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APPLICATION OF BINOMIAL AND BETA-BINOMIAL REGRESSION MODELS ON INCIDENCE OF DIARRHEA AMONG CHILDREN AGED 6-59 MONTHS IN MIESSO DISTRICT, OROMIA, ETHIOPIA

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ABSTRACT

In binomial regression analysis model dependent variable follows a binomial distribution. β-binomial model is a regression model for outcomes following the β-binomial probability distribution. The aim of present study was to fit binomial regression and beta-binomial regression models for incidence of diarrhea, a prominent cause of health disorders/ deaths in under-five year age children. The study was conducted in the children aged 6-59 months in Miesso Wereda, Oromia, Ethiopia from June to September 2017. The data used was obtained from a cross-sectional study using well-structured questionnaires. The Predictors used for the current study were child sex, household food security status, sources of drinking water, and toilet ownership status. Binomial and β-binomial models were fitted to identify the significant predictors. The over-dispersion status of the data was tested and revealed that there was no over-dispersion and the fitted models had similar Akaiki information criteria and Bayesian information Criteria with similar results. The source of water (pipe water) and having toilet facility significantly affected the incidence of diarrhea among the studied group of children. The study recommended that giving attention to environmental sanitation and creating pure water facility shall reduce diarrhea incidence in children.

Key words: Binomial regression, β-binomial regression, over-dispersion, diarrhea, children, Miesso, Ethiopia

INTRODUCTION

Globally, diarrhea is the foremost cause of health disorders and deaths among under-five children. Acute diarrhea and pneumonia accounted for almost one in every four deaths among under-five children worldwide (UNICEF, 2016). Annually, 1.7 billion diarrhea episodes occurred among the children under-5 years worldwide (WHO, 2017). Different types of pathogens could be the cause for diarrhea and of these the major five enteric pathogens are rotavirus (67.6%), adenovirus (41.5%), enterotoxigenic *Escherichia coli* (40.7%), *Salmonella* (38.4%), and *Giardia* (37.0%) (Chisenga *et al*., 201). Predicted estimates indicate that upto 2030, the infectious diseases may cause 4.4 million deaths annually among under-five children and of these 60% deaths may occur in sub-Saharan Africa only (Liu *et al.*, 2015). Diarrhoeal disease is a leading cause of child mortality and morbidity in the world, and mostly results from contaminated food and water sources. Diarrheal diseases are major public health concerns in developing countries, especially amongst under-five children (WHO, 2017). In Ethiopia diarrhea is one of highly prevalent health problems among children aged below five years (Alebel *et al*., 2018).

Regression analysis is an essential element of data analysis which is frequently used to determine the relationship between different variables (Hosmer and Lemeshow, 2000). Currently, Bayesian statistical models are prominently used for enhanced scope estimation (Peter, 2003) in which the probability model is fitted for dataset and the result are summarized by a probability distribution on the parameters of the model and undetected quantities (Gelman *et al.*, 2014). Binomial model is a regression model wherein the response variables follow binomial probability distribution (Weisberg, 2005), which assumes the probability of success is the similar for each successive trial (Hardin and Hilbe, 2014; Martinez *et al.*, 2015). But in real applications of binomial trials the underlying success probability may possibly change from one trial to another. This leads to the over-dispersion of variables under study and fitting β-binomial model for such data is recommended rather than binomial regression model (Hardin and Hilbe, 2014). β-binomial model is a Bayesian regression model for outcomes following the β-binomial probability distribution (Hardin and Hilbe, 2014). WHO estimates indicates that Diarrhea is one of the major contributors to children's deaths in Ethiopia in which it contributes to more than one in every ten (13%) child deaths in Ethiopia. Diarrhea is the 3rd most cause of mortality in under-five children in Ethiopia (Deribew et al., 2016). According to the study conducted in Wonago District, South Ethiopia the prevalence of diarrhea was 30.9% and latrine availability, and hand washing practices during a critical time were among the predictors strongly associated with the prevalence of diarrhea (Tesfaye *et al.*, 2020). Since diarrheal diseases are major public health concerns and no study has been conducted on the incidence of diarrhea among the children aged 6-59 months in Miesso Wereda (Ethiopia), therefore the presented study was aimed to fit binomial regression and β-binomial regression models to identify the significant associated factors responsible for the incidence of diarrhea among the children aged 6-59 months in Miesso Wereda, Oromia, Ethiopia.

