Bangladesh's northern region which is highly filariasis prone. The resultant prediction model indicates that the probability of filariasis is higher in upazilas neighboring another upazila with high occurrences. The result also shows that the disease incidences decreases with increasing distance from the disease affected regions.

Key words: filariasis, geostatistics, kriging, cokriging, spatial interpolation

Citation: Karim, R., & Islam, S.S. (2020). A Geo-Statistical Analysis for Prediction Modeling of Filariasis (Elephantiasis) Transmission Risk in Bangladesh Using Geographic Information Systems. *Central European Journal of Geography and Sustainable Development*, *2*(2), 5-14. https://doi.org/10.47246/CEJGSD.2020.2.2.1

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1. INTRODUCTION

The environment is the basic determinant of health. Health depends on a flexible-equilibrium between human beings and the environment in which they live [1]. The term environment comprises three components: physical, biological, and social. These three components have close relationships with disease and ill health [2]. There is always a constant attempt towards adjustment and re-adjustments between these components of the environment. When an adjustment is achieved, there is health and harmony but on maladjustment between the three component results in disharmony, discomfort, disease, or death. The degree of disease or ill health is proportional to the maladjustment between these components.

Filariasis is a mosquito-borne infectious disease of the human being. Filariasis is a group of human and animal infectious diseases caused by nematode parasites of the order filrioidea, commonly called filariae [3]. It is a communicable parasitic disease caused by Wuchereria bancrofti, Brugia malayi or Brugia timori that can clinically manifest itself in the form of lymphedema or elephantiasis [4]. Filariasis

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has been identified as a major public health problem and is endemic in over 80 countries [5]. It is the world's second leading cause of long-term disability [6].

Throughout the year Bangladesh is a country of divergent climatic condition which has a complex influence on economic and social aspects, mainly for its geographic location and physiographic situation. Most of the people of the country live in rural areas and a large number of them are poor. Various socio-economic and environmental factors play a vital role in the transmission of many infectious diseases of which some are among the most important cause of mortality and morbidity in the developing countries. Many studies were done on filariasis describing the transmission of the disease from the environmental point of view [7,8,9,10]. It was observed in Indonesia that the presence of a water puddle can be a source of filariasis [11]. The research found there was a connection between filariasis and the presence of the water body around the house of filariasis incidences. Education and awareness were directly associated with filariasis disease in Andhra Pradesh, India and there were significant differences of filariasis infection among the illiterate/undergraduate and the graduate respondents [12].

Temperature fluctuations during winter and summer seasons have a significant influence on the occurrences of filariasis [1]. It was observed that there existed a positive association with filariasis occurrence and annual daily temperature. Distribution of mosquitoes is also affected by different sites, depending on temperature, salinity, organic load, etc. [13]. In Ghana the incidences of filarial attacks considerably increase throughout wet seasons compared to the dry season [14].

In Bangladesh, very few studies have been conducted for the prevalence, spread, or cause of infectious diseases by the geographers. Most of these studies were done by researchers from the medical field. Recently some studies have been done on health and environmental fields. Recent advances in the availability of climatic and environmental data and increased use of geographical information systems (GIS) and remote sensing (RS) make the researchers build an operational disease Early Warning Systems (EWS) quoted in a report of World Health Organization [15]. The purpose of the present study was to create a filariasis prediction model using certain predictors with the help of GIS tools and focuses on morbidity situations due to filariasis, the physical environment, and socio-economic aspects of the northern region of Bangladesh.

2. MATERIALS AND METHODS

2.1. Study area

The study area (Rangpur division) is a part of the northern region of Bangladesh. Administratively the region is under the Rangpur division. It covers a surface area of 16320.26 and is situated between 25°20′ and 26°37′ north latitudes and between 88°50′ and 89°53′ east longitudes. The region consists of eight districts. It is bounded on the north by the Assam and on the west by the West Bengal state of India. The annual mean temperature is about 39°C in Summer and 7°-10°C in the winter. It receives rainfall from the monsoon started in the middle of June and continued till the end of September. But the total amount of rainfall in the region is low comparing to the rest of the regions of the country.

