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Climate Change and Economic Growth: A Time Series Analysis

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ABSTRACT

This study examined the relationship between climate change and economic growth in Zambia using annual data from 1990 to 2023. The study employed an Autoregressive Distributed Lag (ARDL) model to analyse the impact of rainfall variability, crop production index as a proxy for agriculture production, Foreign Direct Investment (FDI), trade openness, natural resource depletion and control of corruption on economic growth. The ARDL bounds test shows the existence of cointegration among the variables. Rainfall, natural resource depletion and control of corruption were found to have a positive and statistically significant effect on economic growth in the long run, while the crop production index had a negative and significant effect, reflecting structural weaknesses and climate vulnerability in the agricultural sector. FDI and trade openness were found to have insignificant effects on growth. In the short run, rainfall exhibited both positive and negative lagged effects, highlighting the disruptive nature of climate variability. The study recommends strengthening climate resilience through climate-smart agriculture, improved water management, irrigation development and early warning systems to support sustainable economic growth in Zambia.

INTRODUCTION

Climate change refers to long-term shifts in temperatures and weather conditions caused primarily by carbon emissions and Greenhouse Gases (GHGs). It affects the distribution of rainfall and temperature, and this tends to affect crop yields, especially those crops cultivated under rain-fed conditions (Thurlow *et al.,* 2012). Climate variability is manifested at different scales and one of the ways it does this is through rainfall variability. Historically, excessive rainfall leads to the destruction of arable land, impairment of cultivated crops, increased growth of weeds and post-harvest loss while a significant reduction in rainfall may culminate in drier land, reduction in water level in streams and rivers, increase in farmers' search for water for irrigation and consequently resulting in invaluable man-hour losses and reductions in crop yield (Nnamchi & Ozor, 2009). The consequences of changes in rainfall patterns and extreme weather events such as rising floods, droughts and storms are more pronounced in low- and middle-income countries and such variabilities have the capacity to adversely affect economic activities (Intergovernmental Panel on Climate Change [IPCC], 2023). Climate variability has also contributed to biodiversity loss by intensifying migration, urban expansion and pressure on natural resources, particularly where vulnerable populations depend heavily on land, forests and water resources for livelihoods (Tafur Anzualdo *et al.,* 2024).

Rainfall is a critical component for water resources, hydropower generation, agriculture, fisheries, aquaculture and climate systems (Yao *et al.,* 2023; Tan *et al.,* 2021). However, the proportion of land experiencing below-average rainfall has increased globally, while the area with above-average rainfall is shrinking. Since 2000, drought frequency and duration have risen by nearly one-third (Zaveri *et al.,* 2023). Approximately 1.8 billion people (about 25% of the global population) have faced abnormal rainfall each year over the past three decades, with over 85% of those affected residing in low- and middle-income countries (Damania *et al.,* 2017). Adapting to this variability remains a challenge due to the unpredictability of duration, magnitude and frequency of deviations (Adams *et al.,* 2013).

Climate change has varying impacts on different sets of countries. In low- and middle-income countries, moderate to extreme droughts reduce Gross Domestic Product Per Capita (GDPPC) growth between 0.39 and 0.85 percentage points, on average, depending on the level of development and baseline climatic conditions (Zaveri *et al.,* 2023). On the other hand, in high-income countries, moderate droughts have minimal impact and only extreme droughts have adverse effects, reducing growth by about 0.3 percentage points, a little less than half the impact felt in the low- and middle-income country sample for the same intensity of drought (Zaveri *et al.,* 2023).

Zambia, a low-income country in Sub-Saharan Africa, has in the recent past experienced erratic rainfall resulting from climate change. The effects of climate effects have been particularly pronounced in the nation as an erratic rainfall pattern has the capacity to cause severe droughts, most recently the 2023/2024 drought and previously the 2018/2019 drought (Ministry of Finance and National Planning [MOFNP], 2024). Climate variability has especially affected the agricultural sector in Zambia, which is heavily dependent on rainfall due to the country's limited irrigation capacity (Ngoma *et al.,* 2021). Rainfall

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variability threatens economic stability and development. The country's dependence on rain-fed agriculture makes it highly vulnerable to climate shocks, as seen during the 2018/2019 and 2023/2024 drought seasons, which caused severe crop losses (UNICEF, 2025). Rainfall deficits have also led to declining water levels, undermining electricity generation, as 83% of is hydro-based and disrupting output in sectors like manufacturing (Energy Regulation Board [ERB], 2023; UNICEF, 2025; Chisanga *et al.,* 2023). The 2023/2024 drought, intensified by El Nino events, highlights the growing influence of extreme weather on Zambia's economy. Research shows a strong correlation between El Niño and drought severity in Southern Africa, including Zambia (Sousa *et al.,* 2018). These events continue to heighten food insecurity and deepen rural poverty.

