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Dietary diversity and nutritional adequacy of children by agro-ecological zones of Ghana

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Abstract Children's early year's life is essential. Those who receive inadequate nutrition are more likely to suffer from sickness and death in the short term, contributing to behavioral disorders, poor cognitive development, and poor education performance. This paper assesses children's dietary diversity, food groups, and nutrition adequacy with agro-ecological zone potentials. We used the 24-hour recall method, the newest national representative, a cross-sectional dataset from Ghana's Demographic and health survey with broad coverage in all agro-ecological zones, and 2451 children aged 6-59 months old for the final analysis. Multivariate logistic regression models were used to examine the relationship between food groups, adequate dietary diversity intake, and marginal effects were applied to estimate the magnitude of nutritional adequacy between different agro-ecological zones. We found that the average dietary diversity score for all food groups was low, 2.23 out of 7. Out of the total food consumed daily, the food group which constitutes the highest proportion are grains, roots, and tubers, with an average daily intake (45.6% to 49.6%), and the least are vitamin A-rich fruits and vegetables (2.6% to 10.0%). The main results were that adequate dietary diversity intake decreased from the least affected climatic zone (12.7%) to the most vulnerable zones (1.7%). There is also a relationship between food groups, adequate dietary diversity, and agro-ecological zones. Implementing climate-smart agriculture, especially in areas prone to extreme climatic stress, will help reduce climate change effects, enhance sustainable food production, and provide adequate food supply and nutrition.

Keywords: *Agro-ecological zones, nutritional adequacy, dietary diversity, food groups, Ghana*

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1. Introduction

The early years of a child's life are crucial. Inadequate nutrition increases the risk of illness and mortality in the near term and contributes to behavioral issues, poor cognitive development, and poor academic performance [1]. Nutritional status is regarded as one of the predictors of national growth since a well-nourished and healthy populace is essential for economic and social development [2]. One of the major challenges confronting the world is fulfilling the food demand of the rising population, which is why researchers and key stakeholders are encouraging a sustainable expansion of agricultural output to increase the population's nutrition [3,4,5]. While previous studies indicated improved overall global nutrition, child malnutrition remains a widespread issue in sub-Saharan Africa that affects individual and national development [6,7,8]. Many households in sub-Saharan Africa, especially vulnerable groups such as low-income households, children, and women, eat monotonous foods of low quality and increase the risk of micronutrient deficiencies [9,10].

Ghana is amongst the most food-insecure regions globally, with 22% of the population experiencing a prevalence of undernourishment [11]. It remains the only sub-region with a rising number of stunted children [12]. Childhood undernutrition is Ghana's most severe health issue [13,14]. In Ghana, one-third of the child mortality rate is attributed to malnutrition [15]. Stunting and underweight are estimated to affect 22.7% and 13.4% of Ghanaian children under five, respectively [16]. The current prevalence rates of wasting (6.4%) in children under five years of age in Ghana remain higher than the average for the African region [17]. Poor nutrition worsens the plight of the poor, especially children and women. Child malnutrition is closely associated with poor eating choices, a monotonous diet, poor caregiver nutritional knowledge, and household wealth [18,19,20]. Food availability and accessibility challenge has brought a major public health problem among young children in many developing countries, especially in sub-Saharan Africa [21]. Since most poor households lack sufficient food and the purchasing power to buy enough food, those living in poverty eat low-quality foods and change their consumption habits to suit their circumstances [22,23].

Previous studies have found that most Ghanaians eat a monotonous diet, and a traditional menu consists mainly of stew comprising vegetables such as pepper, onion, tomato, and garden eggs with staple crops including cassava, plantain, yam, rice, maize [24,25,26].

A recent body of literature has shown that farming and food system methods across a range of agro-ecological transitions help improve food security and nutrition outcomes [27,28,29,30]. Some studies emphasize that, despite the low usage of agricultural technologies, peasant systems, which depend primarily on local resources and complex cropping patterns, are relatively efficient [31,32]. Studies by Kerr et al. [27,30] and Ndirangu et al. [28] indicate that poor and vulnerable farmers can use agro-ecological practices to improve food and nutritional security in sub-Saharan Africa. An empirical study by Azupogo et al. [29] to understand agro-ecological zones and hemoglobin and anemia status of rural school-aged children and adolescents in Ghana revealed that agro-ecological zone were the main predictors of hemoglobin and anemia among the rural school-aged children and adolescents.

Given frequent climate change, food shortages, and a lack of food-based techniques to boost and strengthen sustainable agricultural food productivity, agro-ecological land management has gained attention as an innovative system to improve food security [33]. According to FAO research, an agro-ecological zone (AEZ) is a land resource mapping unit characterized by climate, landform and soils, and land cover, with a particular range of potential and land-use limitations [34]. AEZ technique is a proven strategy used in land assessment to help farmers implement sustainable agricultural development [35,36]. AEZ analyzes resource constraints and possibilities based on plant eco-physiological features, climatic and edaphic crop needs and utilizes them to evaluate crop suitability and production potentials under particular input and management circumstances [35]. Any effort to improve agricultural productivity to support the 2030 Agenda for Sustainable Development requires a holistic approach; all fundamental problems affecting agricultural areas need great attention [37]. One such consideration is the agricultural production capacity of the land, which is inextricably related to rural communities' nutritional and health situation that depends on subsistence farming. Understanding the most viable crop possibilities and having control over the limitations imposed by agro-ecological circumstances allows for more strategic crop planning selections , acts as a trigger for choosing more productive alternatives, and is also resilient to environmental fluctuation [38,39]. Ghana has been hampered by many problems dealing with nutrition, including low priority, lack of sufficient resources, and the capacity to develop comprehensive national policies to improve food production and sustainable agriculture [6]. The inadequate resources, low priority, and lack of comprehensive policy affect food production and crop yield, especially in agricultural areas vulnerable to climate change.

