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DETERMINANTS OF UNDERWEIGHT AMONG UNDER-FIVE CHILDREN IN ETHIOPIA: APPLICATION OF MULTILEVEL ORDINAL LOGISTIC REGRESSION

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Declaration

I, the undersigned, declare that the thesis entitled "**determinants of underweight among under five children in Ethiopia: application of multilevel ordinal logistic regression** " is my original work, has not been presented for degree or diploma in this or any other university and all sources of materials used for the thesis have been duly acknowledged.

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Date of submission: July, 2019

Approval sheet

I hereby certify that the thesis entitled "**determinants of underweight among under-five children in Ethiopia: application of multilevel ordinal logistic regression**" is a bona fide record of research work done by **Nigussie Adam Birhan** under my guidance in Bahir Dar University, Ethiopia. I recommend that the thesis be submitted to the department of Statistics.

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As a member of the Examining Board of the MSc. Thesis Open Defense Examination, I certify that I have read and evaluated the Thesis prepared by **Nigussie Adam Birhan** and examined the candidate. I recommend that the thesis be accepted as fulfilling the thesis requirement for the degree of Master of Science in Statistics (Bio-statistics).

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Internal Examiner	Signature	Date
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External Examiner	Signature	Date

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ACRONYMS AND ABBREVIATIONS

ACM	Adjacent categories ordinal logistic model
AIC	Akaike Information Criteria
BMI	Body Mass Index
BIC	Bayesian information Criteria
CSA	Central Statistical Agency
CRM	Continuation ratio ordinal model
df	degree of freedom
EA	enumeration area
EDHS	Ethiopian Demographic Health Survey
EMDHS	Ethiopian Mini Demographic Health Survey
GDP	Gross Domestic Product
GLM	Generalized Linear Model
GOM	Generalized ordered logit model
HH	House Hold
HGLM	Higher Generalized Linear Model
ICC	Intra-class Correlation Coefficient
Logit	Log of Odds
ML	Maximum Likelihood
MDGS	Millennium Developmental Goals
NCHS	National Center for Health Statistics
OR	Odds Ratio
PO	Proportional Odds
POM	Proportional Odds Model
PQL	Penalized Quasi Likelihood
PPOM	Partial Proportional Odds Model
SPSS	Statistical Package for Social Science
SLM	Stereotype logistic regression model
US	United Nations
UNICEF	United Nations International and Children's Emergency Fund
WHO	World Health Organization

ABSTRACT

Background: *Malnutrition is associated both under nutrition and over nutrition which causes of the body gets un proper amount of nutrients to maintain tissues and organ function. Malnutrition and diet are the biggest risk factors for the global burden of disease.*

Objective: *To determine associated factors to underweight among under-five year children in Ethiopia.*

Method: *The data source for analysis was the 2016 EDHS data from under-five children weight-to- age anthropometric index (Z-score) child underweight divided in to three categories: severely underweight (Z-score<-3.00), moderately underweight* $(-3.00 \leq Z - score \leq -2.01)$ *and normal* ($Z - score \geq -2.00$)*. In order to achieve our objective descriptive, cross-tabulation, standard ordinal logistic regression and multilevel ordinal logistic regression analysis were used. Thus several ordinal models such as POM, GOM, PPOM, ACM, CRM and SLM models were fitted.*

Result: *The descriptive result revealed that about 7.08% of children were severely underweight and 16.72% were moderately underweight while 76.19% were normal. Among the fitted model, PPOM fits the data better than other models. The test of heterogeneity suggested that, the underweight varies among region and multilevel ordinal model fit data better than single level ordinal model. For selected multilevel PPOM shows that mother education, wealth index of family, religion of mother, birth order, birth type, sex of child, birth size of child, diarrhea two weeks before the survey, fever two weeks before the survey, mother BMI, age of child and duration of breast feeding were significant determinants of underweight among under-five children.*

Conclusion: *In order to reduce severity of underweight, awareness creation efforts have to improve their economic status, improve the level of education of mothers. It is recommended that design and implement primary health care and nutrition programs which would fit the features of each region to safeguard children from nutritional deficiency.*

Key words: underweight, partial proportional odds model, multilevel partial proportional odds model, under-five year children, Ethiopia

CHAPTER ONE

INTRODUCTION

1.1. Background of study

Nutrition is process by which individual achieve their physical and mental growth throughout in their life cycle(Webb, 2014).

Adequate nutrition is important in early childhood to ensure healthy growth, correct organ formation and function, a strong immune system, neurological and mental development. Economic growth and human development require nourished populations who can learn new skills, perform better in school , grow into healthy adults ,think critically and contribute to their communities, and in turn give their children a better start in life(Haddad et al., 2015).

Improving nutritional status of people has a direct impact on economy performance of the country by boosting national productivity, improve health, increase opportunity in labor market, and schooling performance(UNICEF, 2014).

Under nutrition is the result of insufficient intake of food in terms of either quantity or quality, poor utilization of nutrients due to contaminations or other illnesses, or a combination of these factors. It is occurred significant deficiencies in any or all form of the energy, protein, or essential vitamins, minerals and caused by a range of factors including inadequate maternal health or childcare practices, inadequate access to health services, limited health services and unhealthy environment and poor financial(von Grebmer et al., 2017, Dessie et al., 2019).

Malnutrition is associated both under nutrition and over nutrition which causes of the body gets un proper amount of nutrients to maintain tissues and organ function (Gamecha et al., 2017, Ali et al., 2016). Malnutrition represents the main health problem in developing countries. The physical and/or cognitive development of children can be progress of poor nutrition during childhood which leads to the cause of disease and death (Das and Gulshan, 2017, Debeko and Goshu, 2015).

Worldwide, millions of people are affected by under nutrition and micronutrient malnutrition which leads to stunting. Under nutrition costs the economy of the world about 2 to 3 percent of GDP in every year(IFPRI, 2014). Globally, malnutrition is causing the deaths of 3.5 million children under 5 years old per year and it is the third level of disease burden. Approximately 30%

of children are undernourished and 60% of children die of common diseases like malaria and diarrhea which they would survive, if their bodies had not been weakened by malnutrition(Yilkal and Kassahun, 2016).

Under nutrition remains a serious problem in many developing countries affecting over 815 million children causing more than half of children's deaths. Around 195 million under-five year's children were affected by malnutrition; among those 90% were live in sub Saharan Africa and South Asia. Ethiopia has the highest prevalence of under-five mortality. At least 53% of children death can be attributed directly or indirectly to malnutrition(Temesgen and Haile, 2017). Ethiopia was the second most malnourished country in Sub-Saharan Africa(Yilkal and Kassahun, 2016).

The prevalence of underweight has consistently decreased from 41% to 24% over the 16 years period, which is serious problem for Ethiopia. There is also a huge variation in children's underweight among regions in Ethiopia (CSA, 2016).

1.2. Statement of problem

Malnutrition is a major public health problem faced by every country among their children as it inhibits their cognitive and physical development as well as contributes to child morbidity and mortality. It has impact on child survival, better health, mental development in the current and succeeding generations and are more likely to transfer poverty to the next generation(Mawa and Lawoko, 2018).

Worldwide in 2016, about 155 million under-five children were stunted, 52 million under-five children were wasted and 17 million were severely wasted. Among the stunted children two out of five stunted and more than half of all wasted children live in Southern Asia. In addition more than one third of under five children are stunted and more than one quarter wasted children lives in Africa(Unicef, 2018).

Malnutrition and diet are the biggest risk factors for the global burden of disease. Every country is facing a serious public health challenge from malnutrition, one in three people are malnourished and approximately 45% of deaths of children are related to malnutrition and its economic consequences represent 11% losses of GDP every year in Africa and Asia (Achadi et al., 2016).

In last decade, Ethiopia plan to reduce child under nutrition, but significant improvement cannot obtain still due to multidimensional and complex factors. Yearly Under nutrition is cause of 24% child mortality(UNICEF, 2014).

A number of studies have been conducted to identify covariates related to underweight among under five children in Ethiopia by using binary logistic regression(Haile and Amboma, 2018, Fekadu et al., 2015, Brhane and Regassa, 2014) and multilevel binary logistic regression(Alom et al., 2012, Mohammed, 2015). However, binary logistic regression classifies underweight in to two categories to fulfill the requirements of binary logistic regression since multiple underweight status level is collapsed. Besides, binary logistic regression does not provide sufficient information for studying the pattern of severity of underweight among under five children and Standard regression assumes that all experimental units are independent in the sense that any variable affecting underweight has the same effect in all regions.

A multilevel ordinal modeling relaxes this assumption and allows these variable effects to vary across the region and also provide a full picture of the severity of the problem on country level. That is, it allows the simultaneous examination regional level and individual level predictors and analysis within and between regional variations among under-five children in Ethiopia. However, the underweight status of a child is usually classified as normal, moderately underweight and severely underweight. In this study, we have assumed region has an effect on modeling the determinants of underweight among under five children which was due to the heterogeneity in regions of the study(Goldstein, 2011).

In this study, we have explained level of underweight and identify potential predictors among under-five children in Ethiopia

Research question

- ✓ What are factors for underweight among under-five children in Ethiopia?
- ✓ Is there a significant regional variation with regard to underweight among under-five children?

1.3 . Objective of the study

1.3.1. General objective

The aim of this study was to identify factors associated with underweight among under-five children in Ethiopia application of multilevel ordinal logistic regression.

1.3.2. Specific objectives of the study

- ✓ To identify the factors associated with underweight among under-five children in Ethiopia.
- ✓ To examine the extent of the variation in underweight among under-five children between regions of Ethiopia.

1.4. Significant of the study

This study was set out to investigate factors associated to underweight among under-five children that accelerate child mortality and case of disease in Ethiopia. In addition this study may provide information to policy makers and stakeholders that would be useful for policy implications from a global health perspective and at country-specific viewpoint. From a global health perspective it will help to evaluate the progress made by countries towards achieving the MDGs. Country level, governments will be better informed about where to allocate their scarce resources in their effort to improve the underweight among under-five children. So, this study may intend to create awareness for governmental and non-governmental organizations and other concerned body to develop nutrition programs and set appropriate plans to solve nutrition problems.

Moreover, this research finding could serve as one source material in the area of underweight, other researchers, development planners and policy makers might also find it as an input for further study and investigations.

1.5. Limitation of study

The limitation of the study was a convergence problem for analyzing multilevel random coefficient model with interaction terms that helps to see the effect of interaction terms and also the data used was secondary which was obtained from cross sectional survey. As a result, there may be cause and effect relationship between response and predictors.

1.6. Organizational overview of the Study

The study was organized into five chapters. Following the introductory chapter one, chapter two discusses reviews related to determinants of underweight among under-five children in Ethiopia. Chapter three discusses the data and methodology of the study such as sources of data and variables included in the study. Methods of data analysis also described in detail in this chapter. Chapter four presents statistical data analysis and discussion of each of the covariates as per the output. Finally, conclusions and policy recommendations of the study are dealt with in chapter five.

CHAPTER TWO

LITERATURE REVIEW

2.1. Over views of underweight among Under-five children

Adequate, appropriate and safe food and nutrition means the regular and sufficient consumption of nutritious foods across the life span, including breastfeeding, to support normal growth and development of children and promote physical, emotional, and social well-being for all people. The international reference standard that is most commonly used (and recommended by the WHO) is that of the data on the weights and heights of a statistically valid population (US National Center for Health Statistics (NCHS)) of healthy infants and children in the US.

Globally, the prevalence of under five children stunting, wasting and underweight has declined from 32.7%, 9% and 25% in 2000 to 22.9%, 7.7% and 15% in 2016, respectively, Sub-Saharan Africa and South Asia still has the highest prevalence of child Under nutrition, with sub-Saharan Africa contained about one third of all undernourished children. In Sub-Saharan Africa, about 39% were stunted, 10% wasted, and 25% underweight (Akombi, 2017).

The proportion of stunting among under five children in developing world decreased from 40% to 29% between 1990 and 2008 (Kasirye, 2010). According to EDHS Progress in reducing malnutrition has been accelerated in the 2000–2016 period compared with the 1990s. There is wide regional and residence setting variation in under-five nutritional status in the country. The prevalence of stunting has decreased considerably from 58% in 2000 to 38% in 2016, an average decline of more than 1 percentage point per year. This declined also to 43.4% in 2011 and to 40% in 2014 .wasting changed little over the same time period, with a wasting rate of 10% at the time of the EDHS 2016, which was the same level as in 2011 and it was 12% in 2005, and also underweight has decreased from 41% to 24% over the 16-year period(CSA, 2016).

2.2. Expression of Nutrition Indices

Anthropometric indices can be expressed in relationship to the reference population in two different statistical terms: standard deviations from the median or percentage of the median.

Standard deviation or Z-score is the difference between the value for an individual and the median value of the reference population for the same age or height divided by the standard deviation of the reference population. Z-score will be able to describe how far a child's weight is from the median weight of a child at the same height in the reference value. According to WHO and UNICEF, the three most commonly used anthropometric indices to assess child growth status are weight-for-height, height-for-age and weight-for-age(WHO, 2006).

Low weight-for-height: Wasting or thinness indicates in most cases a recent and severe process of weight loss, which is often associated with acute starvation and/or severe disease. However, wasting may also be the result of a chronic unfavorable condition.

Low height-for-age: Stunted growth reflects a process of failure to reach linear growth potential as a result of suboptimal health and/or nutritional conditions. Stunting reflects failure to receive adequate nutrition over a long period of time and is affected by recurrent and chronic illness. Height-for-age, therefore, represents the long-term effects of malnutrition in a population and is not sensitive to recent, short-term changes in dietary intake.

Low weight-for-age: known as underweight reflects body mass relative to chronological age. It is influenced by both the height of the child (height-for-age) and his or her weight (weight-for height) which reflect composite index both acute and chronic malnutrition.

2.3. Empirical literature on underweight among under-five children

According to study conducted on (Alemayehu et al., 2014) child sex, child age, presence of toilet for the household are significantly associated with nutritional status of children. Girls were twice underweight than boys. Children born from household who does not have toilet are more likely underweight than who have.

According to research finding on nutritional status of under five children in Ethiopia by using systematic review and meta-analysis showed that child age, child sex, diarrheal diseases, maternal education, residential area and socio- economic status were significant risk factors for under nutrition(Abdulahi et al., 2017).

According to study conducted on nutritional status of under five children in Hawassa zuria by using binary and multinomial regression revealed that source of drinking water, maternal education, birth type, age of child, sex of child were an important variables to determine the nutritional status of under five children (Debeko and Goshu, 2015).

According to research finding in Ethiopia by using multilevel binary logistic regression on Socio-Economic determinants of nutritional status of children in Ethiopia showed that age of child, residence, wealth index, toilet access, region were found to be significant determinants of under-five nutritional status in Ethiopia(Mohammed, 2015).

A study conducted by (Das and Gulshan, 2017) used Bangladesh Demographic and Health Survey conducted in 2014 to examine determinants of nutritional status of under five children by logistic regression model. The result showed that age of children, place of residence, religion, BMI of mothers, wealth index and toilet facilities used by the household have significant association with child underweight.

A study done in Bangladesh on factors associated with malnutrition among under-five children using ordinal logistic regression model which is known as proportional odds model showed that mother's education, wealth index, and mother's BMI were found important determinants factors for child malnutrition(Talukder, 2017).

A research finding on prevalence and associated factors of malnutrition among rural children in Ethiopia by using logistic regression analyzed based on EMDHS 2014 data indicated that maternal education improves children malnutrition. The result also indicated that age of the children, wealth status, and region were factors independently associated with malnutrition of children(Endris et al., 2017).

The result of study on the assessment of nutritional status and associated factors of children under 5 years of age in Dabat Town, North Gondar, Ethiopia revealed that the educational status of the mother, age of the mother, marital status of the mother were significantly associated with malnutrition(Adugnga et al., 2017).

The study examined on key determinants of malnutrition of children under five years of age in Rwanda based on Rwanda Demographic and Health Survey data, using the joint model of a multivariate generalized linear mixed model the age of the child, gender of the child, birth order, incidence of recent fever, multiple births, education level of the mother, BMI of mother, source of drinking water and wealth quintiles are the key determinants of malnutrition of children under five years of age(Habyarimana, 2016).

The research conducted on children's nutritional status and its determinants in small towns, Sebeta Hawassa district, Oromia, Ethiopia by using bivariate and multivariate logistic regression model. Multivariate model revealed that age of child, number of under-five children in the household, maternal education, monthly income, breast feeding status were positively and child birth order was negatively associated with child malnutrition (Haile and Amboma, 2018).

On the application of logit regression model on determinants of among under five children malnutrition is strongly associated with the child's age, child's gender, family size, water source and latrine use(Zewdie and Abebaw, 2013).

According to study conducted in Zambia to examine the determinants of child nutritional status by using method of multivariate analysis. The result showed that sex of child, residence and age of child has significant effect on nutritional status of under five children (Masiye et al., 2010).

Study performed on semi-parametric analysis of children nutritional status in Ethiopia using the bayesian semi-parametric regression model was used to investigate effects of selected socioeconomic, demographic, health and environmental covariates. The study showed that child age, mother BMI, sex of child, birth order of child, place of residence, mother's education level, toilet facility, number of household members, household economic status, cough, diarrhea and fever were the most important determinants of children nutritional status in Ethiopia(Takele, 2013).

According to Bayesian Gaussian regression analysis malnutrition for children under five years of age in Ethiopia based on EMDHS 2014 showed that sex of a child, age of the child, source of water, mother's BMI, head of house hold sex, mother's age at birth, wealth index, birth order, diarrhea, and duration of breast feeding were significant factors on children malnutrition in Ethiopia, and also age of child, mother's age at birth and mother's BMI were important factors with linear effect for the child malnutrition in Ethiopia(Mohammed and Asfaw, 2018).

The research on the determination of nutritional status of under-five year children employing multiple interrelated contributing factors in southern part of Bangladesh showed that the covariate Breast feeding practice and monthly family income are significantly factors on the underweight of children(Roy et al., 2015).

The study conducted on nutritional status of under-five children in Bangladesh by used a multilevel binary logistic regression analysis showed that child's age, mother's education, and family wealth index are significant factor of malnutrition of under five children (Alom et al., 2012).

The study on risk factors of underweight in children aged 6–59 months in Ethiopia by applying bivariate and multivariate logistic regression analyses shows that age of children ,sex of children, maternal education, maternal occupation and house hold income were the determinant factor for underweight among children (Tosheno et al., 2017).

The study on Prevalence and risk factors for under nutrition among children under five at Haramaya district, Eastern Ethiopia by using multivariate logistic regression model showed that children having diarrhea, BMI of mother, source of drinking water and birth order of children were the significant determinants of underweight among children(Yisak et al., 2015).

The study conducted on urban-rural differential in children under nutrition in Ethiopia showing that region, child age, mother age at first birth, maternal education, wealth status types of toilet facility and source of drinking water factors independently associated with child underweight in the rural Ethiopia(Reta et al., 2019).

A study conducted on nutritional status of children under five years of age in Shire Indaselassie, North Ethiopia: Examining the prevalence and risk factors shows that the main contributing factors of underweight among the children using binary logistic regression were found to be household size, marital status of mothers, contracting diarrhea two weeks preceding the survey(Brhane and Regassa, 2014).

The study on stunting, wasting and underweight in sub-Saharan Africa using a systematic review analysis the most consistent factors associated with childhood stunting, wasting and underweight were mother's education, child's age, sex of child, wealth index, mother's age, source of drinking water, mother's BMI, birth size, diarrhea, and place of residence (Akombi et al., 2017).