The share of the agriculture sector in GDP has declined over the past decade from 9.4% in 2010 to 3.4% in 2021 and 1.8% in 2024 (MOFNP, 2025). The decline has been primarily attributed to variability in rainfall patterns as Zambia has faced adverse weather conditions. Over the last decades, floods, intense and prolonged droughts have hit Zambia, affecting its crop production adversely (Ngoma *et al.,* 2021).

Climate variability poses a significant threat to Zambia's poverty reduction efforts, as a large share of the poor population resides in rural areas and relies heavily on agriculture for their livelihoods. The country's agricultural sector is particularly vulnerable to climate shocks, largely because more than 90% of smallholder production is rain-fed (Wineman & Crawford, 2017). World Bank (2023) adds that the sector employs nearly 70% of Zambia's labour force and remains the main source of income in rural areas. Yet, agriculture's GDP contribution has declined from 9.2% in 2012 to just 3.1% in 2022 (Zambia Statistics Agency [ZamStats], 2022). Consequently, fluctuations in rainfall patterns can substantially reduce agricultural productivity, undermining household incomes and food security in rural areas. These setbacks highlight a crucial link between climate change, particularly rainfall variability and economic growth.

Research Gap and Contribution of the study

Although the relationship between climate change and economic growth has received increasing attention globally, notable research gaps remain, particularly within the Zambian context. This study responds to these gaps and contributes meaningfully to both academic inquiry and policy discourse.

One major gap lies in the scarcity of Zambia-specific empirical studies that examine the economic impacts of climate variability. Most existing literature tends to generalize findings across regions, offering little guidance on context-sensitive policy responses for countries like Zambia. Moreover, the practical policy implications of these studies often remain underdeveloped. Another key gap is the limited integration of natural capital such as rainfall, water resources, and biodiversity into mainstream macroeconomic models. The role of environmental assets in sustaining economic growth, particularly in resource-dependent economies, has not been adequately explored in empirical research.

This study addresses these gaps by conducting a Zambia-focused analysis using the ARDL model to explore the relationship between economic growth and climate-sensitive variables. Furthermore, the study seeks to offer policy recommendations aimed at enhancing climate adaptation and mitigation. By providing evidence-based insights, it also seeks to support the formulation of strategies that promote economic resilience and sustainable development in Zambia amidst increasing climate variability.

LITERATURE REVIEW

Theoretical Review

Natural Resource-Based Growth Theory

The Natural Resource-Based Growth perspective draws from the resource curse literature and environmental economics, particularly the works of Sachs & Warner (2001), Auty (2014), and Barbier (2005), and posits that natural resources can contribute to long-term economic development only when supported by strong governance, institutional capacity and sustainable management practices. The resource curse literature demonstrates that resource abundance alone does not guarantee economic prosperity, rather, many resource-rich countries experience slower growth when resource revenues are poorly managed (Sachs & Warner, 2001). Earlier contributions by Auty (2014) similarly emphasize that weak institutions and inadequate policy frameworks can undermine the growth benefits of natural resource wealth.

Barbier (2005) further argues that the effective utilization of natural capital requires complementary investments in human capital, infrastructure and environmental sustainability. Without such investments, resource exploitation may lead to environmental degradation and increased poverty. Moreover, resource-dependent economies are particularly vulnerable to climate change, as shocks to climate-sensitive sectors such as agriculture, hydropower and mining can significantly disrupt economic activity (World Bank, 2021). Therefore, this perspective underscores that the transformation of natural resource wealth into sustained economic growth depends on prudent resource governance, institutional quality and the integration of climate resilience into development strategies.