MATERIALS AND METHODS

Study area

The present study was conducted in Miesso district, West Hararghe zone, Ethiopia. Miesso is one of the *Weredas* in the Oromia region of Ethiopia. As per the population projection values of 2017 the population of Miesso is 174,916 of which 89,052 were men and 23.42% population is urban dwellers (CSA, 2013).

Sampling technique and sample size

The sampling technique used in this study was two stage systematic random sampling method. In 1st stage, 9 *Kebeles* were randomly selected among 33 *Kebeles* which comprised of about 30% of *Kebeles* in the district. In 2nd stage from the list of households who had children aged between 6 and 59 months in the selected *Kebeles* were selected by using systematic random sampling. Finally, a total of 296 children, aged 6-59 months within 9 *kebeles* in *Miesso* district, were included in the analysis.

Data collection

The data used for present study was obtained by cross sectional data collection method using well-structured questionnaires. The data collection on the field was done from June to September 2017. The questionnaire was first organized in English and translated into *Afan Oromo* by fluent speakers of both languages. Experienced health workers who could communicate in *Afan Oromo* were employed for data collection.

Study variables

Dependent variable: incidence of diarrhea among children aged 6-59 months

Predictors used: 1) child sex, 2) household food security status, 3) sources of drinking water, and 4) toilet ownership status

For Stata software analysis the variables in the present study were described with their names and details as follows:

Diarrhea: The number of diarrhea cases

N: The total number of children in the category

Proportion: The proportion of diarrhea cases

Toilet: The status of household whether they have toilet or not (0 = No, 1 = Yes)

Water: whether they use pipe water for drinking purpose or not (0 = No, 1 = Yes)

HFSS: Household food security status (0 = Secure, 1 = Insecure)

Child-sex: Whether the child is male or Female (1 = M, 2 = F)

Data processing and analysis

In present study SPSS was used to organize the original data set and the table format was copied on excel to get the data set in the form of data shown in Table 1. Finally, the organized data was imported to Stat version 14 for further statistical analysis. After data set import to Stata, the binomial regression and β-binomial regression models were fitted by using the command proposed and used by Hardin and Hilbe (2014). The two models were compared by using Akaike Information Criteria and Bayesian information criteria (BIC).

β-probability distribution

The probability density function of random variable which follows the β-distribution with shape parameters α and β as per Soong (2004) is given by:

$$f(x) = \begin{cases} \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} x^{\alpha-1}(1-x)^{\beta-1}, \ for\, 0 \le x \le 1, \alpha > 0, \beta > 0 \\ 0 \ Otherwise \end{cases} \tag{1}$$

The coefficient of

$f(x)$, $\frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)}$, can be represented by $\frac{1}{B(\alpha,\beta)}$

Where $B(\alpha,\beta) = \frac{\Gamma(\alpha)\Gamma(\beta)}{\Gamma(\alpha+\beta)}$, (2)

which is known as the β-function.

The mean and variance of a beta-distributed random variable X were,

$$E(x) = \frac{\alpha}{\alpha+\beta} \tag{3}$$

$$Var(x) = \frac{\alpha\beta}{(\alpha+\beta)^2(\alpha+\beta+1)} \tag{4}$$

Binomial distribution

Let X stands for the number of successes in the n number of binomial trials, then X is said to be a binomial random variable with parameters (n, p) (Ross, 2010). The probability mass function of a binomial random variable having parameters (n, p) is given as follows:

$$P(X = x) = \binom{n}{x} p^x (1-p)^{n-x}, \ \ x = 0,1,...,n \tag{5}$$

Where p, $0 \le p \le 1$, is the probability that the trial is a success.

