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A generalised poisson regression analysis of COVID-19 cases in Ghana

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Abstract

The World Health Organization (WHO) proclaimed COVID-19 a worldwide pandemic in December 2019, and a number of mathematical models have been developed to forecast its spread. Since March 14, 2020, when it reported its first incidence, COVID-19 has spread throughout Ghana as a whole. Despite the preventative and control measures that the government and stakeholders have subjected to and accepted, the illness continues to spread at an alarming rate. The goal of this work was to develop a generalized Poisson regression model to forecast the growth rate of COVID in Ghana over the next years as well as the country's outcome in terms of this pandemic. To conduct this study, a daily historical dataset of COVID-19 cases in Ghana from March 14, 2020, to August 26, 2022, was employed. The generalized Poisson linear regression model was the methodology employed in the investigation. Since it was assumed that the data would have a probability distribution, the log-linear model provided a good hypothesis for the data, and the estimators we had under the probability model's hypothesis were valid. The estimators and actual data were compared, and the log-linear model was evaluated. The analysis's findings showed that there was over-dispersion in the dataset since the variance of the recorded instances was higher than the mean. The residual deviation was bigger than the degree of freedom, according to a confirmatory study based on over-dispersion that was carried out once more. The over-dispersion outcomes from the generalized Poisson model were then corrected using the Quasi Poisson to make the model appropriate. The Quasi Poisson model showed that the number of COVID-19 cases was falling by 56.02% on a daily basis. Despite the fact that the mortality rate was rising by 98.7%. This demonstrates that the number of documented death cases each day is not a factor in death cases.

Keywords: COVID-19, generalized Poisson linear regression, log-linear model, quasi poisson, over-dispersion

Introduction

Within three months of the coronavirus (SARS-Cov-2) initially emerging in China, 4,291 associated fatalities and about 118,000 confirmed cases were documented internationally [1, 28, 20, 24]. Because of how swiftly it spread, the World Health Organization (WHO) classified the sickness as a worldwide pandemic less than six months after it first appeared [2, 21, 18, 25]. As of September 24, 2022, there have been 620,000,000 instances reported worldwide, along with 65,500,000 associated fatalities. Africa is the least affected continent, with just about 3,872,085 cases, 102,286 fatalities, and 3,421,548 recoveries. Ghana now has 170,000 instances that have been reported, with 1459 fatalities and 160,046 recoveries. However, a number of nations, health agencies, and lawmakers have proposed measures to either curb the spread of cases or manage those that have already been discovered [25, 26, 21]. The use of nose masks in public places, routine hand washing with soap and running water, refraining from touching the face, sanitizing hands and surfaces with alcohol-based sanitizers, and keeping physical social distance are a few preventative measures. A few management efforts include engaging medical professionals, providing front-line workers with incentives, and providing treatment facilities and equipment. Despite the preventative and control measures recommended and accepted by numerous governments and stakeholders, the illness is still spreading at an alarming rate [27, 19, 22].

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For instance, as of April 7, 2020, only around 10,268 confirmed cases and 491 fatalities were reported in Africa [3, 19, 23]. When compared to the most current statistics for Africa, it is clear that the dispersion is expanding. This growth has been observed in Ghana and several other countries across the world. The rise in cases and fatalities recorded shows that management and prevention methods are failing. This shows even more that we still don't fully grasp the mechanics of the disease. The lack of qualified medical staff, equipment, and facilities for treating the condition is to blame for the bulk of fatalities in Ghana [17, 19, 29]. By anticipating the volume of cases, governments may better allocate resources for effective case management. A predictive tool is necessary in order to manage the avoidance of the instances efficiently. On March 12, 2020, Ghana received its first two reports of COVID-19 infections. As of the beginning of April 2020, there have been 204 reports of the virus, with 5 fatalities and 51 recoveries. Model development is, therefore, necessary for the effective treatment and prevention of coronavirus infection since models have the capacity to forecast the future. (COVID-19). It is possible to design successful anti-virus techniques using data, modeling, and scientific findings like vaccinations. [4, 5, 12, 27] (Sivasankarapillai *et al.*, 2020). This research seeks to develop a generalized Poisson regression model to forecast the growth rate of COVID in Ghana over the next years as well as the country's outcome in terms of this pandemic.