The Environmental Kuznets Curve Hypothesis

The hypothesis was postulated by and named after Simon Kuznets. The hypothesis is the idea that economic growth (high-income levels) of a country will reduce environmental degradation levels after initially increasing environmental degradation at low-income levels. The relationship that exists between environmental degradation and economic growth and the growth of incomes follows an inverted U-shaped relationship (Vo *et al.,* 2022). Grossman & Krueger (1991) are among the first scholars to explain the Environmental Kuznets Curve (EKC) hypothesis and established that economic growth significantly affects environmental quality in three varying stages of economic growth. During the early stages of economic growth and development, as a result of scale effects, increases in economic growth are accompanied by increased natural resources demand like land to foster various economic activities and as a result, this causes serious bad effects on environmental quality depicted on the graph as the rising portion of inverted U-shaped figure 1 below. The second stage is the turning point of the inverted U-shaped EKC which is due to a composition effect. At this stage, the structure of the economy slowly begins to transform and begins to prefer and adopt environmentally friendly means for economic activities. The third stage involves technical effect, the methods of economic activities like industrial production are changed from the usual traditional technologies to more environmentally-friendly methods of production (Grossman & Krueger. 1991).

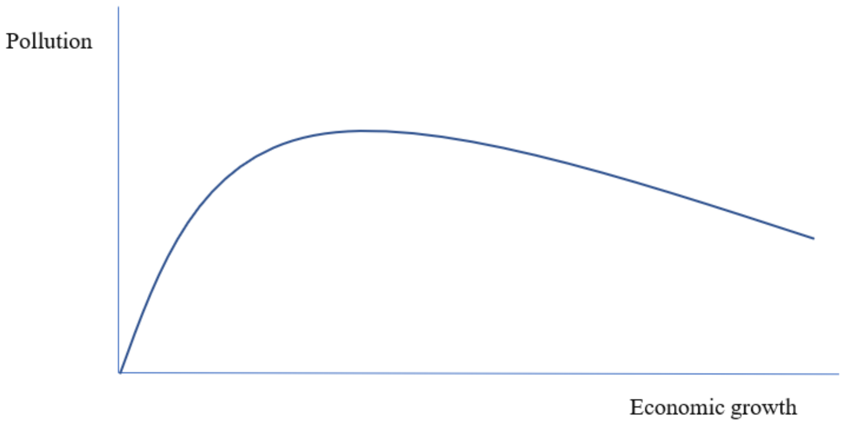

Figure 1: The Environmental Kuznets Hypothesis

Figure 1 above depicts growth in environmental pollution during the early stages of economic growth but after some time environmental pollution starts to decline as economic growth continues to increase.

Porter's Hypothesis

This hypothesis was postulated by an economist named Michael Porter in 1991. According to this hypothesis, enforcement of strict environmental policies and regulations has the potential to encourage innovation and induce efficiency in the use of resources and this can bring about commercial competitiveness. The hypothesis further stresses that strict environmental policies and regulations can trigger the discovery and utilization of cleaner environmental-friendly innovations that can improve environmental quality. Additionally, the innovation effect resulting from strict environmental regulations induces efficiency in production processes and the cost savings as a result of efficiency can overcompensate compliance and innovation costs. Firms that innovate earlier than those that innovate later enforcement of strict environmental regulations dominate the competition in a given market (Wagner, 2009).

Empirical Review

Empirical evidence by Olanrewaju (2019) shows that rainfall variability is a significant determinant of economic growth in Africa. Using panel data for 43 countries over the period 1991-2015 and applying a linear regression model, the study finds that variations in rainfall have a statistically significant impact on GDP per capita growth, with results indicating that rainfall explains a substantial share of growth fluctuations. The study further identifies agriculture and hydroelectric power as the main transmission channels, given their heavy dependence on rainfall, and concludes that both current and lagged rainfall effects influence economic performance. Overall, the findings underscore the importance of climate variability in shaping economic outcomes in African economies and highlight the need for climate-resilient policies and investment