The study on prevalence and factors associated with stunting, underweight and wasting: a community based cross sectional study among children age 6-59 months at Lalibela town, Northern Ethiopia by using binary logistic regression showed that wealth quintile to the households, age of the child, number of children aged 6-59 months in the household, duration of breast feed the child were remained to be significantly and independently associated with underweight(Yalew et al., 2014).

The study conducted on prevalence of under nutrition and its associated factors among under five children in Gonder city, northwest Ethiopia using logistic regression shows that birth order and sex of child were significant factor for underweight of children(Gelano et al., 2015).

The study established in Sheka zone South West Ethiopia revealed that under-five children who had fever last two weeks before survey date were more likely to be severely malnourished than who had no fever. The analysis also showed that size of child at birth and had diarrhea in last two weeks before survey date were significant factors for under-five children malnutrition(Yilkal and Kassahun, 2016).

CHAPTER THREE

DATA AND METHODOLOGY

3.1. Data source

The source of data for this study was the Ethiopia demographic and health survey (EDHS 2016) which was obtained from Central Statistical Agency (CSA) under the auspices of the Ministry of Health. The survey was conducted from January 18, 2016 to June 27, 2016 based on a nationally representative sample that provides estimates at the national and regional levels and for urban and rural areas. The survey was the fourth in a series of similar surveys conducted at five year intervals since 2000.

The 2016 EDHS sample was selected using a stratified, two-stage cluster design and enumeration areas (EA) were the sampling units for the first stage. A total of 18,008 households were selected for the sample, of which 17,067 were occupied, of the occupied households 16,650 were successfully interviewed, yielding a response rate of 98 %. The strata considered in the survey were at the regional and residence levels. In the first stage, a total of 645 enumeration areas (EA) (202 in urban areas and 443 in rural areas) were selected with probability proportional to EA size (based on the 2007 population census) and with independent selection in each sampling stratum. A household listing operation was carried out in all of the selected EAs from September to December 2015. The resulting lists of households served as a sampling frame for the selection of households in the second stage. In the second stage of selection, a fixed number of 28 households per cluster were selected with an equal probability systematic selection from the newly created household listing. From each selected house hold under-five children were measured anthropometric measurements height and weight. Thus, the analysis presented in this study was based on under-five years' children weight-for-age anthropometric measurement which refers underweight status among under-five children.

3.2. Variables of the study

3.2.1. Response variable

The response variable of the study is underweight which is measured by weight for age Z-score. Weight and age measurements of children were converted into Z-scores based on the National Center for Health Statistics (NCHS) reference population recommended by the World Health

Organization (WHO). Underweight can be categorized into three groups: Severely underweight (Z-score< -3.00), moderately underweight ($-3.00 \leq Z - score \leq -2.01$) and normal (Z-Score≥ -2.00). From the anthropometrics measures, we use weight-for-age to analysis underweight of children's. Weight-for-age is a composite index of height-for-age and weight-for-height and it is overall indicator of population's nutritional health. It takes into account both chronic and acute malnutrition(CSA, 2016, Mohammed and Asfaw, 2018). Weight-for-age represents a combination of both wasting and stunting and has a high positive predictive value as indicator of child malnutrition. Most widely, it uses for analysis of child nutritional status in developing countries(Abshoko et al., 2016).

3.2.2. Explanatory variables

The predictor variables which studied as determinants of children nutritional status are grouped in to socio-economic, demographic, health, environmental and community factors.

i. Socio-economic predictor variables are :

Education status of the mother, occupational status of mother, household wealth index, and duration of breast feeding status

ii. Demographic predictor variables are :

age of the child, sex of the child, sex of household head, marital status of mother, number of children less than 59 months in HH, number of household member, age of mother at first birth, type of birth, Birth order, birth size and religion.

iii. Environmental and community predictor variables are :

region, place of residence, toilet facility for HH, and source of drinking water for HH.

iv. health related predictor variables are :

mother BMI, had diarrhea in the two weeks before survey, had fever in the two weeks before survey, and had cough in the two weeks before survey.

3.3. Methods of data analysis

3.3.1. Single level ordinal logistic regression model

The ordinal logistic regression procedure empowers one to select the predictive model for ordered dependent variables. It describes the relationship between an ordered response variable and a set of explanatory variables. The explanatory variables may be continuous or discrete (or any type). Ordinal response models have major importance in social sciences as well as demography and many social phenomena. The responses are discrete or qualitative rather than continuous or quantitative in nature and a preferred modeling tool which does not assume normality or constant variance, but requires the assumption of parallel lines across all levels of the outcome variable(McCullagh and Nelder, 1989). There are well known logistic regression model to analyze ordinal response variables. These are proportional odds model, continuation ratio model, adjacent-categories model and stereo type model**.** Among these proportional odds model is the common (Liu and Koirala, 2013, Agresti, 2002, McCullagh and Nelder, 1989).

3.3.1.1. Proportional Odds Model (POM)

The proportional odds model, which is also called cumulative odds model(Agresti, 2002, O'Connell, 2006, McCullagh and Nelder, 1989, Hosmer Jr et al., 2013) is one of the most commonly used models for the analysis of ordinal categorical data and comes from the class of generalized linear models. The most frequently used ordinal logistic regression model in practice is the constrained cumulative logit model called the proportional odds model. It is used as a tool to model the ordinal nature of a dependent variable by defining the cumulative probabilities differently instead of considering the probability of an individual event. The POM is the most widely used in epidemiological and biomedical applications. The proportional odds model assumes that the cumulative logit can be represented as parallel linear functions of independent variables, and it estimates simultaneously multiple equations of cumulative probability. That is, for each cumulative logit the parameters of the models are the same, except for the intercept. Consequently, according to the proportional odds assumption, odds ratio is the same for all categories of the response variable (Agresti, 2002). POM leads to strong assumptions that may lead to incorrect interpretations if the assumptions adequate cell count and parallel lines are violated. If the data fail to satisfy the proportional odds assumption, a valid solution is fitting a partial proportional odds model (Das and Rahman, 2011).

The proportional odds model is used to estimate the odds of being at or below a particular level of the response variable. If there are K levels (categories) of ordinal outcomes, the model makes K-1 predictions, each estimating the cumulative probabilities at or below the k^{th} level of the outcome variable. This model can estimate the odds of being at or beyond a particular level of the response variable as well, because below and beyond a particular category are just two complementary directions.

When response categories are ordered, logits can directly incorporate the ordering. The cumulative probabilities are the probability that the response Y falls in category k or below, for each possible k the k^{th} cumulative probability is $pr(Y \le k) = \pi_1 + \pi_2 + \cdots + \pi_k$.

This model compares the probability of a response less than or equal to a given category (k = 1, 2, ..., K-1) to the probability of a response greater than this category. In addition, this model is composed of K-1 parallel linear equations. In the particular case of only two categories (k = 2), the POM corresponds exactly to the traditional binary logistic regression model.

Let Y takes categorical response variable with K ordered categories, and let the cumulative probability of the first K-1 of Y is $pr(Y \le k) = \pi_k$, k=1,2,…K-1

Then the odds of the first K-1 cumulative probabilities are

$$odds(pr(Y \le k)) = \frac{pr(Y \le K)}{1 - pr(Y \le k)} = \frac{\pi_k}{1 - \pi_k} \quad \text{.. (3.1)}$$

The cumulative probabilities reflect the ordering, with $pr(y \le 1) \le pr(y \le 2), \dots, pr(y \le K) = 1$.

The proportional Odds model, models the log odds of the first K-1 cumulative probabilities as

$$logit(pr(Y \le k)) = \log(\frac{pr(Y \le K)}{1 - pr(Y \le k)}) = \log(\frac{\pi_k}{1 - \pi_k}) \quad \text{...........................(3.2)}$$

Consider a collection of p explanatory variables denoted by the vector of $X' = (x_1, x_2, \dots, x_p)$ the relationship between the predictor and response variables is not a linear function in logistic regression; instead, the logistic regression function is uses the logit transformation of π.

$$\pi_k = \frac{\exp^{(\alpha_k - (\beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p))}}{1 + \exp^{(\alpha_k - (\beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p))}} \quad \text{... (3.3)}$$

The logit or log-odds of having $pr(Y \le k) = \pi_k$ is modeled as a linear function of the explanatory variables as:

$$\eta_k = logit\big(pr(Y \le k)\big) = \log\left(\frac{pr(Y \le k)}{1 - pr(Y \le k)}\right) = \log\left(\frac{\pi_k}{1 - \pi_k}\right)$$

$$= \alpha_k - (\beta_1 x_1 + \cdots + \beta_p x_p) = \alpha_k - \sum_{l=1}^{p} \beta_p x_p \quad 0 \le \pi_k \le 1 \text{ ----------------- (3.4)}$$

l=1, 2,…, p and k=1,2,…,K-1

Where, k indexes the cut-off points for all categories (K) of the response variable, $\pi_k = pr(Y \le y_k)$ is the cumulative probability of the event $Y \le y_k$, α_k represents a separate intercept or threshold value for each cumulative probability which satisfies the condition $\alpha_1 \le \alpha_2 \le \alpha_3 \le \cdots \le \alpha_k$ and their values do not depend on the values of the independent variable for a particular case. $\beta = \beta_1, \beta_2, \dots, \beta_k$ is the vector of the un known regression coefficient corresponding to $x_1, x_2, \dots, x_p$ (McCullagh and Nelder, 1989).

Odds of being at or below category k equal the probability of being at or below a category divided by the probabilities of being above that category. The equation is given as;

$$odds(y \le k) = \frac{pr(y \le k)}{pr(y > k)} = \frac{pr(y \le k)}{1 - pr(y \le k)} \quad \text{.................................. (3.5)}$$

Like binary logistic regression, the odds ratio of PO is the change of the odds (being at or below a category versus being above that category), and it is obtained by exponentiated logit coefficients $exp^{(\beta)}$.

Testing of Parallel Lines

Ordinal logistic regression assumes that the coefficients that describe the relationship between, say, the lowest versus all higher categories of the response variable are the same as those that describe the relationship between the next lowest category and all higher categories, etc. This is called the proportional odds assumption or the parallel regression assumption. Thus, in order to assess the appropriateness of the model proportional odds assumption is normally evaluated (O’Connell, 2010). The test of parallelism contains -2log - likelihood for the constrained model, the model that assumes the planes or surfaces are parallel and -2log - likelihood for the general model, the model that assumes planes or surfaces are separated. The chi-square statistic is the log-likelihood difference between the two models. If the lines or planes are parallel, the observed significance level for the change should be large, since the general model doesn’t improve the fit very much and the parallel model is adequate. If there is evidence to reject the null hypothesis, it is possible that the link function selected is incorrect or that the relationships between the independent variables and logits are not the same for all logits.

If the proportional odds assumption is not met, then we may want to go with several options: the first is to collapse two or more levels, particularly if some of the levels have small sample size. The second is do bivariate logistic analyses, to see if there is one particular independent variable that is operating differently at different levels of the dependent variables. This can be done in various ways, including adjacent and global methods. The third is to use the partial proportional odds model. The last option is to use multinomial logistic regression(Agresti, 2010).

3.3.1.2. Generalized ordered logit model (GOM)

In the case where the proportional odds assumption is violated, the proportionality constraint may be completely or partially relaxed for the set of explanatory variables. Generalized ordered logit model is an ordinal logistic regression which considers order of category of the response variable with p set of explanatory variables. This model results K-1 logits without constrained the effect of each explanatory variable is equal across the logits(Fu, 1999, Williams, 2006).

The model can be expressed as follows:

$$\eta_k = logit\big(pr(Y > k)\big) = \log\left(\frac{pr(Y > k)}{1 - pr(Y < k)}\right) = \log\left(\frac{\pi_k}{1 - \pi_k}\right)$$

$$= -\alpha_k + \beta_{1k}x_1 + \beta_{2k}x_2 + \cdots + \beta_{pk}x_p = -\alpha_k + \sum_{l=1}^{p} \beta_{pk}x_p \quad \text{.......................... (3.6)}$$

$0 \le \pi_k \le 1$, l=1,2,…,p and k=1,2,…,K-1

Where, α_k are the intercept or cut points and $\beta_{1k}, \beta_{2k}, \dots, \beta_{pk}$ are logit coefficients. This model estimates the odds of being beyond a certain category relative to being at or below that category. A positive logit coefficient indicates that an individual is more likely to be in a higher category as opposed to a lower category of the outcome variable. Generalized ordered logit model estimates the regression parameters for each explanatory variable on K-1 logit of the probability being beyond the k^{th} category in every logit to have different estimated values. Hence, this model has too many parameters and different interpretation to the p^{th} explanatory variable in the K-1 logit.

3.3.1.3. Partial Proportional Odds Model (PPOM)

The partial proportional odds model allows non-proportional odds for all or subset q of the explanatory variables(Peterson and Harrell Jr, 1990). It is an extension of the proportional odds model. As the proportional odds assumption is difficult to achieve in practice, the PPOM may be used as parsimonious alternative. It is rare for all the co-variables included in the model to display the proportional odds property. To contemplate a more realistic situation, the partial proportional odds model allows for some co-variables to be modeled with the proportional odds assumption. The other variables in which this assumption is not met, specific parameters are included in the model that varies for the different categories that are compared (Williams, 2006, Liu, 2015, Liu and Koirala, 2012).

When the relationship between a co-variable and the response variable is not proportional, a kind of tendency is frequently expected. Peterson & Harrell proposed a model that is applicable when there is a linear relationship between the logit for a co-variable and the response variable (Ananth and Kleinbaum, 1997, Peterson and Harrell Jr, 1990). In this case, restrictions (represented by the gamma parameters and which are fixed scalars) can be inserted as parameters in the model in order to incorporate this linearity. The choice of the restriction can be decided in various ways. Ideally, it should be determined by using either a data bank from a pilot study or a predefined value.

$$\lambda_k = logit(y \leq k/X) = log\left\{\frac{pr\left(y = 1/X\right) + \cdots + pr\left(y = k/X\right)}{pr\left(y = k+1/X\right) + \cdots + pr\left(y = K/X\right)}\right\}$$

$$= log\left\{\frac{\sum_1^k pr\left(y = k/X\right)}{\sum_{k+1}^K pr\left(y = K/X\right)}\right\}$$

$$\lambda_k = \alpha_k - \{\tau_k[(\beta_1 + \gamma_1)x_1 + (\beta_q + \gamma_q)x_q] + (\beta_{q+1}x_{q+1}) + \cdots + (\beta_p x_p)\} \text{ ------- (3.7)}$$

k=1,2,…,K-1

Where, τ_k parameters are fixed scale parameters which take the form of restrictions allocated to the parameters and X is set of explanatory variables $x_1, x_2, \ldots, x_p$.

3.3.1.4. Continuation ratio logistic model (CRM)

Continuation ratio logistic model is proposed by Fienberg which compares the probability of a response equal to a given category, say Y = k, to the probability of a higher response Y > k (Fienberg, 2007). The model also called sequential model in which ordinal response represents successive stages. Sequential model is also known as the unconstrained continuation ratio model and the effects of the independent variables are allowed to differ for each outcome(Tutz, 2012).

The advantage of continuation ratio logistic model can be adjusted according to k binary logistic regression models. It is more appropriate when there is intrinsic interest in a specific category of the response variable, and not merely an arbitrary grouping of a continuous variable (Ananth and Kleinbaum, 1997). The model is given as:

$$\frac{\pi_1}{\pi_2}, \frac{\pi_1 + \pi_2}{\pi_3}, \dots, \frac{\pi_1 + \pi_2 + \cdots + \pi_{k-1}}{\pi_K}$$

$$\log\left(\frac{\text{pr(y=k)}}{\text{pr(y>}k)}\right) = \log\left(\frac{\pi_k}{\pi_{k+1} + \cdots + \pi_K}\right) = \alpha_k - \beta_k X \quad \dots\dots\dots\dots\dots\dots (3.8)$$

k=1,2,…,K-1 α_k is cut point of response variable and $\beta = \beta_1, \beta_2, \dots, \beta_p$ are coefficients of the corresponding predictor variables for $X = x_1, x_2, \dots, x_p$ respectively.

The odds of continuation regression model are the probability of being in category divided by the probability of being beyond that category. The formula is given as:

$$odds = \frac{pr(y=k)}{pr(y>k)} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.9)$$

The odds ratio is the change in the odds for a one unit increase from any value of x to the value of x+1. It is the odds of being in a category relative to being above that category, and it is obtained by exponentiated logit coefficients exp^{β}.

3.3.1.5. Adjacent-categories logistic regression model (ACM)

It is the modeling of pairs of adjacent categories of the ordinal response variable. The model estimates the odds of being in a category versus being in adjacent category of the ordinal response variable. i.e. it compares the lower category relative to the higher category (Agresti, 2010, Hosmer and Lemeshow, 2000, Liu, 2015). If we assume that the log-odds does not depend on the response and the log-odds is linear in the coefficients. It is ratios of probabilities for successive categories as:

$$\frac{\pi_1}{\pi_2}, \frac{\pi_2}{\pi_3}, \dots, \frac{\pi_{k-1}}{\pi_k}$$

The model can be expressed as

$$logit\left(y = {}^{k}\!\Big/\!\left(x_1, x_2, \dots, x_p\right) \right) = \log\left(\frac{\pi_k}{\pi_{k+1}}\right) = \alpha_k - (\beta_1 x_1 + \beta_2 x_2 + \dots + \beta_p x_p) \quad \text{..........} \ (3.10)$$

k=1,2,…,K-1 Where, α_k is the intercept, $\beta_1, \beta_2, \dots, \beta_p$ are the coefficients for each explanatory variables.

The odds of adjacent category model can be expressed as

$$odds(y = k \text{ Versus } y = k + 1) = \frac{pr(y=k)}{pr(y=k+1)} \quad \text{..........................} \ (3.11)$$

The odds ratio is the adjacent categories model is the ratio of two odds, and obtained by exponentiated logistic coefficientexp^{β}. In these model odds are the probabilities of comparison between the lower category to higher category of the adjacent categories.

3.3.1.6. Stereotype logistic regression model (SLM)

Stereotype model is the alternative model when PO assumption is violated. The stereotype model should be used when the response variable is intrinsically ordinal and not a discrete version of some continuous variable.

This is the most flexible model for analyzing ordinal responses and can be considered an extension of the multinomial regression model. However, the stereotype logit model does not assume the PO assumption, and allows the effect of each predictor to vary across the ordinal categories. Although the theory of the stereotype logit model has existed, this model seemed to be underutilized: the illustration and application of this model were rare(Liu, 2015, Greenland, 1994).

The model is written as:

$$\text{logit}(\pi(k, K)) = \log\left(\frac{\pi(y=k)}{\pi(y=K)}\right) = \alpha_k - \phi_k(\beta_1 x_1 + \beta_2 x_2 + \dots + \beta_p x_p) \quad \text{..................} \ (3.12)$$

k=1,2,…,K-1

where K is the reference category, α_k is the intercept(cut point of the response variable) , $\beta_1, \beta_2, \ldots \beta_p$ is the coefficients of the predictor variables, $x_1, x_2, \ldots, x_p$ respectively, and ϕ_k is the constraints or scale parameters which are used to ensure the response variable is ordinal, if the following condition satisfied $1 = \phi_1 > \phi_2 > \cdots > \phi_{k-1} = 0$.

