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Construction of generalized linear model using environmental factors in Diarrhoea and Cholera diseases

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ABSTRACT

Diarrhoea and cholera have become a main concern for health authorities all over the world mostly in the tropical countries. This paper, therefore, attempts to examine the environmental factors that may influence the recent diarrhoea and cholera outbreak. The aim of this study is twofold, firstly it is to establish a statistical model to describe the relationship between the number of diarrhoea and cholera cases and a range of explanatory variables and secondly, to identify the explanatory variables which affect the diarrhoea and cholera incidence the most. The explanatory variables involved include the level of cloud cover, percentage of relative humidity, rainfall, maximum temperature, minimum temperature and wind speed. The Poisson and Negative Binomial regression analyses were used in this study. In the Poisson regression, we observed that cholera cases the largest association between wind speed and hospital admissions relative risk (RR) value is 1.0404 with statistically significant and diarrhoea cases the largest association between humidity and hospital admissions RR value is 1.0328 was statistically significant. We also observed that negative binomial regression, cholera the largest association between wind speed and hospital admissions RR value is 1.0431 was not statistically significant and diarrhoea the largest association between minimum temperature and hospital admissions RR value is 1.1176 was not statistically significant.

Key words: *Diarrhoea, Cholera, Environmental factors, Poisson regression, Negative binomial regression.*

Introduction

Human beings are exposed to climate change through changing weather patterns (temperature, precipitation, sea-level rise and more frequent extreme events) and indirectly through changes in water, air and food quality and changes in ecosystems, agriculture, industry and settlements and the economy. The main findings of the IPCC TAR (McMichael *et al.*, 2001) were as follows: An increase in the frequency or intensity of heat wave swill increase the risk of mortality and morbidity, principally in older age groups and among the urban poor. This group of diseases embraces conditions produced by bacteria such as cholera and typhoid. Infections with cholera and typhoid bacteria are development on awareness of the pathogens in water and food (Mc Michael *et al*., 2003a).

Changes in climate, including changes in climate variability, would affect many vector-borne infections. Populations at the margins of the current distribution of diseases might be particularly affected. Water-related diseases can be classified by route of transmission, thus distinguishing between water-borne (ingested) and water-washed diseases (caused by lack of hygiene). There are fourma in considerations to take into account when evaluating the relationship between health out comes and exposure to changes in rainfall, water availability and quality: link ages between water availability, house hold access to improved water and the health burden due to diarrhoeal diseases; the role of extreme rainfall (intense rainfall or drought) in facilitating water-borne out breaks of diseases through piped water supplies or surface water; effects of temperature and runoff on microbiological and chemical contamination of coastal, recreational and surface waters; direct effects of temperature on the incidence of diarrhoeal diseases.

Several studies have shown that transmission of enteric pathogens is higher during the rainy season (Nchito *et al*., 1998; Kang *et al.,* 2001). Drainage and storm water management is important in low-income urban communities, as blocked drains are one of the causes of increased disease transmission (Parkinson and Butler, 2005). Climate extremes cause both physical and managerial stresses on water supply systems, although well managed public water supply systems should be able to cope with climate extremes (Nicholls, 2003; Wilby *et al.*, 2005). Reductions in rainfall lead to low river flows, reducing effluent dilution and leading to increased pathogen loading (Raguraman and Sasikumar, 2019). This could represent an increased challenge to water-treatment plants. During the dry summer of 2003, low flows of rivers in the Netherlands resulted in apparent changes in water quality (Senhorst and Zwolsman, 2005).

Extreme rainfall and runoff events may increase the total microbial load in water courses and drinking-water reservoirs (Kistemann *et al.,* 2002), although the linkage to cases of human diseases less certain (Schwartz and Levin, 1999; Aramini *et al.,* 2000; Schwartz *et al.,* 2000; Lim *et al.,* 2002). A study in the USA found an association between extreme rainfall event sand monthly reports of outbreaks of water-borne disease (Curriero *et al.,* 2001). These asonal contamination of surface water in early spring in North America and Europe may explain some of these asonality inspora diccases of water-borne diseases such as cryptosporidiosis and campylobacteriosis (Clark *et al.,* 2003; Lake *et al.,* 2005). The marked seasonality of cholera out breaks in the Amazonis associated with low river flow in the dry season (Gerolomo and Penna, 1999), probably due to pathogen concentrations in pools.