The mean and variance of a binomial random variable X are,

$$\begin{aligned} E(x) &= np \\ Var(x) &= np(1-p) \end{aligned} \tag{6}$$

β-Binomial distribution

Let y be the number of occurrences of a random variable Y in n Bernoulli trials with success probability p (0 < p < 1). Then, its probability function is as given in equation (5), and its mean and variance are expressed in equation (6). Using the principles of Bayesian inference, let us suppose that p, the probability of success in binomial distribution, is a random variable that follows a β-distribution with parameters α and β, in which its probability density function is as expressed in equation (1). In this case p is random variable, so according to equation (1) the distribution for random variable p gives the following equation:

$$f(p) = \begin{cases} \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} p^{\alpha-1}(1-p)^{\beta-1}, \ for\, 0 \le p \le 1 \\ 0 \ Otherwise \end{cases} \tag{7}$$

From the above expressions, we can derive the following equation

$$P(X = x \mid n,\alpha,\beta) = \int_0^1 P(X = x \mid n,p) \times f(p \mid \alpha,\beta)dp$$

$$= \frac{1}{B(\alpha,\beta)} \int_0^1 p^{x+\alpha-1}(1-p)^{n-x+\beta-1}dp$$

Thus, $$P(X = x \mid n,\alpha,\beta) = \binom{n}{x} \frac{B(x+\alpha, n-x+\beta)}{B(\alpha,\beta)} \tag{8}$$

The expression in equation (7) is the probability function of a β-binomial distribution, when a random variable "X" is distributed conferring a β-binomial distribution.

Then, generally if *p ~ Beta(α, β)* and *X ~ Binomial(n, p)*, then *X ~ BetaBinomial(n, α, β)*.

Binomial and β-binomial regression models

The β-binomial model is a parametric mixture model the marginal distribution permits more variation and has better fitness for over-dispersed data than the binomial (Agresti, 2002; Gelman *et al.*, 2014; Edilberto and Maria, 2017) which exhibit daily occurrences (Demetrio and Hinde, 1998). Thus, a model using β-binomial is a way to handle over-dispersion occurring in ordinary binomial models (Agresti, 2002). In order to solve the over-dispersion estimation problems in binomial regression model, the 'p' parameter is expected to follow β-distribution as a random variable (Hardin and Hilbe, 2014) shown in equation (1). In present study, the fitting of the model for predictors of child diarrhea infection has been attempted. Consequently, we fitted the regression models constructed in Stata software by Hardin and Hilbe (2014) with the outcome variable diarrhea as the numerator of binomial response and the variable N (the total number of children in a single category) as the denominator of binomial response.

The syntax for fitting binomial regression model in Stata statistical software is as follows:

glm Diarhea toilet watersource HFSS Childsex, family(binomial N) nolog eform vce(robust)

β-binomial regression is the generalization of binomial regression. The syntax for fitting β-binomial regression model in Stata statistical software is as follows:

betabin Diarhea toilet watersource HFSS Childsex , n(N) nolog eform link(cloglog) # syntax for the model

RESULTS AND DISCUSSION

The data organized in 16 children types constituting the outcome for 296 children selected from Miesso district, Oromo, Ethiopia is given in Table 1. Child types were defined by predictors like possession of toilet by the family of children, use of pipe water for drinking, family household food security status, and sex of children.

Table 1: The rearranged data suitable for binomial regression analysis in Stata software

S. No.	Diarrhea cases	Total (N)	Toilet using status[a]	Water sources[b]	Household food security status[c]	Child sex[d]
1	7	26	0	1	0	1
2	3	21	0	1	0	2
3	20	66	0	1	1	1
4	14	45	0	1	1	2
5	2	6	0	0	0	1
6	2	4	0	0	0	2
7	4	7	0	0	1	1
8	2	6	0	0	1	2
9	0	11	1	1	0	1
10	1	11	1	1	0	2
11	2	21	1	1	1	1
12	5	24	1	1	1	2
13	3	12	1	0	0	1
14	2	10	1	0	0	2
15	2	15	1	0	1	1
16	2	11	1	0	1	2