Previous research has highlighted the reliability of dietary diversity as a proxy for child nutritional adequacy and its usefulness as a measure of food security [40,41,42]. Several studies have explored the association between dietary diversity and child nutritional status in Ghana and other parts of the world [43,44,45,46]; however, very few studies have examined dietary diversity and agro-ecological zone potentials. Almost all studies in Ghana on child malnutrition focus only on socioeconomic aspects [47,48,49,50]. No study has explored child malnutrition along all agro-ecological zones. The dearth of studies and inconclusive empirical evidence about the association between agro-ecological, dietary diversity, and food security with nutritional status in Ghana and other sub-Saharan African regions have prompted this research to contextualize agro-ecological, dietary diversity, and child nutritional status. Therefore, the research aims to assess children's dietary diversity, food groups, and nutrition adequacy with agro-ecological zone potentials in Ghana.

Our research is innovative and relevant. First, empirical studies on the dietary diversity along agro-ecological zones are limited. As far as the authors know, the current work is the first study to assess child malnutrition along all agro-ecological lines in Ghana. Second, the study uses nationally representative data with a large sample to contribute to existing literature and better-informed decisions. Thirdly, most empirical studies focus on total food consumption or specific food items; however, this current study uses specific food groups in its analysis. The study tested the hypothesis that dietary diversity will represent the resulting variations in the nutritional status of children in Ghana when comparing agro-ecological areas with different agricultural production and capacity. The study measured the magnitude and assessed the relationship between agro-ecological zones, dietary diversity, and child nutritional adequacy. Specifically, we hypothesized that:

a. The agro-ecological zone influences adequate dietary diversity due to different agricultural potentials and production.
b. Children in a high potential agro-ecological zone will have more dietary diversity than those with lower potential agro-ecological zones due to better climatic conditions suitable for growing different agricultural products.
c. Agro-ecological zones potentials influence children's dietary diversity
d. Children's consumption of specific food groups is associated with agro-ecological zones
e. Children in wealthy households will have adequate dietary diversity because they can buy varieties of food.

The rest of the paper is organized as follows. Section 2 introduces our data, dependent variables, primary explanatory and control variables, and statistical analysis. Section 3 presents the detailed results of the study. Discussing our empirical results follows this, and the final section concludes the paper and offers some suggestions.

2. Materials and Methods

2.1. Study Area, Samples, and Data

The research covers Ghana's five main agro-ecological zones: Savannah, Transitional Zone, Deciduous Forest, Tropical Rain Forest, and Coastal Savannah (Figure 1).

The Ghana agro-ecological zones are divided based on specific characteristics such as rainfall patterns, soils, and types of crops grown in that particular region [51]. Ghana's climate is tropical, with two primary seasons: rainy and dry. The dry wind blows in northern Ghana from December to March, reducing humidity and triggering hotter days and cooler nights [52]. Generally, the southern part of Ghana is characterized by more rainfall than the northern part. The annual average rainfall ranges from 1000 mm in the Guinea/Sudan Savannah to 2200 mm in the Tropical Rain Forest. The country's average annual temperature ranges from 26.1°C along the coast to 28.9°C in the north. Seasonal variations in rainfall temperature along different agro-ecological zones affect the suitability of rain-fed agriculture and reduce agricultural production in regions that experience low rainfall and high temperature [53,54].

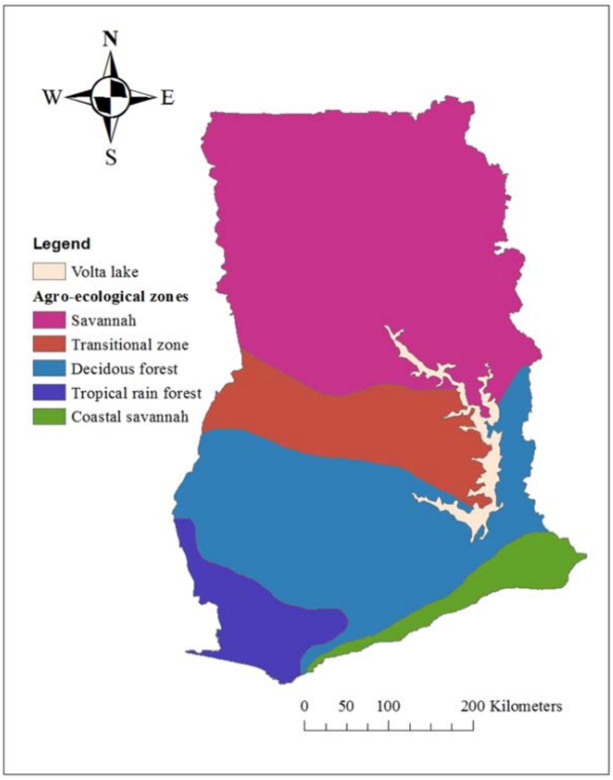

Figure 1. Agro-ecological map of Ghana

This study used a nationally representative, cross-sectional data set from the 2014 Ghana Demographic and Health Survey (2014-GDHS) [55]. The choice of 2014-GDHS was based on the fact that it is the most recent nationally representative data set and offers comprehensive, detailed information on nutrition, health, geographical region, and child feeding variables required for this study. The 2014-GDHS used a two-stage survey design. The first stage was to choose clusters made from enumeration areas (EAs) for the 2010 Population and Housing Census, and a total of 427 clusters were chosen, 216 urban and 211 rural. In the second stage, systematic random sample techniques were used to select households. A total sample size of 12,831 households was chosen, with 12,010 inhabited. 11,835 inhabited households were successfully interviewed, resulting in a 99% response rate. In the interviewed household, 9,396 women aged 15-49 and 4,388 men aged 15-59 were successfully interviewed [56]. The 2014-GDHS used three types of questionnaires to collect data: the Woman's Questionnaire, Man's Questionnaire, and Household Questionnaire. The standard women's questionnaire successfully interviewed 9,396 out of 9,656 eligible women, resulting in a response rate of 97% [55,56]. The women's questionnaire contains a children's health section administered to only women with a child born in the last five years before the survey, and 3446 were successfully interviewed [55]. Out of this, the study chose mothers having born children aged 6-59 months old. Hence, this study limited the final analysis to children aged 6-59 months old, resulting in a sample size of 2451. The 2014-GDHS used the 24-hour recall method to collect data on young children aged 6-59 months old through mother interviews, where mothers recalled the number of food items consumed by their children over the last 24 hours. The survey collected data on 21 food items the child had consumed the previous day.