Higher temperature was found to be strongly associated with increased episodes of diarrhoeal disease in adults and children in Peru (Checkley *et al.,* 2000; Speelmon *et al.,* 2000; Checkley *et al*., 2004; Lama *et al*., 2004). Associations between monthly temperature and diarrhoeal episodes have also been reported in the Pacific islands, Australia and Israel (Singh *et al.,* 2001; Mc Michael *et al.,* 2003b; Vasilev, 2003). Although there is evidence that the bimodal seasonal pattern of cholerain Bangladesh is correlated with sea-surface temperatures in the Bay of Bengal and with seasonal plankton abundance (a possible environmental reservoir of the cholera pathogen,Vibriocholerae) (Colwell, 1996; Bouma and Pascual, 2001), winter peaks in disease further in land are not associated with sea-surface temperatures (Bouma and Pascual, 2001). In many countries choleratrans mission is primarily associated with poor sanitation. The effect of sea-surface temperatures in cholera transmission has been most studied in the Bay of Bengal (Pascual *et al.,* 2000; Lippetal, 2002; Rodo *et al.,* 2002; Koelle *et al.,* 2005). In sub-Saharan Africa, cholera outbreaks are often associated with flood events and faecal contaminate on of the water supplies.

The aim of this study is to determine whether there is an association between environmental factors and number of hospital admissions for diarrhoea and cholera diseases in Tirunelveli district, Tamil Nadu.

Materials and Methods

This study was conducted in Tirunelveli District, Tamil Nadu, India with a population of several thousands. Diarrhoea and cholera cases data were extracted from the list of all admissions to the particular ward at the Melapalayam government hospital, Tirunelveli starting from January 2012 until July 2017. However, for diarrhoea and cholera cases, almost all patients are from Tirunelveli and surrounding areas. In order to model the diarrhoea and cholera incidence, several climatic factors were used as explanatory variables.

Daily observations of environmental factors data such as maximum temperature (°C), minimum temperature (°C), rainfall (mm), wind speed (mph), cloud (%) and humidity (%) were obtained from www.worldweathearonline.com.

The Poisson regression analysis was used the distribution of cholera and diarrhoea cases data is in a procedure of Poisson distribution. Poisson distribution appears to be suitable when the response variable contains of nonnegative integers and is not normally distributed Haliza (2000) and Fxiuji *et al*. (2007). Moreover, the incidence must be random and independent of each other. Poisson regression is describe count or discrete data of the occurrences of some event over a specified interval Cameron *et al*. (1999) and Pindyck *et al*. (1998). The dependent variable used is the number of cholera and diarrhoea cases, although the independent variables were cloud, humidity, rainfall, maximum temperature, minimum temperature and wind speed. The Poisson regression analysis undertakes that the fundamental distribution of the response variable Y under consideration is Poisson. The Poisson distribution with parameter ë is

$$\Pr(Y,\lambda)=\frac{e^{-\lambda_i}\lambda_i^{\;Y_I}}{Y_i\;!}=i=0,1,\dots,\infty \qquad ..\ (1)$$

where Y_i is a random variable representing the number of cholera and diarrhoea cases at day i for a given period, λ_i is both mean and variance of Y_i . In order to develop a cholera and diarrhoea, λ_i is expressed as a function of approximately explanatory variable through log link function is given by,

$$\ln\,\lambda_i=\beta' x_i\;(or)\;\lambda_i=\exp(\beta'\,x_i) \qquad ..\ (2)$$

The logarithm of the response variable is linked to a linear function of explanatory variables is

$$\log_e(Y)=\beta_0+\beta_1X_1+\beta_2X_2+\dots+\beta_iX_i \qquad ..\ (3)$$

and

$$Y=\left(e^{\beta_0}\right)\left(e^{\beta_1X_1}\right)\left(e^{\beta_2X_2}\right)\dots\left(e^{\beta_iX_i}\right) \qquad ..\ (4)$$