2.2. Databases

This study has collected filariasis morbidity data from the Filaria Hospital at Syedpur in 2014-15, which is under the Nilphamari district of the region. It is a specialized hospital for the disease. This research has collected the data from the register book of the hospital and compiled them according to upazila (sub-units of districts) wise. Upazila wise socio-economic and geo-environmental data such as, population density, Literacy, kutcha households (Referrers to the households which are made of earth, bamboo, wood and corrugated iron sheets (CGI) or thatch as roofs.), jhupri households (Referrers to the households which are shacks made from branches, bags, tarpaulin, jute, etc.), having no sanitary, no toilet, Irrigated areas, annual maximum temperature, annual minimum temperature, annual mean rainfall, annual mean humidity were collected from respected government sources. The data relating to the socio-economic status were collected from Bangladesh Bureau of Statistics, Bangladesh Meteorological Department provided the necessary weather data. The spatial dataset which comprises the vector map coverages of 58 upazilas of Rangpur Division (1:50000 scale), were collected from LGED which depict many human and physical features (Administrative boundaries, Rivers, Lakes, Roads, Hospitals, etc.).

2.3. Stepwise Multiple Linear Regression analysis

Variables have been selected in the light of the surveyed literature and found that several socio-economic and geo-environmental parameters are associated with filariasis morbidity [11,1,14]. Multiple Stepwise Linear Regression was conducted for filariasis occurrences of the 58 upazilas (dependent variable) with various socio-economic and geo-environmental parameters (Independent variables) using SPSS version 20 to find out the helping parameters which may have influences for the filariasis occurrences in the study area.

2.4. Geostatistical methods

Nowadays geostatistics is a frequently used technique for analyzing the spatial relationships among the datasets. It is a statistical technique used to analyze and predict the values associated with spatial or spatiotemporal phenomena incorporating the spatial (and in some cases temporal) coordinates of the data within the analyses [16]. A Geostatistical method investigates the presence of spatial correlation among the variables related to distance and direction in a landscape. Using kriging and cokriging techniques of ArcGIS geostatistical wizard this paper aims to find out how the different socio-economic and environmental variables are spatially correlated with filariasis and what their spatial effect in the surface of the region. In Bangladesh, very few studies have been conducted to study the spatial pattern of the disease using GIS tools and, in this context, the approach taken in this study kriging and cokriging techniques of the geostatistics methods are new to analyzing the spatial spread of filariasis.

Recently, increases in applications of kriging and cokriging are noted in the field of medical geography. Geographers are using these techniques for creating a risk model of a disease and assessment of necessary establishments of public health [17,18]. Using kriging has emerged in the last decade or so including the mapping of influenza-like illness in France [19].

Different spatial interpolation techniques including kriging and cokriging can improve the evaluation process of vector patterns mosquito, characterized their habitats and breeding conditions which are the cause of various infectious diseases [20].

In India researchers were succeeded to predict and forecast filariasis using different environmental variables as predictor vector mosquito density during different months and able to forecasting vector (mosquito) densities in forthcoming seasons [21]. Filariasis prediction for Africa showed that populations at risk to filariasis may range from 543 and 804 million currently, and that these cases could rise to between 1.65 to 1.86 billion in the future depending on the climate scenario used and thresholds applied to signify infection presence [7].

The geo-statistical predictive model was statistically significant and thus the resultant delineated map of filariasis transmission risk zone was useful for decision making to implement the filariasis control in India [9]. A geo-environmental risk model was succeeded to create a filariasis transmission risk map for India using spatial interpolation methods of the geostatistical technique of GIS [22].

There will be many situations in which a certain spatial analysis technique provides part of the answer and for this reason, it is always necessary to take into consideration the using of other techniques to get the total picture. Therefore, this study will examine the filariasis situation using kriging and cokriging methods of ArcGIS geostatistics analysis wizard and evaluate the influence of the different socio-economic and geo-environmental parameters to the disease and the consequences on the study surface. A complete methodological framework adopted in this study has been shown in Figure 1.

