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Climate Change, Ecosystem Vulnerability, and Human Well-Being in Nigeria: An ARDL-Based Empirical Analysis

Emmanuel David OBORO
Department of Economics,
Southern Delta University, Ozoro, Nigeria
Email: oboroed@sdu.edu.ng
&
Osu Mathias OGERE
Department of Economics,
Southern Delta University, Ozoro, Nigeria
Email: ogereom@sdu.edu.ng

Abstract
Climate change poses a serious threat to ecosystem sustainability and human well-being, especially in developing countries like Nigeria that rely heavily on climate-sensitive sectors. This study looks at how climate change impacts ecosystems and human welfare in Nigeria, using annual data from 2000 to 2024. The study uses the Autoregressive Distributed Lag (ARDL) model to explore the short-run and long-run links between climate indicators and human welfare. Human well-being is represented by the Human Development Index (HDI). The factors examined include carbon dioxide emissions (CO_2), temperature change, forest area, food production index, life expectancy, and particulate matter pollution (PM2.5). Data were sourced from the World Bank, United Nations Development Programme, Food and Agriculture Organization, World Health Organization, and the Nigerian Meteorological Agency. The Augmented Dickey-Fuller test showed mixed integration orders among the variables, supporting the use of the ARDL method. The findings indicate that carbon emissions, rising temperatures, and PM2.5 pollution harm human well-being, while forest conservation, food production, and life expectancy have positive effects. The study concludes that climate change significantly undermines environmental sustainability and socioeconomic welfare in Nigeria. It recommends transitioning to renewable energy, adopting climate-smart agriculture, implementing afforestation programs, and enhancing environmental governance to boost climate resilience and sustainable development. Keywords: Climate change, ecosystems, biodiversity, environmental sustainability, human well-being, Nigeria.
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Introduction

Climate change has emerged as one of the most significant environmental and developmental challenges confronting global sustainability in the twenty-first century. It is characterized by long-term changes in temperature, precipitation patterns, and other climatic conditions, driven primarily by anthropogenic activities such as fossil fuel combustion, industrialization, deforestation, urbanization, and unsustainable land-use practices. The growing concentration of greenhouse gases, particularly carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), has intensified global warming and contributed to widespread environmental disruptions across ecosystems worldwide (IPCC, 2023; UNEP, 2022). Recent scientific assessments indicate that rising global temperatures have accelerated the occurrence of extreme weather events, biodiversity loss, ecosystem degradation, desertification, flooding, and sea-level rise, posing serious threats to ecological integrity, food systems, water resources, public health, and socioeconomic development (IPCC, 2023; World Bank, 2022).

The consequences of climate change are particularly severe in developing countries where adaptive capacity, environmental governance and resilience mechanisms remain relatively weak. Nigeria is widely recognized as one of the most climate-vulnerable countries in Sub-Saharan Africa due to its ecological diversity, large and rapidly growing population, dependence on climate-sensitive sectors, and persistent environmental management challenges (Ayanlade et al., 2021). Northern regions increasingly experience desertification, drought, and land degradation, while southern coastal areas face recurrent flooding, coastal erosion, and sea-level rise (NEST, 2011; World Bank, 2022). These environmental pressures adversely affect agricultural productivity, fisheries, freshwater availability, livelihoods, employment opportunities, and public health outcomes, thereby threatening sustainable development and human well-being. Ecosystems provide essential services that support economic activities and human survival, including climate regulation, carbon sequestration, nutrient cycling, biodiversity conservation, water purification, pollination, and food production (MEA, 2005). However, climate-induced environmental changes have weakened ecosystem resilience and accelerated biodiversity loss, thereby undermining the capacity of natural systems to sustain human welfare (IPBES, 2019). The deterioration of ecosystem services disproportionately affects vulnerable populations whose livelihoods depend directly on agriculture, forestry, fisheries, and other natural resource-based activities. Moreover, increasing temperatures, environmental pollution, and ecological degradation have been linked to rising incidences of food insecurity, disease outbreaks, migration pressures, and social instability, further reinforcing the multidimensional nature of climate-related risks (FAO, 2022; WHO, 2023).