2.2. Variables

2.2.1. Dependent Variable

The primary outcome variables for this study are the dietary diversity score (DDS) and adequate dietary diversity score (ADDS). To calculate the dietary diversity score (DDS), we first categorized the food items into seven food groups based on the WHO Infant and Young Child Feeding (WHO IYCF) practices recommendations [57,58]. The food groups include (1) Grains, roots, and tubers (soup/clear broth or bread, noodles, other grains or fortified baby food or potatoes, cassava, tubers); (2) Legumes and nuts (beans, peas, and lentils); (3) Dairy products (formula milk or tinned powdered/fresh milk or cheese, yogurt, other milk products, or yogurt); (4) Flesh foods (liver, heart, other organ meat or fish, shellfish or chicken, duck or other birds); (5) Eggs (Eggs); (6) Vitamin-A rich fruits and vegetables (pumpkins, carrots, squash or dark green leafy vegetables or mangoes, papayas, vitamin A fruits); and (7) Other fruits and vegetables (any other fruits and vegetables). If a child consumed a specific food group in the past 24 hours, the group scored one, otherwise scoring zero. The DDS was calculated by summing scores for all seven groups for a child. Thus, the DDS yielded a range from zero to seven, where the value of zero showed that the child consumed none of the food groups, and the value of 7 showed that the child consumed at least one of the food items in each of the seven food groups. A binary variable was created from the DDS to obtain ADDS. When a child scored four or more for the DDS, they were deemed to have ADDS, while children who scored three or fewer for the DDS were considered dietary diversity inadequate [57,58]. Food groups were also used as dependent variables to show the association between the agro-ecological zone and the consumption of specific food groups.

2.2.2. Explanatory Variables

The primary independent variable is the agro-ecological zones. The 2014-GDHS contains comprehensive geographical information data on the food consumption of young children aged 6-59 months old. The demarcations of Ghana's agro-ecological zones map are based on the climatic conditions and the soil types as used by Food and Agriculture Organization (FAO) and the International Institute for Applied Systems Analysis (IIASA) in the AEZ modeling framework [35]. In Ghana's agricultural system, agro-ecological zoning is divided into five major agro-ecological zones characterized by climate, reflected by natural vegetation, and influenced by soil types [59]. The agro-ecological zone variable was created from the agro-ecological map of Ghana. [51,60].

2.2.3. Other Covariates

Our regression models included other socioeconomic and demographic variables of community, households, individuals, and variables generally considered theoretically affecting child diet [60,62,63]. They were grouped into three main levels: child, mother, and household/community-level characteristics. The study included one categorical variable and two continuous variables as child-level characteristics. The categorical variable included was the child's gender (female/male), and two continuous variables were: age (6-23 months, 24-59 months) and birth order (1, 2, 3, and 4+).

The maternal-level variables included in the study comprised three categorical and one continuous variable. The categorical variable included were: marital status (single/divorced/widowed, married), mother's occupation (unemployed, technical/managerial, agriculture, sales/services), and mother's education (no education, primary, secondary, higher). Mother's age (15-24, 25-34, 35-44, and 45+) was measured as a continuous variable.

The third level of characteristic measured was the household/community factors. The household/community characteristics included were: the number of children in the household (1-2, 3-5, 6+), religion (Christianity, Islam, Traditionalist, and no religion), ethnicity (Akan, Mole-Dagbani, Ewe, Ga/Dangwe, others). Another vital variable included in the analysis was household wealth. The DHS wealth index is calculated based on asset ownership and housing quality [64,65]. Principal component analysis was used to assign weights to each household asset [66,67]. The asset scores were then summed up, assigning the household wealth index value to all household members. The Wealth Index was then classified into rank-based quintiles: poorest, poorer, middle, richer, and richest.

2.3. Statistical Analysis

The analysis was performed using Stata 16 version, and sample weights were used for all analyses. Sample weights were determined based on a non-proportional allocation to separate survey clusters and residents (agro-ecological zones). The sample weight was designed to ensure our study was nationally representative and sufficiently applied to all survey clusters. Descriptive statistics are provided to offer general knowledge of the sample populations' characteristics. The frequencies (f) and percentages (%) are estimated. We use means estimation to compare the average consumption of specific food groups and adequate dietary diversity in children aged 6-59 months old by agro-ecological zones (AEZ).

2.3.1 Multivariate Analysis

First, we used ordinary least squares (OLS) regressions and robust standard errors to estimate the relationship between dietary diversity and agro-ecological zones. They are presented in a two-part model, model 1 adjusted for only child characteristics, but Model 2 further adjusted for mother and household/community characteristics. We first estimated the following regression model:

$$Y = \alpha + \beta_1 AZ + \beta_2 G + \beta_3 A + \beta_4 BO \qquad (1)$$

$$Y = \alpha + \beta_1 AZ + \beta_2 G + \beta_3 A + \beta_4 BO + \beta_5 MS + \beta_6 MO$$
$$+ \beta_7 MA + \beta_8 ME + \beta_9 HHN + \beta_{10} HH + \beta_{11} E \qquad (2)$$

Where Y is the dependent variable (DDS), AZ is the agro-ecological zone, G is the child's gender, A is the child's age, BO is birth order, MS is mother's marital status, MO is mother's occupation, MA is mother's age, ME is mother's education, HHN is a number of children in household, HHW is household wealth, and E is ethnicity.