The odds in the Stereotype logit model are the ratio of the probabilities of being in a particular category in to the probabilities of being in the base categories. It is defined as:

$$odds(y = k\ vs\ y = K) = \frac{pr(y=k)}{pr(y=K)} = \frac{\pi_k}{\pi_K} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.13)$$

Odds ratio of being in categories k versus the category K is given as $((\alpha_k - \alpha_K) - (\phi_k - \phi_K)\beta)$ since α_K and ϕ_K is zero, the equation becomes$(\alpha_k - \phi_k\beta)$.

The odds ratio of being in category k versus the base line K for a unit change in the predictor variable is $e^{-\phi_k\beta}$ hold other predictor variable constant.

3.4. Parameter estimation

The parameters are usually estimates using maximum likelihood. The method of maximum likelihood correspond too many well-known estimation methods in statistics. The estimation produces values of the unknown parameters that best match the predicted and observed probability values. It usually used a very effective and well known Fisher scoring algorithm to obtain ML estimate(McCullagh, 1980).

$$L = \prod_{j=1}^{n}\left[\prod_{k=1}^{K}\pi_k(x_j)^{y_{kj}}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.14)$$

$$= \prod_{j=1}^{n}\left[\prod_{k=1}^{K}(p\left(y \leq k/x_j\right) - p(y \leq k-1/x_j))^{y_{kj}}\right]$$

$$= \prod_{j=1}^{n}\left[\prod_{k=1}^{K}\left(\frac{exp^{(\alpha_k+\beta' x_j)}}{1+exp^{(\alpha_k+\beta' x_j)}} - \frac{exp^{(\alpha_{k-1}+\beta' x_j)}}{1+exp^{(\alpha_{k-1}+\beta' x_j)}}\right)^{y_{kj}}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.15)$$

$$L(\hat{\beta}) = \prod_{j=1}^{n}\left[\pi_1(x_j)^{y_{1j}}\pi_2(x_j)^{y_{2j}} * \ldots * \pi_K(x_j)^{y_{Kj}}\right]$$

It follows that log-likelihood function is

$$L(\hat{\beta}) = \sum_{k=1}^{n} y_{1j}\log[\pi_1(x_j)] + y_{2j}\log[\pi_2(x_j)] + \cdots + y_{Kj}\log[\pi_K(x_j)] \qquad \text{.......................} (3.16)$$

Differentiating (3.15) with respect to β and equating to zero, we will get the estimates of β. The maximum possible value of the likelihood for a given data set occurs if the model fits the data exactly. This occurs if observed counts are close with predicted. The difference between the log-likelihood functions for two models is a measure of how much one model improves the fit over the other.

3.5. Model selection

Fitting a model is the main issue and select best model that well fit the data. To achieve these task selection criteria's such as BIC and AIC should be considered. It is much better to compare models based on their results, reasonableness, and fit as measured; we can make comparisons among the possible models using the above selection criteria. In the case of logistic regression the model selection criteria will be taken as AIC. The AIC computation is based on the likelihood of the fit and the number of parameters in the model is considered. Therefore, if the model contains many variables there will be many parameters to be estimated. Therefore, this may penalize the AIC criteria. The variables included in the model should be selected based on their significance and relationship with the response variable.

Variable selection Methods such as forward, backward, and stepwise selection are available, but in logistic as in other regression methods are not to be recommended, because they give incorrect estimates of the standard errors and p-values; can discard variables that are important to be included in the model (Harrell, 2001). It judges a model by how close its fitted values tend to be to the true values, in terms of a certain expected value and the model with small value of this criterion is the optimal model, that means a model that close to actual one and the model which have few parameters to be estimated(Agresti, 2002). (Akaike, 1974) showed that this criterion selects the model that minimizes

AIC=-2(maximized log likelihood-number of parameters in the model)

This penalizes a model for having many parameters.

3.5.1. Test of overall model fit

Likelihood ratio test

For the selected model before proceeding to examine the individual coefficients, we should look at an overall test of the null hypothesis that the location coefficients for all of the variables in the model are zero. It can base this on the change in -2log-likelihood when the variables are added to a model that contains only the intercept. The change in likelihood function has a chi-square distribution even when there are cells with small observed and predicted counts. This value provides a measure of how well the model fits the data. The larger the value of the log likelihood the more unexplained observations and a poorly fitting model. Therefore, a good model means a small value for -2LL. If a model fits perfectly, the likelihood is 1 and -2log1=0 (Agresti, 2002).The likelihood-ratio test statistic is given

$\chi^2 = -2log\lambda = -2(ll_0 - ll_1)$ the distribution has chi-square with p-k-1 df. .... (3.17)

Where, p and k are the number of parameter and number of category of the response variable respectively, and $ll_0 and\ ll_1$ are the maximized log-likelihood functions of the null model and the selected model respectively.

3.5.2. Test of a single predictors

Wald test

The significance of a single predictor or explanatory variable can be tested by using Wald test in the model. Wald test statistic is the square of the ratio of the estimated coefficient to its standard error.

$H_0: \widehat{\beta_l} = 0\ vs\ H_1: \widehat{\beta_l} \neq 0$ l=1,2,…..,p

$$W = (\frac{\widehat{\beta_l}}{s.e(\widehat{\beta_l})})^2 \quad \text{...} (3.18)$$

Where, p number of predictor variables, W has a chi-square distribution with one degree of freedom and $\widehat{\beta_l}$ is estimated coefficient of each predictor variable.

3.5.3. Goodness-of-Fit Measures

A goodness-of-fit is used to check whether the explanatory variables fit the final model well or not. Most of the goodness of fit hypothesis is:

H_0: the model fits the data well versus H_1: the model doesn't fit data well.

The Pearson goodness-of-fit statistic is given by:

$$\chi^2 = \sum\sum\left(\frac{o_{ij}-e_{ij}}{e_{ij}}\right)^2 \qquad \text{.......} (3.19)$$

The deviance measure is also given as:

$$D = 2\sum\sum o_{ij}log\,(\frac{o_{ij}}{e_{ij}}) \qquad \text{.......} (3.20)$$

Where, o_{ij} and e_{ij} are the observed and expected frequencies from i^{th} and j^{th} columns of the cross tabulation. The observed frequency is obtained from the data on the response but the expected frequency is obtained from the estimated probabilities of the response.

3.6. Model adequacy checking

In regression analysis Model building is not the final goal because after the model has been fitted, model adequacy checking/diagnostics is the basic issue to check the fitted model is good or not and it can be measured based on diagnosing residuals and measure of influence. In logistic regression, some of the usual diagnostic statistics are the residuals and measures of influence.

Model Evaluation- Residuals

Residuals are the basic building blocks for logistic regression diagnostics. They can be useful for identifying potential outliers (observations not well fit by the model) or misspecification models and checking normality. For log-linear models this can be thought of checking how well the asymptotic theory holds. The residuals for logistic regression model are typically defined as the difference between observed response, and the estimated probability of the response, conditional on the covariates.

Let Y_i denote the binomial variate for n_i trials at setting i of the explanatory variables. i=1,2,…,N. let π_i denote the model estimate of P(Y=1) , then $n_i\pi_i$ the fitted number of successes. However, in logistic regression we have binomial errors and, as a result, the error variance is a function of the conditional mean. For a GLM with binomial random component, the Pearson residual for this fit is given (Agresti, 2002).

$$e_i = \frac{Y_i-n_i\widehat{\pi_i}}{(var(Y_i))^{1/2}} = \frac{Y_i-n_i\widehat{\pi_i}}{n_i\widehat{\pi_i}(1-\widehat{\pi_i})} \qquad \text{.......} (3.21)$$

is the standardizes by dividing the difference by the estimated binomial standard deviation of Y_i. These residuals relate to the Pearson goodness-of fit statistics by:

$$\chi^2 = \sum_{i=1}^{N} e_i^{\,2} \quad \text{.. (3.22)}$$

Each squared Pearson residual is a component of χ^2.

Pearson residual values fluctuate around zero, following approximately a normal distribution when n_i is large. When the model holds these residuals are less variable than standard normal (that is $e_i \sim N(o, 1)$.

Deviance residual is another type of residual. It measures the disagreement between the maxima of the observed and the fitted log likelihood functions. The deviance residual is useful for determining individual points are not well fit by the model. The deviance residual for the i^th^ observation is the signed square root of the contribution of the i^th^ case to the sum for the model deviance, for the i^th^ observation, and is given by:

$$\sqrt{d_i}\delta(y_i - n_i\tilde{\pi}_i) \quad \text{.. (3.23)}$$

Where $D_i = \pm\{-2[Y_i log\hat{\pi}_i + (1 - Y_i)\log(1 - \hat{\pi}_i)]\}^{1/2}$

Where the sign is positive when $Y_i \geq \hat{\pi}_i$ and negative otherwise. An observation with a residual that is far from 0 (that is greater than two in either direction) is poorly fit by the model.

Influence measures

It measures the effect that deleting an observation has on the regression parameters or the goodness-of-fit statistics. An observation is said to be influential if removing the observation substantially changes the estimate of coefficients. Influence can be thought of as the product of leverage and outlier. It may be informative to report the fit of the model after deleting one or two observations, if the fit with them seems misleading.

Leverages are the diagonal elements of the logistic equivalent of the hat matrix in general linear regression and value greater than one for the i^th^ observation indicates that observation is influential.

The logistic regression analog of Cook's influence statistic is a measure of how much the residual of all cases would change if a particular case were excluded from the calculation of the regression coefficients. Cook's distance is a direct influence measure relative to the fitted regression coefficients and observation with higher Cook's distance is the more influential point. For logistic regression the Cook's distance has the form:

$$CD_i = \frac{\chi_i{}^2 h_i}{1-h_i} \quad \text{...} \quad (3.24)$$

A large Cook's distance indicates that excluding a case from computation of the regression statistics changes the coefficients substantially. The lowest value of Cook's distance can assume is zero but for logistic regression, a case is identified as influential if its Cook's distance is greater than one(Hosmer and Lemeshow, 2000).

DFBETA(S) is a diagnostic that measure the effect of the i^{th} observation on the estimates of the logistic regression coefficients. These are computed by dropping the i^{th} observation. If DFBETA(S) is less than unity, this implies no specific impact of an observation on the coefficient of a particular predictor. While DFBETA of i^{th} observation greater than one, implies the observation is an outlier. It is computed as

$$DFBETA_p(i) = \frac{(X'vX)^{-1} x_i e_i}{1-h_i} \quad \text{...} \quad (3.25)$$

Where, e_i and $h_i$are the Pearson residual and leverage value respectively.

3.7. Multilevel ordinal logistic regression

Multilevel model is statistical model which allow not only independent variables at any level of hierarchical structure but also at least one random effect above level one group(Hox et al., 2017).

The problem of dependencies between individual observations also occurs in survey research, where the sample is not taken randomly but cluster sampling from geographical areas is used instead. In this case, the use of single-level statistical models is not reasonable. Hence, in order to draw appropriate inferences and conclusions from multistage stratified clustered survey data, we may require complicated modeling techniques like multilevel modeling. Multilevel models contain variables measured at different levels of the hierarchy(Goldstein, 2011).

Multilevel ordinal logistic regression model is the analysis of hierarchical and ordinal dependent variable. It is used to model the ordinal categorical dependent variable by one or more independent variables. The ordinal categorical dependent follows the logistic distribution and nested with higher levels(Liu, 2015).

First we have taken a sample of units from the higher level in our case from the 9 regions and two towns administrative and next we sample the sub units from available units (in our case from children). In such samples the individual observations are generally not completely independent. It also assumes that there is a hierarchical data set, with one single dependent variable that is measured at the lowest level and explanatory variables at all existing level group(Hox et al., 2017). Multilevel models are used to assess whether the effects of predictors vary from region to region. In a study of child nested within regions, not only unexplained variation between children but also unexplained variation between regions is regarded as random variable. Such variation can be analyzed through statistical models known as random coefficients models. The main statistical model of multilevel analysis is the HGLM, an extension of the GLM that includes nested random coefficients(Goldstein, 2011).

Multilevel Proportional odds model is the common and most applicable approach for hierarchical ordinal data and is an extension of multilevel binary logistic regression model. It is also the generalization of single level proportional odds model for nested data structure or hierarchical. For K-level ordinal response, there are K-1 probabilities and cumulative logit model for the response Y_{ij} for i^{th} child and j^{th} region(Snijders, 2011).

In this study, the clustering of the data points within geographical regions offers a natural 2-level hierarchical structure of the data, i.e. children are nested within regions.

Let the Y_{kij} ordered categorical response of i^{th} child in the j^{th} region with K ordered categories coded as k=1,2,…,K-1.

Then the cumulative probability for ordered response up to category K is $p_{kij} = pr(y_{ij} \leq k)$. The overall model is given as: level 1

$$\eta_{ij} = logit(\pi_{kij}) = \log\left(\frac{\pi(y_{ij} \leq k)}{\pi(y_{ij} > k)}\right)$$

$$\alpha_k - (\beta_{0j} + \sum_{l=1}^{p} \beta_{lj} x_{lij}) \qquad (3.26)$$

Where, l=1, 2, ..., p

Level 2 $\beta_{0j} = \gamma_{00} + \mu_{0j}$, $\beta_{1j} = \gamma_{10} + \mu_{1j}$, $\beta_{2j} = \gamma_{20} + \mu_{2j}, \ldots, \beta_{pj} = \gamma_{p0} + \mu_{pj}$

Thus, substituting this in to level 2 into level 1 equation, we get the composite equation:

$$= \alpha_k - (\sum_{l=1}^{p} \gamma_{p0} x_{pij} + \mu_{0j} + \sum_{l=1}^{p} \mu_{pj} x_{pij}) \text{ .... (3.27)}$$

Where, α_k is the cut point with k=1,2,…,K-1, and $x_{1ij}, x_{2ij}, \dots, x_{pij}$ are the predictor variables of i^{th} children for j^{th} regions, $\gamma_{10}, \gamma_{20}, \dots, \gamma_{p0}$ are the coefficients of fixed effect variable, μ_{0j} is the intercept variation of the model and normal distributed with mean 0 and variance $\sigma_{\mu 0}^2$ and $\mu_{1j}, \mu_{2j}, \dots, \mu_{pj}$ are the slope variations of the model and normal distributed with mean 0 and their variance-covariance matrix. As the single level PO model, multilevel PO model also assume that logit coefficients for each predictor variable are the same across the categories of the ordinal response variable.

3.7.1. Empty model

The model formed by without explanatory variable at any level. This model uses as the baseline model for future model comparison and estimates the overall average of the outcome variables across all subjects and the between-groups and with-in group variances. A null model contains only a response variable, and no explanatory variables other than an intercept. According to (Liu, 2015) multilevel random intercept (base model) cumulative log odds model for ordinal response is written as: Level 1 $\eta_{ij} = logit(\pi_{kij}) = \log\left(\frac{\pi(y_{ij} \leq k)}{\pi(y_{ij} > k)}\right) = \alpha_k - \beta_{oj}$

Level 2 $\beta_{0j} = \gamma_{00} + \mu_{0j}$ .... (3.28)

When we substitute level 2 in to level 1 equation we get the following composite model

$$\eta_{ij} = logit(\pi_{kij}(y_{ij} \leq k)) = \alpha_k - \gamma_{00} - \mu_{0j}$$

γ_{00} is the overall logit of being at or below a particular underweight status across regions and it set zero since the cut off points α_k estimated. Then the null model becomes

$$\eta_{ij} = logit(\pi_{kij}(y_{ij} \leq k)) = \alpha_k - \mu_{0j} \text{ .... (3.29)}$$

μ_{0j} is the random term of region level and is assumed to follow independently and normal distribution $N(0, \sigma_{\mu 0}^2)$. Thus, $\sigma_{\mu 0}^2$ measures regional variations of under-five children underweight and also known as random intercept variance. $Logit(\pi_{kij})$ is the logit link for the cumulative probabilities of being at or below a particular category of k for the i^{th} child and j^{th} region.

3.7.1.1. Intra class correlation coefficient

Intra class correlation coefficient is used as assessment of how many variations in the response categories lies at the level two (region level). The intra-class correlation indicates the proportion of the variance explained by the grouping structure in the population and simply states that it is the proportion of group-level variance compared to the total variance. Its value is between 0 and 1. When the value is near to 0, multilevel model is not analysis the data well. Whereas, the value is large multilevel analysis is required. When logistic model is used the residual at level one (child level) are assumed to follow the standard logistic distribution with mean 0 and variance$\frac{\pi^2}{3} = 3.29$ (Liu, 2015, Snijders, 2011). It is expressed as:

$$ICC = \frac{\sigma^2_{\mu 0}}{\sigma^2_{\mu 0} + \frac{\pi^2}{3}} \qquad \text{...} \quad (3.30)$$

$\sigma^2_{\mu 0}$ is the variance of the higher level(regions)

3.7.2. The Random Intercept Model

We include the level one predictor in empty model. The intercept is allowed to vary randomly across regions and the slope for predictor variable to be fixed to zero. But the relation between explanatory and response variables can differ between groups in more ways.

We assess the contribution of each explanatory variable, the significance of each predictor, and what changes occur in the second-level variance terms.

For hierarchical and proportional odds assumption is satisfied the model is known as multilevel proportional odds model(Liu, 2015). The model is given as follow:

The level l model

$$\eta_{ij} = logit(\pi_{kij}) = \log\left(\frac{\pi(y_{ij} \leq k)}{\pi(y_{ij} > k)}\right) = \alpha_k - (\beta_{oj} + \beta_{1j}x_{1ij} + \beta_{2j}x_{2ij} + \cdots + \beta_{pj}x_{pij})$$

$$= \alpha_k - (\beta_{0j} + \sum_{l=1}^{p} \beta_{lj}x_{lij}) \qquad \text{.....................................} \ (3.31)$$

The level 2 model $\beta_{0j} = \gamma_{00} + \mu_{0j},\ \beta_{1j} = \gamma_{10}, \beta_{2j} = \gamma_{20}, \dots, \beta_{pj} = \gamma_{p0}$

When we substitute level 2 in to level 1 equation and $\gamma_{00}$is set to zero in STATA, the composite model is expressed as:

$$\eta_{ij} = logit\big(\pi_{kij}(y_{ij} \le k)\big) = \alpha_k - (\gamma_{10}x_{1ij} + \gamma_{20}x_{2ij} + \cdots + \gamma_{p0}x_{pij} + \mu_{0j})$$

$$= \alpha_k - (\textstyle\sum_{l=1}^{p} \gamma_{p0}x_{pij} + \mu_{0j}) \quad \ldots\ldots (3.32)$$

From the above equation $\alpha_k - \sum_{l=1}^{p} \gamma_{p0}x_{pij}$ is called fixed part of the model. μ_{0j} is the intercept variation of the model, $x_{1ij}, x_{2ij}, \ldots, x_{pij}$ are the fixed predictors, and $\gamma_{10}, \gamma_{20}, \ldots, \gamma_{p0}$ are the coefficients of the predictor variables.