[a] 0 = No, 1 = Yes; [b]whether they use pipe water for drinking purpose or not (0 = No, 1 = Yes); [c] 0 = Secure, 1 = Insecure.
[d] 1 = Male, 2 = Female

Table 2: The frequencies of the variables studied

Variables in the study		Frequency*
Children suffering from diarrhea in last two weeks	No	225 (76.0%)
	Yes	71 (24.0%)
Sex of the child	Male	164 (55.4%)
	Female	132 (44.6%)
Household toilet	No	115 (38.9%)
	Yes	181 (61.1%)
Pipe or other better drinking water source	Yes	225 (76.0%)
	No	71 (24.0%)
Household food security status	Secure	101 (34.1%)
	Insecure	195 (65.9%)

*The figures in parenthesis are percentages

Descriptive analysis

The 24% of children in the study area had diarrheal problem within two weeks before the survey. Also, 55.4% children were male whereas 38.9% children belonged to the families having no toilet facility, 24% children belonged to the families having no access to pure water and > 60% children were belonged to the families where food insecurity prevailed. In present study the prevalence of diarrhea among children aged 6-59 months was 24% in Miesso district, Oromia, Ethiopia (Table 2 and Figure 1). The values were higher than reported diarrheal incidence from their areas in Ethiopia such as in Debre Berhan town 16.4% (Shine *et al.,* 2020), in Sheka zone 21.8% (Gashaw *et al.,* 2019), and in North Gondar zone 22.1% (Getachew *et al.,* 2018).

Binomial regression analysis

The availability of two variables "toilet" and "water source" in the family were significant predictors of dependent variable which indicates that the source of water and having toilet were important associated factors for incidence of diarrhea among the children in the study area. The output for the binomial regression model is shown in Table 3.

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Table 3: Binomial regression analysis model output

Parameters	Odds ratio	Robust standard error	Z-value	P-value	95% Confidence Interval	
Toilet availability	0.3329062	0.0849597	-4.31	0.000	0.2018785	0.5489766
Pipe water source	0.5085243	0.1184866	-2.90	0.004	0.3220929	0.8028647
HFSS	1.4622300	0.2983139	1.86	0.063	0.9803016	2.1810820
Child sex	1.0210310	0.1624177	0.13	0.896	0.7475438	1.3945740
Intercept	0.5663165	0.2024311	-1.59	0.112	0.2810575	1.1410990

HFSS = Household food security status; The predictors with P-value < 0.05 have significant contribution.

