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Agricultural Diversification, Nutrition and Health Outcomes in Nigeria: Evidence from an ARDL Time-Series Analysis, 1990–2024

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Abstract

This study examines long-run and short-run relationships between agricultural diversification, nutrition and health outcomes in Nigeria using annual time-series data covering 1990–2024. Agricultural diversification is represented by a composite index incorporating crop, land-use and agricultural value-added diversity, while nutrition and health outcomes are measured using composite deprivation indices. The study employs Augmented Dickey-Fuller (ADF) unit root test, Autoregressive Distributed Lag (ARDL) bounds testing and error-correction modelling. The ARDL bounds tests indicate long-run relationships in nutrition and health models, with F-statistics of 4.933 and 14.327, respectively, exceeding their reported 5% upper critical bounds. The long-run estimates reveal a positive but statistically insignificant association between agricultural diversification and nutrition deprivation ($\beta = 0.116$, $p = 0.896$). Conversely, agricultural diversification exhibits a negative and statistically significant association with health deprivation ($\beta = -1.287$, $p < 0.001$). The short-run relationship with health deprivation is also negative and statistically significant ($\beta = -2.974$, $p < 0.001$). The error-correction coefficients of −0.662 and −1.156 for the nutrition and health models, respectively, indicate adjustment towards long-run equilibrium, with evidence of overshooting in the health model. However, residual serial correlation, borderline functional-form diagnostics and unresolved integration-order concerns necessitate cautious interpretation. The findings provide stronger statistical evidence of an association between agricultural diversification and health deprivation than between diversification and nutrition deprivation within the estimated models. The study recommends integrating agricultural diversification initiatives with policies that improve dietary quality, food accessibility, sanitation, healthcare delivery and household purchasing power to support sustainable improvements in nutritional and population-health outcomes.

Keywords: Agricultural Diversification, Nutritional Status, Dietary Diversity, Health Outcomes, ARDL.

Introduction

Agricultural diversification involves expanding agricultural production through crop diversity, livestock integration and cultivation of nutrient-rich crops to improve food security, dietary diversity and household welfare (Di Bene et al., 2022). It may contribute to improved nutrition by increasing access to diverse foods and reducing malnutrition, commonly measured through stunting, wasting, underweight and micronutrient

deficiencies (Barman et al., 2022). Agricultural diversification may also influence health outcomes, including life expectancy, infant mortality, under-five mortality and maternal mortality.

The relationship between agricultural diversification, nutrition and health operates through direct consumption of nutrient-rich foods and indirect income generation that improves access to food and healthcare services (Ruel et al., 2018). However, these benefits depend on market accessibility, household income, gender and socioeconomic conditions (Tacconi et al., 2022; Khonje et al., 2022).

Agriculture has historically contributed substantially to Nigeria's economy, providing employment, food and export earnings. However, increasing dependence on petroleum reduced its relative contribution to national output, with agriculture accounting for approximately 20–26% of GDP in recent years (World Bank, 2023; FAO, 2022). Agricultural policies have largely emphasised staple crops such as maize, cassava and rice, improving food production without necessarily ensuring adequate dietary diversity and nutritional well-being (Ruel et al., 2018).

Despite Nigeria's agricultural potential, malnutrition remains a major concern, with persistent child stunting, micronutrient deficiencies and increasing cases of overweight and obesity (FAO et al., 2023; United Nations Children's Fund, 2024). Although agricultural diversification offers opportunities for improving nutrition and health, its benefits are influenced by household purchasing power, sanitation, healthcare access and broader economic conditions. Furthermore, existing Nigerian studies have largely focused on household food security and dietary diversity, with limited national time-series evidence distinguishing nutritional outcomes from broader population-health outcomes.

Against this background, this study examines the long-run and short-run relationships between agricultural diversification, nutrition and health outcomes in Nigeria from 1990 to 2024 using the Autoregressive Distributed Lag (ARDL) approach. Specifically, it investigates the separate relationships of agricultural diversification with nutrition and health deprivation while accounting for selected demographic and macroeconomic factors. The study provides national-level evidence to inform agricultural, nutritional and public-health policies.

Statement of the Problem

Although agricultural diversification can expand food variety and household income opportunities, Nigeria continues to experience substantial nutritional and health challenges, including child malnutrition, micronutrient deficiencies and preventable mortality. Greater agricultural production diversity does not necessarily result in equivalent improvements in dietary intake and health because both outcomes depend on purchasing power, sanitation, market access, healthcare provision and other socioeconomic conditions.

Existing Nigerian studies largely emphasize household food security, livelihoods and dietary diversity, frequently using cross-sectional or subnational data. Comparatively little national-level time-series evidence distinguishes the long-run and short-run relationships

of agricultural diversification with composite nutrition deprivation from those with composite health deprivation. This distinction matters because programmes that increase agricultural variety may require separate nutrition and health-system interventions to improve human well-being.

Objectives of the Study

The general objective is to examine the long-run and short-run relationships between agricultural diversification, nutrition and health outcomes in Nigeria over the period 1990–2024. Specifically, the study seeks to:

i. examine the long-run and short-run relationships between agricultural diversification and nutrition outcomes;
ii. investigate the corresponding relationships between agricultural diversification and health outcomes; and
iii. explore the joint dynamic relationships and differences in the reported associations across the two outcomes.

Research Questions

What are the long-run and short-run relationships between agricultural diversification and nutrition outcomes in Nigeria?

What are the long-run and short-run relationships between agricultural diversification and health outcomes in Nigeria?

How do the estimated relationships and adjustment dynamics differ across nutrition and health outcomes?

Research Hypotheses

H_{01}: Agricultural diversification has no statistically significant long-run relationship with nutrition outcomes in Nigeria. H_{11}: Agricultural diversification has a statistically significant negative long-run relationship with the composite nutrition-deprivation index.