In this study, we have used multilevel partial proportional odds model to relax the proportional odds assumption. Multilevel partial proportional odds model is the extension of partial proportional model which allows one or more independent variables have different effect on K-1 cumulative logits(Hedeker and Mermelstein, 1998). The model is given as: Level 1

$$\eta_{ij} = logit\big(\pi_{kij}\big) = \log\left(\frac{\pi(y_{ij} \le k)}{\pi(y_{ij} > k)}\right) = \alpha_k - \big(\beta_{0j} + \textstyle\sum_{l=1}^{p} \beta_{lj}x_{lij} + \sum_{h=1}^{q} \nu_{kq}w_{qij}\big) \quad \ldots\ldots (3.33)$$

The level 2 $\beta_{0j} = \gamma_{00} + \mu_{0j}, \beta_{1j} = \gamma_{10}, \beta_{2j} = \gamma_{20}, \ldots, \beta_{pj} = \gamma_{p0}$

When we substitute level 2 in to level 1 equation, we get the following composite model:

$$\eta_{ij} = logit\big(\pi_{kij}(y_{ij} \le k)\big) = \alpha_k - (\textstyle\sum_{l=1}^{p} \gamma_{p0}x_{pij} + \sum_{h=1}^{q} \nu_{kq}w_{qij} + \mu_{0j}) \quad \ldots\ldots (3.34)$$

$\alpha_k - (\sum_{l=1}^{p} \gamma_{p0}x_{pij} + \sum_{h=1}^{q} \nu_{kq}w_{qij})$ is the fixed part of the model. μ_{0j} is the intercept variation of the model, $x_{1ij}, x_{2ij}, \ldots, x_{pij}$ are the fixed predictors variables that satisfies proportional odds assumption., and $\gamma_{10}, \gamma_{20}, \ldots, \gamma_{p0}$ are the coefficients of the fixed predictor variables which satisfies proportional odds model. w_{qij} is h x1 vector containing the value of observation ij of the set of h covariates for which proportional odds is not assumed and ν_{kq} is hx1 vector of regression coefficient associated with w_{qij} and it contains category k, due to this h covariates are allowed to vary across K-1.

3.7.3. Random Coefficient Model

This is used to assess whether the slope of any of the explanatory variables has a significant variance component between the regions. This implies that the coefficients of explanatory variables are random at level two. All variables included in the random intercept model are included in random coefficient model.

The proportional odds assumption is satisfied the model is called multilevel proportional odds model and it is given as follow: for single predictor is given by:

level 1 $\eta_{ij} = logit(\pi_{kij}) = \log\left(\frac{\pi(y_{ij} \leq k)}{\pi(y_{ij} > k)}\right) = \alpha_k - (\beta_{oj} + \beta_{1j}x_{1ij})$ ....(3.35)

When we come to level 2 $\beta_{0j} = \gamma_{00} + \mu_{0j}, \beta_{1j} = \gamma_{10} + \mu_{1j}$

Substitute level 2 into level 1 equation and STATA set γ_{00} zero, the composite equation is expressed as:

$$\eta_{ij} = logit(\pi_{kij}(y_{ij} \leq k)) = \alpha_k - (\gamma_{10}x_{1ij} + \mu_{0j} + \mu_{1j}x_{1ij}) \quad \text{.................................} (3.36)$$

Thus, the variances and covariance of the level-two random effects is

$$var(\mu_{0j}) = \sigma^2_{\mu 0}, var(\mu_{1j}) = \sigma^2_{\mu 1} \; and \; cov(\mu_{0j}, \mu_{1j}) = \sigma_{u01}$$

$\alpha_k - \gamma_{10}x_{1ij}$ is the fixed part of the model, whereas $\mu_{0j} + \mu_{1j}x_{1ij}$ is random part of the model, μ_{1j} slope variation of the model and $\sigma^2_{\mu 1}$ is slope variance.

The model for a single explanatory variable discussed above can be extended by including more variables that have random effects. Level 1

$$\eta_{ij} = logit(\pi_{kij}) = \log\left(\frac{\pi(y_{ij} \leq k)}{\pi(y_{ij} > k)}\right) = \alpha_k - (\beta_{oj} + \beta_{1j}x_{1ij} + \beta_{2j}x_{2ij} + \cdots + \beta_{pj}x_{pij})$$

$$= \alpha_k - (\beta_{0j} + \textstyle\sum_{l=1}^{p} \beta_{lj}x_{lij}) \quad \text{.......................................} (3.37)$$

Level 2 $\beta_{0j} = \gamma_{00} + \mu_{0j}, \beta_{1j} = \gamma_{10} + \mu_{1j}, \beta_{2j} = \gamma_{20} + \mu_{2j}, \ldots, \beta_{pj} = \gamma_{p0} + \mu_{pj}$

When we combined level 1 and level 2 equations together, we get the composite equation

$$\eta_{ij} = logit(\pi_{kij}(y_{ij} \leq k))$$

$$= \alpha_k - (\gamma_{10}x_{1ij} + \gamma_{20}x_{2ij} + \cdots + \gamma_{p0}x_{pij} + \mu_{0j} + \mu_{1j}x_{1ij} + \mu_{2j}x_{2ij} + \cdots + \mu_{pj}x_{pij})$$

$$= \alpha_k - (\textstyle\sum_{l=1}^{p} \gamma_{p0}x_{pij} + \mu_{0j} + \sum_{l=1}^{p} \mu_{pj}x_{pij}) \quad \text{..................................} (3.38)$$

Thus, $\alpha_k - \sum_{l=1}^{p} \gamma_{p0}x_{pij}$ is the fixed part of the model, $\mu_{0j} + \sum_{l=1}^{p} \mu_{pj}x_{pij}$ is the random part of the model, α_k is the cut point of the model, μ_{0j} is intercept variation of the model,

$\mu_{1j}, \mu_{2j}, \dots, \mu_{pj}$ slope variation of the model, $\gamma_{10}, \gamma_{20}, \dots, \gamma_{p0}$ are the coefficients of the predictor variables.

When we come to the proportional odds assumption is violated the model is called multilevel partial proportional odds model (Hedeker and Mermelstein, 1998).

The model is given as: level 1

$$\eta_{ij} = logit(\pi_{kij}) = \log\left(\frac{\pi(y_{ij} \leq k)}{\pi(y_{ij} > k)}\right)$$

$$= \alpha_k - (\beta_{oj} + \beta_{1j}x_{1ij} + \beta_{2j}x_{2ij} + \cdots + \beta_{pj}x_{pij} + w_{1ij}\nu_{k1} + w_{2ij}\nu_{k2} + \cdots + w_{qij}\nu_{kq})$$

$$= \alpha_k - (\beta_{0j} + \textstyle\sum_{l=1}^{p} \beta_{lj}x_{lij} + \sum_{h=1}^{q} \nu_{kq}w_{qij}) \dots \dots \quad (3.39)$$

level 2 $\quad \beta_{0j} = \gamma_{00} + \mu_{0j}, \beta_{1j} = \gamma_{10} + \mu_{1j}, \beta_{2j} = \gamma_{20} + \mu_{2j}, \dots, \beta_{pj} = \gamma_{p0} + \mu_{pj}$

We combined them together and γ_{00}set zero, we get

$$\eta_{ij} = logit(\pi_{kij}(y_{ij} \leq k))$$

$$= \alpha_k - (\gamma_{10}x_{1ij} + \gamma_{20}x_{2ij} + \cdots + \gamma_{p0}x_{pij} + w_{1ij}\nu_{k1} + w_{2ij}\nu_{k2} + \cdots + w_{qij}\nu_{kq} + \mu_{0j} + \mu_{1j}x_{1ij} + \mu_{2j}x_{2ij} + \cdots + \mu_{pj}x_{pij})$$

$$= \alpha_k - (\textstyle\sum_{l=1}^{p} \gamma_{p0}x_{pij} + \sum_{h=1}^{q} \nu_{kq}w_{qij} + \mu_{0j} + \sum_{l=1}^{p} \mu_{pj}x_{pij}) \dots \dots \quad (3.40)$$

Thus, $\alpha_k - (\sum_{l=1}^{p} \gamma_{p0}x_{pij} + \sum_{h=1}^{q} w_{qij}\nu_{kq})$ is the fixed part of the model,$(\mu_{0j} + \sum_{l=1}^{p} \mu_{pj}x_{pij})$ is the random part of the model, α_k is the cut point of the model, μ_{0j} is intercept variation of the model, $\mu_{1j}, \mu_{2j}, \dots, \mu_{pj}$ slope variation of the model, $\gamma_{10}, \gamma_{20}, \dots, \gamma_{p0}$ are the coefficients of the predictor variable. w_{qij} is h x1 vector containing the value of observation ij of the set of h covariates for which proportional odds is not assumed and ν_{kq} is hx1 vector of regression coefficient associated with w_{qij} and it contains category k, due to this h covariates are allowed to vary across K-1.

3.8. Parameter estimation for multilevel ordinal logistic model

The estimation method of most of the statistical models (e.g. linear regression, logit models, and log-linear models) regularly used are well established. But this is not true for multilevel models for ordinal data. Parameter estimation for multilevel ordinal logistic model is not straightforward like the methods for simple ordinal logistic regression model. In this study we are focused on hierarchical ordinal logistic regression models, which can be fitted using STATA 14 command GLLAMM and provides highly useful tools for fitting generalized linear mixed models, of which the hierarchical ordinal logistic model is a special case. Therefore, in this study, we use Maximum Likelihood method using adaptive Gaussian quadrature(Snijders and Bosker, 1999). Besides, there are other estimation methods: Maximum Likelihood Method (several simulation based; (McCulloch, 1997)), Bayesian methods using Markov Chain Monte Carlo (MCMC), and the Iterative Bootstrap method, penalized quasi-likelihood (PQL) and full PQL. Quasi-likelihood functions are used to approximate ML methods and have similar properties to true likelihood functions. PQL is the most useful estimation for HGLMs, although the data is dichotomous it yield biased estimates of the variance components and fixed effects(Hox, 2010).

3.9. Significance testing in multilevel ordinal logistic model

As a single level, we can consider significance tests for individual estimates, such as intercepts, slopes, and their variances, as well as whether the full model accounts for a significant amount of variance in the dependent variable. In between, there is also the possibility of determining whether the subset of predictors contribute significantly.

3.9.1. Significance testing for fixed effects

The fixed effects in multilevel regression are typically tested in a familiar way, by creating a ratio of the intercept or slope estimate to the estimate of the standard error. The usual null hypothesis test is whether the coefficient, either intercept or slope, is significantly different from zero. This kind of ratio, usually distributed as a z or t, is used in many statistical tests(Raudenbush and Bryk, 2002)

$$t = \frac{\widehat{\beta_p}}{s.e(\widehat{\beta_p})} \quad \text{..} \quad (3.41)$$

$\widehat{\beta_p}$ is the intercept or slope of the predictors coefficients, $s.e(\widehat{\beta_p})$ is the standard error estimate. The z-test is often referred to as a Wald test.

3.9.2. Significance testing for random effects

Random effects tests examine hypotheses about whether the variance of intercept or slopes (or their covariance) is significantly different from zero. The tests of variances and covariance are made using a Wald z-test and chi-square test. The Wald test for variances is simply a ratio of the variance estimate divided by the standard error estimate. Significance tests of variances (but not covariance) using this approach should be interpreted after dividing the p-Value from the output into half (Snijders and Bosker, 1999).

3.10. Goodness of fit test

3.10.1. Likelihood-Ratio Test (LRT)

Likelihood-ratio test is used to assess the adequacy of any two or more than two nested models. It compares the maximum likelihood under the alternative hypothesis with the null hypothesis. The likelihood ratio test is defined as:

$$\chi^2 = -2\log\left(\frac{L_0}{L_1}\right) = -2(logL_0 - logL_1) \quad \text{..} (3.42)$$

Where L_0 and L_1 are the maximized log-likelihood of models under the null and alternative a hypothesis respectively.

This has a chi-square distribution, as a result this test of statistics will be compare with the tabulated chi -square with a degree of freedom, the difference between the degree of freedom of the model under null hypothesis and the alternative hypothesis respectively. This method is not appropriate for models which are not nested one on the other.

3.10.2. Information Criteria (IC)

If there are several models to be compared in order to select the best model which fits the data instead of using the likelihood ratio test, it can be easily select by using the Akaike information criteria (AIC) and Bayesian information criteria (BIC).

3.10.2.1. Akaike Information Criteria (AIC)

The AIC penalized a model with larger number of parameters, and it is defined as

$$AIC=-2logL+2P \quad \text{..} (3.43)$$

. Where, logL the maximized likelihood function for the estimated model and -2logL offers summary information on how much discrepancy exists between the model and the data, where p

is the number of parameters in the model(Konishi and Kitagawa, 2008). A relatively small value of AIC is preferred for the fitted model.

3.10.2.2. Bayesian Information Criteria (BIC)

Unlike, the Akaike information criteria the Bayesian information matrix (BIC) takes in to account the size of the data under considered. It is given by

$$BIC = -2\ln L + p\log(n) \quad (3.44)$$

Where L is the log likelihood of a model that will compare with the other models, n is the sample size of the data and p is the number of parameters in the model including the intercept. The good model is the one which has the minimum BIC value(Konishi and Kitagawa, 2008).

CHAPTER FOUR

RESULT AND DISCUSSION

In this study, the result of statistical analysis and discussions carried out to answer the basic research questions and the objectives of the study were present based on the EDHS, 2016 survey collected data. The data management and analysis was done using SPSS 20 and STATA 14 statistical Software.

4.1. Descriptive statistics

This research utilized the national wide EDHS 2016 collected data on the underweight among under-five children. The analysis presented in the study is based on 9657 under-five children with complete weight-for-age anthropometric index as indicator of a children's underweight. Table 4.1 shows that the relative frequency distributions of child underweight; 76.19% were normal, 16.72% were moderately underweight and 7.08% were severely underweight.

Table 4. 1 : Proportion of under-five children underweight based on EDHS 2016.

Underweight status	Frequency	Percent	Cumulative percent
Normal	7358	76.19	76.19
Moderately underweight	1615	16.72	92.92
Severely underweight	684	7.08	100.00
Total	9657	100.00	

From table 4.2 we show that the regional distribution of underweight varies from region to region. The highest percentage of severely underweight is observed in Afar (14.23%) and moderately underweight is observed in Benishangul Gumize (22.54%). Whereas, the smallest percentage of severely underweight (0.32%) and moderately underweight (4.87%) is observed in Addis Ababa.

Prevalence of underweight also varies based on place of residence; children living rural areas were moderately and severely underweight with (17.58%) and (7.39%) respectively. The result also shows prevalence of children who were born from non-educated mothers severely (8.63%) and moderately (18.85%) underweight.

The percentage of severely underweight was (9.30%) for children who live in family have no toilet facilities. There were also the percentage variation among religion of mother (8.02%) and

(16.78%) of muslim followers were severely and moderately underweight of their child, whereas (17.52%) orthodox followers were moderately underweight of their child. Similarly, children who were born from lower income (poor) families were more severely (9.55%) and moderately (19.66%) underweight. However, children who were born from higher income (rich) families were less severely (4.02%) and moderately underweight (12.34%).

The percentage of underweight also differs with birth order of children; a higher percentage of severely underweight was found for 4 and above order (8.16%) and the lower percentage was found in first birth (4.94%). The percentage of higher severely underweight was found in multiple births (16.27%) and the lower percentage was found in single birth (6.86%).

Sex specific prevalence of severely underweight was male (7.71%) while for female was (6.43%). The percentage of severely underweight among Under-five children who had been affected by diarrhea was (9.59%) severely underweight and who had not affected by diarrhea was (6.74%) during the Last two weeks before the survey. Similarly, the percentage of severely underweight was (8.18%) among under-five children who had been affected by a fever during the last two weeks before the survey and (6.89%) among those who had not affected by fever during the last two weeks before the survey.

The highest percentage (8.31%) severely underweight among under-five children was found in the age group 24-35 months and the lowest percentage (4.05%) was found in the age group between 6 and 11 months.

The highest prevalence of severely underweight was found among under-five children whose duration of breast feeding was ever breast feeding (7.64%) unlike to the lowest prevalence of severely underweight from children whose breast feeding status is still breast feeding (6.58%).

Table 4. 2: Result of descriptive summary for predictors of underweight among under five children in Ethiopia, (EDHS, 2016).

Variable	Categories	Underweight status				Person chi square(p-value)
		Normal (%)	Moderately underweight (%)	Severely underweight (%)	Total count	
Region	Tigray	77.48	17.46	5.06	654	298.05 (0.000)
	Afar	63.87	21.90	14.23	92	
	Amhara	70.84	20.78	8.38	1892	
	Oromia	77.40	15.84	6.76	4213	
	Somali	72.12	17.97	9.91	404	
	Benishangul	65.88	22.54	11.58	101	
	SNNPR	78.19	15.02	6.80	2009	
	Gambela	82.11	12.18	5.71	22	
	Harari	80.16	14.29	5.54	20	
	Addis Ababa	94.81	4.87	0.32	212	
	Dire Dawa	72.16	19.43	8.40	38	
Residence	Urban	76.19	16.72	7.08	1040	140.04 (0.000)
	Rural	75.03	17.58	7.39	8617	
Mother education	No education	72.52	18.85	8.63	6336	221.04 (0.000)
	Primary	81.86	13.77	4.37	2658	
	Secondary &higher	88.62	8.21	3.17	662	
Toilet	No	70.76	19.94	9.30	3690	134.22 (0.000)
	Yes	79.55	14.74	5.71	5967	
Religion	Orthodox	76.11	17.52	6.37	3341	75.62 (0.000)
	Muslim	75.20	16.78	8.02	3915	
	Other	77.93	15.52	6.55	2401	
Wealth index	Poor	70.79	19.66	9.55	4057	321.62 (0.0000
	Middle	76.75	16.94	6.32	2029	
	Rich	83.64	12.34	4.02	3121	
Current Marital status	Married	76.25	16.73	7.02	9081	0.004 (0.998)
	Single	75.28	16.58	8.14	576	
Mother occupation	No work	75.59	16.92	7.49	5347	7.98 (0.018)
	Had work	76.94	16.48	6.58	4310	
Birth order	First	79.93	15.13	4.94	1779	63.68 (0.0000
	2-3	76.99	16.42	6.59	2981	
	4 & above	74.35	17.49	8.16	4897	

Birth type	Single	76.75	16.38	6.86	9429	22.09 (0.000)
	Multiple	52.94	30.80	16.27	228	
Sex child	Male	74.72	17.58	7.71	4955	7.22 (0.027)
	Female	77.75	15.83	6.43	4702	
Birth size	>average	67.89	20.84	11.27	2566	142.53 (0.000)
	Average	77.52	16.12	6.36	4074	
	> average	81.47	14.04	4.49	3017	
Diarrhea	No	77.17	16.13	6.74	8482	12.64 (0.002)
	Yes	69.37	21.04	9.59	1175	
Fever	No	77.07	16.04	6.89	8225	8.12 (0.017)
	Yes	71.15	20.67	8.18	1432	
Cough	No	76.49	16.58	6.93	7672	0.27 (0.875)
	Yes	75.06	17.28	7.66	1985	
Number of children in HH	2 and less	76.12	16.74	7.14	7969	3.68 (0.159)
	Above 2	76.55	16.65	6.80	1688	
sex of HH head	Female	75.17	16.21	8.63	1311	2.98 (0.105)
	Male	76.35	16.80	6.84	8346	
Number of house hold member	4 & less	77.56	17.00	5.43	2484	21.34 (0.000)
	5-6	76.72	15.32	7.96	3389	
	7 and above	74.82	17.80	7.38	3784	
BMI	Thin	69.87	20.96	9.17	1877	205.95 (0.000)
	Normal	76.80	16.28	6.92	7182	
	Overweight	88.69	8.80	251	598	
Age child	Less than 6	87.66	7.46	4.87	1323	210.25 (0.000)
	6-11	83.89	12.06	4.05	828	
	12-23	76.08	15.65	8.28	1919	
	24-35	73.55	18.14	8.31	1814	
	36-47	73.49	18.69	7.82	1832	
	48-59	70.23	22.91	6.87	1941	
Mother age at 1st birth	18 & less	75.75	17.30	6.94	5042	18.39 (0.0000
	>18	76.67	16.09	7.24	4615	
Duration of breast feeding	Ever breast	73.99	18.37	7.64	4702	42.33 (0.000)
	Never breast	70.94	22.72	6.34	340	
	Still breast	78.82	16.60	6.58	4615	
Source of water	Not improved	74.85	17.85	7.30	4286	25.55 (0.000)
	Improved	77.27	15.82	6.91	5371	

4.2. Result of ordinal logistic regression analysis

Before building the ordinal logistic regression model for analyzing the categorical data, we first checked the association of each explanatory variable with response variable.