Relevant Literature Review

Researchers from the fields of science, epidemiology, and even economics have worked very hard to better understand the dynamics of COVID-19. Even while there are certain COVID-19 vaccines in use right now, others are still through various phases of clinical research [5, 11, 18, 22, 26]. Along with developing vaccines, several governments are working tirelessly to provide researchers with resources like financing and data repositories. On August 17, 2020, medical professionals in South Africa assess patients and give them an experimental vaccination developed by Novavax. The Bill and Melinda Gates Foundation gave this experiment a USD $15 million donation. The application of social and behavioral science expertise to ensure that human behavior conforms with the COVID-19 safety regulations developed by epidemiologists and public health experts has also been studied by certain researchers. Using a q-statistical functional form that accurately captures the facts available to all countries, Tsallis and Tirnakli conducted research and predicted the peak of COVID-19 cases globally [6, 16, 17]. Senior citizens had higher COVID-19 morbidity and mortality rates. Milani conducted research on how the interconnectedness of nations affects the spread of viruses. The authors showed that social networks can be used to explain viral spread, as well as the spread of risk perceptions and social estrangement behavior across national boundaries, and to pinpoint factors that increase an individual's susceptibility to the virus. Several authors have predicted, projected, and simulated COVID-19 cumulative cases in order to better understand the dynamics of cumulative occurrences across time [14, 25, 30]. Data from already-existing social networks across nations were used to estimate the vector autoregression (VAR) model in order to forecast the epidemiological countries. Some researchers have developed simple COVID-19 epidemic models to examine potential containment strategies. Using data from the first 120 days of the pandemic, the researchers assessed and contrasted the virus distribution patterns in Nigeria and seven additional countries [7, 13, 15]. The spreading patterns of COVID-19 have been seen in the nations of Cameroon, Ghana, and Egypt. The development and application of several mathematical and statistical modeling techniques to analyze the dynamics, project, and foresee a COVID-19 viral outcome. A detailed examination has been done in order to highlight trends in the modeling methods used for predicting and forecasting. The major topic of their discussion was examining the precision and accuracy of forecasts. They were able to achieve their goal by comparing predicted and observed values for cumulative cases and deaths as well as uncertainties of these predictions. The most popular models in studies and forecasts include the compartmental model, susceptible-infected-recovered (SIR) and susceptible-exposed-infected-recovered (SEIR), statistical models, growth models, time series, artificial intelligence models, Bayesian approaches, network models, agent-based models [27, 28, 30]. The results of the experiments demonstrated that Bayesian statistical models are more accurate than conventional statistical models. Bayesian methods can give more accurate predictions even with little data sets [10, 11, 16]. The study discovered a significant negative correlation between the predictions, the observed values, and the modeling time period. This implies that using longer time periods will likely result in more accurate estimations from models [8, 27, 28]. Using prediction models, the spatial-temporal patterns of the epidemic in Africa were investigated, revealing heterogeneity in both time and place across the research region. Since a cubic model is more accurate in predicting confirmed cases and deaths than other exponential models, it was discovered to perform better in comparison [17, 19]. The study placed a lot of emphasis on the necessity to encourage self-isolation in order to prevent the virus from spreading. Using fractional-order derivative-based modeling, stochastic meta-population models to estimate the virus's worldwide spread, and a mathematical model to assess the effectiveness of the lockdown in Ghana are some other modeling approaches. For the purpose of predicting COVID-19 confirmed cases, deaths, and recoveries in Ghana, the decomposition and ensemble model has been widely employed [9, 14]. Researcher investigations into the dynamics of COVID-19 in Ghana are still needed. Geospatial technologies have been used on Ghana's COVID-19 data to analyze case-level patterns and forecast near-term developments. This study found that areas in the south with larger population densities were more likely to have the virus [10]. The interaction between humans, environments, and humans was studied by the researchers using mathematical analysis and optimal control theory. Following safety precautions, such as sticking to proper coughing etiquette, covering one's nose or mouth when coughing or sneezing with tissues or a towel, and washing one's hands after coughing or sneezing are the most economical ones, according to their results. Other academics examined the relationship between urban architecture and public health to aid decisions and tactics in the "battle" against the virus. The majority of Ghanaians live in less sanitary circumstances than those who reside in organized towns, causing them to be more susceptible to the epidemic. They also thought about how to exploit the pandemic to build better cities. The researchers used cumulative COVID-19 data, time series models, and growth curves to examine whether the COVID-19 basic reproductive number differs from patterns of the COVID-19 pandemic for the top 16 nations where 78% of global cumulative cases are high. The researchers have additionally adapted a deep learning ensemble approach in order to identify the most effective auto-regressive integrated moving average (ARIMA) model for predicting and forecasting cumulative COVID-19 cases across multi-region nations. The daily cumulative number of COVID-19 cases in Ghana was examined using nonlinear growth models according to Gompertz, Richards, and Weibull. The exponential decay model was used to estimate and predict the total number of COVID-19 infections in Italy. (EDM). These authors compared the Gompertz model to the EDM. Growth models like Gompertz's appear to be inferior at forecasting the number of COVID-19 instances, as opposed to the exponential decay model applied to the weighted and averaged growth rates, [11]. In this study, linear and polynomial models are utilized to anticipate and predict the cumulative cases in Ghana as well as to explain the upward trend in the total number of COVID-19 cases. The COVID-19 data from Ghana were used to test these models, and the best model was chosen after comparison. Following an examination of the findings, conclusions were made [12].