H_{02}: Agricultural diversification has no statistically significant long-run relationship with health outcomes in Nigeria. H_{12}: Agricultural diversification has a statistically significant negative long-run relationship with the composite health-deprivation index.

Literature Review

Conceptual Review

Agricultural Diversification

Agricultural diversification involves cultivating different crops, integrating livestock and adopting complementary farming practices to improve food availability, income stability and household welfare. In Nigeria, where smallholder farming remains an important livelihood activity, diversification may reduce production risks, strengthen food security and improve nutrition and health outcomes (Ogunniyi et al., 2021). Major forms include

crop diversification, livestock integration and mixed farming systems, which promote efficient resource utilisation and increase access to diverse food products.

Agricultural diversification differs from livelihood diversification, which includes agricultural and non-agricultural income-generating activities. Oke and Ogundokun (2023) highlighted the relevance of household socioeconomic characteristics and livelihood activities to food security in Oyo State. Agricultural diversification may improve welfare through direct consumption of nutrient-rich foods and income generation for purchasing food and accessing healthcare. However, these benefits depend on market access, household income and other socioeconomic conditions.

Nutrition Outcomes

Nutrition outcomes reflect dietary adequacy, nutrient intake and nutritional status, commonly assessed through dietary diversity, micronutrient adequacy, stunting, wasting and underweight. Agricultural diversification may improve nutrition by increasing the availability of cereals, legumes, vegetables, fruits and animal-source foods. Kolliesuah et al. (2023) highlighted the importance of socioeconomic and household factors in determining dietary diversity.

However, increased agricultural production diversity does not automatically guarantee improved nutritional status because food affordability, household resource allocation, market access and nutrient utilisation also influence dietary outcomes. This study measures nutrition using a composite nutrition-deprivation index, where higher values indicate poorer nutritional conditions.

Health Outcomes

Health outcomes reflect population well-being through indicators such as life expectancy, infant mortality, under-five mortality and maternal mortality. Agricultural diversification may be associated with improved health through better food consumption, income stability and increased access to healthcare. However, these relationships are influenced by sanitation, healthcare delivery, household income and socioeconomic conditions.

Doss (2018) emphasised the importance of gender and resource allocation in agricultural productivity, highlighting the relevance of household decision-making to welfare outcomes. Unlike nutritional indicators, population-health outcomes reflect broader demographic and institutional conditions. Accordingly, this study employs a composite health-deprivation index, with higher values indicating poorer health outcomes.

Empirical Evidence from Nigeria

Agricultural Diversification, Food Security and Livelihood Resilience

Empirical studies in Nigeria demonstrate the importance of agricultural activities and household resources in determining food security. Ogunniyi et al. (2021) identified socioeconomic factors associated with food security among smallholder maize farmers, while Babatunde and Qaim (2010) established the relevance of off-farm income to

household food security and nutrition. Similarly, Oke and Ogundokun (2023) examined household socioeconomic characteristics and food security in Oyo State.

These studies indicate that agricultural and livelihood opportunities contribute to household welfare. However, their emphasis on household conditions and income diversification differs from the national agricultural-production diversification index employed in the present study.

Agricultural Activities and Nutritional Outcomes

Amare et al. (2020) examined the role of agriculture in reducing child undernutrition in Nigeria, highlighting the relevance of agricultural and consumption-related factors. Similarly, Babatunde and Qaim (2010) associated additional income opportunities with improved household nutritional welfare. These findings suggest that agricultural production and household purchasing power are important for nutrition, although improved agricultural output does not necessarily translate directly into better nutritional status.

Unlike these household-level investigations, the present study examines the long-run and short-run relationships between agricultural diversification and a national composite nutrition-deprivation index.

Agricultural Development and Health Outcomes

Existing Nigerian empirical studies have largely concentrated on food security, dietary diversity and child nutrition, with comparatively limited attention to national population-health indicators. Although agricultural diversification may support health through improved food availability and household income, its relationship with life expectancy and mortality depends on broader conditions, including healthcare provision, sanitation and socioeconomic development. Therefore, examining health deprivation separately from nutritional deprivation provides additional insight into the relationship between agricultural development and human well-being.

Methodological Synthesis and Research Gap

The reviewed studies establish the importance of agricultural activities, income and socioeconomic conditions in explaining household food security and nutrition. However, most rely on household surveys and cross-sectional approaches, providing limited evidence of national long-run and short-run relationships.

Furthermore, relatively few of the reviewed Nigerian studies distinguish agricultural diversification's relationship with nutritional deprivation from its relationship with broader population-health deprivation. This study addresses the identified gap using separate Autoregressive Distributed Lag (ARDL) models and annual national data covering 1990–2024. The analysis provides evidence of conditional relationships between agricultural diversification, nutrition and health deprivation, rather than establishing causal effects.

Methodology

Theoretical Framework

This study is anchored in Becker's (1965) Household Production Theory, Singh et al.'s (1986) Agricultural Household Model and Markowitz's (1952) Portfolio Theory. These theories explain the relationships between agricultural diversification, nutrition and health outcomes through household consumption, income generation and risk management.

Becker's (1965) theory suggests that agricultural diversification may improve nutrition and health through increased food availability and household income. Similarly, Singh et al. (1986) emphasize the interdependence of agricultural production and consumption decisions, particularly under imperfect market conditions. Markowitz's (1952) Portfolio Theory explains how diversification reduces production risks and income instability, potentially improving food security and access to healthcare.

Collectively, these theories provide the foundation for examining agricultural diversification's relationship with nutrition and health outcomes. However, the estimated models establish conditional statistical associations rather than causal relationships.