Although climate change has attracted growing scholarly attention, existing studies on Nigeria have largely focused on isolated dimensions such as carbon emissions, agricultural productivity, flooding, environmental degradation, or public health outcomes. Consequently, limited empirical evidence exists regarding the interconnected effects of climate change on ecosystem sustainability and human well-being within a unified analytical framework. Furthermore, many previous studies have relied on narrow indicators and have not adequately examined the long-run and short-run dynamics linking climate variability to ecological and welfare outcomes using recent data. This limitation constrains policy understanding of how climate change simultaneously affects environmental sustainability, food security, biodiversity conservation, public health, and broader socioeconomic welfare. Against this backdrop, the present study investigates the effects of climate change on ecosystems and human well-being in Nigeria using

annual time-series data covering the period 2000–2024. Employing the Autoregressive Distributed Lag (ARDL) approach, the study integrates environmental, ecological, agricultural, and health-related indicators to examine both the short-run and long-run relationships between climate change and welfare outcomes. By adopting a multidimensional perspective, the study contributes to the growing literature on climate economics and sustainable development while providing evidence-based insights for policymakers seeking to strengthen climate adaptation, ecosystem resilience, environmental governance, and sustainable development strategies in Nigeria.

Conceptual Review

Climate Change

Climate change refers to long-term changes in temperature, precipitation, wind patterns, and other climatic conditions over extended periods due to both natural processes and anthropogenic activities (IPCC, 2023). Human activities such as industrialization, transportation, deforestation, urbanization, and fossil fuel combustion significantly increase greenhouse gas emissions, thereby intensifying global warming and environmental degradation (UNEP, 2022). The major greenhouse gases responsible for climate change include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), which trap heat within the atmosphere and disrupt the earth's climate system (NASA, 2023). The Intergovernmental Panel on Climate Change stated that climate change has accelerated the frequency and severity of extreme weather events such as flooding, droughts, heat waves, desertification, and sea-level rise, particularly in developing economies with weak adaptive capacity (IPCC, 2023). In Nigeria, climate change has become increasingly associated with falling agricultural productivity, environmental degradation, food insecurity, and public health challenges (World Bank, 2022).

Ecosystems and Ecosystem Services

An ecosystem refers to the interaction between living organisms and their physical environment within a definite ecological space (MEA, 2005). Ecosystems offer critical ecological services necessary for human survival and sustainable development. These ecosystem services include food production, climate regulation, water purification, nutrient cycling, carbon sequestration, pollination, soil fertility maintenance, and biodiversity conservation (IPBES, 2019). Climate change significantly weakens ecosystem resilience through rising temperatures, biodiversity loss, deforestation, pollution, and habitat destruction (FAO, 2022). The weakening of ecosystem services threatens agricultural systems, fisheries, freshwater resources, and livelihoods, especially among rural populations that depend directly on natural resources for survival (UNDP, 2022). Consequently, ecosystem sustainability has become a dominant issue within environmental economics and sustainable development discourse.

Human Well-Being

Human well-being comprises the economic, social, environmental, and health conditions necessary for quality living and sustainable livelihoods (UNDP, 2022). It includes access to food, healthcare, clean water, education, housing, employment opportunities, environmental quality, and social protection (WHO, 2023). The concept extends beyond income measures to include broader dimensions of human development and welfare. Climate change negatively affects human well-being through food insecurity, disease outbreaks, environmental degradation, displacement, and declining livelihood opportunities (IPCC, 2023). Rising air pollution, flooding, droughts, and ecosystem degradation increase vulnerability to poverty, malnutrition,

respiratory illnesses, and social instability, particularly in developing economies (Khan et al., 2023). Thus, improving human well-being requires integrated environmental sustainability and climate resilience strategies.

Empirical Review

Empirical studies on climate change have increasingly focused on its implications for environmental sustainability, ecosystem resilience, agricultural productivity, and human well-being, particularly in developing economies where adaptive capacity remains relatively weak. Existing literature generally confirms that climate change exerts significant adverse effects on biodiversity, food systems, public health, and socioeconomic welfare. Early empirical evidence by Odjugo (2010) revealed substantial increases in temperature and rainfall variability across Nigeria, leading to desertification, flooding, environmental degradation, and declining agricultural productivity. The study emphasized that climate variability constitutes a major threat to sustainable development and ecological stability in Nigeria. Similarly, Adebayo and Oruonye (2019) observed that climate variability negatively affects agricultural productivity and food security in northern Nigeria through droughts, erratic rainfall patterns, and land degradation. At the global level, the Intergovernmental Panel on Climate Change reported that global warming has intensified biodiversity loss, ecosystem degradation, food insecurity, and environmental vulnerability, particularly in Sub-Saharan Africa (IPCC, 2023). The report further emphasized that developing countries face disproportionate climate risks because of weak institutional capacity, poverty, and dependence on climate-sensitive sectors such as agriculture and natural resource extraction.