How COVID-19 is Transmitted

According to recent research, the virus is typically transmitted between individuals who are in close proximity to one another, as while they are conversing. When an infected person speaks, sneezes, sings, or coughs, the virus can be disseminated through their mouth or nose in minute liquid droplets. When short-range aerosol transmission, also known as short-range airborne transmission, or when infectious particles come into contact with the eyes, nose, or mouth, a second person may then get infected with the virus (droplet transmission) [15, 25, 29, 6]. The virus can also spread in crowded, poorly ventilated interior areas where individuals frequently spend extended periods of time. This is due to the fact that aerosols can linger in the air or move beyond the range of human discourse. (this is often called long-range aerosol or long-range airborne transmission). When a person touches their eyes, nose, or mouth after contacting surfaces or things that have been contaminated by the virus, they run the risk of contracting the disease.

Materials, Methods, and Theoretical Framework

Materials

Sittings

West African nations include the Republic of Ghana. Its borders with the Ivory Coast, Burkina Faso, and Togo are to the west, north, and south, respectively, and it borders the Gulf of Guinea and the Atlantic Ocean to the south. Ghana has a total area of 238,535Km2 (92,099 sq mi), comprising a variety of biomes that include anything from tropical rainforests to coastal savannas. Approximately 31 million people live there, according to the 2021 census. After Nigeria, Ghana is the nation with the second-highest population in West Africa. Accra is the biggest capital city; other significant cities include Kumasi, Tamale, and Sekondi-Takoradi. Based on the elaboration of the most recent United Nations statistics, Ghana's population is 32,564,737 as of Saturday, October 22, 2022.

Trial design

The trend in Ghana's daily and recovered COVID-19 instances were examined using generalized Poisson regression. Because the variation of the data was greater than the mean, the research demonstrates that Ghana's COVID-19 cases are over-dispersed.

Sample size

The data collection period, which ran from March 14, 2020, to August 26, 2022, was based on the daily COVID-19 cases in Ghana.

Methods

The study's strategy for analyzing the kinds and sources of data that will support the analysis and assist it to achieve its goals is described. The generalized Poisson linear regression model is one of the most important models for categorical (qualitative) data. The log-linear model for the data will thus be a good hypothesis, and the estimators we had under the probability model's hypothesis are correct. It was assumed that the data obtained will follow a probability distribution.