Model Specification

The study employs two Autoregressive Distributed Lag (ARDL) models to examine the long-run and short-run relationships between agricultural diversification and nutrition and health deprivation in Nigeria. The ARDL approach is adopted because it permits the estimation of conditional level relationships involving variables integrated of order zero, I(0), and order one, I(1), if none of the model variables is integrated of order two, I(2).

The nutrition model is specified as:

Model 1a (nutrition): $NTRI_t = \beta_0 + \beta_1 AGRDV_t + \beta_2 LPOP_t + \beta_3 INF_t + \beta_4 LM2_t + \beta_5 LFPI_t + \beta_6 LSANS_t + \varepsilon_t$.

The health model is specified as:

Model 1b (health): $HLTHOUC_t = \alpha_0 + \alpha_1 AGRDV_t + \alpha_2 LHLTHEXP_t + \alpha_3 LPOP_t + \alpha_4 INF_t + \alpha_5 LM2_t + \upsilon_t$.

Where NTRI represents the composite nutrition-deprivation index, HLTHOUC denotes the composite health-deprivation index, and AGRDV represents the agricultural-diversification index. POP denotes total population, INF represents inflation, M2 denotes broad money supply, FPI represents the food production index, SANS indicates access to basic sanitation services, and HLTHEXP represents current health expenditure. The prefix L denotes the natural logarithm of the corresponding variable, while the composite indices and inflation are retained in levels.

The two models are estimated separately to examine the relationship between agricultural diversification and each dimension of deprivation while accounting for the selected control variables. The resulting coefficients are interpreted as conditional associations rather than causal effects.

Estimation Procedures

The study employs descriptive statistics, correlation analysis, Augmented Dickey–Fuller (ADF) unit-root tests, Autoregressive Distributed Lag (ARDL) bounds testing, error-correction modelling and diagnostic tests. Descriptive statistics and correlation analysis examine variable distributions, relationships and potential multicollinearity, while ADF tests assess stationarity and the integration orders required for ARDL estimation.

The ARDL bounds-testing approach of Pesaran et al. (2001) examines conditional long-run relationships, while error-correction modelling estimates short-run dynamics and adjustment towards equilibrium. Model adequacy is assessed using Breusch–Godfrey serial-correlation, ARCH-LM heteroskedasticity, Jarque–Bera normality and Ramsey RESET tests.

Data and Composite-Index Measurement

The study uses 35 annual observations covering Nigeria from 1990 to 2024, obtained from World Bank Development Indicators, FAOSTAT, UNICEF/WHO/World Bank Joint Malnutrition Estimates, Nigeria Demographic and Health Surveys, and Central Bank of Nigeria.

Agricultural diversification is measured using a composite index of crop, land-use and agricultural value-added diversity. Nutrition and health outcomes are represented by composite deprivation indices, with higher values indicating poorer outcomes. The health index incorporates life expectancy, infant mortality, under-five mortality and maternal mortality. Population, health expenditure, money supply, food production and sanitation variables are logarithmically transformed, while inflation and the composite indices remain in levels.

Theoretical Framework

This study is anchored in Becker's (1965) Household Production Theory, Singh et al.'s (1986) Agricultural Household Model and Markowitz's (1952) Portfolio Theory. These theories explain how agricultural diversification may influence nutrition and health outcomes through food consumption, income generation, resource allocation and risk management. Becker's (1965) theory suggests that diversified agricultural production may improve household welfare through increased food availability and income for healthcare. Similarly, Singh et al. (1986) emphasise the interdependence of agricultural production and consumption decisions, particularly under imperfect market conditions. Markowitz's (1952) Portfolio Theory explains how diversification reduces production risks and income instability, potentially improving household food security and access to healthcare.

Collectively, these theories provide the foundation for examining agricultural diversification's relationship with nutrition and health outcomes. However, nutritional outcomes depend more directly on dietary intake, while health outcomes are additionally influenced by sanitation, healthcare access and socioeconomic conditions. The estimated

models therefore examine conditional statistical associations rather than causal relationships.

Model Specification

The study employs the Autoregressive Distributed Lag (ARDL) modelling approach to examine the long-run and short-run relationships between agricultural diversification, nutrition and health outcomes in Nigeria over the period 1990–2024. The ARDL approach is suitable for analysing conditional level relationships involving variables integrated of order zero, I(0), and order one, I(1), provided none of the variables included in the estimated model is integrated of order two, I(2). The approach also allows for the examination of short-run adjustments through an error-correction representation (Pesaran et al., 2001).

To distinguish the relationships between agricultural diversification and the two dimensions of human well-being, separate models are specified for nutrition deprivation and health deprivation. The nutrition model incorporates agricultural diversification, population, inflation, broad money supply, food production and sanitation access, while the health model incorporates agricultural diversification, health expenditure, population, inflation and broad money supply.

Model 1a: Nutrition Outcomes

The functional relationship for the nutrition model is expressed as:

$$\mathrm{NTRI}_t = f(\mathrm{AGRDV}_t, \mathrm{LPOP}_t, \mathrm{INF}_t, \mathrm{LM2}_t, \mathrm{LFPI}_t, \mathrm{LSANS}_t) \qquad (1)$$

The corresponding econometric specification is:

$$\mathrm{NTRI}_t = \beta_0 + \beta_1 \mathrm{AGRDV}_t + \beta_2 \mathrm{LPOP}_t + \beta_3 \mathrm{INF}_t + \beta_4 \mathrm{LM2}_t + \beta_5 \mathrm{LFPI}_t + \beta_6 \mathrm{LSANS}_t + \varepsilon_t \qquad (2)$$