Based on cross tabulation analysis result on table 4.2 last column, shows that the values of Pearson chi-square measures with p-value for uni-variable analysis this enabled us to select those significant variables which contribute to underweight. Accordingly, region, residence, mother education, toilet facility, religion, wealth index, mother occupation, birth order, birth type, sex of child, birth size, diarrhea for last two weeks before survey, fever for last two weeks before survey, BMI of mother, source of water, age of child, number of HH member, mother age at first birth, and duration of breast feeding was found to be associated with underweight among under-five children. Whereas predictors sex of HH head, marital status, cough for last two weeks before survey and number of children less than 59 months have no significant association to underweight among under-five children at 5% significance. Therefore, those variables are excluded from the analysis and the other was taken into multivariable analysis.

Goodness of fit test

The result displayed on table 4.3 shows the likelihood ratio statistic with p-value, indicates that all models are significant with 5% significance. That is, the null hypothesis is that there is no difference between the model with only a constant and the model with independent variables was rejected. Therefore, all models are adequate for analysis of underweight among under-five children, meaning that at least one of the predictors is significantly related to underweight among under-five children.

Table 4. 3: Result of likelihood ratio test for overall measures of goodness of fit of the final model

Model	LL(null)	LL(model)	df	LRT	p-value
POM	-6463.069	-5962.623	42	1000.89	0.0000
GOM	-6463.069	-5926.498	82	1073.14	0.0000
PPOM	-6463.069	-5940.679	48	1044.79	0.0000
CRM	-6463.069	-5925.511	82	1075.12	0.0000
ACM	-6463.069	-5926.48	82	1073.18	0.0000
SLM	-6463.069	5963.232	46	446.755(wald)	0.0000

Model Selection Criteria

Several model selection methods have been proposed in the literature. The most commonly used method was information based criteria. Six models described at table 4.5 and appendixes A.2 – A.5 were fit the data.

As shown in appendix A.2 the test of brant produced a significant overall chi-square value of 69.82 with 40 degree of freedom (p-value=0.002) that reject the null hypothesis that the slope coefficients are the same across response categories. Therefore, parallel lines assumption is no longer appropriate for the evidence that we see in our data. Hence, POM and ACM was not appropriate to analyze underweight among under five children. Therefore, we do not compare them with other models. The remaining models are not assuming the parallel line assumption. The AIC and BIC values for each model are presented in table 4.4. The GOM had the largest AIC and BIC values, demonstrating a poor fit underweight among under five children compared to SLM and CRM. Further, PPOM model had smaller AIC as compared with the SLM and CRM models, indicating better fit underweight among under-five children. Thus PPOM model is the most appropriate and preferred model among five models for describing under five children underweight.

Table 4.4 : Model selection criteria for the single level ordinal logistic regression Models

Model	Df	AIC	BIC
GOM	82	12017.06	12599.01
PPOM	**48**	**11977.35**	**12318.03**
CRM	82	12015.02	12597.04
SLM	43	12012.46	12317.67

4.2.1. Result for partial proportional odds model (PPOM)

PPOM is a model that relaxes the assumption of proportionality for those variables that did violate assumption to have different effect in all logits. Based on analysis of partial proportional odds model table 4.5 region, educational level of mother, wealth index of house hold, religion of mother, birth order of child, birth type, sex of child, birth size of child, diarrhea two weeks before survey, fever two weeks before survey, body mass index of mother, age of child and duration of breast feeding were significant at 5% significance. Whereas, mother occupation, residence, toilet facility of HH, source of water, number of family member, and mother age at first birth are not significant at 5% significance.

Among the predictor variables, wealth index of HH(rich), religion(muslim) and age of child at category 11-12, 24-35, 36-47 and 48-59 are constraints that parallel line assumption were failed. This indicates that each explanatory variable has different effect on each categories of underweight and the other variables did not violate the test of PO assumption. This shows that each explanatory variable had same effect with each category of underweight of under-five children. Therefore, in PPOM analysis the variable which satisfied the proportional odds assumption and does not satisfy the PO assumption was interpreted individually is better.

Table 4.5 : Result of PPOM analysis for determinants of child underweight with three ordered categories in Ethiopia.

Variables	**Normal versus (moderately and severely underweight)**						
	Coeff	Std.Err	Z	p-value	OR	95% CI	
Region(ref=Tigray)	0				1		
Afar	0.190	0.143	1.32	0.185	1.209	0.913	1.601
Amhara	0.266	0.113	2.35	0.019	1.305*	1.045	1.630
Oromia	-0.169	0.130	-1.30	0.192	0.844	0.55	1.090
Somalia	-0.066	0.143	-0.46	0.642	0.936	0.708	1.238
Benishangul	0.478	0.133	3.60	0.000	1.613*	1.244	2.092
SSNP	-0.165	0.141	-1.17	0.240	0.848	0.643	1.117
Gambela	-0.520	0.169	-3.08	0.002	0.595*	0.427	0.828
Harari	-0.095	0.171	-0.55	0.580	0.910	0.651	1.272
Addis Ababa	-1.022	0.272	-3.75	0.000	0.360*	0.211	0.614
Dere Dawa	0.036	0.165	0.22	0.827	0.802	0.702	0.916
Moedu(ref=no education)	0				1		
Primary	-0.221	0.068	-3.25	0.001	0.802*	0.702	0.916
Secondary and above	-0.459	0.133	-3.45	0.001	0.632*	0.487	0.820
Moccu(ref=had no work)	0				1		
Had work	-0.064	0.057	-1.11	0.266	0.938	0.839	1.049
Windex(ref=poor)	0				1		
Middle	-0.273	0.081	-3.38	0.001	0.761*	0.650	0.892
Rich	-0.613	0.086	-7.09	0.000	0.542*	0.457	0.642
Residence(ref=urban)	0				1		

Rural	-0.170	0.104	-1.63	0.103	0.844	0.688	1.035
Toilet(ref=no)	0				1		
Yes	-0.082	0.064	-1.28	0.202	0.921	0.812	1.045
Religion(ref=orthodox)	0				1		
Muslim	0.284	0.097	2.94	0.003	1.329*	1.099	1.607
Other	0.328	0.110	2.97	0.003	1.388*	1.118	1.723
Bord(ref=first)	0				1		
2-3	0.075	0.082	0.91	0.363	1.078	0.917	1.267
4 and above	0.229	0.092	2.49	0.013	1.258*	1.050	1.506
Btype(ref=single birth)	0				1		
Multiple birth	0.704	0.157	4.47	0.000	2.201*	1.484	2.752
Sexchild(ref=male)	0				1		
Female	-0.1.66	0.051	-3.27	0.001	0.847*	0.766	0.936
Birthsize(ref=large)	0				1		
Average	0.276	0.065	4.27	0.000	1.318*	1.161	1.496
Small	0.640	0.069	9.25	0.000	1.897*	1.656	2.172
Diarrhea(ref=no)	0				1		
Yes	0.252	0.082	3.09	0.002	1.286*	1.096	1.510
Fever(ref=no)	0				1		
Yes	0.158	0.075	2.11	0.035	1.172*	1.011	1.358
BMI(ref=thin)	0				1		
Normal	-0.465	0.058	-8.05	0.000	0.628*	0.561	0.704
Over weight	-1.047	0.129	-8.09	0.000	0.351*	0.272	0.452
Water(ref=not improved)	0				1		
Improved	0.098	0.056	1.76	0.079	1.103	0.989	1.230
Agechild(ref=less than 6)	0				1		
6-11	0.401	0.136	2.95	0.003	1.494*	1.144	1.949
12-23	1.021	0.110	9.33	0.000	2.777*	2.241	3.442
24-35	1.377	0.118	11.65	0.000	3.964*	3.144	4.997
36-47	1.444	0.127	11.35	0.000	4.237*	3.301	5.437
48-59	1.547	0.130	11.89	0.000	4.696*	3.639	6.059
Nohh(ref=less than 5)	0				1		
5-6	-0.027	0.075	-0.36	0.718	0.973	0.840	1.127
Above 6	-0.053	0.084	-0.62	0.532	0.949	0.804	1.119
Durbreast(ref=ever breast)	0				1		
Never breast	0.105	0.133	0.79	0.432	1.110	0.855	1.441
Still breast	0.308	0.079	3.92	0.000	1.361*	1.166	1.587

Moage(ref=18 & less)	0				1		
Greater than 18	0.013	0.052	0.25	0.803	1.013	0.915	1.122
Constant	-2.138	0.212	-10.06	0.000	0.118	0.078	0.179
(Normal and moderately underweight) versus severely underweight							
Region(ref=Tigray)	0				1		
Afar	0.190	0.143	1.32	0.185	1.209	0.913	1.601
Amhara	0.266	0.113	2.35	0.019	1.305*	1.045	1.630
Oromia	-0.169	0.130	-1.30	0.192	0.844	0.55	1.090
Somalia	-0.066	0.143	-0.46	0.642	0.936	0.708	1.238
Benishangul	0.478	0.133	3.60	0.000	1.613*	1.244	2.092
SSNP	-0.165	0.141	-1.17	0.240	0.848	0.643	1.117
Gambela	-0.520	0.169	-3.08	0.002	0.595*	0.427	0.828
Harari	-0.095	0.171	-0.55	0.580	0.910	0.651	1.272
Addis Ababa	-1.022	0.272	-3.75	0.000	0.360*	0.211	0.614
Dere Dawa	0.036	0.165	0.22	0.827	0.802	0.702	0.916
Moedu(ref=no education)	0				1		
Primary	-0.221	0.068	-3.25	0.001	0.802*	0.702	0.916
Secondary and above	-0.459	0.133	-3.45	0.001	0.632*	0.487	0.820
Moccu(ref=had no work)	0				1		
Had work	-0.064	0.057	-1.11	0.266	0.938	0.839	1.049
Windex(ref=poor)	0				1		
Middle	-0.273	0.081	-3.38	0.001	0.761*	0.650	0.892
Rich	-0.854	0.128	-6.65	0.000	0.426*	0.331	0.548
Residence(ref=urban)	0				1		
Rural	-0.170	0.104	-1.63	0.103	0.844	0.688	1.035
Toilet(ref=no)	0				1		
Yes	-0.082	0.064	-1.28	0.202	0.921	0.812	1.045
Religion(ref=orthodox)	0				1		
Muslim	0.522	0.116	4.49	0.003	1.685*	1.342	2.116
Other	0.328	0.110	2.97	0.003	1.388*	1.118	1.723
Bord(ref=first)	0				1		
2-3	0.075	0.082	0.91	0.363	1.078	0.917	1.267
4 and above	0.229	0.092	2.49	0.013	1.258*	1.050	1.506
Btype(ref=single birth)	0				1		
Multiple birth	0.704	0.157	4.47	0.000	2.201*	1.484	2.752
Sexchild(ref=male)	0				1		
Female	-0.1.66	0.051	-3.27	0.001	0.847*	0.766	0.936
Birthsize(ref=large)	0				1		
Average	0.276	0.065	4.27	0.000	1.318*	1.161	1.496

Small	0.640	0.069	9.25	0.000	1.897*	1.656	2.172
Diarrhea(ref=no)	0				1		
Yes	0.252	0.082	3.09	0.002	1.286*	1.096	1.510
Fever(ref=no)	0				1		
Yes	0.158	0.075	2.11	0.035	1.172*	1.011	1.358
BMI(ref=thin)	0				1		
Normal	-0.465	0.058	-8.05	0.000	0.628*	0.561	0.704
Over weight	-1.047	0.129	-8.09	0.000	0.351*	0.272	0.452
Water(ref=not improved)	0				1		
Improved	0.098	0.056	1.76	0.079	1.103	0.989	1.230
Agechild(ref=less than 6)	0				1		
6-11	0.401	0.136	2.95	0.003	1.494*	1.144	1.949
12-23	0.793	0.149	5.033	0.000	2.210*	1.651	2.959
24-35	1.077	0.154	7.00	0.000	2.935*	2.171	3.967
36-47	0.955	0.166	5.80	0.000	2.600*	1.881	3.587
48-59	0.980	0.167	5.87	0.000	2.665*	1.921	3.698
Nohh(ref=less than 5)	0				1		
5-6	-0.027	0.075	-0.36	0.718	0.973	0.840	1.127
Above 6	-0.053	0.084	-0.62	0.532	0.949	0.804	1.119
Durbreast(ref=ever breast	0				1		
Never breast	0.105	0.133	0.79	0.432	1.110	0.855	1.441
Still breast	0.308	0.079	3.92	0.000	1.361*	1.166	1.587
Moage(ref=18 and less)	0				1		
Greater than 18	0.013	0.052	0.25	0.803	1.013	0.915	1.122
Constant	-3.346	0.231	-14.49	0.000	0.352	0.022	0.05

chi2(34)=26.35 Prob >chi2=0.8033 * Significant at 0.05, Ref = indicates the reference category

A global Wald test performed for the final model with constrained versus the original unconstrained model indicates that the final model does not violate the parallel lines assumption. As the global Wald test shows, thirty four constraints have been imposed in the final model, the chi2 (34) =26.35, with P = 0.8033 which not a significant value indicating that the final model does not violate the proportional odds or parallel lines assumption.

Region has significant effect to underweight among under-five children, the odds of severely underweight child who reside from Amhara and Benishangul Gumize were 1.305 (OR=1.305, CI: 1.045, 1.630) and 1.613 (OR=1.613, CI: 1.244, 2.092) times the odds of severely underweight child who reside in Tigray respectively, controlling the other variable fixed. However, the odds of severely underweight child who live in Gambela and Addis Ababa were 0.595 and 0.360 times lower than the odds of severe underweight child who live in Tigray respectively, controlling the other variable fixed.

In this study educational level of mother has a significant effect to underweight among under-five children, the odds of severely underweight for child from mother who had primary education were 0.802 times lower than the odds of severely underweight for child from mother who had no education, controlling the other variables constant(OR=0.802, 95% CI:0.702, 0.916). Similarly, The odds of severely underweight for child from mother who had a secondary and above education level was 0.632 times lower than the odds of severely underweight for child from mother who had no education controlling the other variables in the model fixed(OR=0.399; 95% CI:0.487, 0.820). That is, not educated women were at higher risk of being in severely underweight status of their child compared to those attained education.

This study revealed that birth order of child had significant effect to underweight among under five-children, the odds of severely underweight for child with four and above birth was 1.258(OR=1.258, 95% CI: 1.484, 2.752) times higher than the odds of severely underweight for child with first birth controlling for other variable in the model.

This study also revealed that birth type of child had significant effect to underweight among under five-children, the odds of severely underweight for child with multiple births was 2.201(OR=2.201, CI:1.484, 2.752) times higher than the odds of severely underweight for child with single birth controlling for other variable in the model. That means multiple birth was more likely of being in higher levels of underweight.

Sex of child is also significant predictor of severity of underweight among under-five children, the estimated odds ratio (OR=0.847) shows that the odds of severely underweight for female children were 0.847 times lower than the odds of severely underweight for male keeping other covariates fixed (OR=0.847, CI: 0.766, 0.936).

The birth size of children was significant determinant of underweight among under-five children, the estimated odds ratio (OR=1.318) revealed that the odds of severely underweight children whose birth size was average were 1.318 times higher than the odds of severely underweight whose birth size was large. Whereas, the estimated odds ratio (OR=1.897) revealed that the odds of severely underweight for child born with smaller than average size were 1.897 times higher than the odds of severely underweight for child born with large size, holding other variables constant.

This study also shows that had diarrhea for last two weeks before the survey had significant effect to underweight among under-five children. The odds of severely underweight for child who had diarrhea within last two weeks before the survey date were 1.286 (OR=1.286, CI: 1.096, 1.510) times higher than the odds of severely underweight for child who had no diarrhea, keeping other variable constant. Similarly, the odds of severely underweight for child who had fever two weeks before the survey date were 1.172 (OR=1.172, CI: 1.011, 1.358) times higher than the odds of severely underweight for child who had no fever two weeks before the survey date, keeping other variable constant.

The finding of this study also revealed that mother BMI has a significant effect to underweight status among under-five children. The odds of severely underweight for child form mother with BMI normal were 0.628 (OR=0.628, CI: 0.561, 0.704) times the odds of severely underweight for child with BMI thin. However, the odds of severely underweight for child from mother with BMI overweight were 0.351 (OR=0.351, CI: 0.272, 0.452) times the odds of severely underweight for child from mother with BMI thin controlling other variable fixed.

Duration of breast feeding status also had significant effect to underweight among under-five children, the estimated odds ratio (OR=1.361) shows that the odds of severely underweight for child who still breast feeding were 1.361 times the odds of severely underweight for child who ever breast, holding other variables constant(OR=1.361, CI:1.166,1.587).

When we come to the variables which is violated the parallel line assumption the interpretation is separately for each cut points.

In this study, religion of mother had significant effect to underweight of children, when normal status is compared to (moderately and severely underweight status) showed that the odds of moderately or severely underweight for child born from mother who follow muslim were 1.329 (OR=1.329, CI: 1.099, 1.609) times the odds of moderately or severely underweight for child born from mother who follow orthodox, holding other variables constant. Similarly, the odds of moderately or severely underweight for child born from mother who follow other were 1.388 (OR=1.388, CI: 1.118, 1.723) times the odds of moderately or severely underweight for child born from mother who follow orthodox, holding other variables constant. Whereas, normal and moderately underweight status is compared to severely underweight, the odds of severely underweight for child born from mother who follow muslim were 1.685 (OR=1.685, CI: 1.342, 2.116) times the odds of severely underweight for child born from mother who follow orthodox keeping other variables fixed. Similarly, the odds of severely underweight for child born from mother who follow other were 1.388 (OR=1.388, CI: 1.118, 1.723) times the odds of severely underweight for child born from mother who follow orthodox holding other variables constant.

The result also indicates house hold wealth index is significantly associated with underweight among under-five children, when normal is compared to moderate and severe underweight showed that the odds of moderately or severely underweight for child born from family with middle wealth index were 0.761 (OR=0.761, CI: 0.650, 0.892) times the odds of moderate or severely underweight for child born from family with poor wealth index keeping other variables constant. Similarly, the odds of moderately or severely underweight for child born from family with rich wealth index were 0.542 (OR=0.542, CI: 0.457, 0.642) times the odds of moderate or severely underweight for child born from family with poor wealth index keeping other variables constant. Furthermore, (normal status and moderately underweight) compared to severely underweight shows that the odds of severely underweight for child born from family with middle wealth index were 0.761 (OR=0.761, CI: 0.650, 0.892) times the odds of severely underweight for child born from family with poor wealth index keeping other variables constant. The odds of severely underweight for child born from family with rich wealth index were 0.426 (OR=0.426 CI: 0.331, 0.548) times the odds of severely underweight for child born from family with poor wealth index, controlling other variable fixed.