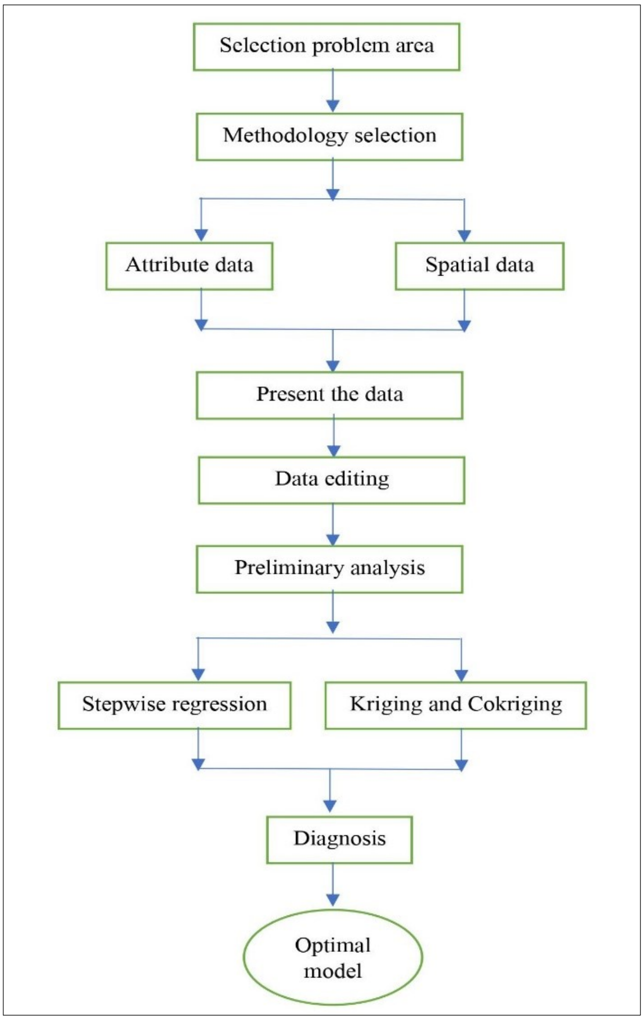

Figure 1. Methodological framework

3. SPATIAL DISTRIBUTION OF FILARIASIS IN BANGLADESH

Filariasis is at present endemic in 23 districts, mostly bordering India [23]. In a health bulletin report published by the Directorate General of Health Services [24] shows that the northern region of Bangladesh is filaria prone. Currently, outbreaks of filariasis occur in seven of the eight districts of this study area. The Endemicity districts are Nilphamari, Dinajpur, Rangpur, Thakurgaon, Panchagar, Kurigram, and Lalmonirhat districts of the study area (Figure 2). The report also shows 88.33% of filariasis infections exist in this northern region (38582 out of 43678).