Model 1b: Health Outcomes

Similarly, the functional relationship for the health model is expressed as:

$$\mathrm{HLTHOUC}_t = f(\mathrm{AGRDV}_t, \mathrm{LHLTHEXP}_t, \mathrm{LPOP}_t, \mathrm{INF}_t, \mathrm{LM2}_t) \qquad (3)$$

The corresponding econometric specification is:

$$\mathrm{HLTHOUC}_t = \alpha_0 + \alpha_1 \mathrm{AGRDV}_t + \alpha_2 \mathrm{LHLTHEXP}_t + \alpha_3 \mathrm{LPOP}_t + \alpha_4 \mathrm{INF}_t + \alpha_5 \mathrm{LM2}_t + u_t \qquad (4)$$

Definition of Variables

NTRI = composite nutrition-deprivation index; HLTHOUC = composite health-deprivation index; AGRDV = agricultural diversification index; POP = total population; INF = inflation rate; M2 = broad money supply; FPI = food production index; SANS = sanitation access; and HLTHEXP = current health expenditure. The prefix L denotes the natural logarithm of the corresponding variable, while *t* denotes time. The parameters β_0 and α_0 are intercepts; β_1–β_6 and α_1–α_5 are regression coefficients; and ε_t and u_t represent stochastic error terms.

Note: Equations (1)-(4) represent the functional and static econometric relationships underlying the two ARDL models. The complete dynamic ARDL specifications additionally include lagged variables and short-run adjustment terms.

Estimation Procedures

The study employs descriptive statistics, correlation analysis, Augmented Dickey–Fuller (ADF) unit-root tests, ARDL bounds testing, error-correction modelling and diagnostic tests. Descriptive statistics and correlation analysis examine variable distributions, relationships and potential multicollinearity, while ADF tests assess stationarity to ensure that no variable is integrated beyond order one. The ARDL bounds-testing approach of Pesaran et al. (2001) examines conditional long-run relationships, while error-correction modelling estimates short-run dynamics and adjustment towards equilibrium. Model adequacy is assessed using Breusch–Godfrey serial-correlation, ARCH-LM heteroskedasticity, Jarque–Bera normality and Ramsey RESET tests.

Data and Composite-Index Measurement

The study uses 35 annual observations covering Nigeria from 1990 to 2024, obtained from World Bank World Development Indicators, FAOSTAT, UNICEF/WHO/World Bank Joint Malnutrition Estimates, Nigeria Demographic and Health Surveys, and the Central Bank of Nigeria. Agricultural diversification is measured using a composite index of crop, land-use and agricultural value-added diversity. Nutrition and health are represented by composite deprivation indices, with higher values indicating poorer outcomes. The health index incorporates life expectancy, infant mortality, under-five mortality and maternal mortality. Population, health expenditure, money supply, food production and sanitation variables are logarithmically transformed, while inflation and the composite indices remain in levels. The descriptions, measurements and sources of the study variables are presented in Table 1.

Table 1: Description and Sources of Data

Variable	Description / Measurement	Source	Period
AGRDV	Agricultural diversification index (composite measure of crop, land-use and value-added diversity)	FAOSTAT; World Bank WDI	1990-2024
NTRI	Composite nutrition index (higher value = worse nutrition outcomes)	UNICEF/WHO/World Bank Joint Malnutrition Estimates; NDHS	1990-2024
HLTHOUC	Composite health-outcomes index (higher value = worse health outcomes)	World Bank WDI (life expectancy, infant and under-5 mortality, maternal mortality)	1990-2024
HLTHEXP	Current health expenditure (% of GDP)	World Bank WDI (SH.XPD.CHEX.GD.ZS)	1990-2024
POP	Total population (millions)	World Bank WDI	1990-2024
INF	Inflation, consumer prices (annual %)	World Bank WDI; Central Bank of Nigeria	1990-2024

Variable	Description / Measurement	Source	Period
M2	Broad money supply (% of GDP)	World Bank WDI; Central Bank of Nigeria	1990-2024
FPI	Food production index (2014-2016=100)	FAOSTAT; World Bank WDI	1990-2024
SANS	People using at least basic sanitation services (% of population)	World Bank WDI	1990-2024

The variables presented in Table 1 reflect agricultural, demographic, economic and health-related conditions that may influence nutritional and population-health outcomes. Agricultural diversification serves as the principal explanatory variable, while the remaining explanatory variables are selected to account for relevant socioeconomic and institutional conditions. The composite nutrition and health indices are interpreted as deprivation measures, such that higher scores indicate poorer outcomes.

The index-construction procedures, including component selection, orientation, standardisation, weighting and aggregation, require documentation from the original data-processing records. These procedures are necessary to establish the reproducibility and interpretation of the composite indices.

A Priori Expectations

The expected relationships between the explanatory variables and nutrition and health deprivation are informed by the theoretical frameworks and previous empirical literature. Agricultural diversification is expected to exhibit negative relationships with both deprivation indices because increased agricultural diversity may improve the availability of nutrient-rich foods and support household income generation.

Population growth may increase pressure on food supplies and healthcare services, although its relationship with health outcomes may depend on wider socioeconomic conditions. Inflation is expected to worsen deprivation by reducing household purchasing power, while improved sanitation and healthcare expenditure are expected to support better health-related conditions. Increased food production may also contribute to nutritional welfare through improved food availability.

The theoretical expectations concerning the explanatory variables are summarised in Table 2.