In this study age of child had also significant effect to underweight status among under-five children; when we compare normal status to moderately and severely underweight status the odds of moderately or severely underweight for child with age group 6-11, 12-23, 24-35, 36-47, and 48-59 months were 1.494 (OR=1.494, CI: 1.144, 1.949), 2.777 (OR=2.777, CI:2.241, 3.442), 3.964 (OR=3.964, CI:3.144, 4.997), 4.237 (OR=4.237,CI: 3.301, 5.437) and 4.696 (OR=4.696, CI:3.696,6.059) times the odds of moderately or severely underweight for child with age less than 6 months respectively controlling other variable fixed. Whereas, normal and moderately underweight is compared to severely underweight shows that the odds of severely underweight for child with age group 6-11, 12-23, 24-35, 36-47, and 48-59 months were 1.494, 2.210, 2.935, 2.600, and 2.665 times the odds of severely underweight with age less than 6 months respectively controlling other variable fixed.

4.2.2. Result of marginal effects analysis

In PPOM the probability of a single level of the response variable is not possible. The sign of the coefficients does not always determine the direction of the effect of the intermediate outcomes. Therefore, there is a need find another way of finding the contribution of each explanatory variables on the categories of the response which can be done by computing average marginal effects. Average marginal effect is used to measure the magnitude and types of association between the levels of the explanatory variable on the probability of levels of the response variable.

From table 4.6 shows that, the marginal effects have larger magnitudes of impact on the first two outcomes, normal and moderate level of underweight and smaller impact on the last outcome, severe level of underweight. Age of child has the largest magnitude of marginal impact on the outcome probabilities. Age of child between 48 and 59 month experienced a larger increase in the probability of having a moderate level of underweight, i.e. increase by about 17%, while the probability of having a severe level of underweight experienced a larger increase by age between 24 and 35, which is increased by about 6.4%.

The probability of child being normal, moderately and severely underweight on average becomes 13.8% higher, 8.9% lower and 4.9% lower for region Addis Ababa.

Table 4. 6 : Result of marginal effect of child underweight with three ordered categories

Variables	normal		Moderately underweight		Severely underweight	
	MER	P>Z	MER	P>Z	MER	P>Z
Region						
Afar	-0.340	0.181	0.020	0.187	0.014	0.181
Amhara	-0.048	0.018	0.028	0.019	0.021	0.019
Oromia	0.028	0.197	-0.017	0.193	-0.112	0.204
Somalia	0.011	0.643	-0.007	0.642	-0.005	0.644
Benishangul	-0.090	0.000	0.049	0.000	0.041	0.000
SSNP	0.028	0.242	-0.017	0.240	-0.011	0.246
Gambela	0.080	0.002	-0.050	0.0002	-0.030	0.002
Harari	0.016	0.579	-0.010	0.579	-0.006	0.578
Addis Ababa	0.138	0.000	-0.089	0.000	-0.049	0.000

Dere Dawa	-0.006	0.828	0.004	0.828	0.003	0.828
Moedu						
Primary	0.037	0.001	-0.022	0.001	-0.015	0.001
Secondary and above	0.074	0.000	-0.045	0.000	-0.029	0.000
Moccu						
Had work	0.011	0.265	-0.006	0.266	-0.004	0.263
Windex						
Middle	0.048	0.001	-0.028	0.001	-0.021	0.000
Rich	0.101	0.000	-0.049	0.000	-0.052	0.000
Residence						
Rural	0.029	0.110	-0.017	0.101	-0.013	0.122
Toilet						
Yes	0.014	0.203	-0.008	0.205	-0.008	0.201
Religion						
Muslim	-0.047	0.003	0.012	0.273	0.035	0.000
Other	-0.054	0.003	0.034	0.003	0.020	0.004
Bord						
2-3	-0.012	0.360	0.07	0.362	0.005	0.357
4 and above	-0.038	0.011	0023	0.012	0.016	0.010
Btype						
Multiple birth	-0.133	0.000	0.069	0.000	0.064	0.000
Sexchild						
Female	0.028	0.001	-0.016	0.001	-0.012	0.001
Birthsize						
Average	-0.044	0.000	0.027	0.000	0.017	0.000
Small	-0.110	0.000	0.064	0.000	0.046	0.000
Diarrhea						
Yes	-0.044	0.003	0.035	0.002	0.019	0.004
Fever						
Yes	-0.027	0.039	0.016	0.036	0.012	0.043
BMI						
Normal	0.084	0.000	-0.048	0.000	-0.037	0.000
Over weight	0.168	0.000	-0.101	0.000	-0.067	0.000
Water						
Improved	-0.016	0.077	0.010	0.077	0.007	0.078
Agechild						
6-11	-0.042	0.004	0.024	0.004	0.018	0.005
12-23	-0.130	0.000	0.088	0.000	0.042	0.000
24-35	-0.193	0.000	0.129	0.000	0.064	0.000

36-47	-0.206	0.000	0.152	0.000	0.054	0.000
48-59	-0.226	0.000	0.170	0.000	0.056	0.000
Nohh						
5-6	0.005	0.718	-0.002	0.718	-0.002	0.719
Above 6	0.009	0.533	-0.005	0.532	-0.004	0.534
Durbreast						
Never breast	-0.017	0.440	0.010	0.435	0.007	0.447
Still breast	-0.052	0.000	0.030	0.000	0.022	0.000
Moage						
Greater than 18	-0.002	0.803	0.001	0.803	0.001	0.803

4.3. Model diagnostics: influential observations and outliers

After the model has been fitted, the next step is check whether the model fit the data well or not. To accomplish this goal, a model is created that includes all predictor variables which are useful in predicting the response variable. To satisfy this it is useful to check the adequacy of the selected model.

Result on appendix A.6 and appendix B shows that summary of model diagnosis and plots of standardized Pearson residuals, deviance residuals, Cook's distance, and leverage value with predicted probability respectively which indicates all explanatory variable DFBETAs were less than unity indicates that no one value has an effect on the estimate of a regression coefficient of a particular predictor variable. This is an indication that there is no serious problem with the fitted model. Similarly, in cook's distance also no one observation has an effect on a group of regression coefficients.

Even if they are far away they may not be considered as real influential because no observation has a value of Cook's distance greater than one. A value of the leverage statistic less than unity confirms that no observation is far apart from the others in terms of the levels of the independent variables.

Deviance and standard residual has similar pattern. In both cases none of the observation has standard and deviance residuals larger than three in absolute. As a result no of observation can take worthy attention. This indicates the values for the independent variable are not in an extreme region. In addition observed responses for those points have similar form with the predicted probability of the response. Generally, graph also uses to see the pattern of all cases.

4.4. Result for multilevel PPOM analysis of the data

4.4.1. Test of heterogeneity

For the proper application of multilevel analysis first we have to test for heterogeneity of underweight among regional states. The chi-square test was applied to assess heterogeneity among regions. The test yields χ^2 =298.0539 with degree of freedom 20 (P-value=0.000) which is significant at 5% significance, implying strong evidence of heterogeneity for underweight status among under-five children across regional states. Therefore, multilevel analysis is attempted.

4.4.2. Goodness of Fit Test

An overall evaluation of the multilevel partial proportional odds model was assessed using the deviance. The test is done by comparing the deviance of two models by subtracting the smaller deviance from the larger deviance. The difference is a chi-square test with the number of degrees of freedom equal to the number of different parameters in the two models. The significance of this chi square test indicates that the model is a good fit. Similarly, it was also assessed by using AIC and BIC. Based on Table 4.7 random intercept with fixed slope model have a significant deviance chi square and the value of AIC and BIC is less than the model that obtained from empty and random coefficient model. So, we conclude that the model is a good fit.

4.4.3. Model Comparisons in Multilevel PPOM

From table 4.7 deviance of the empty model with random intercept (12854.148) is greater than the deviance of the random intercept model with fixed coefficients (11894.3346) and also the deviance of random coefficient model (11907.362) is greater than the deviance of the random intercept model with fixed coefficients (11894.3346). The smaller the deviance the better the model; hence random intercept model with fixed coefficients is the better fit to the data.

Table 4.7 : Summary result for multilevel PPOM selection criteria

Tests	Random intercept only model	Random intercept with fixed effect model	Random coefficient model
Log likelihood	-6427.074	-5947.1673	-5953.681
Deviance	12854.148	11894.3346	11907.362
AIC	12860.148	11978.3346	11995.36
BIC	12881.44	12060.28057	12307.66

4.4.4. Result of Random Intercept Only Model

From table 4.8, the empty model is considered as a parametric version of assessing heterogeneity of regions variance of the random effect ($\sigma_{\mu 0}^2 = 0.596$, S.E =0.345) and the Wald test statistic is (the square of the Z-ratio), Z=$(0.596/0.345)^2$ =2.98, which is compared with a chi-squared distribution on 1 degree of freedom is significant and $\sigma_{\mu 0}^2 = 0.596$ indicates that intercept variance across all regions. The result of the hypothesis $H_0: \sigma_{\mu 0}^2 = 0$ is provided showing that there is no cross-regional variation for underweight among under-five children. For this hypothesis, we see that the value of the test statistic is 71.99 with p=0.000. Therefore, the null hypothesis is rejected and there is evidence of heterogeneity or cross regional variation in underweight among under-five children. This shows that an empty model for underweight among under-five children with random effect is better than an empty model for underweight among under-five children without random effect. Therefore, we conclude that there is significant variation between regions for underweight among under-five children.

The intra-class correlation coefficient (ICC) is a measure of variation of underweight among under-five children with in region. The intra-class correlation coefficient in intercept only model is determined by using equation (3.30) and it becomes (ICC=0.153), meaning that 15.3% of variation in the underweight can be explained by grouping in regions (higher level units) and the remaining 84.7% of the variation is explained within region (lower level units).

Table 4. 8: Result of parameter estimate of empty model

	Estimates	Std.Err	Z	p-value	95% Conf. Interval	
Cut1	1.020	0.034	30.42	0.000	0.955	1.086
cut2	2.377	0.045	52.71	0.000	2.289	2.465
Random-effects Parameters			Estimate	Std.Err	95% Conf. Interval	
Region: Var(_cons)			0.596	0.345	0.192	1.854

LR test vs. ologit model: chibar2(01) = 71.99 Prob >= chibar2 = 0.0000

From table 4.8 we see that the estimates of the fixed part of the model are 1.020 and 2.377 with p-value of 0.000 which implies that the average log odds of underweight among under-five children are significantly different from zero. The fixed part of the model is interpreted as the grand mean of log odds of being at or below the given category of underweight among under-five children.

The average probability of under-five children being normal were $\frac{exp^{1.020}}{1+exp^{1.020}} = 0.737$ and being normal or moderately underweight were $\frac{exp^{2.377}}{1+exp^{2.377}} = 0.915$ which means the chance of being normal is 73.5% on average and chance of being normal or moderately underweight is 91.5 % on average.

4.4.5. Result of fixed random intercept PPOM

Multilevel random intercept PPOM allowed the probability of the underweight to vary across regions, but we assumed that effects of explanatory variables are the same for each region. That is, the random intercept varies across regions, but levels of explanatory variables are fixed across region in predicting under-five underweight in Ethiopia.

The random part of empty random intercept multilevel model show that the intercept variance of the random effect is 0.59548923, whereas the intercept variance for the random intercept model with fixed is 0.092663675. The variance of random effect of the random intercept multilevel model decrease compared to random effects of empty random intercept model. The reduction of the random effect of the intercept variance is due to the inclusion of fixed explanatory variables. That is, taking in to account the fixed independent variables can provide extra predictive value on underweight in each region.

Table 4.9: Result of random intercept with fixed PPOM of underweight among under- five children in Ethiopia.

Predictor variable that satisfied parallel line assumption							
Variables	Coeff.	Std.Err	Z	p-value	OR	95% CI OR	
Moedu(ref=no education)	0				1		
Primary	-0.227	0.068	-3.35	0.001	0.797*	0.698	0.910
Secondary and above	-0.497	0.133	-3.72	0.000	0.608*	0.468	0.790
Moccu(had no work)	0				1		
Had work	-0.056	0.057	-0.99	0.322	0.945	0.845	1.057
Residence(ref=urban)	0				1		
Rural	-0.132	0.105	-1.26	0.208	0.877	0.714	1.076
Toilet(ref=no)	0				1		
Yes	-0.081	0.064	-1.26	0.207	0.922	0.814	1.046
Bord(ref=first)	0				1		
2-3	0.074	0.082	0.90	0.368	1.077	0.916	1.265
4 and above	0.229	0.092	2.49	0.013	1.257*	1.050	1.505
Btype(ref=single birth)	0				1		
Multiple birth	0.700	0.157	4.45	0.000	2.013*	1.479	2.740
Sexchild(ref=male)	0				1		
Female	-0.165	0.051	-3.25	0.001	0.848*	0.767	0.936
Birthsize(ref=large)	0				1		
Average	0.276	0.065	4.28	0.000	1.318*	1.162	1.496
Small	0.142	0.069	9.29	0.000	1.900*	1.659	2.175
Diarrhea(ref=no)	0				1		
Yes	0.253	0.082	3.10	0.002	1.288*	1.097	1.511
Fever(ref=no)	0				1		
Yes	0.154	0.075	2.05	0.040	1.167*	1.007	1.352
BMI(ref=thin)	0				1		
Normal	-0.463	0.058	-8.02	0.000	0.630*	0.562	0.705
Over weight	-1.057	0.129	-8.18	0.000	0.347*	0.270	0.448

Water(ref=not improved)	0				1		
Improved	0.097	0.056	1.75	0.080	1.102	0.988	1.229
Nohh(ref=less than 5)	0				1		
5-6	-0.027	0.075	-0.36	0.716	0.973	0.840	1.127
Above 6	-0.053	0.084	-0.63	0.528	0.948	0.804	1.118
Durbreast(ref=ever breast)	0				1		
Never breast	0.105	0.133	0.79	0.429	1.111	0.856	1.441
Still breast	0.310	0.078	3.94	0.000	1.363*	1.169	1.590
Moage(ref=18 & less)	0				1		
Greater than 18	0.008	0.052	0.15	0.883	1.008	0.910	1.116
Predictors that does not satisfied parallel line assumption							
Normal versus (moderately underweight and severely underweight)							
Agechild(ref=less than 6)	0				1		
6-11	0.415	0.137	3.04	0.002	1.514*	1.158	1.981
12-23	1.026	0.110	9.36	0.000	2.790*	2.251	3.459
24-35	1.381	0.118	11.68	0.000	3.979*	2.251	3.459
36-47	1.448	0.127	11.38	0.000	4.255*	3.317	5.463
48-59	1.550	0.130	11.91	0.000	4.711*	3.651	6.078
Windex(ref=poor)	0				1		
Middle	-0.251	0.082	-3.07	0.002	0.778*	0.663	0.913
Rich	-0.610	0.086	-7.06	0.000	0.543*	0.458	0.643
Religion(ref=orthodox)	0				1		
Muslim	0.285	0.093	3.08	0.002	1.330*	1.110	1.595
Other	0.278	0.108	2.58	0.010	1.320*	1.069	1.631
Constant	-3.289	0.485	-6.78	0.000	0.037*	0.014	0.097
(Normal and moderately underweight) versus severely underweight							
Agechild(ref=less than 6)	0				1		
6-11	0.255	0.208	1.23	0.220	1.290	0.858	1.941
12-23	0.723	0.162	4.45	0.000	2.061*	1.498	2.832
24-35	1.009	0.167	6.05	0.000	2.743*	1.978	3.804

36-47	0.889	0.177	5.03	0.000	2.433*	1.719	3.442
48-59	0.925	0.179	5.16	0.000	2.522*	1.774	3.582
Windex(ref=poor)	0				1		
Middle	-0.437	0.130	-3.36	0.001	0.646*	0.501	0.834
Rich	-0.877	0.129	-6.79	0.000	0.416*	0.323	0.536
Religion(ref=orthodox)	0				1		
Muslim	0.593	0.124	4.78	0.000	1.809*	1.419	2.307
Other	0.494	0.148	3.33	0.001	1.639*	1.226	2.192
Constant	-0.150	0.686	-0.22	0.827	0.861	0.224	3.307
Random effect parameter		Estimate		Std.Err			
Level 2(region) Var(1):		0.093		0.050			

* Significant at 0.05, ref=indicates reference category

4.4.6. Interpretation of multilevel parameters estimation

Mother education was significant determinant of underweight among under-five children. The odds of worse underweight for child from mother who had primary education were 0.797 times lower than the odds of worse underweight for child from mother who had no education controlling for other variables in the model and random effect at level two(OR=0.797, CI: 0.698,0.910). Whereas, the odds of severely underweight for child from mother who had secondary and above education were 0.608 times lower than the odds of severely underweight for child from non-educated mother controlling for other variables in the model and random effect at level two (OR= 0.608, CI: 0.468,0.790).

The birth order of children also has significant effect to underweight among under-five children in Ethiopia. The odds of having worse underweight status for children with birth order 4 and above were 1.257 times higher than the odds of worse underweight status for children with first birth, controlling for other variables in the model and random effect at level two (OR=1.257, CI: 1.050,1.505).

Birth type of child had significant effect to underweight status among under-five children; the estimated odds of severely underweight status for child born with multiple were 2.013 (OR=

2.013, CI : 1.479, 2.740) times higher than the odds of severely underweight for child born with single controlling for other variables in the model and random effect at level two.

Sex of child is also significant determinant of underweight among under-five year's children. The odds of severely underweight status for male child were 1.179 (OR = 0.848, CI: 0.767, 0.936) times higher than the odds of severely underweight status for female controlling for other variables in the model and random effect at level two.

The study found that size of child at birth has the significant effect to underweight status among under-five children. The estimated odds ratio (OR =1.318) indicates that the odds of severely underweight for child born with average size were 1.318 times higher than the odds of severely underweight for child born with larger than average size controlling for other variables in the model and random effect at level two (OR=1.318, CI: 1.162, 1.496). Similarly, The estimated odds ratio (OR = 1.891) indicates that the odds of severely underweight for child who born with smaller than average size were 1.900 times higher than the odds of severely underweight for child born with larger than average size controlling for other variables in the model and random effect at level two (OR=1.900 ,CI: 1.659, 2.175).

This study revealed diarrhea in the last two weeks before the date of survey date had significant effect to underweight among under-five children. The estimated odds ratio (OR=1.288) revels that the odds of severely underweight for under-five children who had diarrhea in the last two week before date of survey were 1.288 (OR=1.288, CI: 1.079, 1.511) times higher than the odds of severely underweight for under-five children those who had no diarrhea in the last two week controlling for other variables in the model and random effect at level two.

The odds of severely underweight for child who had fever in the last two weeks before the date of survey were 1.167 times higher than the odds of severely underweight for child who had no fever in the last two weeks before the date of survey controlling for other variables in the model and random effect at level two (OR=1.167, CI: 1.007, 1.352).