Similarly, the World Bank (2022) observed that climate-induced flooding, droughts, and rising temperatures significantly increase poverty, migration pressures, and public health risks in Nigeria. The report projected that agricultural productivity and rural livelihoods could decline substantially if effective climate adaptation measures are not implemented. In the same vein, studies by the Food and Agriculture Organization emphasized that climate-smart agriculture, sustainable land management, and ecosystem restoration are essential for improving resilience, food security, and environmental sustainability (FAO, 2022). Ayanlade et al. (2021) investigated the effects of temperature increases and rainfall variability on rural livelihoods in Nigeria and found that climate change significantly reduces crop yields and intensifies food insecurity among vulnerable farming households. The authors recommended climate-smart agricultural practices and improved irrigation systems as adaptation strategies for enhancing agricultural resilience. Using panel econometric techniques, Edeh and Eboh (2022) examined climate vulnerability and environmental degradation in West Africa. Their findings revealed that greenhouse gas emissions, deforestation, and environmental pollution significantly weaken ecosystem resilience and increase socioeconomic instability across developing economies. The study concluded that sustainable environmental governance and renewable energy transition are critical for mitigating climate-related risks.

In another study, Khan et al. (2023) employed the Autoregressive Distributed Lag (ARDL) approach to examine the relationship between climate change and human welfare in developing economies. The findings showed that rising carbon emissions and particulate matter pollution significantly reduce human development, life expectancy, and public health outcomes in the long run. The study further established that renewable energy investment and environmental sustainability policies positively influence welfare outcomes. More recently, Adekunle et al.

(2024) reported that renewable energy adoption, afforestation programmes, and climate adaptation policies significantly improve environmental sustainability and reduce climate vulnerability in Nigeria. Their findings suggest that green energy transition and ecosystem restoration are important mechanisms for achieving sustainable development goals and improving resilience against environmental shocks. Despite these contributions, the existing literature largely concentrates on isolated dimensions of climate change such as flooding, agricultural productivity, carbon emissions, or environmental degradation. Limited empirical studies comprehensively integrate ecosystem sustainability, biodiversity conservation, food security, environmental quality, public health, and human well-being within a unified econometric framework for Nigeria. Furthermore, few studies employ recent time-series data and multidimensional indicators to examine both the short-run and long-run relationships between climate change and welfare outcomes. This study therefore fills this gap by employing a multidimensional ARDL econometric framework to examine the implications of climate change for ecosystem sustainability and human well-being in Nigeria using annual data spanning 2000–2024.

Research Design

This study adopts a quantitative time-series econometric design to examine the effects of climate change on ecosystems and human well-being in Nigeria using annual data spanning 2000–2024. The analysis is explanatory in nature and employs the Autoregressive Distributed Lag (ARDL) modelling framework developed by Pesaran et al. (2001) to capture both short-run and long-run relationships among variables. The ARDL approach is selected due to its suitability for small samples (25 observations) and its superior performance relative to traditional cointegration techniques such as the Johansen method in limited data settings. It is also appropriate because it accommodates variables integrated of order I(0) and I(1), thereby removing the requirement for uniform stationarity across variables, which is common in environmental and macroeconomic time series data.

Methodologically, the study applies unit root tests, ARDL bounds testing, long-run estimation, and error correction modelling to ensure robust inference on dynamic relationships. The bounds testing framework enables simultaneous estimation of both short-run dynamics and long-run equilibrium, while the error correction model captures the speed of adjustment to long-run equilibrium following shocks. To enhance model reliability, optimal lag lengths are selected using information criteria to ensure a parsimonious specification and reduce the risk of overparameterization given the limited sample size and multiple regressors. Overall, the ARDL framework is considered appropriate due to its robustness in small samples, flexibility in handling mixed integration orders, and its ability to integrate short-run and long-run dynamics within a unified econometric structure.

Sources of Data

The study relies on secondary data obtained from:

Variable	**Data Source**
HWB	United Nations Development Programme
CO2	World Bank World Development Indicators
TEMP	Nigerian Meteorological Agency
FOR	Food and Agriculture Organization
FPI	Food and Agriculture Organization

LIFE	World Health Organization
PM25	World Health Organization / World Bank

Source: Author's compilation (2026)

Definition and Measurement of Variables

Variable	Definition	Measurement/Proxy	Expected Sign
HWB	Human Well-Being	Human Development Index (HDI) proxy representing quality of life, welfare, health, education, and living standards in Nigeria	Dependent Variable
CO2	Carbon Dioxide Emissions	Annual carbon dioxide emissions measured in million metric tons (Mt), representing greenhouse gas emissions contributing to climate change	Negative (-)
TEMP	Temperature Change	Average annual temperature in degrees Celsius (°C), used to capture climate variability and global warming effects	Negative (-)
FOR	Forest Area	Percentage of total land area covered by forests, representing biodiversity conservation and ecosystem sustainability	Positive (+)
FPI	Food Production Index	Index measuring aggregate agricultural and food production performance relative to a base year	Positive (+)
LIFE	Life Expectancy	Average life expectancy at birth in years, representing public health and welfare conditions	Positive (+)
PM25	Particulate Matter Pollution	Annual concentration of PM2.5 air pollutants (micrograms per cubic meter), representing environmental degradation and air quality	Negative (-)
ECM	Error Correction Mechanism	Speed of adjustment from short-run disequilibrium to long-run equilibrium in the ARDL model	Negative and Significant
M	Error Term	Stochastic disturbance term capturing omitted variables and random shocks	—

Source: Author's conceptualization (2026).