Table 2: A-priori Expectations of Model Variables

Variable	Expected sign on NTRI (higher = worse nutrition)	Expected sign on HLTHOUC (higher = worse health)	Justification
AGRDV	Negative	Negative	Diversification improves dietary variety and household income, lowering malnutrition and health deprivation

Variable	Expected sign on NTRI (higher = worse nutrition)	Expected sign on HLTHOUC (higher = worse health)	Justification
HLTHEXP	-	Negative	Higher health spending improves service delivery, lowering health deprivation
POP	Positive	Positive/Ambiguous	Larger population raises pressure on food and health systems but may expand the tax/financing base
INF	Positive	Positive	Inflation erodes purchasing power for food and health services, worsening both outcomes
M2	Negative	Negative	Higher money supply reflects economic activity/liquidity supporting agriculture and health financing
FPI	Negative	-	Higher aggregate food production supports dietary adequacy
SANS	Negative	Negative	Better sanitation access reduces disease burden and improves nutrient absorption

As indicated in Table 2, the anticipated signs reflect theoretical expectations rather than predetermined empirical outcomes. These expectations provide a basis for interpreting whether the estimated coefficients are consistent with the proposed relationships. Variables not included in a particular model are not assigned an empirical coefficient in that model.

Results and Discussion

Descriptive Statistics

The descriptive statistics of the variables employed in the study over the period 1990–2024 are presented in Table 3. The analysis covers agricultural diversification (AGRDV), nutrition deprivation (NTRI), health deprivation (HLTHOUC), health expenditure (HLTHEXP), population (POP), inflation (INF), broad money supply (M2), food production index (FPI) and sanitation access (SANS). The statistics provide information on the central tendencies, dispersion and distributional characteristics of the variables before formal econometric estimation.

Table 3: Descriptive Statistics of Study Variables (1990-2024)

Statistic	AGRDV	NTRI	HLTHOUC	HLTHEXP	POP	INF	M2	FPI	SANS
Mean	-0.030	0.039	0.089	3.373	153.721	21.269	18.171	79.786	36.271
Std. Dev.	0.447	1.755	1.948	0.238	40.290	15.265	4.083	24.643	5.492
Minimum	-0.528	-3.106	-2.918	3.000	95.600	6.900	9.000	45.000	28.000
Maximum	0.988	3.181	2.993	3.900	227.900	72.800	25.000	118.600	46.500
Skewness	1.095	-0.319	0.091	0.537	0.301	2.303	-0.485	0.120	0.192
Kurtosis	0.046	-0.652	-1.565	-0.475	-1.121	4.917	-0.023	-1.449	-1.100
Jarque-Bera	6.424	1.319	3.400	2.024	2.359	52.536	1.306	3.005	2.013
J-B p-value	0.040	0.517	0.183	0.363	0.307	0.000	0.520	0.223	0.366

The results in Table 3 indicate that agricultural diversification recorded a mean value of −0.030 and a standard deviation of 0.447, with minimum and maximum values of −0.528 and 0.988, respectively. These values indicate variation in the agricultural-diversification index over the study period. The nutrition-deprivation index recorded a mean value of 0.039 and a standard deviation of 1.755, while the health-deprivation index recorded a mean of 0.089 and a standard deviation of 1.948. The relatively large standard deviations of the deprivation indices indicate considerable variation over the period.

Health expenditure recorded a mean value of 3.373, while population averaged 153.721 million. Inflation exhibited substantial variability, with a mean of 21.269%, a standard deviation of 15.265 and a maximum value of 72.800%. The observed variability reflects the changing macroeconomic conditions experienced in Nigeria during the study period.

The Jarque–Bera statistics further provide information concerning the normality of the variables. Inflation exhibited a statistically significant departure from normality ($p < 0.001$), while agricultural diversification also departed significantly from normality at the 5% level ($p = 0.040$). In contrast, the remaining variables did not exhibit statistically significant departures from normality based on the reported probabilities. These distributional characteristics provide preliminary information about the variables, although they do not independently establish causal relationships or the time-series properties required for econometric estimation.

Correlation Analysis

Correlation analysis was conducted to examine the preliminary associations among the variables and identify potential multicollinearity among the explanatory variables. The pairwise correlation coefficients for agricultural diversification, nutrition deprivation, health deprivation and the selected control variables are presented in Table 4.

Table 4: Correlation Matrix (Pairwise Correlation Matrix of Study Variables)

	AGRD	NTRI	HLTHOUC	HLTHEXP	POP	INF	M2	FPI	SANS
AGRDV	1.000	-.701	-0.816	0.675	0.909	-.090	0.754	0.885	0.893
NTRI	-0.701	1.000	0.796	-0.830	-.839	0.359	-.867	-.826	-.817
HLTHOUC	-0.816	0.796	1.000	-0.706	-.973	0.376	-.889	-.988	-.978
HLTHEXP	0.675	-.830	-0.706	1.000	0.726	-.409	0.629	0.733	0.696
POP	0.909	-.839	-0.973	0.726	1.000	-.317	0.925	0.995	0.998
INF	-0.090	0.359	0.376	-0.409	-.317	1.000	-.420	-.340	-.332
M2	0.754	-.867	-0.889	0.629	0.925	-.420	1.000	0.909	0.931
FPI	0.885	-.826	-0.988	0.733	0.995	-.340	0.909	1.000	0.995
SANS	0.893	-0.817	-0.978	0.696	0.998	-.332	0.931	0.995	1.000

Table 4 shows that agricultural diversification is negatively correlated with nutrition deprivation (r = −0.701) and health deprivation (r = −0.816). These negative associations suggest that higher agricultural-diversification scores are observed alongside lower deprivation scores within the sample. The relationships are consistent with the expected directions proposed in the theoretical framework, although correlation coefficients do not establish causation.

The nutrition-deprivation index is positively correlated with health deprivation (r = 0.796), suggesting that the two dimensions of deprivation exhibit related patterns over the study period. However, they remain conceptually distinct because nutritional deprivation principally concerns dietary and nutritional conditions, whereas health deprivation encompasses broader indicators of survival and mortality.