In other words, the typical Poisson regression model expressed the log outcome rate as a linear function of a set of predictors. However, in multivariate time series analysis, the influence of the explanatory variables X on Y is infrequently instantaneous. In most cases, for instance the cholera and diarrhoea cases, Y responds to climatic factors of X after a interval of time. Thus, the cholera and diarrhoea cases are regressed with the individual lagged climates variable datasets on the basis on the Finite Distributed Lagged (FDL) Model. In FDL, a change in independent variable does not automatically lead to an immediate change in the dependent variable Kelinbaum *et al.* (1998) and Miaou and Lum (1993). The Poisson regression analysis with FDL for each of the datasets will consider the following model:

$\log_e$(diarrhoea and cholera cases) = β_0 + β_1 (cloud)$_{t-i}$ + β_2 (humidity)$_{t-i}$ + β_3 (mintemp)$_{t-i}$ + β_4 (maxtemp)$_{t-i}$ + β_5 (rainfall)$_{t-i}$ + β_6 (wind)$_{t-i}$ .. (5)

where β_0 is constant, β_1 , β_2, ..., β_6 are the unknown parameter values to be estimated and i is a determinate distributed lag operator.

In Poisson regression model, one of the mainexpectations is the equality of the mean and variance. If this assumption is violated, an over dispersion problem can arise. In order to overcome the over dispersion, this study considered the generalization of Poisson model that is the negative binomial regression model Green (2003). The negative binomial distribution is a form of the Poisson distribution in which the distribution's parameter is itself considered a random variable. The difference of this parameter can account for a variance of the data that is higher or lower than the mean. This condition where by the variance is higher than the mean is known as 'over dispersion'. When over dispersion occurs, the variance function in negative binomial is introduced. Negative binomial regression can be considered as a generalization of Poisson regression and assumes that the conditional mean λ_i of Y_i is not only determined by X_i but also a heterogeneity component λ_i unrelated to X_i. The construction can be conveyed as,

$$\lambda_i=\exp(X_i\,\beta_i+e_i)=\exp(X_i\,\beta_i)\exp(e_i) \qquad ..\ (6)$$

where $\exp(e_i)\sim Gamma\;(\alpha^{-1},\alpha^{-1})$.

As a result, the density function of Y_i can be derived as

$$f(Y_i\,|\,X_i)=\frac{\Gamma(Y_i+\alpha^{-1})}{\Gamma(Y_i+1)\Gamma(\alpha^{-1})}\left(\frac{\alpha^{-1}}{\alpha^{-1}+\lambda_i}\right)+\left(\frac{\mu_i}{\alpha^{-1}+\lambda_i}\right)^{Y_i} \qquad ..\ (7)$$

where Γ means the gamma integral which specializes to a factorial integer argument Xiuji *et al.*, (2007).

The estimation of the parameters is done by maximizing the log likelihood function is

$$\ln L(\beta)=\sum_{i=1}^{n}\left(y_ix_i'-\exp(x_i'\beta)-\ln y_i\,!\right) \qquad ..\ (8)$$

This study used the maximum likelihood ratio statistics or commonly known as Deviance (D) statistics to test for the goodness of fitted model for both Poisson and Negative Binomial model. Deviance D in the normal linear regression is similar to R^2 or coefficient of determination which is used to provide the descriptive information about the model fit and is calculated by,

$$R^2 = \frac{\sum(\hat{y}-\bar{y})^2}{\sum(y-\bar{y})^2} \quad .. (9)$$

where y is the observed value of y, $\hat{y}$ is the value of y predicted from the model and $\bar{y}$ is the mean value of y.