Generalised Poisson Regression

It is inappropriate to use a linear model based on the normal distribution to describe the relationship between the response variable and a set of predictor variables when the response variable is a count data type (which can take on nonnegative-integer values, (0, 1, 2, …, n). Again, it is also not possible to use the logistic regression model because the response variable is not a binary variable (0, 1). The widely used tool to express it in this instance is the Generalised Poisson Regression Model. The Poisson Regression (PR) model is frequently used to examine how a set of predictor factors affects the frequency of small numbers of counts or events. The PR model has been used in a variety of fields, including biology, economics, and demography. The PR model in health demand studies models data on the frequency with which people use healthcare services and calculates the influence of insurance and health status. This approach resulted in several studies to calculate the number of accidents an aeroplane had over a certain time span. The PR model in biomedical research, which includes epidemiology, investigates the occurrence of certain diseases in exposed and unexposed participants in experimental and observational research. The PR model to investigate the prevalence of cancer among male

Swedish veterinarians and other veterinary professionals. The model can be used to examine how peripartum environmental, animal, and management factors affect the prevalence of milk fever in cow grazing settings. However, in reality, the observed variance of the data may be bigger or smaller than the corresponding mean, contrary to the Poisson regression model’s assumption that the mean and variance of the response variable are equal. In these situations, either an over-dispersion of the variance greater than the mean or an under-dispersion of the variance smaller than the mean may be present in the data. The generalised Poisson regression is the proper model under these circumstances, not the PR model. The generalised Poisson regression (GPR) model established by the consul is used to explain count data that are affected by a variety of known predictor variables, [14]. Numerous researchers have used the GPR model to address overdispersion and under-dispersion. This model has been used to model homes' fortuity data set and injury data. The main goal of this project is to highlight these models to forecast and determine a generalised linear model for COVID-19 daily cases in Ghana.

Theoretical framework

Suppose Y_i is a count response variable that follows a Generalised Poisson Distribution. The probability density function $Y_i = 1,2,\ldots,n$ is given by:

$$f(y_i) = P_r(Y_i = y_i) = \left(\frac{\lambda_i}{1+\alpha\lambda_i}\right)^{y_i} \frac{(1+\alpha y_i)^{y_i-1}}{y_i!} exp\left[\frac{-\lambda_i(1+\alpha y_i)}{1+\alpha\lambda_i}\right] \quad (1)$$

$$y_i = 0,1,2, \ldots$$

Then the mean and variance of y_i are given by:

Mean: $E(x_i) = \lambda_i$

Variance: $var(x_i) = \lambda(1 + \alpha\lambda_i)^2$

Where α is called the dispersion parameter.

The Dispersion Parameter

The estimate of α and β in the GPR model are obtained using the method of maximum likelihood, the Newton-Raphson method, etc. The Generalised Poisson Distribution is a natural extension of the Poisson Distribution. When α = 0, the probability density function *f (Yi)* reduces to the Poisson regression model so that the mean is equal to the variance and this is a case of equip-dispersion, (Rashwan and Kamel, 2011) [18]. In practical application, this assumption is often untrue since the variance can either be greater or smaller than the mean. If the variance is not equal to the mean, the estimates in the PR model are still consistent but are inefficient, which leads to the invalidation of inference based on the estimated standard errors.

When $a > 0$, then the variance is larger than the mean, for this situation, the GPR model represents count data with overdispersion. When $a < 0$, The variance is smaller than the mean, and for this situation, the GPR model represents count data with under-dispersion.The estimate of α and β in the GPR model are obtained using the method of maximum likelihood. The log-maximum likelihood function of the Generalised Poisson regression model is given by.

$$\frac{\partial ln(\beta,\alpha)}{\partial\alpha} = \sum_{i=1}^{n} \left[\frac{-y_i\lambda_i}{1+\alpha\lambda_i} + \frac{y_i(y_i-1)}{1+\alpha y_i} - \frac{\lambda_i(y_i-\lambda_i)}{(1+\alpha\lambda_i)^2}\right] \quad (2)$$

$$\frac{\partial ln(\beta,\alpha)}{\partial\beta} = \sum_{i=1}^{n} \left[y_i x_i - \frac{\alpha\lambda_i y_i x_i}{1+\alpha\lambda_i} - \frac{\lambda_i(y_i-\lambda_i)}{(1+\alpha\lambda_i)^2}\right] \quad (3)$$

Goodness of fit test

The log-likelihood statistic may be used to gauge how well these models fit their data; regression models with higher log-likelihood values perform better than those with lower values. To determine if the GPR model is superior to the PR model given that it reduces to the PR model when α = 0, one may test the following.

$H_0: \alpha = 0$

Vs

$H_1: \alpha \neq 0$

The test H_0 shows the significance of the dispersion parameter when H_0 is rejected, and is recommended to use the GPR model in place of the PR model to carry out the test.