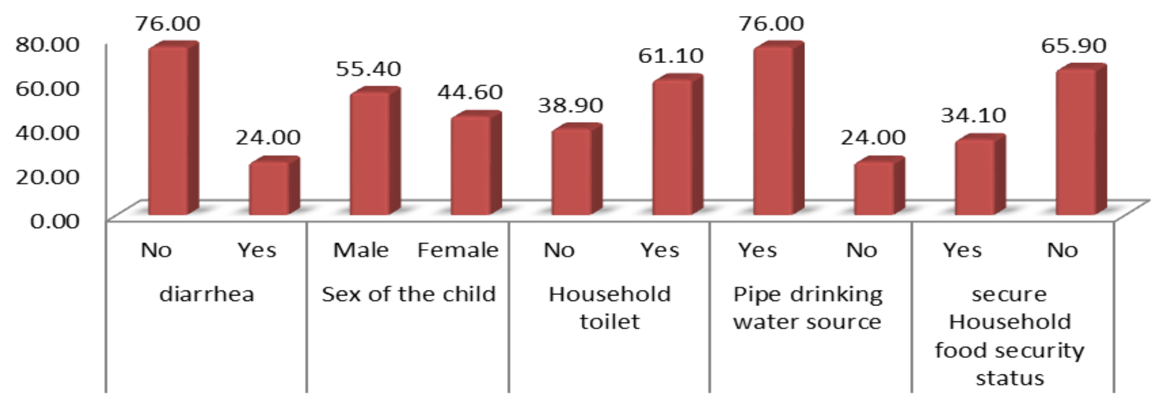

Fig. 1: The frequencies of the variables studied

When we run the command of binomial regression model, we automatically got the output (Table 3) with the following model fitting information

```
. glm DiarheaNo Toil Water HFSSs Childsex , family(binomial N ) nolog eform vce(robust)

Generalized linear models                         No. of obs      =         16
Optimization     : ML                             Residual df     =         11
                                                  Scale parameter =          1
Deviance         =  7.367135453                   (1/df) Deviance =   .6697396
Pearson          =  6.476997028                   (1/df) Pearson  =   .5888179

Variance function: V(u) = u*(1-u/N)               [Binomial]
Link function    : g(u) = ln(u/(N-u))             [Logit]

                                                  AIC             =   3.676238
Log pseudolikelihood = -24.40990695               BIC             =  -23.13134
```

Fig. 2: Model fitting information for binomial regression model

From this we noted that Pearson dispersion statistic was approximately 0.589, which clearly indicated that there was no over-dispersion in the data. Akaike's information criterion and Bayesian information criterion for the above model (Table 6) was 58.82 and 62.68, respectively. **C**onsequently, to fit the binomial regression model by using complementary log-log link in place of the canonical logit link used in above output, might be best-fitted standard generalized linear model for the data (Hardin and Hilbe, 2014). The command of fitting binomial regression model for Diarrhea infection proportion with log-log link was as follows:

glm Diarhea toilet watersource HFSS Childsex, family(binomial N) link(cloglog) nolog eform vce(robust)

The results shown in Table 3. The Table 4 presents approximately the same outputs. The significant variables were “toilet” and “water source”. The binomial regression model with log-log link function

Table 4: Binomial regression model output with log-log link

Variables in the model	Odds ratio	Standard error	Z-value	P-value	95% Confidence interval	
Toilet availability	.3808267	.0857687	-4.29	0.000	0.2449188	0.5921511
Pipe Water source	.5632523	.1050504	-3.08	0.002	0.3907941	0.8118166
HFSS	1.382235	.2398018	1.87	0.062	0.9838028	1.942028
Child sex	1.002525	.1320841	0.02	0.985	0.7743695	1.297903
Intercept	.4592516	.1325852	-2.70	0.007	0.2608015	0.808707

HFSS = household food security status; The predictors with P-value < 0.05 have significant contribution.

gave approximately similar result with output of binomial regression without log-log link function. The Akaike information criteria and Bayesian information was 58.82 and 68.62, respectively, which was similar to Akaike information criteria and Bayesian information of binomial regression without log-log link function.

```
. glm DiarheaNo Toil Water HFSSs Childsex , family(binomial N ) link(cloglog) nolog eform vce(robust)

Generalized linear models                          No. of obs      =         16
Optimization     : ML                              Residual df     =         11
                                                   Scale parameter =          1
Deviance         =  7.368988013                    (1/df) Deviance =    .669908
Pearson          =  6.436940331                    (1/df) Pearson  =   .5851764

Variance function: V(u) = u*(1-u/N)                [Binomial]
Link function    : g(u) = ln(-ln(1-u/N))           [Complementary log-log]

                                                   AIC             =   3.676354
Log pseudolikelihood = -24.41083323                BIC             =  -23.12949
```

Fig. 3: The Binomial model information with log-log link function

β-binomial regression analysis

β-binomial regression is the generalization of binomial regression (Hardin and Hilbe, 2014). The β-binomial regression was fitted for the data and the result for β-binomial regression is shown in Table 5. This standard generalized linear model appeared similar to the classical binomial regression model for the data. The Akaike information criteria and Bayesian information statistics were similar to the Akaike information criteria and Bayesian information of binomial regression model with values of 58.82167 and 62.68461, respectively, which indicated that there was no important improvement over the binomial model.