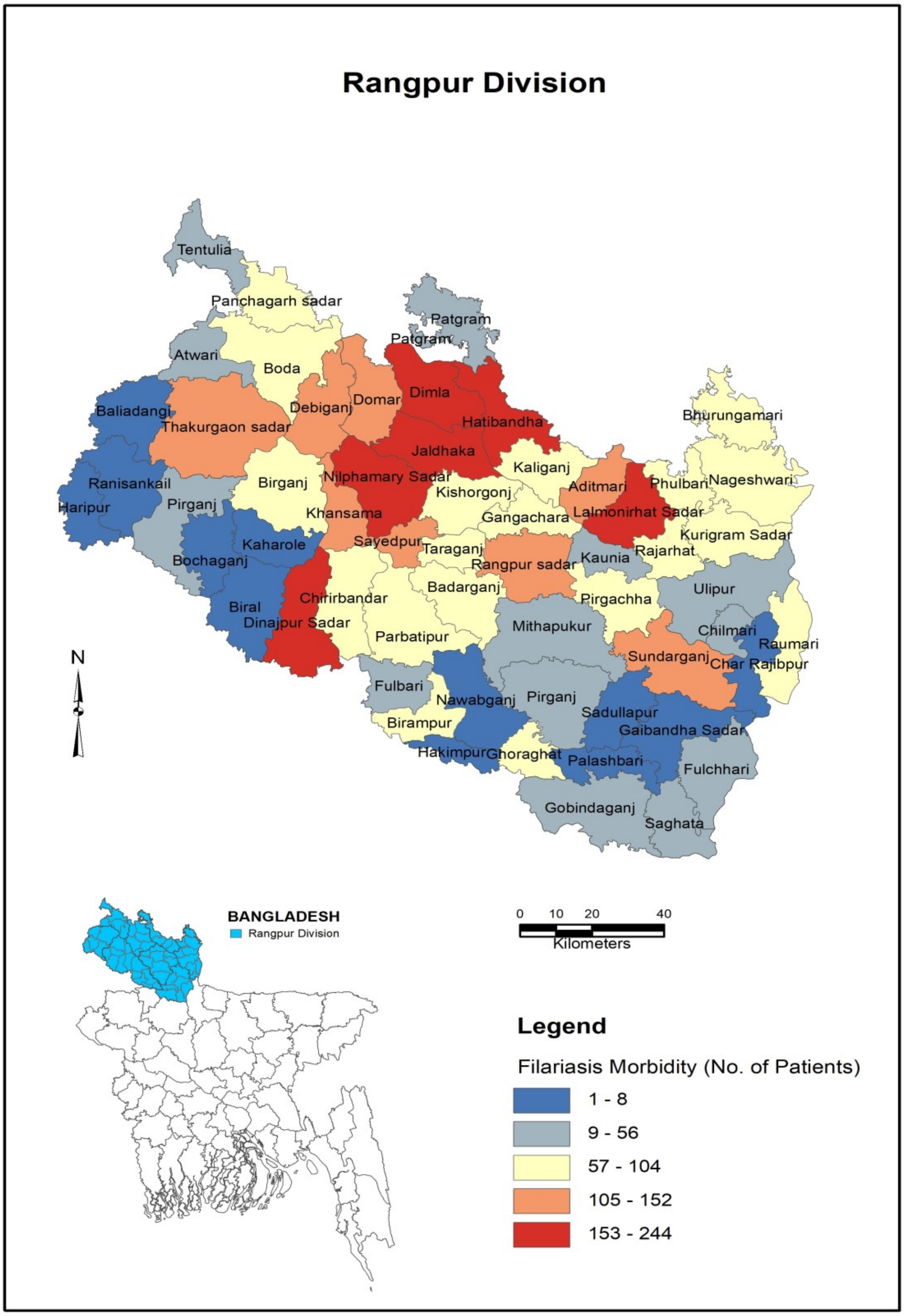

Figure 2. Distribution of Filariasis morbidity of the study area
Data Source: Filaria Hospital Sayedpur, Map: Own processing

4. RESULTS AND DISCUSSION

4.1. Preliminary analysis

Summary statistics of filariasis occurrences and other related data are given in Table 1. It can be seen that there was an average of 64.37 filariasis patients from each district who had been admitted or had taken treatment of the disease from the hospital. The maximum and the minimum number were 244.00 and 8.00 for the whole region. The other socio-economic and geo-environmental parameters had been selected through a lot of literature review. Table 1 shows the Pearson's correlation coefficients rounded to two decimal places. It depicts the relationship between irri area (Irrigated Area) and filariasis is the strongest (r = 0.77) but there is also a strong relationship between two of the independent variables (annual mean maximum temperature, r = 0.66 and jhupri households, r = 0.70) and a moderate relationship can be found for annual mean rainfall (r = 0.56).

Table 1. Descriptive Statistics of the socio-economic and geo-environmental variables

	Minimum	Maximum	Mean	Std. Deviation	Correlation coefficient (with Filariasis)
Filariasis	8	244	63.43	47.580	
Pop_den	526	2174	985.67	309.894	0.40
Literacy	31.2	64.3	46.490	6.2189	0.30
Kutcha	61	91	77.48	7.749	0.30
Jhupri	0.50	7.0	3.560	1.9352	0.70
No_sanitary	31	35.3	34.738	10.3324	0.26
Temp_max	31.0	36.0	33.148	1.1243	0.66
Temp_min	9.0	13	10.95	.945	0.42
Rain	1414	2014	1824.26	172.408	0.56
Humidity	72	90	78.92	7.045	0.21
Irrigated_area	6102	78351	42471.00	17412.384	0.77

Source: Stepwise multiple regression analysis using SPSS, Version 20

4.2. Reporting regression

For ordinary cokriging analysis, multiple linear regression was carried out using SPSS version 20 to investigate the relationship between population density, literacy, kutcha, jhupri, maximum temperature, minimum temperature, rainfall, humidity, irrigated area filariasis.