In Poisson regression, the residuals are neither normally distributed, nor do they have constant variance. Due to non-linear characteristic of the conditional mean, some measures alternatives to R^2 have been suggested Haliza (2000) and Kelinbaum *et al.*, (1998). The log likelihood Ratio Statistic (Deviance) is introduced to check the appropriateness of a chosen response distribution when explanatory variables are added or excluded from the model. The Deviance value is defined as:

$$Deviance(D) = 2\left\{\sum_i \left[y_i \ln(y_i / \hat{\mu}_i) - (y_i - \hat{\mu}_i)\right]\right\} \quad .. (10)$$

For a well fitted model with appropriate link function, error distribution and functional form, the expected value of residual deviance should approximately be equal to the number of degree of freedom, regardless of the value of μ.

The explanation to the usual of maximum likelihood estimator can be used to construct RR, 95% confidence intervals (CI) on individual model parameters using R Software.

Results and Discussion

The descriptive statistics for during the 6 years and 7 months of the study, there were cholera and diarrhoea diseases hospital admissions and corresponding climate factors data are shown in Table 1. In the time plots, an increase in environmental factors was observed in the months prior to the appearance of the epidemics (Figures 1 and 2).

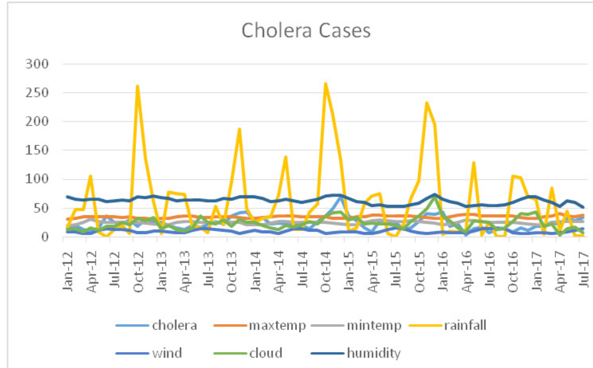

Fig. 1. Time Plots of Number of Cholera Cases and Environmental Factors in Tirunelveli City from January 2012 to July 2017.

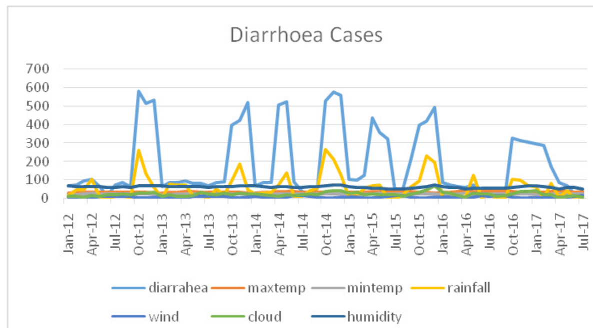

Fig. 2. Time Plots of Number of Diarrhoea Cases and Environmental Factors in Tirunelveli City from January 2012 to July 2017.

Our result suggest that towards the end of August and beginning of September, an increase in the average rainfall above expected (Pre-established based on historical data) followed by potential increase in cholera and diarrhoea cases during October to November.

Table 1. Descriptive analysis of Cholera and Diarrhoea diseases and Climate Factors.

Characteristics	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum
Cholera	3.00	16.00	22.00	23.91	28.50	70.00
Diarrhoea	7.00	66.00	86.00	191.30	323.50	580.00
Max. Temp.	30.00	33.00	35.00	34.60	36.50	41.00
Min. Temp.	20.00	24.00	25.00	25.07	27.00	31.00
Rainfall	0.00	9.79	43.22	60.58	76.30	366.06
Wind Speed	6.00	7.20	8.90	9.52	11.50	15.00
Cloud	3.00	16.00	22.00	23.91	28.50	70.00
Humidity	51.00	59.00	63.00	62.67	67.00	74.00

Association of Climate Factors, Cholera and Diarrhoea Diseases using Poisson Regression Model

Poisson regression model indicated that the concentrations of climate factors were significantly associated with monthly hospital admissions due to cholera and diarrhoea diseases shown in Table 2.