Beta-binomial regression		Number of observations	= 16
Link	= cloglog	LR chi2(4)	= 13.79
Dispersion	= β-binomial	Prob > chi2	= 0.0080
Log likelihood	= -24.410833	Pseudo R2	= 0.2202

Table 5: β-binomial regression analysis result

Variables in the model	Odds ratio	Standard error	z-value	P-value	95% Confidence interval	
Toilet availability	0.3808267	0.1134845	-3.24	0.001	0.2123603	0.682938
Pipe water source	0.5632523	0.1633364	-1.98	0.048	0.3190545	0.994354
HFSS	1.382235	0.3688837	1.21	0.225	0.8192518	2.332094
Child sex	1.002525	0.2412995	0.01	0.992	0.6254866	1.606839
Intercept	0.4592516	0.2170369	-1.65	0.100	0.1818791	1.159628
Lnsigma	-24.31596	.	.	.	.	.
Sigma	2.75e-11	.			.	.

HFSS = House hold Food Security Status; the predictors with p-value<0.05 have significant contribution.

Table 6: AIC and BIC for binomial and β-binomial regression model

Parameter	Binomial model without log-log	Binomial model with log-log	β-binomial model
Obs	16	16	16
ll(null)	-	-	-31.304
ll(model)	-24.41	-24.411	-24.411
Df	5	5	5
AIC	58.8198	58.8217	58.8217
BIC	62.6828	62.6846	62.6846

The significant predictors in this model are similar to the previous models. The availability of two variables i.e. availability of toilet and water source in the family were significant predictors of dependent variable which indicates that the source of water and having toilet were important associated factors for incidence of diarrhea among the children in the study area.

The current study revealed that the water source and toilet facility significantly affected the diarrhea incidence in children aged 6-59 months in Miesso district. This was similar to the earlier studies conducted in semi-urban areas of northeastern Ethiopia which concluded that children from households that got water from unimproved sources were almost three times more likely to develop acute diarrhea than those in households that got water from improved sources (Natnael *et al.*, 2021). Also, present findings are similar to the studies conducted in south Ethiopia which state that the number of family members, animal presence within households, latrine availability, and hand washing practices during a critical time were strongly associated with the prevalence of diarrhea (Tesfaye *et al.*, 2020).

Conclusions: β-binomial regression model was approximately same as the binomial regression when there was no over dispersion in the data. The response used in this study had no over-dispersion and the fitted models yielded similar results. The use of β-binomial model instead of binomial regression is necessary when there is over-dispersion. Giving attention to environmental sanitation and pure water use may reduce the incidence of diarrhea among children.

Conflicts of interest: The author declares that they have no conflicts of interest regarding the publication of this paper.

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REFERENCES

Agresti, A. 2002. *Categorical Data Analysis* (2nd edn.). John Wiley & Sons, New Jersey, USA.

Alebel, A., Tesema, C., Temesgen, B., Gebrie, A., Petrucka, P. and Kibret, G.D. 2018. Prevalence and determinants of diarrhea among under-five children in Ethiopia: A systematic review and meta-analysis. PLoS One **13**(6): e0199684. [*https://doi. org/10.1371/journal.pone.0199684]*.

Andrew, G., John, B., Carlin, Hal S., Stern, D.B. Dunson, A.V. and Donald, B.R. 2014. *Bayesian Data Analysis* (3rd edn). Taylor & Francis, New York, USA.

Central Statistical Agency (CSA). 2013. *Population Projection of Ethiopia for All Regions at Wereda Level from 2014-2017*. *Ethiopian Statistics Services*, Addis Ababa, Ethiopia.

Chisenga, C., Bosomprah, S., Laban, N., Mwila, K.M.J., Simuyandi, M. and Chilengi, R. 2018. Aetiology of diarrhoea in children under five in Zambia detected using Luminex x TAG gastrointestinal pathogen panel. *Pediatric Infectious Diseases,* **3**(2): 1-6.

Demetrio, C. and Hinde, J. 1998. Over-dispersion: Models and estimation. *Computational Statistics and Data Analysis,* **27**: 151-170.

Deribew, A., Tessema, G.A., Deribe, K., Melaku, Y.A., Lakew, Y., Amare, A.T., Abera, S.F., Mohammed, M., Hiruye, A., Teklay, E., Misganaw, A. and Kassebaum, N. 2016. Trends, causes, and risk factors of mortality among children under 5 in Ethiopia, 1990-2013: Findings from the global burden of disease study 2013. *Population Health Metrics,* **14**(1): 42. [*https://pophealthmetrics.biomedcentral.com/articles/10.1186/s12963-016-0112-2*].

