https://doi.org/10.51483/IJMRE.4.2.2024.69-85 ISSN: 2710-141X

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Research Paper Open Access

Does Climate Change Impact Tax Revenue? Lesson from Rwanda

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Article Info

Volume 4, Issue 2, July 2024
Received : 18 January 2024
Accepted : 08 June 2024
Published : 05 July 2024
doi: 10.51483/IJMRE.4.2.2024.69-85

Abstract

This study investigates the impact of climate changes and weather abnormalities on tax revenue compliance in Rwanda, spanning the period from 2006Q1 to 2021Q4. Through a comprehensive analysis of tax revenue trends and key environmental variables, it unravels the intricate relationship between climate dynamics and fiscal performance. Descriptive statistics highlight patterns in tax revenue and climate-related factors, offering nuanced insights. The historical trends reveal fluctuations in Domestic Tax, Tax on Goods and Services, and Tax on International Trade and Transactions, indicating robust growth in domestic revenue mobilization. The study explores the repercussions of climate-induced events on vital economic sectors, identifying challenges posed by events such as droughts and floods. Regression analysis identifies unemployment and the informal sector as significant factors inducing low tax revenue in Rwanda. This research recommends diversifying revenue sources away from climate-vulnerable sectors, investing in resilient infrastructure, integrating climate adaptation into policies, fostering inclusive economic growth, prioritizing unemployment mitigation, implementing continuous monitoring, and promoting international collaboration.

Keywords: *Climate changes, Weather abnormalities, Tax revenue, Rwanda*

1. Introduction

1.1. Background and Rationale

Climate change represents an existential challenge of our time, transcending borders and affecting ecosystems, economies, and societies on a global scale. While it is undeniably a worldwide phenomenon, the profound consequences of climate change are often most acutely experienced at the local and regional levels. Rwanda, a small, landlocked nation in East Africa, emerges as a poignant example of a region confronting significant ramifications resulting from the dynamic shifts in climate. Notably, Rwanda has garnered recognition for its extraordinary strides in economic and social development over recent years, making it a compelling case study for understanding the intersection of climate change and socioeconomic progress.

Contemporary research, as exemplified by Acemoglu *et al.* (2021), has underscored the substantial implications of climate change for directed innovation and the enduring outcomes of the shale gas revolution. This research elucidates

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the intricate linkages between environmental variables and the trajectory of directed technical change. Furthermore, prior scholarly endeavors, such as the work conducted by Acemoglu *et al.* (2012), have delved into the multifaceted relationship between environmental factors and the dynamics of directed technical change, revealing the transformative influence of environmental shifts on innovation.

The Rwandan economy is inextricably connected to the nuanced dynamics of climate and environmental variations. Agriculture stands as a cornerstone of the Rwandan economy, a sector profoundly susceptible to the unpredictable nature of climate and weather patterns. Additionally, pivotal sectors including tourism, energy, and infrastructure are significant contributors to the nation's tax revenue, holding a central role in its economic sustainability. A recent study by Acemoglu *et al*. (2018) further underscores the multifaceted implications of climate change for directed innovation and the long-lasting consequences of the shale gas revolution. This study accentuates the interconnectedness of environmental fluctuations with broader economic narratives, necessitating a more comprehensive understanding of these linkages.

Climate changes, ranging from extreme weather events to alterations in precipitation patterns, bear the potential to disrupt these critical sectors. The repercussions of such disruptions cascade, affecting the Rwandan government's ability to collect tax revenue, which plays a pivotal role in sustaining public services, development initiatives, and governance. The implications are substantial and far-reaching, prompting a compelling need to dissect the intricate relationship between climate changes, weather abnormalities, and the stability of tax revenue in Rwanda.

This research embarks on an ambitious journey to explore this nexus in depth, aiming to shed light on the complex ways in which environmental transformations influence the fiscal stability of the Rwandan government. By conducting a comprehensive analysis of the associations between climate variations, key economic sectors, and tax revenue, this research aspires to provide invaluable insights crucial for informed policy-making, sustainable economic development, and climate adaptation in Rwanda. Beyond its immediate applicability to Rwanda, this research demonstrates the broader significance of understanding the intricate interplay between climate change and public finance for nations grappling with the complexities of an evolving global landscape

1.2. Problem Statement

Climate change and its associated weather abnormalities represent a complex and urgent global challenge with far-reaching implications. In the Rwandan context, a country celebrated for its remarkable progress in economic and social development, these environmental shifts have emerged as pivotal factors influencing various facets of the nation's socioeconomic fabric. Of particular concern is their potential impact on tax revenue, the lifeblood of public finance that sustains government operations, funds critical services, and drives developmental initiatives.