One can use the asymmetrically normal Wald type (t) statistic defined and the ratio of the estimate of α to its standard error alternative test for the hypothesis. To use the likelihood ratio test, the likelihood ratio is $t = 2(L1 - L0)$ where $L1$ and $L0$ are the model's log-likelihood under the respective hypothesis. Under $H0$, t is approximately chi-square distribution with one degree of freedom. Also, there are two other procedures that can be used to measure the goodness-of-fit, the first, is based on the Pearson chi-square. It has approximately chi-square distribution with $(n - k)$ degrees of freedom. The second, based on the deviance statistic, the deviance is equal to $2(L(yiy)-L(\lambda_i y))$, where $L(yiy)$ are the log-likelihood evaluated under y and λ respectively. The deviance also has approximately chi-square distribution with $(n - k)$ degree of freedom. Also, to the degree of freedom (n-k) the model may be adequate.

Results and Analysis

A graph of COVID-19 daily cases in Ghana is shown in Fig. 1. It is clear from the plot that the data is not linear since the daily instances are the observations on the y-axis and their related days are on the x-axis. As a result, the mean and variance must be calculated. Table 1 demonstrates that the data may be excessively distributed since the variance is substantially higher than the mean. The parameters are obtained from Table 3 using Maximum Likelihood Estimation. (MLE). By giving the levels of the category variables—also known as indicator variables—some sort of numerical representation, categorical variables—also known as indicator variables—are handled as dummy variables.

According to the general rule, if a factor variable has k categories, the output of the general linear model will have k-1 categories, with the last 1 serving as the base categories. The values of the coefficients β0 (intercept), β1, are found in Table 3's first column, titled Estimate. The metric calculates.

Exp(β0): The effect of the mean when *X=0*. *Exp*(β): With every unit increase in *X*, the predictor variable has a multiplicative effect of *Exp*(β) on the mean of *Y*.

If β=0, then *Exp*(β) =1, and the expected count is *Exp*(β) then *Y* and *X* are not related.

If β>0, then *Exp(*β*)*>1, and the expected count is *Exp(*β*)* times larger than when X =0.

If β<0, then *Exp(*β*)* <1, and the expected count is *Exp(*β*)* times smaller when X=0.

Effect of the Explanatory Variables

We examine the p values in Table 3 to determine which explanatory variable affects the response variable. Since all of the p values in Table 3's summary are less than 0.05, it follows that both the explanatory variables "days" and "death cases" have a significant impact on days. Each variable's relevance is indicated by the ***. Before interpreting the results, let's determine whether the model exhibits over or under-dispersion. If the residual is bigger than the degrees of freedom, over-dispersion is present, and Table 2 indicates that the Ghana COVID-19 data exhibits over-dispersion. This indicates that while the standard errors (standard deviation) are accurate and taken into consideration by the model, the estimates are inaccurate. The Null deviance illustrates how well the response variable is predicted by a model using only the intercept (grand mean), as opposed to the residual with independent variables. Table 2 shows that by including two additional independent variables, the deviation was reduced from 143586 to 141538 (862 860 = 2). A bad fit results from a larger value difference. The Quasi-Quasi-Poisson model may therefore be used to rectify standard errors. The same coefficients and various standard errors are included in Table 5 for comparison. With this in mind, let's look at the daily. Its value is -0.0001979311, and its exponent is 0.439802. This equals 0.5601979 for the daily. As a consequence of the estimate being negative (-0.0001979311), it can be shown that daily resulted in a reduction in COVID-19 instances in Ghana of 0.5601979 times the intercept. In other words, assuming that all other factors remain constant, the frequency of COVID-19 cases decreases consistently every day by 56.02%. According to the death index of 0.986955, the COVID-19 daily death instances are independent of the day of the week. The number of COVID-19 cases in Ghana was estimated to increase with time to be around 0.000142. But given its natural variety, it's possible that COVID-19 may eventually evolve into various species.