Table 2. Diagnosis of the stepwise multiple linear regression

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.773[a]	.597	.590	30.469	.597	83.000	1	56	.000
2	0.814[b]	.662	.650	28.143	.065	10.636	1	55	.002
3	0.834[c]	.696	.679	26.954	.034	5.962	1	54	.018
4	0.849[d]	.721	.700	26.070	.025	4.725	1	53	.034

a. Predictors: (Constant), Irrigated_area

b. Predictors: (Constant), Irrigated_area, Kutcha

c. Predictors: (Constant), Irrigated_area, Kutcha Temp_min

d. Predictors: (Constant), Irrigated_area, Kutcha Temp_min, Temp_max

e. Dependent Variable: Filariasis

Source: Stepwise multiple regression analysis using SPSS, Version 20

Table 2 shows there was a significant relationship between irrigated area and filariasis ($p < 0.000$), kutcha households and filariasis ($p = 0.002$) and mean annual minimum temperature and filariasis ($p = 0.018$), mean annual maximum temperature and filariasis ($p = 0.034$). On the other hand, humidity, no_sanitary, and jhupri variables were excluded from the analysis as their p-value was greater than the usual significance level of 0.05. The adjusted R^2 indicates that 70% of the variation in filariasis can be explained by the model. The stepwise regression result contains 4 variables out of 10 and it provides fairly a reliable model. The result indicates that there exists a strong and moderate correlation between the filariasis and the causal variables in the study area. It suggests that these parameters may help to assess the filariasis incidences and create a prediction model when used as a secondary variable in the ordinary cokriging analysis.

4.3. Performing Kriging and Cokriging

Using the kriging method, the full dataset was used to create interpolation maps from the primary variable, i.e., filariasis incidences data (Figure 2). Cokriging was then used to evaluate the contribution of different covariates when estimating the spatial distribution of filariasis occurrences. Based on the result of the stepwise multiple linear regression different helping covariates used in cokriging analysis were irrigated area, kutcha households, mean annual maximum, and minimum temperature.

4.3.1. Variogram models for Ordinary Kriging analysis

The ordinary kriging analysis requires the estimation of the direct variogram models for filariasis incidences data. Kriging model accuracy was determined by intermodal metrics where stable semivariogram and true anisotropy selections produced the optimal model to predict filariasis occurrences of the kriged surface (Figure 3). The best-fitted variogram models were selected based on the minimum RSS values using a trial-and-error process. The selection of a lag size has important effects on the empirical semivariogram and it provides a reasonably good lag size, as every lag will have at least a few pairs of points in it [25]. The lag size was determined using the Average Nearest Neighbor tool located in Spatial Statistics Tools, under Analyzing Patterns. The variogram parameters are iteratively changed to get the best-fitted model, which produced the minimum RSS [26]. The cross-validation matrix produced a ME value centered around 0 (ME = 0.016), a low RMSE value (1.010), and the least difference among RMS (RMS = 38.440) and ASE (ASE = 38.452). However, with ME > 0, ASE > RMS and RMSE >1 indicates `the model's overestimation in determining the variability between the predicted value from the measured value (Table 3).

Table 3. Summary of the Kriging and Cokriging Prediction Model

Variables	Mean	Root-Mean-Square	Mean Standardized	Root-Mean-Square Standardized	Average Standard Error	Model status
Filariasis	0.837	38.440	0.016	1.010	38.452	Overestimating in the variability of prediction
Kutcha with Filariasis	0.698	38.204	0.014	1.010	38.267	Overestimating in the variability of prediction
Irrigated_area with Filarisis	1.944	38.407	0.035	1.011	39.927	Underestimation in the variability of prediction
Temp_min with Filariasis	1.028	37.846	0.023	1.017	37.483	Underestimation in the variability of prediction
Temp_max with Filariasis	0.447	37.652	0.006	0.995	38.179	Overestimating in the variability of prediction

Source: Kriging and Cokriging analysis using ArcGIS (ArcMap 10.2.1)

4.3.2. Cross-variogram models for Ordinary Cokriging analysis

Table 3 summarizes the accuracy metrics for the kriged surface created from filariasis incidences as well as the metrics from cokriged surfaces created from the helping variables (Irrigated area, kutcha households, mean annual minimum temperature, and mean annual maximum temperature). All models produced ME values centered around 0. Filariasis and kutcha households produced the lowest RMS value (2.166) and lowest ASE value (38.267), Filariasis and irrigated area yield RMS value (38.407) and ASE value (39.927), mean annual temperature with filariasis produced RMS value (37.846) and ASE value (37.483).Mean annual humidity helped to produce RMS value (38.423) and ASE value (38.380). Additionally, the cross-validation statistics for all models also show the RMSE >1.