The correlation matrix also reveals exceptionally strong relationships among several explanatory variables. Population and sanitation access exhibit a correlation coefficient of 0.998, while population and food production are correlated at 0.995. Food production and sanitation access similarly exhibit a correlation coefficient of 0.995. Such high correlations raise concerns about potential multicollinearity and the influence of common trends within the time-series data.

These relationships are important because highly correlated explanatory variables may reduce coefficient precision and complicate the interpretation of their estimated individual

relationships. Consequently, the correlation results provide justification for examining the stationarity properties and specification adequacy of the estimated econometric models.

Unit Root (Stationarity) Test

Before estimating the long-run relationships, the stationarity properties of the variables were examined using the Augmented Dickey–Fuller unit-root test. The test assesses whether the variables are stationary in their levels or require differencing to achieve stationarity. This procedure is important because the ARDL bounds-testing approach requires that no variable included in the estimated model be integrated of order two. The reported unit-root test results are presented in Table 5.

Table 5: Unit Root (Stationarity) Test (Augmented Dickey-Fuller (ADF) Unit Root Test Results)

Variable	ADF (level, trend)	Prob.	ADF (1st diff., constant)	Prob.	Order of integration
AGRDV	-1.928	0.640	-4.819*	0.000	I(1)
NTRI	-3.269**	0.071	-2.572	0.099	I(0)/I(1)[a]
HLTHOUC	-3.665**	0.025	-	-	I(0)
LHLTHEXP	-3.976***	0.009	-	-	I(0)
LPOP	-1.684	0.758	-1.830	0.365	I(1)[b]
INF	-2.145	0.521	-4.398***	0.000	I(1)
LM2	-2.700	0.236	-2.329	0.163	I(1)[b]
LFPI	-1.125	0.925	-1.144	0.697	I(1)[b]
LSANS	-3.672**	0.024	-	-	I(0)

The results in Table 5 indicate that agricultural diversification is non-stationary at level but becomes stationary after first differencing, with a reported first-difference ADF statistic of −4.819 and $p < 0.001$. Inflation also becomes stationary after first differencing, with an ADF statistic of −4.398 and $p < 0.001$. These results support their classification as I(1) variables.

The health-deprivation index is stationary at level at the 5% significance level ($p = 0.025$). Health expenditure and sanitation access are also stationary at level, with reported probabilities of 0.009 and 0.024, respectively. The nutrition-deprivation index exhibits evidence of level stationarity at the 10% significance level ($p = 0.071$), although its classification requires attention to the selected deterministic specification.

However, the reported results for population, broad money supply and food production do not establish stationarity after first differencing. Their respective first-difference probabilities of 0.365, 0.163 and 0.697 exceed conventional significance thresholds. Consequently, these variables cannot be confidently classified as I(1) based solely on the reported ADF results.

This limitation is particularly important because conventional ARDL bounds inference requires the exclusion of I(2) variables. Therefore, the integration properties of these variables must be verified before definitive conclusions are drawn from the bounds-test

results. The reported stationarity findings are retained for transparency, while their implications are recognised in interpreting the subsequent econometric estimates.

ARDL Bounds Cointegration Test

The ARDL bounds-testing approach was employed to investigate the existence of conditional long-run relationships between agricultural diversification and the two deprivation indices. The test examines the joint significance of the lagged level variables in each conditional error-correction specification. The calculated F-statistics are compared with the corresponding lower and upper critical bounds. The reported results for the nutrition and health models are presented in Table 6.

Table 6: ARDL Bounds Cointegration Test (ARDL Bounds Test Results)

Model	Dependent variable	F-statistic	I(0) bound (5%)	I(1) bound (5%)	Decision
Model 1a	NTRI	4.933	2.270	3.500	Cointegration confirmed
Model 1b	HLTHOUC	14.327	2.390	3.380	Cointegration confirmed

The results in Table 6 show that the nutrition model recorded an F-statistic of 4.933, exceeding the reported 5% upper critical bound of 3.500. Similarly, the health model recorded an F-statistic of 14.327, exceeding its reported 5% upper critical bound of 3.380. On the basis of the reported critical values, both statistics provide evidence against the null hypothesis of no level relationship.

These results suggest the presence of conditional long-run relationships among the variables included in the respective models. However, the validity of this interpretation depends on confirmation that the variables satisfy the integration-order requirements and that the critical values are appropriate for the selected model specifications.

The bounds-test results concern the joint relationships among the model variables and do not independently establish that agricultural diversification has a statistically significant long-run coefficient in either model. The individual relationships are therefore examined through the estimated long-run coefficients presented in the subsequent tables.

ARDL Long-Run Estimates

The long-run coefficients of the ARDL models were estimated to examine the conditional relationships between agricultural diversification and nutrition and health deprivation. The nutrition model incorporates agricultural diversification, population, inflation, broad money supply, food production and sanitation access, while the health model incorporates agricultural diversification, health expenditure, population, inflation and broad money supply. The estimated coefficients for the nutrition model are presented in Table 7.

Table 7: ARDL Long-Run Coefficients Dependent Variable: NTRI

Variable	Coefficient	Std. Error	t-statistic	Prob.
AGRDV	0.116	0.888	0.131	0.896
LPOP	57.023	13.653	4.177	0.000
INF	0.019	0.009	2.111	0.032
LM2	9.784	3.134	3.121	0.002
LFPI	25.462	11.864	2.146	0.032
LSANS	-114.927	17.103	-6.719	0.000
Constant	-33.659	30.759	-1.094	0.274

The results in Table 7 indicate that agricultural diversification exhibits a positive but statistically insignificant long-run relationship with nutrition deprivation (β = 0.116, p = 0.896). This finding suggests that the estimated model does not provide sufficient statistical evidence of an independent long-run relationship between agricultural diversification and the composite nutrition-deprivation index after accounting for the selected control variables.