Furthermore, we used a series of multivariable logistics regression models to derive association between specific food groups, ADDS and AEZ. The application of logistic regression was necessary due to the dichotomous nature of the outcome variables [68]. Defined as P_1 the probability that a child had ADDS and specific food group and P_0 the probability that the child had no ADDS and specific food group. The logistic regression model has the form of

$$Y_i = \log\left(\frac{P_{i1}}{P_{i0}}\right) = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \beta_m x_{im} \qquad (3)$$

Where P_{i1}/P_{i0} is called the odds ratio, β_0 is the intercept, $\beta_1 x_{i1} + \beta_2 x_{i2} + \beta_m x_{im}$ is the value of each independent variable (X_i) weighted by its respective beta coefficient (β). The parameters (β_0 to β_m) of the logistic model are estimated with the use of the maximum likelihood method. The probability of a child to have a specific food group or ADDS can be calculated using the logistic regression model

$$P\left(Y = 1/X_i\right) = \frac{e^{b^T X_i}}{1 + \left(e^{b^T X_i}\right)} = \frac{1}{1 + \left(e^{-b^T X_i}\right)} \qquad (4)$$

Where $e^{b^T X_i}$ is the linear predictor of the logistic regression function, Y_i is the outcome variable. Multivariate logistic regression models to examine the relationship between ADDS and AEZ are presented in a two-part model. Model 1 adjusted for only child characteristics but model 2 further adjusted mother characteristics and household/community characteristics.

The study further predicted average marginal effects (AME) of children DDS and ADDS on the various variables. Numerous scholars interpret their statistical model findings using coefficients, standard errors, and p-values. However, some limitations and difficulties with understanding exist, particularly when categorical variables and nonlinear models such as logistic regression are used [69,70]. The usage of AMEs significantly improves the context, intuitiveness, and ease of interpretation of the research findings [68,70,71,72]. As a result, the analysis used AMEs to estimate the overall likelihood of children DDS, ADDS of agro-ecological zones.

All variables of interest were tested using the Wald test to ensure that removing any parameter or variable will not substantially reduce the model's fitness [73]. P-values of 0.05 were used to determine whether or not the associations were significant. We used Variance Inflation Factor (VIF) to assess the possibility of multicollinearity. The mean of the VIF of the independent variables was <4. The results suggest an absence of multicollinearity in the analysis [74,75]. Again, we tested the interaction between agro-ecological zones with the outcome of ADDS. A significant interaction between agro-ecological zones and ADDS was not observed with a P-value of 0.1288. Moreover, we applied robust standard errors in all our analyses to ensure our estimations' robustness.

3. Results

3.1. Descriptive Analysis of the Selected Characteristics

Tables 1 Socio-demographics characteristics of household having children aged 6-59 months in Ghana, GDHS-2014

Selected characteristics	Categories	Frequency	Percentage
Agro-ecological zones			18.9
	Savannah	463	9.6
	Transitional zones	236	33.5
	Deciduous forest	822	10.4
Children characteristics	Tropical rain forest	254	27.6
Child's gender	Coastal savannah	676	53.1
	Male	1301	46.9
Age	Female	1150	36.6
	6-23	896	63.4
Birth order	24-59	1555	23.5
	1	577	20.1
	2	491	17
Mother's Characteristics	3	417	39.4
Marital status	4+	966	12.2
	Single/Divorced/widowed	298	87.8
Mother's occupation	Married	2153	30.4
	Unemployed	745	4.8
	Technical/managerial	118	27.8
	Agriculture	681	37.0
Mother's age	Sales/services	907	18.4
	15-24	451	50.7
	25-34	1243	27.9
	35-44	684	3.0
Mother's education	45+	73	28.7
	No education	702	19.6
	Primary	481	48.3
	Secondary	1185	3.4
Household/community characteristics	Higher	83	
No. of children in household			85.3
	1-2	2091	14.4
	3-5	353	0.30
Household wealth	6+	7	22.5
	Poorest	551	20.4
	Poorer	499	19.9
	Middle	489	18.7
	Richer	458	18.5
Religion	Richest	454	74.9
	Christianity	1836	18.1
	Islam	443	3.4
	Traditionalist	83	3.6
Ethnicity	No religion	89	48.4
	Akan	1186	16.8
	Mole-Dagbani	412	12.8
	Ewe	315	5.7
	Ga/Dangwe	140	16.2
Dietary diversity score	Others	398	
Mean (95%, confidence interval)			2.23(2.15-2.32)

Table 1 presents the distribution of the selected characteristics, consumption of food groups, and dietary diversity score. The sample consisted of 2451 children aged between 6-59 months old. A total of 822 (33.5%) of the children lived in deciduous forest, followed by coastal savannah (27.6%), savannah (18.9%), tropical rain forest (10.4%), and transitional zone (9.6%). More than half (53.1%) of the children surveyed were male, and most of the children (63.4%) were aged between 24-59 months, while 26.6% were aged between 6-23 months old. Less than a quarter (23.5%) of the children were first-order births. Regarding maternal characteristics, most (87.8%) of the mothers were married, more than a quarter (37%) were involved in sales/services trading, and about 30.4% were unemployed. 50.7% of the mothers were 25-34 years old, and almost half (48.3%) of the mothers had secondary education while 28.7% had no education.

Regarding the household factors, 85.3% of the household had 1-2 children, while 22.5% belonged to the poorest quintile and about 18.5% to the richest wealth quintile. Almost half (48.4%) belong to Akan ethnic group, while a majority (74.9%) practiced Christianity, followed by Islam (18.1%). The mean dietary diversity score was low at 2.23 (with a 95% CI of 2.15-2.32). The highest average dietary diversity score was recorded in the tropical rain forest (3.0), followed by coastal savannah (2.6), transitional zone (2.5), deciduous forest (1.8), and lowest in the savannah (1.7) agro-ecological zone (Figure 2).