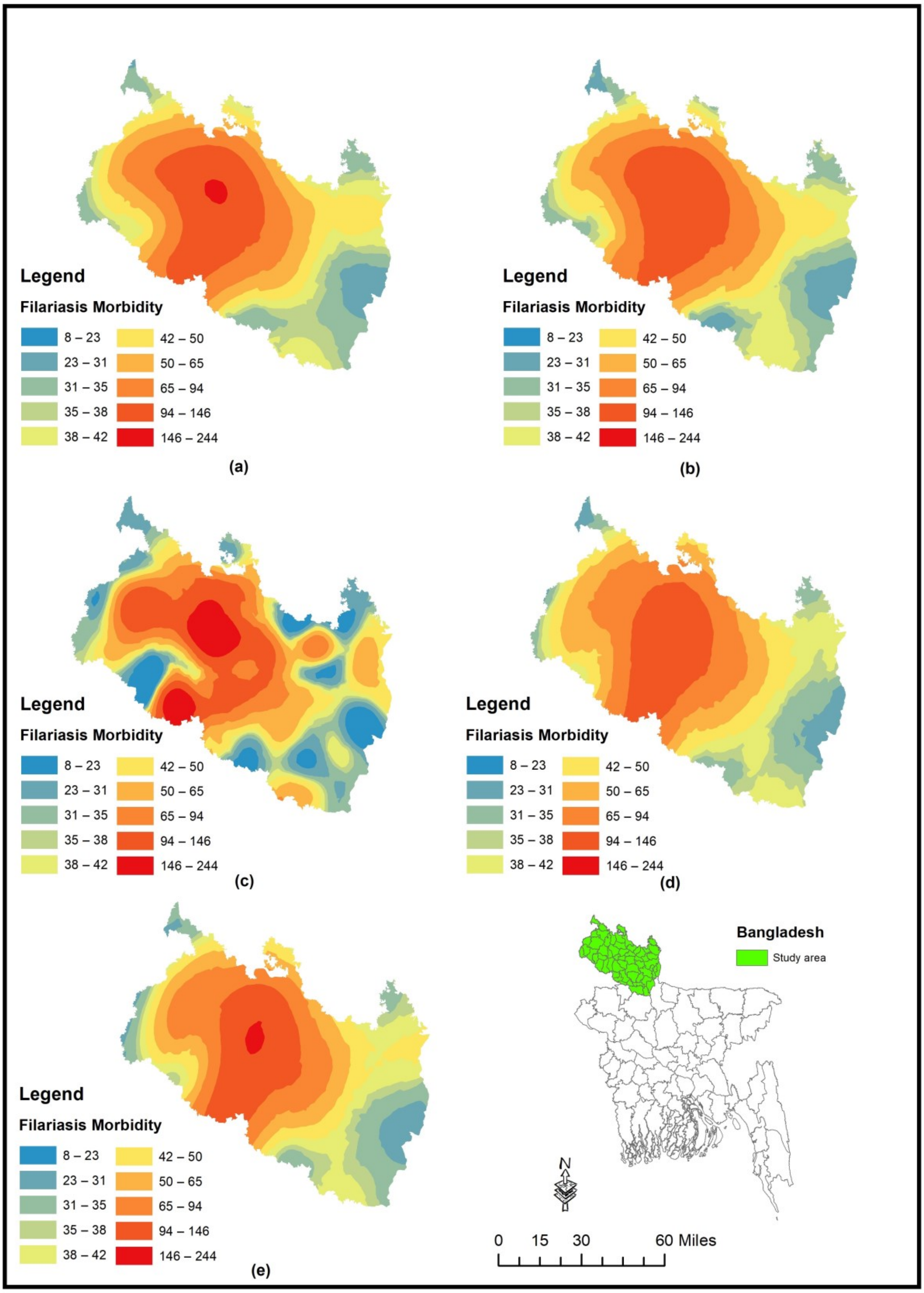

Figure 3. Prediction distribution of Filariasis using kriging and cokriging methods: **(a)** Kriging predictions model for filariasis; **(b)** Cokriging model with kutcha households; **(c)** Cokriging prediction with irrigated areas; **(d)** Cokriging model with maximum temperature; **(e)** Cokriging model with minimum temperature

Data Source: Filaria Hospital Sayedpur, Map: Own processing

Therefore, the RMSE value and the difference between RMS values and ASE values for each surface yield the model's status. As it can be seen from Table 3 that filariasis and kutcha households had the least difference between RMS and ASE (-0.063) followed by filariasis and mean annual maximum temperature (-0.527), filariasis and irrigated area (-1.52), filariasis and mean annual minimum temperature (0.363). The results in Table 3 indicate that the kriging model overestimating the variability of prediction of filariasis. In cases of cokriging analysis, kutcha households with filariasis and annual mean maximum temperature with filariasis are overestimating the variability of our predictions. On the other hand, the irrigated areas with filariasis and mean annual minimum temperature with filariasis are underestimating the variability of the predictions.