Edilberto, C.C. and María, V.C. 2017. Double generalized beta-binomial and negative binomial regression models. *Revista Colombiana de Estadística,* **40**(1): 141. [*http://dx.doi.org/10.15446/rce.v40n1.61779*].

Gashaw, T.A. and Walie, Y.M. 2019. Prevalence and determinate factors of diarrhea morbidity among under five children in shake zone, Southwest Ethiopia, a community based cross-sectional study. *Archives of Community Medicine and Public Health,* **5**(1): 8-14.

Getachew, A., Guadu, T., Tadie, A., Gizaw, Z., Gebrehiwot, M. and Cherkos, D.H. 2018. Diarrhea prevalence and sociodemographic factors among under-five children in rural areas of North Gondar zone, Northwest Ethiopia. *International Journal of Pediatrics,* **2018**: 6031594, 8 [*https://doi.org/10.1155/2018/6031594*].

Hardin, J.W. and Hilbe, J.M. 2014. Estimation and testing of binomial and beta-binomial regression models with and without zero inflation. *The Stata Journal*, **14**(2): 292-303.

Hilbe, J.M. 2013. Beta Binomial Regression. [*https://works.bepress.com/joseph_hilbe/43/*].

Hosmer, D.W. and Lemeshow, S. 2000. *Applied Logistic Regression*. (2nd edn). Wiley-Interscience/ John Wiley & Sons, New Jersey, USA.

Liu, L., Oza, S., Hogan, D., Perin, J., Rudan, I. and Lawn, J.E. 2015. Global, regional, and national causes of child mortality in 2000-2013, with projections to inform post-2015 priorities: An updated systematic analysis. *Lancet*, **385**(9966): 430-440.

Martinez, E.Z., Achcar, J.A. and Aragon, D.C. 2015. Parameter estimation of the beta-binomial distribution: An application using the SAS software. *Ciência e Natura,* **374**: 12-19. [*https://doi.org/10.5902/2179460X17512*].

Natnael, T., Lingerew, M. and Adane, M. 2021. Prevalence of acute diarrhea and associated factors among children under five in semi-urban areas of northeastern Ethiopia. *BMC Pediatrics*, **21**: 290-300. [*https://doi.org/10.1186/s12887-021-02762-5*].

Peter Congdon, 2003. *Applied Bayesian Modelling.* John Wiley & Sons, London, England.

Ross, S. 2010. *A First Course in Probability* (8th edn.). Prentice-Hall, New Jersey, USA.

Shine, S., Muhamud, S., Adanew, S., Demelash, A. and Abate, M. 2018. Prevalence and associated factors of diarrhea among under-five children in Debre Berhan town, Ethiopia: A cross sectional study. *BMC Infectious Diseases,* **20**: 174-179.

Soong, T.T. 2004. *Fundamentals of Probability and Statistics for Engineers.* John Wiley & Sons, Chichester, Sussex, England

Tesfaye, S.T., Magarsa, A.U. and Zeleke, T. M. 2020. Moderate to severe diarrhea and associated factors among under-five children in Wonago district, South Ethiopia: A cross-sectional study. *Pediatric Health, Medicine and Therapeutics,* **11**: 437-443. Dove Press. London, UK.

UNICEF. 2016. One is too many. pp. 1-77. **In**: *Ending Child Deaths from Pneumonia and Diarrhea.* UNICEF, New York, USA.

Weisberg, S. 2005. *Applied Linear Regression* (3rd edn). John Wiley & Sons, New Jersey, USA.

WHO. 2017. *Diarrheal Disease Fact Sheet.* World Health Organization, Geneva, Switzerland [*https://www.who.int/news-room/fact-sheets/detail/diarrhoeal-disease*].

Williams, D. 1975. The analysis of binary responses from toxicological experiments involving reproduction and teratogenicity. *Biometrics,* **31**(4): 949-952.