3.2. Average Intake of Specific Food Groups and Adequate Dietary Diversity Along Agro-Ecological lines

Table 2 presents the average consumption of specific food groups and adequate dietary diversity by children aged 6-59 months old along agro-ecological zones in Ghana. The findings revealed that the tropical rainforest had the highest mean (49.6%) of the grains, roots, and tubers, and the lowest mean (42.1%) was recorded in the deciduous forest. The average consumption of legumes and nuts in the savannah zone was two times more than in the deciduous forest (10.0% vs. 3.5%). The average dairy product intake ranges from 4.2% to 23.5% between savannah and coastal savannah zones. The mean consumption of flesh foods ranged from 21.2% among children in the savannah to 35.2% in the tropical rainforest. A higher variation of the average consumption of eggs was observed between savannah and tropical rainforest (4.8% vs. 18.2%). The study revealed higher differentials of the average consumption of vitamin A-rich fruits & vegetables. For example, the average intake in the savannah was 2.6% compared to 10.0% in the coastal savannah region. Lower differentials were observed in consuming other fruits and vegetables (16.4% vs. 29.4%). The overall prevalence of average ADDS ranges from 7.5% to 22.5% along the agro-ecological zones (Figure 3). The highest ADDS was recorded in the tropical rain forest (22.5%), followed by coastal savannah (16.7%), transitional zone (16.4%), savannah (7.5), and deciduous forest (5.7%) (Figure 2).

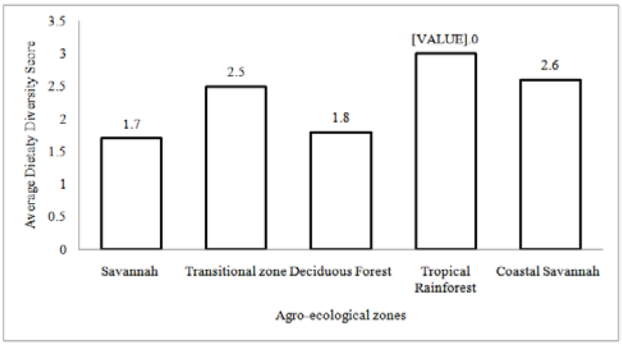

Figure 2. Average dietary diversity score by agro-ecological zones

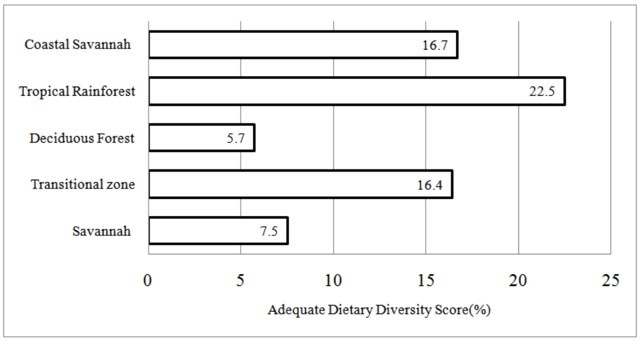

Figure 3. Average adequate dietary diversity score by agro-ecological zones

Table 2. Consumption of specific food groups, and adequate dietary diversity intake in the last 24h among children aged 6-59 months old by Agro-ecological, 2014-GDHS, Ghana

Specific food group	Savannah (%)	Transitional zone (%)	Deciduous forest (%)	Tropical rainforest (%)	Coastal Savannah (%)
Grains, Roots and tubers	45.6 (42.1-49.0)	48.3 (42.6-54.1)	42.1 (38.3-45.9)	49.6 (45.0-54.2)	45.9 (39.7-52.1)
Legumes and nuts	10.0 (7.9-12.1)	7.0 (4.2-10.1)	3.5 (2.1-4.9)	9.0 (6.4-11.7)	5.2 (2.4-8.0)
Dairy products	4.2 (2.8-5.6)	8.9 (5.6-12.1)	7.8 (5.7-10.0)	14.9 (10.5-19.3)	23.5 (19.6-27.4)
Flesh foods	21.2 (18.4-24.1)	33.4 (28.0-38.8)	20.3 (17.2-23.4)	35.2 (30.8-39.6)	22.5 (17.3-27.7)
Eggs	4.8 (3.3-6.2)	7.8 (4.7-10.9)	7.3 (5.3-9.3)	18.2 (13.4-23.0)	14.3 (11.1-17.5)
Vitamin A rich fruits and vegetables	2.6 (1.5-3.7)	7.9 (4.8-11.0)	3.9 (2.4-5.4)	6.8 (3.6-9.9)	10.0 (7.2-12.7)
Other fruits and vegetables	22.6 (19.7-25.5)	28.4 (23.3-33.6)	16.4 (13.5-19.2)	29.0 (23.4-34.7)	29.4 (25.3-33.6)
Adequate dietary diversity score	7.5 (5.6-9.2)	16.4 (12.1-20.7)	5.7 (3.9-7.5)	22.5 (18.6-26.3)	16.7 (12.1-21.4)

Note: Confidence intervals are in parenthesis

3.3. Association Between Dietary Diversity Score and agro-ecological zones

Table 3 presents a two-part linear regression model of the relationship between agro-ecological zones and children's dietary diversity in Ghana. Model 1 controls only child characteristics such as gender, age, and birth order, while model 2 controls child characteristics, mother characteristics, and household characteristics. The study revealed that the agro-ecological zone is statistically significant, with the dietary diversity score at a 5% significant level. Again, AEZ with a coefficient of 0.015 is still statistically significant, with DDS at 5% after controlling for the full characteristics.

The child's age, mother's marital status, and the number of children in a household were statistically significant at a 1% level in model 2. Mother's age and household wealth were also associated with dietary diversity after controlling full characteristics. The results from the linear regression confirm the hypothesis that the agro-ecological location influences the dietary diversity of children in Ghana.