Rwanda's economic stability is intricately connected to sectors highly sensitive to variations in climate conditions, such as agriculture, tourism, and infrastructure. Fluctuations in climate patterns, marked by irregular rainfall, temperature extremes, and natural disasters, can disrupt these sectors, ultimately leading to instability in tax revenue collection. This situation raises a critical and timely question: To what extent do climate changes and weather abnormalities affect the generation and stability of tax revenue in Rwanda?

Compounding this challenge is Rwanda's increased vulnerability to the adverse effects of climate change, a vulnerability shared by many developing nations. Although Rwanda has taken significant steps in climate adaptation and mitigation, understanding the precise mechanisms through which climate-induced factors impact tax revenue remains a gap in the current body of knowledge. Furthermore, climate change operates within a complex interplay of economic, demographic, and political factors that can either magnify or ameliorate its effects on tax revenue.

This research endeavors to bridge this knowledge gap by undertaking a comprehensive exploration of the intricate relationship between climate changes, weather abnormalities, and tax revenue in Rwanda. Its objectives encompass the identification of the underlying causal mechanisms, an assessment of vulnerabilities, and the proposition of informed strategies to bolster the resilience of tax revenue amidst changing climatic conditions. Importantly, the significance of this research transcends Rwanda's borders; it serves as an invaluable case study for understanding the broader implications of climate change on public finance. It underscores the imperativeness of adaptive fiscal policies in a dynamically evolving global climate landscape.

1.2.1. General Objective

The study aims to understand the broader relationship between climate-related factors and government revenue generation in the context of a developing country like Rwanda.

1.2.2. Specific Objectives and Hypothesis

Hypothesis Testing for the Three Specific Objectives**:**

Objective 1: To examine the historical trends of tax revenue in Rwanda over a specific period and identify any significant fluctuations that might be associated with climate changes and weather abnormalities.

> ***Null Hypothesis (H_0):*** *There is no statistically significant relationship between historical climate changes and weather abnormalities and tax revenue fluctuations in Rwanda over the specified period.*
>
> ***Alternative Hypothesis (H_1):*** *There is a statistically significant relationship between historical climate changes and weather abnormalities and tax revenue fluctuations in Rwanda over the specified period.*

Objective 2: To assess the impact of climate changes and weather abnormalities on key economic sectors that contribute significantly to tax revenue, such as agriculture, tourism, energy, and infrastructure.

> ***Null Hypothesis (H_0):*** *Climate changes and weather abnormalities have no significant impact on key economic sectors (agriculture, tourism, energy, and infrastructure) contributing to tax revenue in Rwanda.*
>
> ***Alternative Hypothesis (H_1):*** *Climate changes and weather abnormalities have a significant impact on key economic sectors contributing to tax revenue in Rwanda.*

Objective 3: To analyze the relationship between climate-induced events and fluctuations in tax revenue, taking into account potential time lags and nonlinear effects.

> ***Null Hypothesis (H_0):*** *There is no statistically significant relationship between climate-induced events, time lags, and nonlinear effects on tax revenue fluctuations in Rwanda.*
>
> ***Alternative Hypothesis (H_1):*** *There is a statistically significant relationship between climate-induced events, time lags, and nonlinear effects on tax revenue fluctuations in Rwanda.*

2. Literature Review

2.1. Introduction

Climate change and its associated weather abnormalities are pressing global concerns with multifaceted consequences. The implications of climate change are not limited to environmental and social dimensions; they extend to economic aspects, including tax revenue generation. Rwanda, a landlocked East African nation celebrated for its rapid economic development, faces a unique set of challenges and opportunities in this context. Understanding the intricate relationship between climate changes, weather abnormalities, and tax revenue in Rwanda is essential for informed policy-making and sustainable economic development.

2.2. Climate Change and Weather Abnormalities

Climate change is a global phenomenon characterized by shifts in temperature, precipitation patterns, and extreme weather events. These changes can result in weather abnormalities such as droughts, floods, and erratic rainfall. In Rwanda, climate change manifests as changes in temperature and rainfall patterns, impacting the country's predominantly agricultural economy. Such variations have far-reaching implications for the economic sectors that significantly contribute to tax revenue. Rwanda's economy is heavily reliant on climate-sensitive sectors, particularly agriculture, which employs a substantial portion of the population and contributes significantly to the nation's Gross Domestic Product (GDP) (Nizeyimana *et al.*, 2020). Climate variations have a direct impact on agricultural productivity, affecting crop yields and livestock, which in turn influence the income of farmers and the government's tax revenue (Ebi *et al.*, 2018).

2.3. Rwanda's Economic Landscape

Rwanda's economy heavily relies on sectors such as agriculture, tourism, energy, and infrastructure, which are susceptible to climate-induced disruptions. Agriculture, the backbone of the Rwandan economy, is particularly sensitive to variations in temperature and rainfall. The tourism industry, a significant source of foreign exchange and revenue, is influenced by climatic conditions affecting wildlife and landscapes. Energy and infrastructure development are vital for economic growth but are also vulnerable to climate-related challenges. Climate change is an overarching phenomenon that affects regions worldwide, but its consequences are often localized and specific to particular geographic contexts (Adger, 2006). In Rwanda, the effects of climate change manifest in various ways, significantly influencing the nation's socioeconomic landscape. These changes include alterations in temperature, shifts in precipitation patterns, and an increased frequency of extreme weather events (Nkurunziza *et al.*, 2018).