Thurlow *et al.,* (2009) studied the impact of climate variability on economic growth and poverty in Zambia using an integrated hydro-crop and Dynamic Computable General Equilibrium (DCGE) model. The study found that climate variability has substantial economic and welfare impacts in Zambia. Climate variability significantly reduces crop yields across agroecological zones, leading to macroeconomic losses estimated at US$4.3 billion over a decade, rising to US$7.1 billion under extreme rainfall scenarios. These impacts are spatially concentrated in vulnerable regions, particularly in southern and central Zambia, where food insecurity is highest. In addition, climate variability is shown to increase poverty, keeping approximately 300,000 people below the poverty line, with further increases under adverse climate scenarios. The results also indicate that current climate variability has a more immediate effect on economic outcomes than long-term climate change projections, although declining rainfall can amplify these negative impacts. Overall, the study highlights that climate variability and climate change jointly constrain economic growth and poverty reduction in Zambia.

Gulzar & Aziz (2023) conducted a study that used panel data to analyze the long-run effects of anthropogenic climate change on economic growth in 31 countries in Asia during the period 1971-2021 using the Pooled Mean Group-Autoregressive Distributed (PMG-ARDL) model. These results of the empirical study revealed that rising temperatures have a predominantly negative effect on economic growth at the national level, although a smaller positive effect is observed within urban agglomerations. Overall, the net effect of temperature increases remains negative, indicating that the adverse impacts outweigh any localized benefits. Furthermore, the study shows that increased rainfall in urban areas negatively affects economic growth, likely due to infrastructure stress and heightened vulnerability to flooding. The study also establishes that in the long run, temperature exerts the largest impact on economic growth compared to other macroeconomic variables such as exports, gross capital formation, government expenditure and private consumption. This underscores the dominant role of climate-related factors in shaping long-term economic performance.

Sangkhaphan & Shu (2019) studied the effect of rainfall on the growth of the Gross Provincial Product (GPP) by economic sector and subsector using provincial-level panel data from 1995 to 2015. The Feasible Generalized Least Squares (FGLS) estimator with fixed effect was used in the regression models. The results of the study revealed that the main impacts of the weather occurred through rainfall and reduced GPP growth at the national level. For the sector level, the results showed that rainfall had a significant negative impact on the agricultural and service sectors while it had a positive but not significant impact on the industrial sector. However, rainfall remains vital in poor regions although it could be detrimental to certain subsectors in those regions. The results confirmed that the positive effects of rainfall mostly affected the economies of poor provinces and suggested that average rainfall could be the key climate effect on economic growth in Thailand

Abidoye & Odusola (2015) studied the relationship between climate change and economic growth in 34 African countries over the period 1961 to 2009 and found that climate change has a significant negative impact on economic performance. Their results show that a 1°C increase in temperature reduces GDP growth by approximately 0.67 percentage points, reflecting the high vulnerability of African economies to climate variability, particularly due to their dependence on climate-sensitive sectors such as agriculture, energy and water resources. The study further highlights regional differences, noting that larger economies such as Nigeria and South Africa help moderate the overall negative effects at the continental level, while smaller economies remain more exposed due to limited adaptive capacity.

Ceesay & Fanneh (2022) studied the interplay of economic growth, climate change, and agriculture in Bangladesh by employing the Autoregressive Distributed Lag Model (ARDL) model over the period from 1971 to 2020. The short-run and long-run results revealed a positive and significant impact of the agriculture sectors on economic growth in Bangladesh. Findings further showed that climate change and food security have a positive and insignificant impact on economic development. Food import was found to have a negative and insignificant impact on economic growth in the short-run and an insignificant positive impact in the long-run. The study concludes that Bangladesh should invest in the agriculture sector as an engine of economic growth. Climate change, food security and food imports are essential for Bangladesh's economy.

A study by Gündoğdu & Kahyaoglu (2024) as a panel study of G-20 countries shows that climate change, proxied by carbon dioxide emissions, is closely linked with economic growth, trade openness and financial development. Using a Panel VAR and GMM estimation approach over the period 1980-2020, the study finds that economic and financial variables significantly influence climate outcomes, with GDP per capita, trade openness and financial depth playing an important role in explaining emissions dynamics. The results further indicate dynamic interactions among these variables, where shocks to emissions initially affect financial markets, trade openness and economic growth but dissipate within a few years. Overall, the study concludes that trade openness and financial development can serve as policy tools to promote environmentally sustainable growth, highlighting the interconnectedness between climate change and macroeconomic performance.