Table 3. Regression results for dietary diversity and agro-ecological zone

Variables	Model 1 Coefficient	Model 2 Coefficient
Agro-ecological zones	0.011** (0.005)	0.015** (0.007)
Child's gender	0.008 (0.015)	0.008 (0.015)
Child's age	-0.066*** (0.015)	-0.066*** (0.015)
Birth order	-0.011 (0.007)	-0.010 (0.009)
Mother characteristics		
Marital status	N/A	0.086*** (0.022)
Mother's occupation	N/A	-0.002 (0.006)
Mother's age	N/A	-0.028** (0.013)
Mother's education	N/A	-0.003 (0.010)
Household/community characteristics		
Household wealth	N/A	-0.010* (0.007)
No. of children in household	N/A	0.137*** (0.023)
Ethnicity	N/A	-0.008 (0.006)
Constant	1.537*** (0.043)	1.311*** (0.073)
R-squared	0.511	0.589
Number of observation	2451	2451

Note: ***p < 0.001, **p < 0.05 and *p<0.10. Robust standard errors are in parenthesis

Table 4. Marginal effects of agro-ecological zone and specific foods groups

Variables	Grains, roots, and tubers	Legumes and nuts	Dairy products	Flesh foods
Agro-ecological zones	0.020**	0.004	0.017***	0.035***
	(0.007)	(0.005)	(0.005)	(0.007)
Child Characteristics				
Child's gender	-0.001	-0.003	0.017	-0.006
	(0.015)	(0.010)	(0.011)	(0.016)
Child's age	-0.472***	-0.096***	-0.116***	-317***
	(0.006)	(0.012)	(0.011)	(0.015)
Birth order	-0.014	-0.007	-0.002	-0.012
	(0.009)	(0.006)	(0.006)	(0.009)
Mother characteristics				
Marital status	0.083***	0.042*	0.026	0.112***
	(0.024)	(0.021)	(0.018)	(0.026)
Mother's occupation	-0.002	0.004	0.001	0.004
	(0.006)	(0.004)	(0.008)	(0.006)
Mother's age	-0.018	-0.001	-0.013	-0.004
	(0.013)	(0.010)	(0.009)	(0.014)
Mother's education	-0.012	0.004	0.011	0.010
	(0.011)	(0.007)	(0.008)	(0.011)
Household/community characteristics				
Household wealth	0.010	-0.001	0.039***	-0.012
	(0.007)	(0.005)	(0.005)	(0.008)
Household children	0.119***	0.053***	0.076	0.054**
	(0.020)	(0.012)	(0.014)	(0.022)
Ethnicity	-0.006	0.008	-0.002	0.004
	(0.006)	(0.004)	(0.005)	(0.006)

Table 4. (Continued from the preceding page)

Variables	Eggs	Vitamin A-rich fruits and Vegetables	Other fruits and vegetables
Agro-ecological zones	0.018*** (0.005)	0.013*** (0.004)	0.027*** (0.007)
Child Characteristics			
Child's gender	0.007 (0.011)	0.005 (0.009)	0.005 (0.016)
Child's age	-0.120*** (0.012)	-0.086*** (0.011)	-0.310*** (0.012)
Birth order	-0.010 (0.006)	0.007 (0.005)	-0.018 (0.009)
Mother characteristics			
Marital status	0.037* (0.019)	0.009 (0.016)	0.076** (0.027)
Mother's occupation	0.001 (0.004)	0.006* (0.004)	0.005 (0.007)
Mother's age	0.001 (0.009)	-0.010 (0.008)	0.016 (0.013)
Mother's education	0.011 (0.007)	-0.001 (0.005)	0.012 (0.011)
Household/community characteristics			
Household wealth	0.014*** (0.004)	0.010*** (0.004)	-0.011 (0.007)
Household children	0.025* (0.015)	0.008 (0.013)	0.081*** (0.021)
Ethnicity	0.004 (0.004)	0.006* (0.004)	0.013** (0.006)

Note: ***p < 0.001, **p < 0.05 and *p<0.10. Standard errors are in parenthesis

3.4. Association Between agro-ecological Zones and Specific Food Group Consumption

Table 4 presents the marginal effects of an agro-ecological zone on the consumption of specific food groups among children aged 6-59. The findings revealed that dairy products, flesh foods, eggs, Vitamin A-rich fruits and vegetables, and other fruits and vegetables were statistically significant at a 1% level with marginal effects of 1.7%, 3.5%, 1.8%, 1.3%, and 2.7%, respectively. The results also show that grains, roots, and tubers were statistically significant at a 5% level with a marginal effect of 2.0%. The current study did not reveal statistical significance between legumes and nuts and AEZ. A child's age was found to influence children's consumption of all specific food groups at a 1% significant level. Mothers' marital status was also found be significantly affect children's consumption of specific food groups such as grains, roots and tubers, legumes and nuts, flesh foods, eggs, and other fruits and vegetables with marginal effects of 8.3%, 4.2%, 11.2%, 3.7%, and 7.6% respectively. Children's consumption of vitamin A-rich fruits and vegetables correlates with their mother's occupation. Whether a child consumes dairy products, eggs, vitamin A-rich fruits, and vegetables is highly influenced by household wealth. The number of children in a household was associated with grains, roots and tubers, legumes and nuts, flesh fools, eggs, and vitamin A-rich fruits and vegetables with marginal effects of 11.9%, 5.3%, 5.4%, 2.5%, and 8.1%, respectively. Vitamin A-rich fruits and vegetables and other fruits and vegetables were statistically significant with ethnicity at 10%, 5% significant levels respectively. Overall, children's consumption of specific food groups was strongly associated with agro-ecological zones, child's age, mother's marital status, household wealth, and number of children in a particular household.

3.5. Multivariate Logistic Regression Results: Association Between Adequate Dietary Diversity, Socio-Demographic Factors, and agro-ecological zones

Table 5 presents the marginal effects of a child's adequate dietary diversity intake, socio-demographic factors, and AEZs. The study used ADDS as the dependent variable and AEZ as the primary variable and controlled for other covariates. They are divided into two-part models. Model 1 used an adequate dietary diversity score (ADDS) as a dependent variable and AEZ as a dependent variable and controlled for only child-level factors. Models 2 use ADDS as a dependent variable and AEZ as a dependent variable and adjusted for child, maternal, household/community-level characteristics. In Model 1, the analysis showed that AEZs including transitional zone, tropical rainforest, coastal savannah were statistically significant at a 1% level with ADDS. The Savannah zone was significant at a 10% level with ADDS. The child's age was highly significant with the ADDS. In model 2, after controlling the child's, mother's, and household characteristics, it was found that AEZs, such as transitional zone, tropical rainforest, and coastal savannah, were highly significant with ADDS. Also, socio-demographic characteristics such as child's age, mother's marital status, mother's and the number of children in the household influenced the child's ADDS. Mothers' education and household wealth were statistically significant at 5%. In comparison, ethnicity was 10% statistically with ADDS. Moreover, this current study showed no correlation between ADDS and child's gender, mother's age, and birth order.