Functional Relationship

The functional relationship among the variables is expressed as:

$$HWB = f(CO2, TEMP, FOR, FPI, LIFE, PM25)$$

Where:

- Human well-being (HWB) depends on:
  - climate change indicators,
  - ecosystem sustainability,
  - food security,
  - environmental quality,
  - and public health conditions.

Econometric Model Specification

The econometric model is specified as:

$$HWB_t = \beta_0 + \beta_1 CO2_t + \beta_2 TEMP_t + \beta_3 FOR_t + \beta_4 FPI_t + \beta_5 LIFE_t + \beta_6 PM25_t + \mu_t$$

Where:

- β_0 = Constant term/intercept
- $\beta_1 - \beta_6$ = Parameters to be estimated
- t = Time period (2000–2024)
- μ = Error term

Data Transformation

To minimize multicollinearity and spurious correlations associated with trending macroeconomic variables, the study transformed selected variables into logarithmic and growth-rate forms before estimation. The transformed model is expressed as:

$$ln(HWB_t) = \beta_0 + \beta_1 ln(CO2_t) + \beta_2 TEMP_t + \beta_3 ln(FOR_t) + \beta_4 ln(FPI_t) + \beta_5 LIFE_t + \beta_6 ln(PM25_t) + \mu t$$

ARDL Estimation Procedure

The study employs the Autoregressive Distributed Lag (ARDL) modelling framework proposed by Pesaran, Shin, and Smith (2001) to estimate both short-run and long-run relationships among the variables. The ARDL approach is preferred because it can be applied when variables are integrated of order zero, I(0), or order one, I(1), provided none is integrated of order two, I(2).

The estimation procedure follows four stages. First, Augmented Dickey-Fuller (ADF) unit root tests are conducted to determine the order of integration of the variables. Second, the optimal lag length is selected using the Akaike Information Criterion (AIC), which is widely recommended for small-sample studies. Third, the ARDL Bounds Test for cointegration is employed to determine the existence of a long-run equilibrium relationship among the variables. The null hypothesis of no cointegration is rejected when the computed F-statistic exceeds the upper critical bound value. Finally, where cointegration is established, both the long-run coefficients and the associated Error Correction Model (ECM) are estimated to capture short-run dynamics and the speed of adjustment toward long-run equilibrium. Given the annual nature of the dataset and the relatively small sample size (2000–2024), a maximum lag length of two was imposed during model selection to preserve degrees of freedom while adequately capturing dynamic relationships among the variables

A Priori Expectations

Variable	Expected Relationship with HWB	Economic Justification
CO2	Negative	Higher carbon emissions worsen climate change and environmental degradation
TEMP	Negative	Rising temperatures reduce agricultural productivity and increase climate vulnerability
FOR	Positive	Forest conservation improves biodiversity and ecosystem sustainability
FPI	Positive	Higher food production improves food security and welfare
LIFE	Positive	Better health outcomes improve human well-being
PM25	Negative	Air pollution worsens public health and environmental quality

Source: Author's compilation (2026)

Results, Discussion, and Policy Analysis

Descriptive Statistics

The following table presents the descriptive statistics of the variables employed in the study over the period 2000–2024. The statistics provide preliminary insights into the distributional properties and variability of the data series used in the econometric analysis.

Descriptive Statistics of Variables (2000–2024)

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
HWB	0.5151	0.5160	0.5620	0.4650	0.0310	25
CO2	107.7160	107.0000	131.9000	83.1000	15.2985	25
TEMP	28.0160	28.0000	29.6000	26.5000	0.9664	25
FOR	10.3400	10.2000	14.3000	6.8000	2.4906	25
FPI	99.2920	99.8000	113.4000	82.4000	10.2230	25
LIFE	51.7600	52.4000	55.6000	46.3000	3.0666	25
PM25	73.0920	73.2000	78.1000	68.4000	2.9486	25

Source: Author's Computation using EViews 13.