In the Poisson regression, cholera cases the largest association between wind speed and hospital admissions RR value is 1.0404 and 95% confidence interval value is [1.0153 to 1.0662] was statistically significant (p=0.0014). The effect of cholera disease and maximum temperature RR value 1.0317 and 95% confidence interval value is [0.9758 to 1.0907]. The effect of cholera disease and minimum temperature RR value 0.9666 and 95% confidence interval value is [0.9282 to 1.0059]. The effect on hospital admissions for cholera disease and rainfall was strongly linear, with the largest effect of RR value is 1.0009 and 95% confidence interval value is [0.9998 to 1.0019]. Cholera hospital admissions were significantly associated with cloud with RR value is 1.0075 and 95% confidence interval value is [1.0020 to 1.0128]. The effect of cholera disease and humidity RR value is 1.0348 and 95% confidence interval value is [1.0348 to 1.0132].

In the Poisson regression, diarrhoea cases the largest association between humidity and hospital admissions RR value is 1.0328 and 95% confidence interval value is [1.0250 to 1.0406] was statistically significant (p=0.001). The effect of diarrhoea disease and maximum temperature RR value 1.0100 and 95% confidence interval value is [0.9905 to 1.0298]. The effect of diarrhoea disease and minimum temperature RR value 1.0377 and 95% confidence interval value is [1.0244 to 1.0511]. The effect on hospital admissions for diarrhoea disease and rainfall was strongly linear, with the largest effect of RR value is 1.0024 and 95% confidence interval value is [1.0021 to 1.0028]. The effect of diarrhoea disease and wind speed RR value is 0.8737 and 95% confidence interval value is [0.8656 to 0.8820]. Diarrhoea hospital admissions were significantly associated with cloud with RR value is 1.0139 and 95% confidence interval value is [1.0122 to 1.0157].

Under Poisson regression model, cholera cases has the lowest mean deviance value compared with diarrhoea cases. We conclude that Poisson regression model is suitable indicator for the occurrence of cholera cases using climate data.

Table 2. Association of hospital admissions in Climate Factors using Poisson Regression

Variables	RR	LCL	UCL	P – Value
Cholera Cases				
Maximum Temperature	1.0317	0.9758	1.0907	0.2714
Minimum Temperature	0.9666	0.9282	1.0059	0.0980
Rainfall	1.0009	0.9998	1.0019	0.0880
Wind Speed	1.0404	1.0153	1.0662	0.0014
Cloud	1.0075	1.0020	1.0128	0.0066
Humidity	1.0348	1.0132	1.0566	0.0013
Deviance		335.25		
Mean Deviance		234.75		
AIC		577.25		
Diarrhoea Cases				
Maximum Temperature	1.0100	0.9905	1.0298	0.001
Minimum Temperature	1.0377	1.0244	1.0511	0.314
Rainfall	1.0024	1.0021	1.0028	0.001
Wind Speed	0.8737	0.8656	0.8820	0.001
Cloud	1.0139	1.0122	1.0016	0.001
Humidity	1.0328	1.0250	1.0406	0.001
Deviance		11068.1		
Mean Deviance		5027.5		
AIC		5480.1		

Abbreviation: RR – *Relative Risk*; LCL – *Lower Confidence Limit*; UCL – *Upper Confidence Limit*.

Association of Climate Factors, Cholera and Diarrhoea Diseases using Negative Binomial Regression Model

Negative Binomial regression model indicated that the concentrations of climate factors were significantly associated with monthly hospital admissions due to cholera and diarrhoea diseases shown in Table 3.