The insignificant coefficient contrasts with the theoretical expectation that agricultural diversification may contribute to nutritional improvement through increased food variety and household income. However, this outcome may reflect the influence of factors determining whether agricultural production diversity translates into improved dietary consumption and nutritional status. Such factors include food affordability, market access, household income distribution and nutrient utilisation.

Population exhibits a positive and statistically significant coefficient of 57.023, indicating a positive conditional association with nutrition deprivation. Inflation is also positively associated with nutrition deprivation, with a coefficient of 0.019 and reported p-value of 0.032. This relationship is consistent with the expectation that increases in consumer prices may constrain household purchasing power and access to nutritious foods.

Broad money supply and food production exhibit positive coefficients of 9.784 and 25.462, respectively, contrary to their anticipated negative relationships with nutrition deprivation. These estimates require cautious interpretation because they may reflect interactions among strongly trending macroeconomic variables rather than straightforward economic relationships.

Sanitation access exhibits a negative and statistically significant coefficient of −114.927, consistent with the expectation that improved sanitation may be associated with lower nutritional deprivation. However, the unusually large magnitudes of several coefficients, together with the high correlations among the explanatory variables, indicate the need for caution in attributing independent economic meaning to the estimates. The corresponding long-run estimates for the health-deprivation model are presented in Table 8.

Table 8: ARDL Long-Run Coefficients Dependent Variable: HLTHOUC

Variable	Coefficient	Std. Error	t-statistic	Prob.
AGRDV	-1.287	0.088	-14.625	0.000

Variable	Coefficient	Std. Error	t-statistic	Prob.
LHLTHEXP	-1.623	0.296	-5.483	0.000
LPOP	11.899	0.244	48.766	0.000
INF	0.000	0.001	0.033	0.970
LM2	-3.870	0.147	-26.327	0.000
Constant	-45.463	1.515	-30.008	0.000

Table 8 shows that agricultural diversification exhibits a negative and statistically significant long-run relationship with health deprivation ($\beta = -1.287$, $p < 0.001$). Holding the included explanatory variables constant, a one-unit increase in the agricultural-diversification index is associated with a 1.287-unit decrease in the composite health-deprivation index. The negative coefficient is consistent with the theoretical expectation that agricultural diversification may support health-related welfare through improved food availability, income stability and access to essential services.

Health expenditure also exhibits a negative and statistically significant relationship with health deprivation ($\beta = -1.623$, $p < 0.001$). This association is consistent with the expectation that greater healthcare resources may support improvements in population-health conditions. However, the coefficient represents a conditional relationship and should not be interpreted as proof that increased spending independently causes improved health outcomes.

Population exhibits a positive and statistically significant coefficient of 11.899, while broad money supply has a negative coefficient of −3.870. Inflation, with a reported coefficient close to zero and p-value of 0.970, does not exhibit a statistically significant long-run relationship with health deprivation.

The contrasting findings for agricultural diversification across the nutrition and health models suggest that the estimated statistical relationships differ in direction and significance. While the nutrition model does not provide evidence of a significant long-run agricultural-diversification coefficient, the health model reports a significant negative association.

Nevertheless, the statistical significance of one coefficient and insignificance of another do not independently demonstrate a statistically significant difference between the two coefficients. Their interpretation must also account for differences in the dependent indices, model specifications and diagnostic characteristics.

ARDL Short-Run and Error-Correction Estimates

The short-run relationships and adjustment dynamics were examined using the error-correction representations associated with the estimated ARDL models. The error-correction approach provides information concerning short-run changes and the adjustment of the dependent variables towards their estimated long-run relationships following disturbances. The reported short-run agricultural-diversification coefficients, error-correction terms and model-fit statistics are presented in Table 9.

Table 9: ARDL Short-Run (Error-Correction) Estimates

Variable	NTRI model coefficient	Prob.	HLTHOUC model coefficient	Prob.
ΔAGRDV	47.195	0.001	-2.974	0.000
Error-Correction Term (ECT_{-1})	-0.662	0.000	-1.156	0.000
R-squared	0.823	-	0.890	-
Adjusted R-squared	0.708	-	0.835	-

The results in Table 9 indicate that the short-run coefficient of the change in agricultural diversification is positive and statistically significant in the nutrition model (β = 47.195, reported p = 0.001). This result suggests a positive short-run association between changes in agricultural diversification and nutrition deprivation within the estimated specification. However, the large coefficient requires careful examination because of the potential effects of multicollinearity, model specification and the scaling of the composite variables.

Furthermore, the reported probability value differs from the p-value of 0.004 stated elsewhere in the original discussion. The discrepancy must be resolved using the original econometric output before the result is considered final.

In the health model, the short-run coefficient of agricultural diversification is negative and statistically significant (β = −2.974, p < 0.001). This result indicates that short-run increases in the agricultural-diversification index are associated with reductions in health deprivation, conditional on the model specification and other included variables.

The error-correction coefficients are negative and statistically significant in both models. The nutrition model records an error-correction coefficient of −0.662, indicating that approximately 66.2% of the preceding period's estimated disequilibrium is corrected within one annual adjustment period, subject to the validity of the underlying model.

The health model records an error-correction coefficient of −1.156, indicating an adjustment greater than 100% of the preceding disequilibrium. This coefficient is consistent with an overshooting adjustment pattern rather than smooth monotonic convergence towards equilibrium.

The reported R-squared values are 0.823 and 0.890 for the nutrition and health models, respectively, while the adjusted R-squared values are 0.708 and 0.835. These statistics describe the reported in-sample fit of the estimated equations but do not independently establish model validity or reliability.