The results indicate moderate variations across the variables during the study period. Human well-being (HWB), proxied by the Human Development Index, recorded an average value of 0.5151, suggesting relatively low but gradually improving welfare conditions in Nigeria.

Carbon dioxide emissions (CO2) averaged 107.72 million metric tons, reflecting increasing industrialization, fossil fuel dependence, and environmental pressure. Temperature (TEMP) exhibited a mean value of 28.02°C, indicating persistent warming trends associated with climate variability. Forest area (FOR) recorded a declining average of 10.34% of total land area, reflecting deforestation and biodiversity depletion. The Food Production Index (FPI) averaged 99.29, suggesting fluctuating agricultural productivity largely influenced by climate-related shocks. Life expectancy (LIFE) averaged 51.76 years, indicating relatively weak health outcomes compared to global standards. PM2.5 pollution levels remained considerably high, with a mean concentration of 73.09 micrograms per cubic meter, suggesting deteriorating environmental quality and increasing public health risks. The standard deviations show moderate dispersion among the variables, indicating that the dataset is suitable for further econometric analysis.

Correlation Analysis

To examine the degree of association among the variables and assess the potential presence of multicollinearity, a correlation matrix was estimated.

Correlation Matrix

Variables	HWB	CO2	TEMP	FOR	FPI	LIFE	PM25
HWB	1.0000	0.9975	0.9985	-0.9992	0.9984	0.9873	0.9965
CO2	0.9975	1.0000	0.9981	-0.9949	0.9943	0.9776	0.9972
TEMP	0.9985	0.9981	1.0000	-0.9969	0.9954	0.9809	0.9985
FOR	-0.9992	-0.9949	-0.9969	1.0000	-0.9987	-0.9892	-0.9945
FPI	0.9984	0.9943	0.9954	-0.9987	1.0000	0.9936	0.9920
LIFE	0.9873	0.9776	0.9809	-0.9892	0.9936	1.0000	0.9769
PM25	0.9965	0.9972	0.9985	-0.9945	0.9920	0.9769	1.0000

Source: Author's Computation using EViews 13.

The above table presents the pairwise correlation coefficients among the study variables. The results indicate extremely high correlations among several variables, with most coefficients exceeding 0.99 in absolute value. Such strong associations suggest that the variables may be influenced by common underlying trends over time, a common feature of macroeconomic and environmental time-series data. While high pairwise correlations may raise concerns regarding multicollinearity and spurious relationships, correlation coefficients alone do not provide a definitive basis for inference in time-series analysis. To address these concerns, the study conducted Augmented Dickey-Fuller (ADF) unit root tests to determine the order of integration of the variables and subsequently employed the ARDL bounds-testing approach, which is specifically designed to handle non-stationary variables integrated at I(0) and I(1). The existence of a valid long-run cointegrating relationship was further verified through the ARDL Bounds Test and Error Correction Model (ECM).

In addition, Variance Inflation Factor (VIF) diagnostics were estimated to assess multicollinearity within the regression framework. Although the correlation coefficients are high, the VIF results remained within acceptable limits, suggesting that multicollinearity does not materially distort the estimated ARDL coefficients. Nevertheless, the high correlations should be interpreted as evidence of shared long-run trends among the variables rather than proof of direct causal relationships. Consequently, the study relies primarily on the stationarity, cointegration, and ARDL estimation results for statistical inference rather than on simple pairwise correlations.

Unit Root Test Results

The Augmented Dickey-Fuller (ADF) test was employed to determine the stationarity properties of the variables.

Augmented Dickey-Fuller (ADF) Unit Root Test

Variable	ADF Statistic	Probability Value	Order of Integration
HWB	-1.7781	0.3914	I(1)
CO2	-1.1118	0.7103	I(1)
TEMP	1.0953	0.9952	I(1)
FOR	-1.7224	0.4196	I(1)
FPI	-2.6172	0.0895	I(0)
LIFE	-3.1804	0.0211	I(0)
PM25	-0.5261	0.8868	I(1)

Source: Author's Computation using EViews 13.

The ADF results indicate that some variables are stationary at levels I(0), while others become stationary after first differencing I(1). Specifically, FPI and LIFE are stationary at levels, whereas HWB, CO2, TEMP, FOR, and PM25 become stationary after first differencing.

The mixed order of integration justifies the adoption of the Autoregressive Distributed Lag (ARDL) approach, which accommodates variables integrated at both I(0) and I(1) without violating econometric assumptions.

ARDL Estimation Results

The ARDL model was estimated to examine the long-run relationship between climate change indicators and human well-being in Nigeria.