In the negative binomial regression, cholera the largest association between wind speed and hospital admissions RR value is 1.0431 and 95% confidence interval value is [0.9954 to 1.0931] was not statistically significant (p=0.0656). The effect of cholera and maximum temperature RR value 1.0247 and 95% confidence interval value is [0.9233 to 1.1373] was not statistically significant (p=0.6466). The effect of cholera and minimum temperature RR value 0.9646 and 95% confidence interval value is [0.8924 to 1.0434] was not statistically significant (p=0.3388). The effect on hospital admissions for cholera and rainfall was strongly linear, with the largest effect of RR value is 1.0010 and 95% confidence interval value is [0.9988 to 1.0032]. Cholera admissions were not significantly associated with cloud with RR value is 1.0076 and 95% confidence interval value is [0.9961 to 1.0195], the p value is 0.1781. Humidity RR value is 1.0298, 95% confidence interval value is [0.9905 to 1.0710] but the estimates were not statistically significant (p=0.1431).

In the negative binomial regression, diarrhoea the largest association between minimum temperature and hospital admissions RR value is 1.1176 and 95% confidence interval value is [0.9622 to 1.1573] was not statistically significant (p=0.0904). The effect of diarrhoea and maximum temperature RR value 0.9639 and 95% confidence interval value is [0.8036 to 2.5298] was not statistically significant (p=0.6937). The effect of diarrhoea and rainfall RR value 1.0028 and 95% confidence interval value is [0.9983 to 1.3008] was not statistically significant (p=0.1608). The effect on hospital admissions for diarrhoea and wind speed with RR value is 0.8343 and 95% confidence interval value is [0.7625 to 0.9121]. The effect on hospital admissions for diarrhoea and cloud was strongly linear, with the largest effect of RR value is 1.0224 and 95% confidence interval value is [0.9992 to 1.0470]. Humidity RR value is 1.0279, 95% confidence interval value is [0.9615 to 1.1004] but the estimates were not statistically significant (p=0.4374).

Under negative binomial regression model, cholera cases has the lowest mean deviance value compared with diarrhoea cases. We conclude that negative binomial regression model is suitable indicator

Table 3. Association of hospital admissions in Climate Factors using Negative Binomial Regression

Variables	RR	LCL	UCL	P – Value
Cholera Cases				
Maximum Temperature	1.0247	0.9233	1.1373	0.6466
Minimum Temperature	0.9646	0.8924	1.0434	0.3388
Rainfall	1.0010	0.9988	1.0032	0.3724
Wind Speed	1.0431	0.9954	1.0931	0.0656
Cloud	1.0076	0.9961	1.0195	0.1781
Humidity	1.0298	0.9905	1.0710	0.1431
Deviance		96.144		
Mean Deviance		69.599		
AIC		497.15		
Diarrhoea Cases				
Maximum Temperature	0.9639	0.8036	2.5298	0.6937
Minimum Temperature	1.1176	0.9622	1.1573	0.0904
Rainfall	1.0028	0.9983	1.3008	0.1608
Wind Speed	0.8343	0.7625	0.9121	0.0010
Cloud	1.0224	0.9992	1.0470	0.0300
Humidity	1.0279	0.9615	1.1004	0.4374
Deviance		153.792		
Mean Deviance		71.932		
AIC		798.13		

Abbreviation: RR – *Relative Risk*; LCL – *Lower Confidence Limit*; UCL – *Upper Confidence Limit* for the occurrence of cholera cases using climate data.

Conclusion

We compared two regression models within the similar study and to empirically prove the modification in the effect of cholera and diarrhoea diseases. All cholera and diarrhoea patients in both analyses were engaged with the similar criteria, were evaluated with identical instruments during the similar time period. Both analyses obtainable also included almost the similar set of case intervals, further analyses that limited the Poisson and negative binomial regression to exactly the similar set of case interval did not modify our results (results are exposed in Table 2 and 3).

In our study the relationship of climate factors to hospital admissions for cholera and diarrhoea diseases. In the Poisson regression, we observed that cholera cases the largest association between wind speed and hospital admissions RR value is 1.0404 with statistically significant and diarrhoea cases the largest association between humidity and hospital admissions RR value is 1.0328 was statistically significant. We also observed that negative binomial regression, cholera the largest association between wind speed and hospital admissions RR value is 1.0431 was not statistically significant and diarrhoea the largest association between minimum temperature and hospital admissions RR value is 1.1176 was not statistically significant.

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