The interpretation of the short-run results must also account for the omitted differenced control-variable coefficients and the post-estimation diagnostic findings. Accordingly, the complete short-run coefficient estimates should be provided from the original software results to support comprehensive assessment of the estimated dynamics.

Post-Estimation Diagnostic Tests

Post-estimation diagnostic tests were conducted to assess the adequacy of the estimated ARDL models. The tests examine residual serial correlation, heteroskedasticity, normality

and functional-form specification. These procedures are particularly important in time-series analysis because violations of model assumptions may affect statistical inference and the reliability of estimated relationships. The reported diagnostic results are presented in Table 10.

Table 10: Post-Estimation Diagnostic Tests (ARDL Model Diagnostic Test Results)

Test	NTRI model statistic	Prob.	HLTHOUC model statistic	Prob.
Breusch-Godfrey serial correlation LM (2 lags)	18.884	0.000	5.432	0.066
ARCH-LM heteroskedasticity (2 lags)	5.422	0.067	1.039	0.595
Jarque-Bera normality	2.477	0.290	13.317	0.001
Ramsey RESET (functional form)	3.699	0.070	3.731	0.067
Durbin-Watson	1.916	-	1.976	-

The Breusch–Godfrey serial-correlation LM test indicates statistically significant residual serial correlation in the nutrition model, with a test statistic of 18.884 and $p < 0.001$. This finding suggests that the estimated nutrition model does not adequately eliminate serial dependence from its residuals. Consequently, its standard errors, significance tests and dynamic specification require further examination.

In contrast, the health model records a Breusch–Godfrey statistic of 5.432 and p-value of 0.066, indicating that the null hypothesis of no serial correlation is not rejected at the 5% significance level. However, the result is marginal at the 10% significance level and therefore warrants cautious interpretation.

The ARCH-LM test indicates no statistically significant heteroskedasticity at the 5% level in either model, with p-values of 0.067 and 0.595 for the nutrition and health models, respectively. The nutrition model nevertheless exhibits a borderline result at the 10% level.

The Jarque–Bera normality test indicates that the nutrition-model residuals do not depart significantly from normality at the 5% level ($p = 0.290$). Conversely, the health model exhibits a statistically significant departure from normality ($p = 0.001$), indicating that the normality assumption is not satisfied for its residuals.

The Ramsey RESET test produces p-values of 0.070 and 0.067 for the nutrition and health models, respectively. Although neither result rejects the functional-form null hypothesis at the 5% significance level, both are significant at the 10% level, suggesting possible specification concerns.

The Durbin-Watson statistics of 1.916 and 1.976 are relatively close to two. However, these values do not invalidate the more specific findings of the Breusch–Godfrey tests, particularly in dynamic regression models containing lagged dependent variables.

Overall, the diagnostic results reveal limitations that must be considered in interpreting the estimated ARDL coefficients. The nutrition model exhibits significant residual serial

correlation, while the health model exhibits non-normal residuals and borderline serial-correlation and functional-form results.

Although heteroskedasticity- and autocorrelation-consistent standard errors may improve inference under suitable conditions, they do not independently correct an incorrectly specified dynamic model or eliminate residual serial correlation. Consequently, the estimated relationships should be interpreted as conditional associations, and additional robustness checks are necessary to strengthen confidence in the findings.

Discussion of Findings

The findings reveal differing relationships between agricultural diversification, nutrition and health deprivation in Nigeria. Agricultural diversification exhibits an insignificant long-run relationship with nutrition deprivation but a significant negative association with health deprivation. This suggests that increased agricultural diversity may be associated with improved health outcomes without necessarily translating into equivalent nutritional improvements.

The insignificant nutrition relationship aligns with Becker's (1965) Household Production Theory and Singh et al.'s (1986) Agricultural Household Model, which emphasise the importance of household resources, consumption decisions and market conditions. Similarly, Babatunde and Qaim (2010) and Amare et al. (2020) highlight the roles of income and agricultural activities in nutritional welfare, although their household-level findings are not directly comparable with the present national-level analysis.

The significant negative association with health deprivation is consistent with Markowitz's (1952) Portfolio Theory, suggesting that agricultural diversification may enhance income stability and access to healthcare by reducing production risks. However, the findings remain conditional associations rather than causal effects. Overall, the results highlight the importance of complementing agricultural diversification with improved nutrition, healthcare, sanitation and socioeconomic interventions.

Conclusion

This study examined the long-run and short-run relationships between agricultural diversification, nutrition and health outcomes in Nigeria from 1990 to 2024 using the Autoregressive Distributed Lag (ARDL) approach.

The findings revealed an insignificant long-run relationship between agricultural diversification and nutrition deprivation ($\beta = 0.116$, $p = 0.896$), but a significant negative relationship with health deprivation ($\beta = -1.287$, $p < 0.001$).

Agricultural diversification also exhibited a significant negative short-run association with health deprivation ($\beta = -2.974$, $p < 0.001$). The error-correction estimates indicated adjustment towards long-run equilibrium, with evidence of overshooting in the health model.

The study concludes that agricultural diversification is associated with improved health outcomes but does not independently demonstrate a significant long-run relationship with nutritional improvement.

Recommendations

Based on the findings, the study recommends that Federal and State Governments promote sustainable agricultural diversification through crop variety, livestock integration, agricultural extension services, access to credit and improved market opportunities. Such initiatives should be complemented by nutrition-sensitive interventions that enhance dietary diversity, food affordability and household purchasing power. Furthermore, agricultural development policies should be integrated with improved healthcare delivery, maternal and child health services, safe water and sanitation to support population well-being. Future research should strengthen data quality, ensure transparent construction of composite indices and employ additional observations and robustness tests to improve the reliability of econometric findings.

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