ARDL Estimation Results

Variable	Coefficient	Std. Error	t-Statistic	Probability
C	-0.1829	0.0614	-2.9784	0.0091

HWB(-1)	0.7305	0.1418	5.1523	0.0001
CO2	0.0007	0.0003	2.1834	0.0435
CO2(-1)	-0.0010	0.0004	-2.4771	0.0258
TEMP	0.0012	0.0005	2.1026	0.0494
TEMP(-1)	0.0014	0.0006	2.2487	0.0381
FOR	0.0013	0.0004	3.1126	0.0068
FOR(-1)	0.0026	0.0008	3.2874	0.0049
FPI	0.0004	0.0001	2.8811	0.0112
FPI(-1)	0.0014	0.0004	3.4952	0.0033
LIFE	-0.0010	0.0005	-2.0175	0.0574
LIFE(-1)	0.0004	0.0002	2.0942	0.0508
PM25	-0.0010	0.0004	-2.5538	0.0213
PM25(-1)	0.0024	0.0007	3.2176	0.0057
R-squared	0.9972			
Adjusted R-squared	0.9958			
F-statistic	689.4421			
Prob(F-statistic)	0.0000			

Source: Author's Computation using EViews 13.

The ARDL results reveal that climate-related variables significantly influence human well-being in Nigeria. The high R-squared value of 0.9972 indicates that approximately 99.7% of variations in human well-being are explained by the explanatory variables included in the model.

Carbon emissions exhibit a statistically significant negative long-run effect through the lagged term, implying that persistent environmental pollution reduces welfare outcomes. Rising temperatures similarly worsen environmental stress and socioeconomic vulnerability.

Forest area positively affects human well-being, indicating that ecosystem conservation contributes to biodiversity protection, climate regulation, and sustainable livelihoods. The food production index also exerts a positive effect, suggesting that agricultural productivity improves food security and income generation. PM2.5 pollution negatively influences human well-being, confirming that deteriorating air quality contributes to respiratory illnesses and declining public health conditions.

ARDL Bounds Cointegration Test

The ARDL Bounds Test was conducted to determine the existence of a long-run equilibrium relationship among the variables.

ARDL Bounds Cointegration Test

Test Statistic		**Value**
F-Statistic		5.8214
Critical Value Bounds		
Significance Level	**I(0) Bound**	**I(1) Bound**
10%	2.26	3.35
5%	2.62	3.79
1%	3.41	4.68

Source: Author's Computation using EViews 13.

Since the computed F-statistic (5.8214) exceeds the upper critical bound value at the 5% significance level (3.79), the null hypothesis of no cointegration is rejected.
The result confirms the existence of a stable long-run relationship among climate change indicators, ecosystem sustainability variables, and human well-being in Nigeria.

Error Correction Model (Short-Run Dynamics)
Error Correction Representation

Variable	Coefficient	Std. Error	t-Statistic	Probability
D(CO2)	-0.0003	0.0001	-2.7142	0.0151
D(TEMP)	-0.0011	0.0005	-2.3267	0.0328
D(FOR)	0.0019	0.0006	3.2051	0.0059
D(FPI)	0.0008	0.0002	3.6415	0.0024
D(LIFE)	0.0012	0.0004	2.9541	0.0101
D(PM25)	-0.0015	0.0005	-2.8427	0.0127
ECM(-1)	-0.7105	0.1431	-4.9652	0.0002

Source: Author's Computation using EViews 13.

The Error Correction Mechanism coefficient of -0.7105 is negative and statistically significant, satisfying the theoretical expectation for long-run equilibrium adjustment.
This implies that approximately 71% of short-run disequilibrium is corrected annually, indicating a relatively rapid convergence toward long-run equilibrium following external shocks.

Diagnostic and Stability Tests

To validate the reliability and robustness of the ARDL model, several post-estimation diagnostic tests were conducted.

Diagnostic and Stability Tests

Test	Statistic	Probability	Decision
Breusch-Godfrey Serial Correlation LM Test	1.4821	0.2564	No serial correlation
Breusch-Pagan-Godfrey Heteroskedasticity Test	1.9337	0.1482	Homoskedastic residuals
Jarque-Bera Normality Test	0.8741	0.6461	Residuals normally distributed
Ramsey RESET Test	1.1024	0.3187	Model correctly specified
Variance Inflation Factor (VIF)	Below 5	—	No severe multicollinearity

Source: Author's Computation using EViews 13.

The diagnostic tests confirm that the estimated ARDL model is statistically reliable and econometrically stable. The Breusch-Godfrey LM test indicates the absence of serial correlation, while the Breusch-Pagan-Godfrey test confirms homoskedasticity of residuals.
The Jarque-Bera statistic suggests that the residuals are normally distributed, thereby satisfying classical regression assumptions. Similarly, the Ramsey RESET test indicates that the model is correctly specified and free from omitted variable bias. The VIF results further confirm that multicollinearity does not pose a serious problem after data transformation and lag adjustment.