Albrizio *et al.* (2014) examined the relationship between environmental policies and productivity growth using cross-country data from OECD and non-OECD countries. The study found that well-designed environmental policies do not hinder productivity growth; instead, they can have neutral or even positive effects, particularly when policies are flexible and market-based. While stricter environmental regulations may impose short-term adjustment costs, the evidence suggests that they can stimulate innovation and efficiency improvements over time, thereby supporting long-term economic performance. The study further highlights that policy design and institutional quality play a crucial role in determining outcomes, with poorly designed regulations potentially constraining productivity.

MATERIALS AND METHODS

Data

The study employed a time series econometric analysis to investigate the impact of climate change proxied by rainfall variability on economic growth in Zambia. The study used annual data from 1990 to 2023 which was obtained from the Zambia Meteorological Agency, the IMF and the World Development Indicators (WDIs). Based on the literature, the following variables were adopted to assess the relationship between climate change and economic growth.

Table 1: Description of variables

Variable	Description	Expected Sign
GDP	Gross domestic product growth, a proxy for economic growth	
RAIN	Represents annual average rainfall	Positive
CROPINDX	Index from annual agriculture output	Positive
FDI	Foreign Direct Investment, measured as the net inflows	Positive
TO	Trade Openness, measured as a ratio of total trade (exports plus imports) to GDP.	Positive
SAV	Natural resources depletion (% of GNI)	Negative
CORR	Control of Corruption	Positive

Empirical Model Specification

To empirically assess the impact of climate change on economic growth in Zambia, the study begins by specifying a reduced-form relationship in which GDP is determined by climatic, agricultural, and macroeconomic factors. The baseline functional form is:

$$GDPt = \beta 0 + \beta 1 RAINt + \beta 2 CROPINDXt + \beta 3FDIt + \beta 4TOt + \beta 5SAVt + \beta 6CORRt + \varepsilon t \ldots\ldots\ldots (2)$$

Where εt is the disturbance term capturing unexplained variations in economic growth.

FINDINGS

Stationarity Test

The Augmented Dickey-Fuller test was employed to examine the stationarity properties of the variables. The results in table 2 above indicate a mixed order of integration, with GDP, rainfall (RAIN) and Foreign Direct Investment (FDI) stationary at levels I(0), while crop production index (CROPINDX), savings from natural resource depletion (SAV), control of corruption (CORR) and trade openness (TO) became stationary after first differencing I(1). Given this combination of I(0) and I(1) variables, the Autoregressive Distributed Lag (ARDL) modelling approach is appropriate to investigate the relationship between climate change and economic growth.

Table 2: Stationarity Test Results

Variable	Order of Integration
GDP	I(0)
RAIN	I(0)
FDI	I(0)
CROPINDX	I(1)
SAV	I(1)
CORR	I(1)
TO	I(1)

Cointegration test

The study employed the ARDL bounds testing approach to cointegration developed by Pesaran *et al.* (2001) to examine the existence of a long-run relationship among the variables. This approach is appropriate given the mixed order of integration of the variables, which are integrated of order I(0) and I(1).

The ARDL bounds test results in the table above shows that the computed F-statistic (5.742) exceeds the upper bound critical values at the 1%, 5%, and 10% significance levels. This leads to the rejection of the null hypothesis of no long-run relationship, confirming the existence of cointegration among the variables. The presence of cointegration suggests that climate change variables, particularly rainfall variability, have a persistent and long-term influence on economic growth, rather than just short-term effects. Therefore, there is a need to estimate short run dynamics and long run effects.

Table 3: ARDL Bounds Test Results

F-Statistic Value		**5.742077**
Test Critical Values	**Lower Bound**	**Upperbound**
10%	1.99	2.94
5%	2.27	3.28
2.5%	2.55	3.61
1%	2.88	3.99

ARDL Model

From the table 4 above, the long-run ARDL results indicate that RAIN, SAV and CORR have positive coefficients and are statistically significant at 5% level, indicating that they have a meaningful long-run effect on economic growth. However, TO has a positive coefficient but is statistically insignificant at the 5% level, indicating that it has no meaningful long-run effect on economic growth. In contrast, CROPINDX has a negative coefficient and statistically significant at 5%, implying that it plays a significant role in influencing economic growth over the long run. However, FDI has a negative coefficient and statistically insignificant at 5%, indicating that it has no relationship with economic growth in the long run.