Table 5. Marginal effects of adequate dietary diversity score, agro-ecological zones, and selected characteristics

Variables	Model 1 Marginal effects	Model 2 Marginal effects
Agro-ecological zones		
Savannah	0.009* (0.013)	0.017* (0.016)
Transitional zone	0.077*** (0.021)	0.093*** (0.023)
Tropical forest	0.137*** (0.020)	0.127*** (0.019)
Coastal savannah	0.106*** (0.025)	0.113*** (0.026)
Deciduous Forest	Ref.	Ref.
Child Characteristics		
Child's gender	0.010 (0.012)	0.013 (0.012)
Child's age	-0.069*** (0.013)	-0.069*** (0.012)
Birth order	-0.007 (0.005)	-0.007 (0.007)
Mother characteristics		
Marital status	N/A	0.070***
Mother's occupation	N/A	0.011* (0.005)
Mother's age	N/A	0.005 (0.010)
Mother's education	N/A	0.022** (0.008)
Household/community characteristics		
Household wealth	N/A	0.014** (0.005)
Household children	N/A	0.069*** (0.016)
Ethnicity	N/A	0.009* (0.005)

Note: standard errors are in parenthesis, Ref=reference, ***p < 0.001, **p < 0.05 and *p<0.10

The marginal effects from the multivariate logistics regression model show that the probability of children having adequate dietary diversity scores differed across different AEZs. For instance, the probability of children having adequate dietary diversity in a tropical rain forest is 0.127 (12.7), in coastal savannah 0.113 (11.3%), in transitional zone 0.093 (9.3%), and in savannah 0.017 (1.7%). Children's age had a negative relationship with ADDS. The negative relationship means increasing the child's age by a month decreases the ADDS by 6.9%. Mother's education and household wealth positively correlated ADDS with 2.2% and 1.4% marginal effects, respectively. The positive results show that an increase in the mother's level of education improves the ADDS of the child, and at the same time, an increase in household wealth also increases the child's ADDS by 1.4%. The factors such as the mother's marital status, mothers' occupation, number of children in the household, and ethnicity had a positive relationship with ADDS with marginal effects of 7.0%, 1.1%, 6.9%, and 0.9%, respectively. Generally, children from tropical rain forests had a higher probability of having adequate dietary diversity, followed by coastal savannah, transitional zone, and savannah. Overall, the children from high-potential AEZ's favorable for agricultural production had a higher marginal effect than their counterparts who lived in AEZs vulnerable to climate changes and not suitable for food production. The results confirm the hypothesis that child adequate dietary diversity is influenced by agro-ecological zone due to different agricultural potentials and production.

4. Discussion

Dietary diversity is widely used to measure a child's nutritional adequacy in individual and household levels in many food security studies [76,77,78]. In all the agro-ecological zones of Ghana, the child's nutritional adequacy is low, with a mean dietary diversity score of 2.23 out of 7. Similar findings have also been reported in several child nutrition studies in Ghana [43,79]. The savannah zone is the most affected AEZ, with the lowest average dietary diversity score of 1.7. The DDS from the study confirms the hypothesis that children from low potential AEZs are likely to suffer from dietary diversity due to poor climatic conditions that limit agricultural production and crop varieties. These study findings of children's consumption of monotonous food are consistent with studies by Gyampoh et al. [80] and Roba et al. [81]. They reported that seasonal changes and climatic conditions in different agro-ecological zones affect food production and children's food intake.

The consumption of specific food groups and adequate dietary diversity differ across different AEZs, and consumption of specific food groups is restricted to a few. To improve nutritional adequacy and decrease the prevalence of malnutrition and its adverse effects on children under five years, children need to consume different varieties of diets [82]. The study revealed that children's average intake of vitamin A-rich fruits and vegetables is higher in tropical rainforests (6.8%) than in the savannah zone (2.6%). These findings align with a similar study conducted by Fanzo et al. [83], which reported that climate affects food production and nutrition intake. There is a significant difference in children's daily intake of adequate dietary diversity across all agro-ecological areas, with the maximum at 22.5% and the lowest at 7.5%. In all the AEZs, the food consumed most is grains, roots, and tubers, with an average daily intake ranging from 45.6% to 49.6% of the total food consumption. However, the least consumed food group is vitamin A-rich fruits and vegetables, with an average daily intake ranging from 2.6% to 10.0%. Again, in this study, the probability of children having adequate dietary diversity ranged from 1.7% to 12.7% along AEZs (Table 5). The high prevalence of adequate dietary diversity was reported in the agro-ecological zones that are resilient to climate change and have a high potential for food production. They include tropical rain forests (12.7%), coastal savannah (11.3%), and transitional zones (9.3%). The findings of this current study are consistent with similar studies by Chakona & Shackleton [9] in South Africa and Dulal et al. [84] in Nepal. The studies of Chakona & Shackleton and Dulal et al. reported that the magnitude of children's adequate dietary diversity intake varied in the AEZ due to differences in agro-ecological potentials.