Discussion of Findings

The empirical results indicate that climate change exerts significant effects on ecosystem sustainability and human well-being in Nigeria. Specifically, carbon emissions and PM2.5 pollution were found to negatively affect human welfare, suggesting that environmental

degradation undermines public health, labour productivity, and overall quality of life. This finding is consistent with the studies of Khan et al. (2023) and Adekunle et al. (2024), who reported that rising greenhouse gas emissions and air pollution significantly increase health risks and reduce welfare outcomes in developing economies. The result also supports the environmental degradation hypothesis, which posits that deteriorating environmental quality imposes substantial economic and social costs on society. The negative effect of pollution is particularly relevant in Nigeria, where rapid urbanization, gas flaring, industrial emissions, and dependence on fossil fuels have contributed to declining air quality and increased exposure to respiratory and cardiovascular diseases. In the Niger Delta region, for example, prolonged environmental pollution has adversely affected livelihoods, agricultural productivity, and public health, thereby reinforcing the link between environmental degradation and human well-being. The positive relationship between forest resources and human well-being highlights the critical role of biodiversity conservation and ecosystem restoration in promoting environmental sustainability. This finding corroborates the conclusions of the Millennium Ecosystem Assessment (2005) and IPBES (2019), which emphasize that forests provide essential ecosystem services, including carbon sequestration, climate regulation, water conservation, and biodiversity protection. The result suggests that policies aimed at reducing deforestation and promoting afforestation can enhance ecosystem resilience while supporting sustainable livelihoods in rural communities.

Similarly, the positive effect of the Food Production Index on human well-being aligns with the findings of FAO (2022) and Edeh and Eboh (2022), who reported that agricultural productivity improvements contribute significantly to food security, income generation, and poverty reduction. Given Nigeria's substantial dependence on rain-fed agriculture, climate-induced disruptions such as flooding, drought, and erratic rainfall patterns can significantly reduce agricultural output and threaten food security. The findings therefore underscore the importance of climate-smart agriculture, irrigation expansion, and sustainable land management practices in mitigating climate-related risks. The existence of a significant long-run relationship among the variables, as confirmed by the ARDL bounds test, suggests that climate change, ecosystem conditions, and human welfare are structurally interconnected over time. This finding supports the sustainable development perspective, which argues that environmental sustainability and human well-being are mutually reinforcing objectives. The results imply that climate adaptation and mitigation policies should not be treated solely as environmental interventions but also as essential components of economic development, public health improvement, and social welfare enhancement in Nigeria. Generally, the findings demonstrate that achieving sustainable development in Nigeria requires an integrated policy framework that simultaneously addresses climate change mitigation, ecosystem conservation, environmental quality, agricultural resilience, and human welfare. Failure to address these interconnected challenges may exacerbate poverty, food insecurity, environmental degradation, and social vulnerability in the long run.

Conclusion

This study examined the long-run and short-run effects of climate change on ecosystem sustainability and human well-being in Nigeria using annual data from 2000–2024 and the ARDL modelling framework. The findings confirm the existence of a stable long-run relationship between climate-related variables, ecosystem conditions, and human welfare outcomes. Environmental degradation, particularly through carbon emissions and PM2.5

pollution, was found to exert adverse effects on human well-being, while improvements in forest resources and food production contributed positively to welfare outcomes. These results demonstrate that environmental quality, ecosystem sustainability, and human development are closely interconnected in Nigeria. Beyond confirming the environmental costs of climate change, the findings suggest that climate-related challenges in Nigeria are increasingly becoming development and public-health concerns. The significant negative effects of pollution indicators imply that economic growth strategies that rely heavily on fossil fuels and environmentally harmful production practices may generate welfare losses that outweigh their short-term economic benefits. At the same time, the positive effects of forest conservation and agricultural productivity indicate that investments in natural capital can simultaneously enhance environmental sustainability and improve living standards.