Table 4: Long Run Estimates

Variable	Coefficient	Std. Error	T-Statistic	Prob
RAIN	0.0321	0.0127	2.5184	0.0236**
FDI	-1.0388	0.8041	-1.2919	0.2160
CROPINDX	-0.1707	0.0800	-2.1331	0.0498**
SAV	0.6281	0.2547	2.4661	0.0262**
CORR	0.5390	0.2122	2.5396	0.0227**
TO	0.2866	0.1987	1.4425	0.1697
C	-51.9544	16.7601	-3.0999	0.0075

*** means P-value < 0.05*

Source: Author's own estimation

The results indicate that changes in current RAIN has positive and statistically significant effect, while RAIN with a one-period lag has a negative and statistically significant effect. This suggests short-run fluctuations in RAIN influence economic growth in opposite directions across periods. FDI exhibits a negative but statistically insignificant effect, indicating no meaningful short-run impact. Furthermore, changes in the CROPINDX have a positive but statistically insignificant effect both currently and with a one-period lag, implying limited short-run influence. SAV shows a positive but statistically insignificant effect, suggesting no short-run relationship.

Table 5: Short Run Estimates

Variable	Coefficient	Std. Error	T-Statistic	Prob
D(RAIN)	0.01203	0.004	2.5507	0.0222 **
D(RAIN(-1))	-0.1200	0.0043	-2.7393	0.0152**
D(FDI)	-0.0428	0.1580	-0.2707	0.0790
D(CROPINDX)	0.0347	0.0453	0.7664	0.4553
D (CROPINDX(-1))	0.1086	0.0512	2.1201	0.0511
D(SAV)	0.2666	0.1275	2.0909	0.0540
D(CORR)	0.0974	0.1548	0.6290	0.5388
D(CORR(-1))	-0.4531	0.1708	-2.6531	0.0181**
D(TO)	0.0568	0.0739	0.7685	0.4541
ECT	-0.9552	0.1164	-8.2081	0.0000**

***means P-value < 0.05*

Source: Author's own estimation

Similarly, current CORR has a positive but statistically insignificant effect, while its one-period lag shows a negative and statistically significant effect, indicating that past improvements in corruption control may have a delayed negative short-run effect. The findings also show that TO has a positive but statistically insignificant effect, indicating no significant short-run influence.

Finally, the ECT (CointEq(-1)) is negative and highly statistically significant, confirming the existence of a stable long-run relationship. The coefficient of approximately -0.955 implies a very high speed of adjustment, where about 95.5% of short-run disequilibrium is corrected within one period (year), indicating rapid convergence back to the long-run equilibrium path.

RESULTS AND DISCUSSION

The findings of this study provide insights into the dynamic relationship between climate variability, macroeconomic factors, and economic growth in Zambia. The results reveal both short-run adjustments and long-run equilibrium relationships, confirming that climate-related variables play a critical role in shaping economic performance. Rainfall emerges as one of the most important determinants of economic growth. In the long run, rainfall has a positive and statistically significant effect, indicating that sustained increases in rainfall are associated with improved economic performance. In the short run, rainfall exhibits a positive and statistically significant immediate effect, but a negative and significant effect with a one-period lag. This suggests that while increased rainfall initially boosts economic activity, lagged effects may reflect adverse outcomes such as flooding, soil degradation, or inefficient water management. These findings are consistent with empirical evidence which shows that rainfall variability significantly influences economic growth, particularly in developing economies where agriculture and energy systems are climate-dependent (Olanrewaju, 2019; Gulzar & Aziz, 2023).

The findings also show that FDI has a negative but statistically insignificant effect in both the short and long run. However, this contradicts conventional growth theory, which hypothesizes that FDI promotes economic growth through capital accumulation, technology transfer and job creation. The insignificant effect may be explained by the sectoral concentration of FDI in Zambia, particularly in extractive industries such as mining, which have limited spillovers to the broader economy (Phiri *et al.,* 2025; Libanda *et al.,* 2017).