The output surface of a model created using different input parameters has been examined and it helped to compare each of the geostatistical layers is relative to another model. It can be observed how the filariasis clustered areas are changing with the interplay of different variables (Figure 3a-e). Moreover, the cross-validation statistics in Table 3 indicate that both the kriging and cokriging analysis examined all neighborhoods for the study area and the cross-variogram models yield prediction maps which indicate that some of the socio-economic and geo-environmental variables are associated with filariasis disease. The RSS, ASE, and RMSE of the cross-validation statistics indicate how accurately an interpolator predicts the observed data [27].

May be the kriging and cokriging methods produce overestimating and underestimating the variability of our predictions, however, the resultant models provided a spatial pattern on the disease situation over the surface. This provides a spatial decision support system which may be used for filariasis elimination programmes and to explore possible environmental and socio-economical drivers of disease transmission of the country.

All the models revealed that the upazilas within the central parts of the region are the most intensely affected areas (Figure 3a-e). Six upazilas are very strongly predicted with filariasis disease including the upazilas like Nilphamari Sadar (Sadar upazila belongs the administrative headquarters of the district), Jaldhaka, Kishorganj, Khansama, Chirirbandar, and Sayedpur. Their grouping is within the area encompassed by the second group. There are nine upazilas, in a much tighter spatial grouping, are more strongly and the upazilas are Domar, Badarganj, Taraganj, Parbatipur, Debiganj, Dinajpur sadar and some parts of Birganj, Thakurgaon sadar, Gangachara and Rangpur sadar, and twelve upazilas, has fallen in the next group. Their position is at the outliers of the second group. The model shows that the probability of getting filariasis is higher in upazilas neighboring another upazila with high filariasis occurrences and the influence decreases with the increase of distance. Rests of the upazilas are grouped in the northern and southern part of the study area and reflects a low level of morbidity from filariasis. Therefore, it can be stated that the filariasis clusters vary from one upazila to another. ArcGIS Geostatistical prediction analysis using kriging and cokriging methods analysis can provide decision-makers with an understanding of the spatial patterns of filariasis or any other disease and enabled them to make more informed decisions about how to address the disease occurrences issue and allocate resources in this respect.

5. CONCLUSIONS

The study revealed that Spatial interpolation of filariasis incidences which poses various impact of mean annual minimum and maximum temperature, amount of cropping field under irrigation and having kutcha (house made of straw or bamboo) households. Geostatistical techniques within ArcGIS helped to produce different filariasis prediction models with the helping parameters.

Testing of various methods like correlation, stepwise multiple linear regression helped to do the ordinary cokriging, and using the different semivariogram models produced by kriging and cokriging analysis provides the overall good results. It is noticed that the amount of having kutcha households, areas under irrigation (produce stagnant freshwater and breeding site of mosquito), mean annual maximum and the minimum temperature had moderate to strong influence on the filariasis disease occurrences in the study region. It also found that the central part of the areas is predicted high-risk zones for the disease to show an effective way to help to investigate and increase the knowledge level of risk factors of filariasis (Elephantiasis). The prediction maps generated in this research provide visual representations of the spatial distribution, association with causal variables, and risk zones of filariasis disease.

This study will also help geographers and environmental professionals to do further study in the field of medical geography which will help authorities to take necessary measures for totally eradicating filariasis and other infectious diseases.

ACKNOWLEDGMENTS

This research was supported by the Ph.D. fellowship programme of Bangladesh University Grant Commission (ugc/scho/1.157/mphil and PhD/12/3813). Authors are indebted to the members of the Filariasis Hospital and Centre for Disease Control at Sayedpur for providing the attribute data on filariasis morbidity and necessary information about the disease.

DISCLOSURE STATEMENT

The authors declare that there is no conflict of interest.

FUNDING

This study supported by the Ph.D. fellowship programme of Bangladesh University Grant Commission (ugc/scho/1.157/mphil and PhD/12/3813).

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