The disparities of adequate dietary diversity across AEZs and lack of varied diets are in large part due to Ghana's geography characterized by different climatic conditions and a lack of food-based techniques to improve agricultural production. It has also been reported in similar studies by Fischer et al. [85]. Fischer et al. found that proper application of AEZ procedures helps detect crop suitability of prevailing climate, soil and terrain resources, and land productivity potentials to improve agricultural productivity and limit food insecurity across different geographical areas. Vulnerable farming households face major challenges in Ghana due to severe climatic stress in many agro-ecological areas. While farming households in the tropical rain forest, transitional zone, coastal Savannah zone are the least vulnerable, farming households in the deciduous forest and savannah have higher vulnerability distributions regarding exposure and adaptive potential [86]. The threat posed by climatic stress affects most vulnerable farming household agricultural production and yields. It limits food availability and utilization and different nutritional intake in different agro-ecological zones. Again, agriculture in Ghana is primarily rain-fed. Although farmers in certain agro-ecological zones benefit from two rainy seasons, others have inconsistent rainfall with extended dry intervals, limiting their ability to produce more food.

Our analysis revealed a strong correlation between agro-ecological zones and specific food groups, adequate dietary diversity scores, and socio-demographic factors. Except for legumes and nuts, a significant positive association was found between specific food groups and AEZs. After adjusting other covariates in the multivariate logistic regression model, the study observed high statistically significant differences between AEZs and adequate dietary diversity scores. These observations from the current study are consistent with Buri et al. [87] in Ghana, Devendra, and Thomas [88], and Khan and Akhtar [89]. Buri et al. observed that managing and maintaining soil fertility has been a major problem in Ghana, leading to varying crop production throughout the country's agro-ecological zones. Devendra and Thomas [88] argued that proper agricultural practices, including soil management, proper irrigation system, and mixed farming, can promote sustainable agriculture and improve the productivity of many crops. Fischer et al. [90] argued that global environmental changes, especially climate change, are likely to change the conditions and distribution of land suitability and crop yield, influencing dietary diversity and, therefore, the nutritional quality of children. In Ghana, demand for specific food groups exceeds supply due to seasonal changes, inaccessible areas, and increased prices. Simultaneously, certain farmers in various agro-ecological zones produce agricultural goods in excess of demand due to favorable climatic conditions. The short supply and price changes have a detrimental impact on producers and consumers, and vulnerable groups such as children and women bear more consequences. As hypothesized by this current study, the child's consumption of particular food groups and adequate dietary intake are influenced by the agro-ecological location of the child.

Again, the current analysis has shown that socio-demographic factors also influence adequate dietary diversity intake. The study revealed in model 1 that a child's age is highly significant. The correlation between socio-demographic characteristics and adequate dietary diversity remained significant after adjusting maternal and household/community (model 2). Marital status, mother's education and occupation, number of children in household, household wealth, and ethnicity were statistically significant with adequate dietary diversity intake. The findings from this current study are consistent with Amugsi et al. [91] in Ghana, Ogechi et al. [92], Ali et al. [93] in Bangladesh. The studies above highlighted that Children from higher-income families have a more diverse diet and are less likely to be malnourished.

Furthermore, our analysis shows that children who had mothers with higher socioeconomic status have a higher probability of having adequate dietary diversity. For instance, household wealth, mother's education, and mother's occupation positively correlated with adequate dietary diversity. The above results mean that employed mothers', an increase in household wealth, and the level of education of a mother increases child ADDS. Similar outcomes were found by Estaquio et al. [94], Deshmukh-Taskar [95], Gupta and Mishra [96]. Children's gender, children's age, mother's age, ethnicity, and the number of children in the household were other important variables affecting children's dietary diversity intake, a result consistent with Subramanian and Deaton [97], Kossioni and Bellou [98], Waibel [99]. Over the past 20 years, Ghana has made progress in reducing poverty and improving the malnutrition situation among its population. However, malnutrition persists, mostly in deprived communities. Children from higher socioeconomic status consume varieties of food and have adequate nutrition. High-income households and employed mothers can afford to use their extra income to buy food items and are expected to have more food accessibility and food choices. High-educated mothers are more likely to have in-depth knowledge about nutritious food and the health benefits of different food items.

The data used in this study have specific strengths and limitations. One strength of our research is that we analyzed the dietary diversity of under-five-year-old children in Ghana using nationally representative dietary data from GDHS. Second, the DHS's 24-hour recall process is almost the shortest recall cycle and is deemed more reliable than the longer period because it reduces participants' memory burden and potential recall bias. One limitation of the data used is that the dietary data was only one recall, and recall bias could affect the results. Additional dietary diversity scores in different periods/seasons may help better understand the research population's true dietary diversity. Also, self-reporting dietary data in a food-deprived community could add a potential prejudice since respondents may believe that underreporting intake provided an incentive for food assistance.

5. Conclusion

Inadequate dietary diversity intake poses serious health problems to under-five-year-old children in Ghana. This study explored the relationship between agro-ecological zones and food groups, nutritional adequacy consumed by children, and the magnitude of nutritional adequacy. The study has determined that in Ghana, agro-ecological potentials substantially influence children's nutritional adequacy intake, consumption of varieties of foods, and the different magnitude of dietary adequacy across all the agro-ecological zones. The study has also shown that various socio-demographic characteristics, including child's age, marital status, mother's occupation, mother's educational level, household wealth, ethnicity, and the number of children in household, significantly affect the adequate nutritional intake. The average dietary diversity score was low, 2.23 out of 7 among under-five-year children. The overall prevalence of adequate dietary diversity varies between 7.5% and 22.5% across agro-ecological zones.

In summary, there is a need for nutritional intervention in Ghana to improve children's dietary diversity and nutritional adequacy. An effort to intensify food production would help achieve 2030 sustainable development goals by ending hunger and reducing child mortality by improving child nutritional adequacy. Ghana needs a national policy to improve children's nutritional adequacy dietary diversity and bridge the gap of nutritional adequacy differences among agro-ecological needs to implement agricultural policies that promote an enabling environment for agricultural production. The introduction of climate-smart agriculture, particularly to areas vulnerable to severe climatic stress, can help reduce the effect of climate change, strengthen sustainable agricultural food production, and hence food availability and nutrition adequacy.

Conflicts of Interest The authors declare no conflict of interest relevant to the content of this article.

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