The crop production index was found to have a negative and statistically significant long-run relationship with economic growth, while its short-run effects were positive but statistically insignificant. Although this finding contradicts with studies such as Ceesay & Fanneh (2022), which report a positive contribution of agriculture to growth, it is consistent with the Zambian context, where agriculture is characterized by low productivity, climate vulnerability, limited value addition, and weak market integration. Recent evidence suggests that the sector continues to face structural constraints including inefficient policies, inadequate infrastructure, low technology adoption and climate-related shocks, which significantly undermine productivity and broader economic contribution (IMF, 2023).

Natural resource depletion shows a positive and statistically significant long-run effect, while being positive but insignificant in the short run. This result is contrary to theoretical expectations under the resource curse hypothesis but aligns with the resource-led growth argument. In Zambia, economic growth is heavily driven by extractive industries, particularly mining. As such, increased resource extraction (captured as depletion) may contribute positively to GDP in the long run. This is consistent with Sachs & Warner (2001) and Barbier (2005), who argue that resource-rich economies can experience economic growth when resource revenues are extensively exploited, though this may undermine long-term environmental sustainability.

The findings also show that control of corruption has a positive and statistically significant relationship in the long run, indicating that improved governance enhances economic growth. This finding is consistent with institutional growth theories and empirical evidence showing that stronger governance and lower corruption levels promote long-run economic performance through greater efficiency and reduced rent-seeking behaviour and improved policy implementation (Mauro, 1995; Acemoglu *et al.,* 2001). However, in the short run, control of corruption is positive but statistically insignificant, while its one-period lag is negative and statistically significant. This suggests that improvements in governance and anti-corruption measures may initially generate institutional adjustment costs and temporary disruptions to established economic and administrative processes before yielding long-term economic benefits. Similar findings are reported in studies on anti-corruption reforms, which show that governance interventions often produce delayed growth effects due to transitional institutional frictions and enforcement adjustments (Parrett-Jung, 2025).

Furthermore, the findings show that trade openness has a positive but statistically insignificant effect in both the short and long run. While this suggests that trade may contribute positively to economic growth, the lack of statistical significance indicates that its impact is relatively weak. This may reflect structural constraints in Zambia's trade sector, including limited export diversification, dependence on primary commodities and weak integration into global value chains. This finding is consistent with studies such as Gündoğdu & Kahyaoğlu (2024), which emphasize that trade openness alone is insufficient to drive economic growth without complementary structural reforms.

The Error Correction Term (ECT) is negative and highly statistically significant, confirming the existence of a stable long-run relationship among the variables. The magnitude of approximately -0.955 indicates that about 95.5% of deviations from long-run equilibrium are corrected within one year. This implies a very rapid speed of adjustment, suggesting that the economy quickly returns to its long-run growth path following short-term shocks. Such a high adjustment speed reflects strong internal mechanisms linking climate variables and economic activity.

CONCLUSION

This study examined the relationship between climate change and economic growth in Zambia for the period 1990 -2023. The findings confirm the existence of a stable long-run relationship between economic growth and climate variability as well as macroeconomic variables. In the long run, rainfall is positively associated with economic growth. In the short run, however, rainfall exhibits asymmetric effects, with a positive current period effect and a negative one-period lag effect, reflecting the disruptive consequences of climate variability. Additionally, natural resource depletion contributes positively to economic growth in the long run, suggesting that Zambia's growth remains largely resource-driven, particularly through extractive industries. On the other hand, the negative and significant long-run relationship between agricultural output and economic growth highlights structural weaknesses within Zambia's agricultural sector.

Furthermore, control of corruption positively influences economic growth in the long run, confirming the importance of strong institutions and governance in enhancing economic performance. However, the negative short-run lag effect suggests that governance reforms may involve transitional costs before yielding long-term benefits. In contrast, FDI and trade openness exhibit insignificant effects on economic growth in both the short and long run.

Based on the empirical findings, the study proposes the following recommendations:

- Strengthening climate adaptation and resilience by; investing in irrigation infrastructure such dam development, water harvesting systems and climate-resilient water storage facilities; investing in early warning systems; and promotion of Climate-Smart Agriculture (CSA) practices.
- Transform and modernise the agricultural sector to improve productivity and efficiency.

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