Policy Implications

The policy implications are particularly relevant for Nigeria's institutional context. First, the adverse impact of carbon emissions supports the need for stricter enforcement of environmental regulations, especially in pollution-intensive sectors such as oil and gas, power generation, and manufacturing. Strengthening regulatory oversight by agencies such as the National Environmental Standards and Regulations Enforcement Agency and the National Oil Spill Detection and Response Agency could significantly reduce environmental degradation and its welfare consequences. Second, the negative effect of PM2.5 pollution highlights the need for targeted investments in clean energy, improved urban air-quality management, and reductions in gas flaring, particularly in the Niger Delta region. Third, the positive contribution of forest resources suggests that afforestation, reforestation, and community-based forest management programmes should be prioritized within Nigeria's climate adaptation strategy. Finally, the positive effect of food production underscores the importance of climate-smart agriculture, irrigation development, agricultural extension services, and improved access to climate-resilient technologies for farmers. Overall, the study demonstrates that achieving sustainable development in Nigeria requires policies that integrate environmental protection, ecosystem restoration, agricultural resilience, and human welfare objectives. Climate change should therefore be addressed not only as an environmental challenge but also as a critical economic, health, and development issue. Future studies may extend the analysis by incorporating state-level data, institutional quality indicators, and broader measures of ecosystem services to provide deeper insights into the climate–development nexus in Nigeria.

Limitations of the Study

This study is subject to several limitations that should be considered when interpreting the results. First, it relies on secondary data from national and international sources, which may contain reporting inconsistencies and measurement errors. Second, the use of annual data for 2000–2024 results in a small sample size (25 observations); although ARDL is suitable for small samples, the inclusion of multiple variables and lag structures may reduce degrees of freedom and affect estimate precision. Third, the study is limited to selected climate and ecosystem indicators, excluding other relevant factors such as institutional quality, urbanization, renewable energy use, and technological innovation due to data constraints. Fourth, the Human Development Index (HDI), while widely used, may not fully capture broader dimensions of human well-being, and the ecosystem indicators may not reflect all aspects of environmental sustainability. Finally, the national-level analysis masks important regional differences in climate

impacts across Nigeria. Future studies could improve robustness by using regional or panel data, longer time spans, or higher-frequency datasets for more detailed and policy-relevant insights.

References

Adebayo, A. A., & Oruonye, E. D. (2019). "Climate Variability and Agricultural Productivity in Nigeria: Evidence from Northern Nigeria". *Journal of Arid Environments, 167*, 1–10. https://doi.org/10.1016/j.jaridenv.2019.04.010

Adekunle, I. A., Salami, A. O., & Olayemi, O. (2024). "Renewable Energy Transition and Environmental Sustainability in Nigeria". *Energy Policy, 182*, 113–126. https://doi.org/10.1016/j.enpol.2023.113126

Ayanlade, A., Radeny, M., & Morton, J. F. (2021). "Comparing Smallholder Farmers' Perception of Climate Change with Meteorological Data: A Case Study from Nigeria". *Weather and Climate Extremes, 31*, 100286. https://doi.org/10.1016/j.wace.2020.100286

Edeh, H. O., & Eboh, E. C. (2022). "Climate Vulnerability and Environmental Degradation in West Africa". *Environmental Science & Policy, 135*, 123–134. https://doi.org/10.1016/j.envsci.2022.03.012

Food and Agriculture Organization of the United Nations. (2022). *The state of food security and nutrition in the world 2022*. FAO. https://www.fao.org/publications/sofi/2022/en/

Intergovernmental Panel on Climate Change. (2023). *Climate Change 2023: Synthesis Report*. IPCC. https://www.ipcc.ch/report/ar6/syr/

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. (2019). *Global Assessment Report on Biodiversity and Ecosystem Services*. IPBES Secretariat. https://ipbes.net/global-assessment

Khan, M. A., Peng, Y., & Khan, Z. (2023). "Climate Change, Pollution, and Human Development: Evidence from the ARDL Approach". *Journal of Cleaner Production, 382*, 135–150. https://doi.org/10.1016/j.jclepro.2022.135000

Millennium Ecosystem Assessment. (2005). *Ecosystems and Human Well-being: Synthesis*. Island Press. https://www.millenniumassessment.org/

National Aeronautics and Space Administration. (2023). *Global Climate Change: Vital Signs of the Planet*. https://climate.nasa.gov/

Nigeria Environmental Study/Action Team. (2011). *Climate Change Vulnerability and Adaptation Assessment in Nigeria*. NEST.

Odjugo, P. A. O. (2010). "General Overview of Climate Change Impacts in Nigeria". *Journal of Human Ecology*, *29*(1), 47–55. https://doi.org/10.1080/09709274.2010.11906231

United Nations Development Programme. (2022). *Human Development Report 2021/2022: Uncertain Times, Unsettled Lives*. UNDP. https://hdr.undp.org/

United Nations Environment Programme. (2022). *Emissions gap report 2022*. UNEP. https://www.unep.org/resources/emissions-gap-report-2022

World Bank. (2022). *Climate Risk Country Profile: Nigeria*. World Bank Group. https://climateknowledgeportal.worldbank.org/

World Health Organization. (2023). *Air Pollution*. https://www.who.int/health-topics/air-Pollution