This study also found that mother body mass index was significantly associated with children underweight. The estimated odds ratio (OR=0.630) reveals that the odds of severely underweight for child from mother who had normal BMI were 0.630 times the odds of severely underweight for child from mother who had thin BMI ,controlling for other variables in the model and random effect at level two (OR=0.630, CI: 0.562, 0.705). Similarly, the estimated odds ratio (OR= 0.347) implied that the odds of severely underweight for child from mother who had overweight BMI were 0.347 times the odds of severely underweight of child from mother who had thin controlling for other variables in the model and random effect at level two (OR=0.347, CI: 0.270, 0.448).

Duration of breast feeding status had significant effect to underweight among under five children, the estimated odds ratio (OR=1.363) revels that the odds of severely underweight for child who still breast feed were 1.363 times the odds of severely underweight for child who ever breast feed controlling for other variables in the model and random effect at level two (OR=1.363, CI: 1.169, 1.590).

When we come to the variable does not satisfied parallel line assumption the interpretation is in each cut points separately. Age of child had significant effect to underweight among under-five children. Children normal status is compared to moderately and severely underweight status, the odds of moderately and severely underweight status for child with age group 6-11, 12-23, 24-35, 36-47, and 48-59 were 1.514, 2.790, 3.979, 4.255, and 4.711 times the odds of moderately or severely underweight with age group less than 6 respectively. However, when normal and moderately underweight status were compared to severely underweight status, the odds of severely underweight status of child with age group 12-23, 24-35, 36-47 and 48-59 were 2.061, 2.743, 2.433, and 2.522 times the odds of severely underweight for child age group less than 6 respectively controlling for other variables in the model and random effect at level two.

In this study wealth index of family had also significant effect to underweight among under-five children. The odds of moderately or severely underweight for child born from family with middle wealth index were 0.778 times the odds of moderately or severely underweight status for child born from family with poor wealth index family controlling for other variables in the model and random effect at level two (OR= 0.778, CI: 0.663, 0.913). Similarly, the odds of moderately or severely underweight status of child who resided in rich wealth index family were 0.543 times the odds of moderately or severely underweight status of child who resided in poor wealth index family controlling for other variables in the model and random effect at level two (OR= 0.543, CI: 0.450, 0.643). whereas, normal and moderately underweight status was compared to severely underweight status shows that the odds of severely underweight for child who resided in middle wealth index family were 0.646 times the odds of severely underweight status for child who resided in poor family controlling for other variables in the model and random effect at level two (

OR= 0.646, CI: 0.501, 0.834). Similarly, the odds of severely underweight child who resided in rich family were 0.416 times the odds of severely underweight status of child who resided in poor family controlling for other variables in the model and random effect at level two (OR= 0.416, CI: 0.323, 0.536). That is, children who resided in middle and rich house hold were at lower risk of underweight.

In this study religion of mother had the significant effect to underweight among under-five children. The child born from mother who follow muslim were found 1.330 times more likely to be in moderately or severely underweight status than normal status as compared to child born from mother who follow orthodox controlling for other variables in the model and random effect at level two (OR=1.330 CI: 1.110, 1.595). Similarly, the child born from mother who follow other were found 11.320 times more likely to be in moderately or severely underweight status than normal status as compared to child born from mother who follow orthodox controlling for other variables in the model and random effect at level two (OR=1.320, CI: 1.069, 1.631). However, normal and moderately underweight status was compared to severely underweight status shows that children who born from mother who follow muslim were 1.809 times more likely being severely underweight status compared with children born from mother who follow orthodox controlling for other variables in the model and random effect at level two (OR= 1.809, CI: 1.419, 2.307). Similarly, children who born from mother who follow other were 1.639 times more likely being severely underweight status compared with children born from mother who follow orthodox controlling for other variables in the model and random effect at level two (OR= 1.639, CI:1.226, 2.192).

4.5. Discussion

The main aim of the study was to identify determinant factors of underweight among under-five children in Ethiopia by applying multilevel ordinal logistic regression. Covariates which were included in this study were region, mother education, mother occupation, mother age at first birth, wealth index of house hold, residence, toilet facility for house hold , source of water for house hold, religion, birth order, birth type, sex of child, size at birth of child, diarrhea two weeks before survey, fever two weeks before survey, body mass index of mother, age of child, family size, duration of breast feeding, cough two weeks before survey ,marital status, sex of house hold head, number of children below 59 months. Among those covariates existence of cough two weeks before survey, marital status, sex of house hold head, number of children below 59 months in HH have no any association with 5% significance. The significant variables were included in multivariable analysis.

The finding of this study revealed that educational level of mothers had a significant effect on underweight status. Children who were born from educated mothers are less risk on underweight in line with studies conducted in (Adugnga et al., 2017, Endris et al., 2017). In addition to this, the result of this study indicated that religion of mother has significantly associated to underweight among under-five year's children with those who follow muslim and other religions have higher chances of experiencing underweight compared to those who follow Orthodox Christianity religion. This is consistent with the study of (Das and Gulshan, 2017).

As shown in the analysis the risk of underweight among under five age children associated with higher birth order increases the risk of underweight supported by a studies conducted in(Takele, 2013, Gelano et al., 2015). similarly, the risk of underweight among under five age children associated with multiple births is high relative to single births and this study is similar with the previous study(Debeko and Goshu, 2015).

As the study has revealed that female child have low risks for underweight in line with studies (Abshoko et al., 2016, Gelano et al., 2015, Akombi et al., 2017). Further, the result of this study also suggested that child's size at birth was a significant factor for underweight among under-five age children. Small size children at birth were more severely underweight as compared to large size children. This finding is consistent with other study (Yilkal and Kassahun, 2016).

The findings of this study also show that children who had fever two weeks before date of survey are significantly vulnerable to underweight than those who had not. This finding is consistent with other studies(Habyarimana, 2016, Takele, 2013). Similarly, the study also showed that children who had diarrhea two weeks before date of survey are significantly vulnerable to underweight than those who had not. This has been confirmed by different studies (Fekadu et al., 2015, Brhane and Regassa, 2014).

In this study body mass index of mother was found to be highly related with underweight among under-five age children. Women with high and normal body mass index were less likely to be in higher levels of underweight among under five children as opposed to lower levels of underweight. This result is consistent with the result of studies by (Yisak et al., 2015, Takele, 2013). In this study duration of breast feeding status was found to be a significant factor of underweight among under-five children in Ethiopia. Children whose breast feeding status is still were higher underweight compared with ever breast feeding. This finding consistent with other studies(Mohammed and Asfaw, 2018, Yalew et al., 2014).

In this study age of child was found to be significantly associated with underweight, as age of child increases the risk of being malnourished increases. This finding seemed to be consistent with other studies (Haile and Amboma, 2018, Endris et al., 2017, Alemayehu et al., 2015). Our study also revealed that the odds of child severely underweight are relatively lower for the children belonging to middle and rich category of the wealth index than children from poor. This finding is consistent with other studies (Alom et al., 2012, Reta and Megersa 2019). This study also shows that region has association with underweight among children. This is consistent with the study conducted by(Endris et al., 2017).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

This study intended to identify significant socioeconomic, demographic, environmental and health related determinants and to assess regional variation of underweight among under five children in Ethiopia based on EDHS 2016 data using multilevel ordinal logistic regression model. To identify potential predictors' single level and multilevel ordinal logistic regression model were used. Among the six fitted ordinal logistic regression models, partial proportional odds model is best model to predict underweight among under-five children in Ethiopia. For selected PPOM, the explanatory variables region, education level of mother, religion, birth order, type of birth, sex of child, mother BMI, birth size of child, diarrhea for last two weeks before survey, fever for last two weeks before survey, duration of breast feeding, age child and wealth index are significant factors of underweight among under five children in Ethiopia at 5% significance.

One important finding of this study is that there were significant regional variations on underweight among under-five children in Ethiopia.

From the three multilevel ordinal regressions models, the random intercept model provided the best fit for underweight among under-five children. In fixed part of random intercept model the variables education level of mother, religion, birth order, type of birth, sex of child, mother BMI, birth size of child, diarrhea for last two weeks before survey, fever for last two weeks before survey, duration of breast feeding, age child and wealth index had significant effect to underweight among under-five children at 5% significance.

5.2. Recommendations

The findings of this study have important policy implications. Hence, based on the results of this study we make the following recommendations:

- The government should work closely with both the private sector and civil society to teach women to have sufficient knowledge and awareness on under five underweight and mechanisms of improving and moreover to make children very well.
- Design and implement primary health care and support the HH to develop their economy.

- The government gives special attention to the higher risk areas in order to improve underweight among under-five children.
- Researchers conduct further research in order to improve the health of children in Ethiopia.
- Finally we recommend that further research should be conducted to identify others factors that affect and contribute to underweight among under five years children by considering variations.

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APPENDIXES

Table A. 1: Description of variable in study and coding

No	Variables	Categories	No.	Variables	Categories
1	age of child (months)	0=less than 6 1=6-11 2=12-23 3=24-35 4=36-47 5=48-59	11	Sex of HH head	0=male 1=female
			12	Family size	0= 4 and less than 1= 5-6 2= 7 and above
2	Sex of child	0=male 1=female	13	toilet facility	0=have facility 1= have no facility
3	Mother's Education	0=no education 1=primary education 2=secondary education	14	Birth order	0=first 1=2-3 3= 4 and above
4	HH wealth index	0=poor 1=medium 2=rich	15	Duration of breast feeding	0=ever breast feeding 1=never breast feeding 2=still breast feeding
5	Place of residence	0=urban 1=rural	16	Types of birth	0=single 1=multiple
6	Region	1=Tigray 2=Afar 3=Amhara 4=Oromia 5=Somali 6=Benishangul 7=SNNP 8=Gambela 9=Harari 10=Addis Ababa 11=Dire Dawa	17	Maternal BMI	0=thin 1=normal 2=overweight
			18	Marital status	0=married 1=unmarried
			19	Source of water supply	0=not improved 1=improved
7	Mather occupation	0=no occupation 1= Had occupation	20	mother age at first birth	0=18 and less than 1=above 18
8	Mather's religion	0=Christian 1=muslim 2=other	21	Number of children <59 months	0=2 and less than 1=greater than 2
9	Had diarrhea in two weeks before survey (diarrhea)	0=no 1=yes	22	Had fever in two weeks before survey	0=no 1=yes
10	Had cough two weeks before survey	0=no 1=yes	23	Birth size	0=large 1=average 2=small

Table A. 2: Results of POM using children underweight as three ordered response categories.

Variables	Coeff	Std.Err	z	p-value	95% CI	
Region(ref=Tigray)						
Afar	0.204	0.143	1.43	0.153	-0.076	0.485
Amhara	0.264	0.113	2.33	0.020	0.042	0.485
Oromia	-0168	0.130	-1.29	0.196	-0.422	0.086
Somalia	-0.066	0.143	-0.46	0.645	-0.345	0.214
Benshangul	0.478	0.132	3.61	0.000	0.218	0.737
SSNP	-0.158	0.141	-1.13	0.260	-0.434	0.117
Gambela	-0.512	0.168	-3.04	0.002	-0.842	0.182
Harari	-0.093	0.171	0.54	0.587	-0.428	0.242
Addis Ababa	-1.005	0.272	-3.69	0.000	-01.538	-0.471
Dere Dawa	0.005	0.165	0.27	0.786	-0.278	0.368
Moedu(ref=no education)						
Primary	-0.218	0.068	-3.21	0.001	-0.351	-0.085
Secondary and above	-0.455	0.133	-3.42	0.001	-0.716	-0.195
Moccu(had no work)						
Had work	-0.063	0.057	-1.10	0.273	-0.174	0.049
Windex(ref=poor)						
Middle	-0.276	0.081	-3.42	0.001	-0.434	-0.118
Rich	-0.628	0.086	-7.31	0.000	-0.797	-0.460
Residence(ref=urban)						
Rural	-0.169	0.104	-1.63	0.104	-0.373	0.035
Toilet(ref=no)						
Yes	-0.081	0.064	-1.27	0.205	-0.207	0.045
Religion(ref=orthodox)						
Muslim	0.308	0.096	3.20	0.001	0.119	0.497
Other	0.320	0.110	2.91	0.004	0.105	0.537
Bord(ref=first)						
2-3	0.074	0.082	0.90	0.370	-0.088	0.235
4 and above	0.231	0.092	2025	0.012	0.051	0.537
Btype(ref=single birth)						
Multiple birth	0.708	0.158	4.50	0.00	0.399	1.017
Sexchild(ref=male)						
Female	-0.169	0.051	-3.32	0.001	-0.269	-0.069
Birthsize(ref=large)						
Average	0.275	0.065	4.26	0.000	0.149	0.402

Small	0.641	0.069	9.27	0.000	0.505	0.776
Diarrhea(ref=no)						
Yes	0.254	0.082	3.11	0.002	0.094	0.414
Fever(ref=no)						
Yes	0.157	0.075	2.69	0.036	0.009	0.304
BMI(ref=thin)						
Normal	-0.466	0.058	8.08	0.00	-0.579	-0.353
Over weight	-1.048	0.129	-8.10	0.00	-1.302	-0.795
Water(ref=not improved)						
Improved	0.092	0.056	1.76	0.079	-0.011	0.207
Agechild(ref=less than 6)						
6-11	0.411	0.136	3.02	0.003	0.144	0.676
12-23	1.019	0.109	9.34	0.000	0.805	1.233
24-35	1.366	0.118	11.61	0.000	1.135	1.597
36-47	1.405	0.127	11.09	0.000	1.157	1.653
48-59	1.497	0.230	11.56	0.000	1.243	1.750
Nohh(ref=less than 5)						
5-6	-0.025	0.075	-0.33	0.742	-0.172	0.122
Above 6	-0.053	0.084	-0.63	0.527	-0.219	0.112
Durbreast(ref=ever breast)						
Never breast	0.110	0.133	0.83	0.409	-0.151	0.370
Still breast	0.304	0.079	3.88	0.000	0.150	0.458
Moage(ref=18 & less)						
Greater than 18	0.012	0.052	0.24	0.812	-0.089	0.114
Cut1	2.128	0.212			1.711	2.544
Cut2	3.577	0.215			3.154	3.999

Over all brant test value Chi-square =69.82, df =40, p-value = 0.000

Table A. 3: Results of GOM using children underweight as three ordered response categories.

Variables	Normal				Moderately			
	coeff	p-value	95% CI		coeff	p-value	95% CI	
Region(ref=Tigray)								
Afar	0.139	0.339	-0.147	0.425	0.551	0.023	0.076	1.026
Amhara	0.250	0.030	0.024	0.475	0.470	0.021	0.072	0.868
Oromia	-0.194	0.140	-0.452	0.063	0.083	0.724	-0.378	0.544
Somalia	-0.088	0.540	-0.372	0.196	-0.180	0.466	-0.305	0.667
Benshangul	0.444	0.001	0.120	0.709	0.781	0.001	0.332	1.229
SSNP	-0.198	0.166	-0.477	0.082	0.192	0.427	-0.282	0.667
Gambela	-0.55	0.001	-0.889	-0.221	-0.112	0.691	-0.665	0.441
Harari	-0.104	0.531	-0.448	0.231	0.096	0.750	-0.493	0.685
Addis Ababa	-1.027	0.00	-1.562	-0.492	-2.088	0.042	-4.105	-0.072
Dere Dawa	0.027	0.873	-0.302	0.356	0.239	0.398	-0.315	0.793
Moedu(ref=no education)								
Primary	-0.213	0.002	-0.347	-0.078	-0.521	0.014	-0.499	-0.056
Secondary and above	-0.453	0.001	-0.716	-0.190	-0.521	0.034	-1.003	-0.039
Moccu(had no work)								
Had work	-0.060	0.301	-0.173	0.054	-0.081	0.383	-0.265	0.102
Windex(ref=poor)								
Middle	-0.255	0.002	-0.416	-0.094	-0.434	0.001	-0.701	-1.667
Rich	-0.612	0.000	-0.783	-0.442	-0.840	0.000	-1.131	-0.548
Residence(ref=urban)								
Rural	-0.155	0.140	-0.361	0.051	-0.293	0.088	-0.629	0.044
Toilet(ref=no)								
Yes	-0.081	0.217	-0.209	0.047	-0.094	0.345	-0.288	0.101
Religion(ref=orthodox)								
Muslim	0.290	0.003	0.099	0.482	0.449	0.006	0.127	0.771
Other	0.323	0.004	0.104	0.542	0.344	0.058	-0.012	0.701
Bord(ref=first)								
2-3	0.078	0.348	-0.085	0.242	0.034	0.801	-0.229	0.297
4 and above	0.222	0.018	0.038	0.405	0.254	0.082	-0.033	0.540

Btype(ref=single birth)								
Multiple birth	0.653	0.000	0.334	0.973	0.870	0.000	0.457	1.282
Sexchild(ref=male)								
Female	-0.171	0.001	-0.273	-0.070	0.128	0.111	-0.284	0.029
Birthsize(ref=large)								
Average	0.281	0.000	0.153	0.409	0.248	0.021	0.037	0.459
Small	0.639	0.000	0.501	0.777	0.649	0.000	0.433	0.865
Diarrhea(ref=no)								
Yes	0.237	0.005	0.073	0.400	0.34	0.006	0.099	0.589
Fever(ref=no)								
Yes	0.186	0.015	0.036	0.336	-0.018	0.881	-0.256	0.220
BMI(ref=thin)								
Normal	-0.468	0.00	-0.584	-0.352	-0.432	0.000	-0.604	-0.260
Over weight	-1.039	0.000	-1.294	-0.783	-1.138	0.000	-1.608	-0.668
Water(ref=not improved)								
Improved	0.099	0.081	-0.012	0.210	0.082	0.339	-0.086	0.250
Agechild(ref=less than 6)								
6-11	0.410	0.003	0.142	0.678	0.284	0.178	-0.129	0.697
12-23	1.024	0.000	0.809	1.239	0.730	0.000	0.406	1.054
24-35	1.379	0.000	1.146	1.611	1.015	0.000	0.671	1.359
36-47	1.444	0.00	1.194	1.696	0.893	0.000	0.518	1.269
48-59	1.547	0.000	1.290	1.804	0.924	0.000	0.539	1.309
Nohh(ref=less than 5)								
5-6	-0.035	0.644	-0.185	0.114	0.046	0.699	-0.189	0.282
Above 6	-0.049	0.571	-0.217	0.120	-0.053	0.690	-0.315	0.208
Durbreast(ref=ever breast)								
Never breast	0.108	0.424	-0.157	0.374	0.091	0.667	-0.323	0.506
Still breast	0.308	0.000	0.150	0.465	0.289	0.019	0.055	0.523
Moage(ref=18 & less)								
Greater than 18	0.002	0.095	-0.102	0.105	0.077	0.3 45	-0.082	0.235
Constant	-2.128	0.000	-2.550	-1.707	-3.413	0.000	-4.087	-2.740

Table A. 4: Result for CRM of underweight among under-five children.