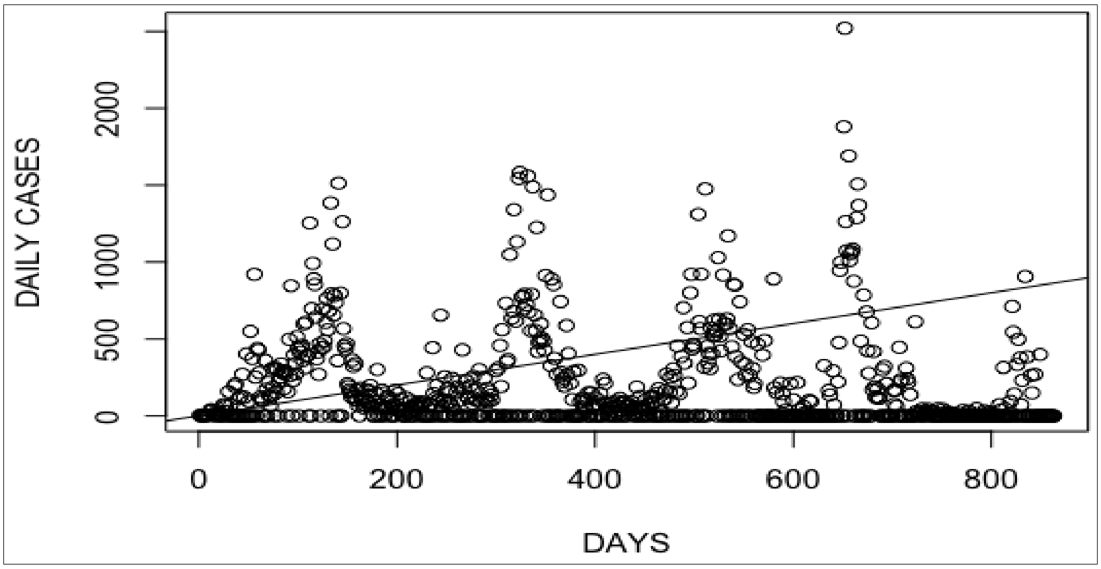

Fig 1: Scatter of Ghana COVID-19 Data

Table 1: Mean and Variance

Central of tendency	Confirmed cases	Death cases
Mean	193.7601	1.683662
Variance	100346.1	11.92882

Table 2: The Deviance

	Dispersion parameter	Degree of freedom
Null deviance	143586	862
Residual deviance	141538	860

Table 3: Generalised poisson estimate

Coefficients	Estimate	Standard Error	z-value	Pr(>|z|)	Significant code
Intercept	6.12600	0.002055	2981.50	0.00000	***
Daily	-0.000198	0.000006	-35.40	0.000000	***
Death	-0.013130	0.000504	-26.03	0.00000	***

Table 4: Quasi poisson estimate

Coefficient	Estimate	Standard Error	t-vale	Pr(>|t|)	Significant codes
Intercept	6.12600	0.024350	251.708	0.00000	***
Daily	-0.000198	0.000066	-2.989	0.002880	**
Death	-0.03130	0.005975	-2.198	0.028240	*

Table 5: Comparison of model

	Coefficient 1	Se. Coefficient 1	Coefficient 2	Se. coefficient 2	Exponent
Intercept	6.12600	11.4797	6.12600	11.4797	457.604
Daily	-0.000198	-0.000173	-0.000198	-0.000152	0.439802
Death	-0.013131	-0.013331	-0.013131	-0.012331	0.986955

$$Y_i = 6.12600 - (0.000198X_1 + 0.013130X_2) \quad (4)$$

Conclusion

The over-dispersed COVID-19 daily instances in Ghana may be modelled using the Generalized Poisson Regression. The Generalized Poisson Regression Model showed that all of the predicted parameter p values were less than 5%, which is considered to be a significant level. However, the model was insufficient based on their standard errors since the residual deviance and the null's different degrees of freedom made the model unfit. Over the years, patterns of the impact of days on COVID-19 daily cases have been studied. The models were important in demonstrating that days in Ghana had an impact on the COVID-19 trend.

The Quasi Poisson model adjusts all the standards (standard deviations), which results in a satisfactory fit for the model. Even though COVID in Ghana has reduced dramatically rate.

Recommendation

Since the model demonstrates that days have no discernible impact on the daily mortality cases of COVID-19 in Ghana, mechanisms and appropriate medicine should be employed to limit the daily death rate.

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