	1 2 vs 0				2 vs 1			
Variables	Coeff.	p-value	95% CI		Coeff.	p-value	95% CI	
Region(ref=Tigray)								
Afar	0.124	0.399	-0.164	0.411	0.612	0.028	0.068	1.166
Amhara	0.244	0.034	0.019	0.470	0.350	0.122	-0.940	0.794
Oromia	-0.203	0.124	-0.461	0.056	0.315	0.240	-0.210	0.840
Somalia	-0.101	0.488	-0.386	0.184	0.334	0.241	-0.224	0.894
Benshangul	0.437	0.001	0.171	0.703	0.570	0.029	0.058	1.081
SSNP	-0.209	0.145	-0.490	0.072	0.447	0.106	-0.095	0.989
Gambela	-0.569	0.001	-0.905	-0.234	0.413	0.207	-0.228	1.055
Harari	-0.119	0.494	-0.459	0.222	0.229	0.508	-0.450	0.909
Addis Ababa	-1.031	0.000	-1.566	-0.496	-1.222	0.252	-3.313	0.869
Dere Dawa	0.023	0.892	-0.307	0.352	0.294	0.364	-0.342	0.930
Moedu(ref=no education)								
Primary	-0.218	0.002	-0.353	-0.083	-0.163	0.213	-0.420	0.093
Secondary and above	-0.470	0.000	-0.733	-0.207	-0.185	0.516	-0.744	0.374
Moccu(ref= no work								
Had work	-0.054	0.355	-0.168	-0.060	-0.046	0.672	-0.259	0.167
Windex(ref=poor)								
Middle	-0.258	0.002	-0.419	-0.096	-0.340	0.030	-0.647	-0.034
Rich	-0.608	0.000	-0.779	-0.437	-0.503	0.00	-0.837	-0.168
Residence(ref=urban								
Rural	-0.158	0.133	-0.364	0.048	-0.227	0.259	-0.621	0.167
Toilet(ref=no)								
Yes	-0.085	0.194	-0.214	0.043	-0.014	0.902	-0.242	0.214
Religion(ref=orthodox)								
Muslim	0.296	0.003	0.104	0.489	-0.284	0.143	-0.096	0.664
Other	0.328	0.004	0.107	0.549	0.139	0.514	-0.277	0.555
Bord(ref=first)								
2-3	0.070	0.402	-0.094	0.234	-0.027	0.864	-0.336	0.282
4 and above	0.212	0.023	0.029	0.395	-0.139	0.412	-0.193	0.471
Btype(ref=single birth)								

Multiple birth	0.692	0.800	0.372	0.013	0.566	0.027	0.065	1.067
Sexchild(ref=male)								
Female	-0.175	0.001	-0.277	0.073	0.277	0.073	0.011	0.196
Birthsize(ref=large)								
Average	0.279	0.000	0.151	0.408	0.036	0.775	-0.211	0.282
Small	0.037	0.00	0.499	0.775	0.247	0.054	-0.004	0.499
Diarrhea(ref=no)								
Yes	0.229	0.006	0.065	0.392	0.224	0.130	-0.066	0.513
Fever(ref=no)								
Yes	0.187	0.015	0.036	0.338	-0.192	0.177	-0.470	0.087
BMI(ref=thin)								
Normal	-0.464	0.020	-0.580	-0.348	-0.140	0.172	-0.342	0.061
Over weight	-1.038	0.000	-1.293	-0.782	-0.472	0.088	-1.014	0.070
Water(ref=not improved)								
Improved	0.103	0.070	-0.008	0.215	0.012	0.904	-0.186	0.210
Agechild(ref=less than 6)								
6-11	0.404	0.003	0.136	0.672	-0.185	0.481	-0.702	0.331
12-23	1.018	0.00	0.803	1.234	-0.222	0.286	-0.630	0.186
24-35	1.373	0.00	1.140	1.605	-0.196	0.367	-0.623	0.230
36-47	1.431	0.000	1.180	1.682	-0.428	0.067	-0.887	0.030
48-59	1.534	0.00	1.277	1.790	-0.487	0.041	-0.955	-0.020
Nohh(ref=less than 5)								
5-6	-0.025	0.743	-0.714	0.124	-0.081	0.561	-0.192	0.355
Above 6	-0.035	0.681	-0.203	0.132	-0.054	0.725	-0.356	0.247
Durbreast(ref=ever breast)								
Never breast	0.120	0.378	-0.147	0.386	-0.048	0.846	0.526	0.431
Still breast	0.304	0.000	0.147	-0.461	0.072	0.607	-0.201	0.344
Moage(ref=18 & less)								
Greater than 18	-0.003	0.954	-0.107	0.101	0.107	0.258	-0.079	0.294
Constant	-2.112	0.000	-2.503	-1.690	0.108	0.047	-0.079	0.294

Table A. 5: Results of SLM using children underweight as three ordered response categories.

Variables	Coeff	Std.Err	z	p-value	95% CI	
Region(ref=Tigray)						
Afar	0.244	0.184	1.33	0.184	-0.116	0.604
Amhara	0.343	0.146	2.36	0.018	-0.058	0.629
Oromia	-0.208	0.166	-1.25	0.211	-0.533	0.118
Somalia	-0.080	0.182	-0.44	0.660	-0438	0.277
Benishangul	0.605	0.171	3.53	0.000	-0.269	0.941
SSNP	-0.193	0.180	-1.07	0.285	-0.546	0.161
Gambela	-0.635	0.215	-2.95	0.003	-1.057	-0.213
Harari	-0.120	0.219	-0.55	0.584	-0.549	0.309
Addis Ababa	-1.390	0.375	-3.71	0.000	-2.125	-0.655
Dere Dawa	0.069	0.211	0.33	0.743	-0.344	0.482
Moedu(ref=no education)						
Primary	-0.285	0.067	-3.27	0.001	-0.455	0.482
Secondary and above	-0.605	0.173	-3.49	0.000	-0.945	-0.114
Moccu(had no work)						
Had work	-0.074	0.073	-1.02	0.307	-0.217	0.068
Windex(ref=poor)						
Middle	-0.362	0.104	-3.48	0.001	-0.567	-0.158
Rich	-0.813	0.115	-7.08	0.000	-1.038	-0.588
Residence(ref=urban)						
Rural	-0.229	0.133	-1.72	0.085	-0.489	0.032
Toilet(ref=no)						
Yes	-0.104	0.082	-1.27	0.203	-0.264	0.056
Religion(ref=orthodox)						
Muslim	0.397	0.124	3.20	0.001	0.154	0.640
Other	0.412	0.142	2.90	0.004	0.133	0.690
Bord(ref=first)						
2-3	0.082	0.105	0.78	0437	-0.124	0.287
4 and above	0.283	0.117	2.43	0.015	0.054	0.512
Btype(ref=single birth)						
Multiple birth	0.934	0.201	4.64	0.000	0.539	1.328
Sexchild(ref=male)						
Female	-0.211	0.064	-3.27	0.001	-0.338	-0.085
Birthsize(ref=large)						
Average	0.342	0.083	4.13	0.000	0.180	0.504

Small	0.807	0.091	8.91	0.00	0.629	0.984
Diarrhea(ref=no)						
Yes	0.312	0.104	3.01	0.003	0.109	0.516
Fever(ref=no)						
Yes	0.201	0.096	2.10	0.036	0.013	0.388
BMI(ref=thin)						
Normal	-0.586	0.075	-7.84	0.000	-0.732	-0.439
Over weight	-1.343	0.173	-7.76	0.000	-1.683	-1.004
Water(ref=not improved)						
Improved	0.128	0.071	1.81	0.070	-0.010	0.267
Agechild(ref=less than 6)						
6-11	0.490	0.172	2.85	0.004	0.153	0.828
12-23	1.248	0.141	8.84	0.000	0.971	1.525
24-35	1.682	0.154	10.91	0.000	1.379	1.984
36-47	1.716	0.164	10.45	0.000	1.394	2.038
48-59	1.828	0.168	10.91	0.000	1.500	2.157
Nohh(ref=less than 5)						
5-6	-00015	0.095	-0.16	0.871	-0.202	0.171
Above 6	-0.055	0.107	-0.52	0.606	-0.264	0.154
Durbreast(ref=ever breast)						
Never breast	0.138	0.169	0.82	0.412	-0.193	0.469
Still breast	0.377	0.100	3.78	0.000	0.181	0.572
Moage(ref=18 & less)						
Greater than 18	0.011	0.066	0.17	0.864	-0.118	0.141
Phil 1	1(constraints					
Phil2	0.312	0.043	7.29	0.000	0.228	0.395
Phil3	0(baseline)					
Theta1	3.575	0.276	12.94	0.000	3.033	4.117
Theta2	1.270	0.130	9.80	0.000	1.016	1.524
Theta3	0(baseline)					

Table A. 6: Summary of descriptive statistics for Outliers and Influential observations diagnostics

Descriptive Statistics

	N	Minimum	Maximum
Analog of Cook's influence statistics	9657	.00001	.34823
Leverage value	9657	.00080	.09739
Standard residual	9657	-1.89250	2.91367
Deviance value	9657	-1.88145	2.91092
DFBETA for constant	9657	-.11075	.15808
DFBETA for region(1)	9657	-.13990	.10531
DFBETA for region(2)	9657	-.13995	.10605
DFBETA for region(3)	9657	-.13856	.10507
DFBETA for region(4)	9657	-.13957	.10525
DFBETA for region(5)	9657	-.14146	.10512
DFBETA for region(6)	9657	-.13924	.10479
DFBETA for region(7)	9657	-.13918	.10524
DFBETA for region(8)	9657	-.20310	.32671
DFBETA for region(9)	9657	-.28360	.34074
DFBETA for region(10)	9657	-.15157	.10287
DFBETA for moedu(1)	9657	-.01905	.01191
DFBETA for moedu(2)	9657	-.01850	.01187
DFBETA for religion(1)	9657	-.00688	.00734
DFBETA for religion(2)	9657	-.00501	.00548
DFBETA for moccu(1)	9657	-.00240	.00228
DFBETA for btype(1)	9657	-.01778	.01935
DFBETA for sexchild(1)	9657	-.00175	.00140
DFBETA for dubreast(1)	9657	-.00527	.00616
DFBETA for dubreast(2)	9657	-.01026	.01753
DFBETA for birthsize(1)	9657	-.00314	.00363
DFBETA for birthsize(2)	9657	-.00259	.00219
DFBETA for diarrhea(1)	9657	-.00529	.00450
DFBETA for fever(1)	9657	-.00407	.00364
DFBETA for agechild(1)	9657	-.00619	.01080

DFBETA for agechild(2)	9657	-.00707	.01336
DFBETA for agechild(3)	9657	-.00527	.00786
DFBETA for agechild(4)	9657	-.00347	.00521
DFBETA for agechild(5)	9657	-.00265	.00323
DFBETA for nohh(1)	9657	-.00534	.00623
DFBETA for nohh(2)	9657	-.00314	.00308
DFBETA for moage(1)	9657	-.00166	.00237
DFBETA for water(1)	9657	-.00180	.00296
DFBETA for toilet(1)	9657	-.00295	.00349
DFBETA for bord(1)	9657	-.00742	.00729
DFBETA for bord(2)	9657	-.00464	.00390
DFBETA for windex(1)	9657	-.00474	.00404
DFBETA for windex(2)	9657	-.00353	.00517
DFBETA for BMI(1)	9657	-.01931	.00809
DFBETA for BMI(2)	9657	-.01837	.00805
DFBETA for residence(1)	9657	-.00901	.01141
Valid N (listwise)	9657		

B. Graphical model diagnosis checking

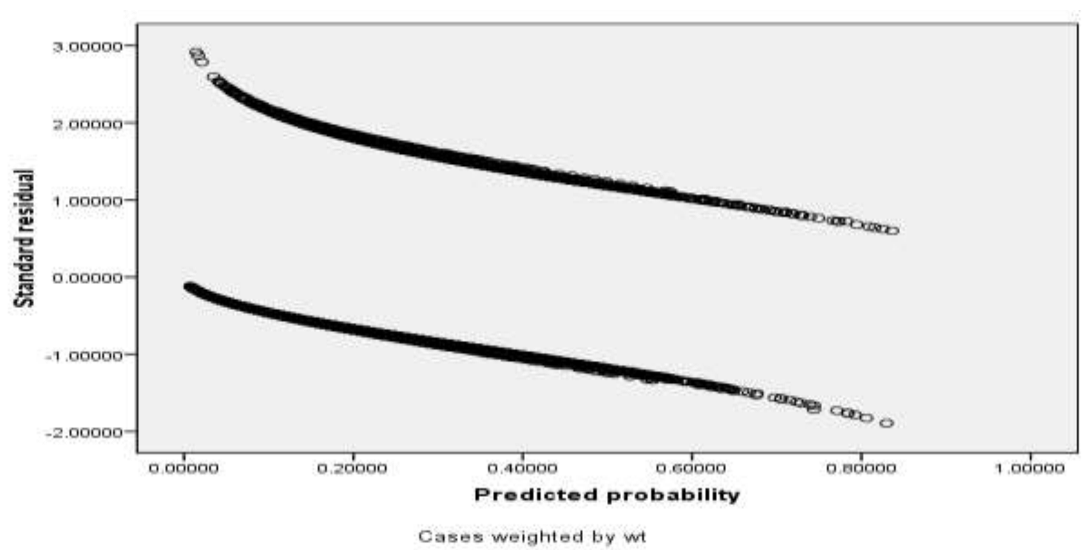

Figure A. 1: plots of Standard residual by predicted probability

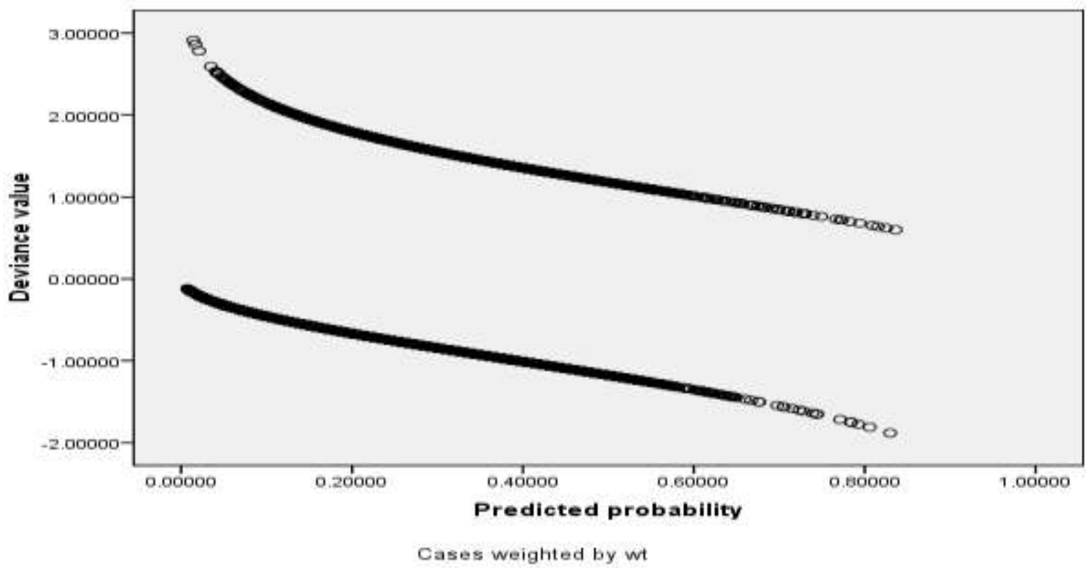

Figure A. 2: Plots of Deviance residual by predicted probability

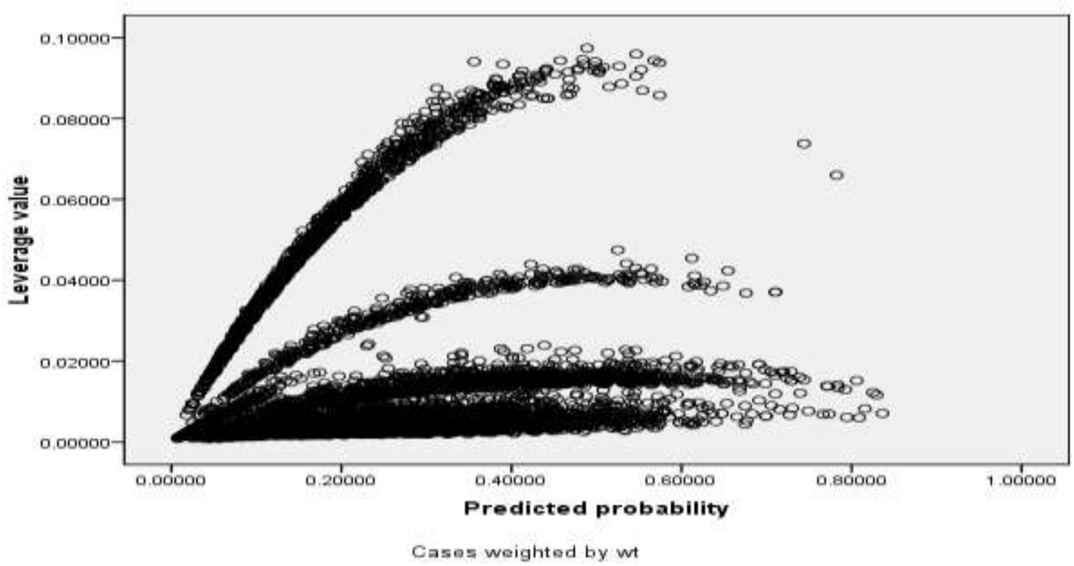

Figure A. 3: Plots of leverage value by predicted probability

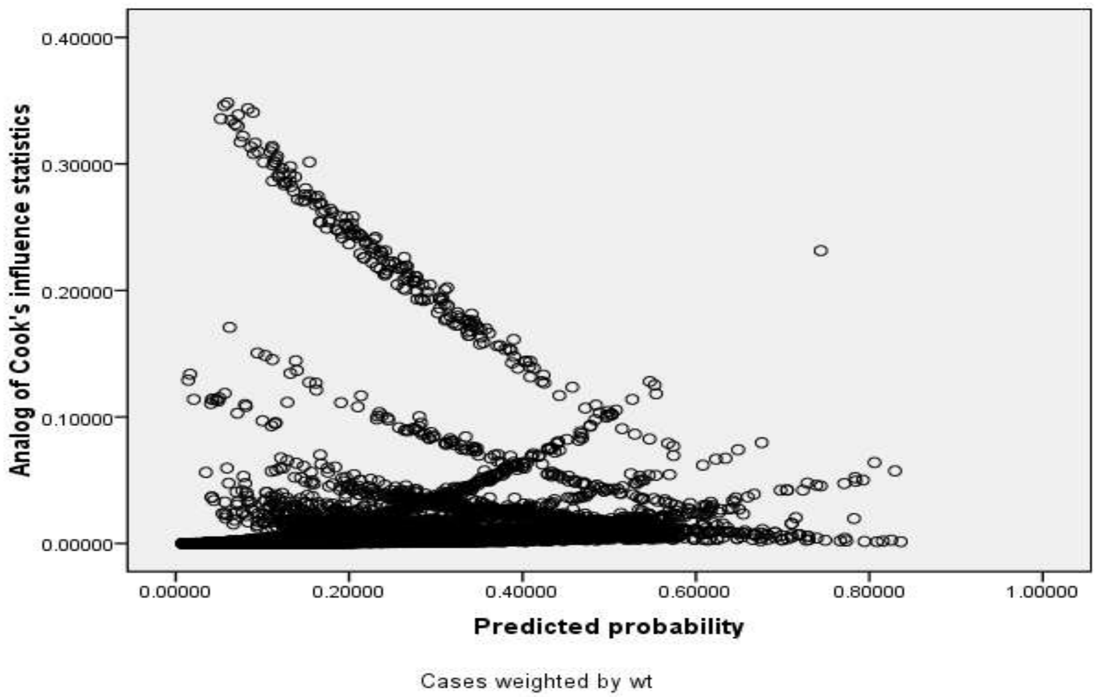

Figure A. 4: plots of cook's influence by predicted probability