2.4. Tax Revenue Collection in Rwanda

Tax revenue is a crucial source of income for the Rwandan government, funding public services, infrastructure projects, and socioeconomic development programs. However, the stability of tax revenue is influenced by various factors, including economic performance, population growth, and external shocks like climate change. Understanding the role of climate changes and weather abnormalities in shaping tax revenue trends is pivotal for effective fiscal management.

2.5. Previous Research

Previous research has explored the relationship between climate change and economic dynamics. Studies like Acemoglu, Aghion *et al.* (2016) have highlighted the far-reaching consequences of climate change on innovation and economic outcomes. Acemoglu *et al.* (2012) have examined how environmental factors affect directed technical change. However, the specific impact of climate changes and weather abnormalities on tax revenue in Rwanda remains an underexplored area of study.

2.6. Research Gaps

Several gaps exist in the current literature. First, while there is an understanding of the broader impact of climate change on economies, there is limited research on its specific influence on tax revenue. Second, the complex interaction of climate changes, economic sectors, and tax revenue, including potential time lags and nonlinear effects, remains insufficiently explored. Third, the unique context of Rwanda, with its remarkable economic growth and vulnerability to climate change, necessitates a focused investigation.

3. Research Methodology

3.1. Research Design

The research design is econometric in nature, focusing on assessing the impact of climate changes and weather abnormalities on tax revenue while controlling for relevant economic and political variables. The design is largely quantitative, employing statistical methods to estimate the model coefficients.

3.2. Data Collection

3.2.1 Data Sources

Data for this study will be collected from various sources, including:

Government Reports: Official reports from the Rwandan government, Rwanda Revenue Authority the National Institute of Statistics Rwanda, and the Meteorology Agency.

International Organizations: Data from international organizations like the World Bank, World Meteorological Organization (WMO) providing statistics on climate, economy, and public finance in Rwanda.

Academic Publications: Relevant research papers, articles, and studies that offer insights and data to supplement the analysis.

3.3. Data Collection Methods

Secondary Data Analysis: Existing data from the specified sources will be collected, compiled, and analyzed spanning the period from 2006Q1 to 2021Q4.This data includes historical tax revenue figures, climate-related information, and economic indicators.

Data Validation: Data quality and validity will be assessed by cross-referencing information from multiple sources

3.3.1. Data Variables

The variables include:

Dependent Variable: Tax Revenue (TR)

Independent Variable: Combined Climate Changes and Weather Abnormalities (CCWA)

Control Variables: Gross Domestic Product (GDP), Inflation (INF), Population (POP), Political Factors (POL)

3.4. Econometric Model Setting

The specified econometric model will be estimated using appropriate techniques to investigate the impact of climate changes and weather abnormalities on tax revenue in Rwanda. The model is structured as a linear regression with the following specifications:

$$TR_{it} = X_{it}\beta + U_{it} + \varepsilon_{it} \quad \text{... (1)}$$

where TR_{it} is the Tax Revenue at time t, X_{it} is the he vector of explanatory variables comprises Climate Changes and Weather Abnormalities (CCWA), combining the effects of climate changes and weather abnormalities. Gross Domestic Product (GDP) serves as a control variable, reflecting economic performance and potentially influencing tax revenue. INF (Inflation) is another control variable representing inflation and its impact on the real value of tax revenue. POP (Population) is a control variable suggesting that a larger population may contribute to higher tax revenue. Lastly, POL (Political Factors) functions as a control variable, considering political influences, including government policies and stability, on tax revenue. Together, they form a vector of regression coefficients. Top of Form, U_{it} is an observable individual-specific effect and ε_{it} is the disturbance term.

The Gauss-Markov conditions for the linear regression model include:

A1: $(\varepsilon_i) = 0$ for $i = 1, ..., N$ (where ε_i is the disturbance term for individual i)

A2: $\text{cov}(\varepsilon_i, \varepsilon_j) = 0$ for $i \neq j$ (the disturbances are uncorrelated between individuals)

A3: $\text{Var}(\varepsilon_i) = \sigma^2$ for $i = 1, ..., N$ (the disturbances have constant variance)

A4: ε_i is independent of the explanatory variables for $i = 1, ..., N$ (No correlation between disturbances and regressors)

3.5. Non-linear Models

An alternative specification for the Tax Revenue is the random effect probit model:

$$h_{i0} = (\phi_l)\ (\beta_0 X_{ui0} + \alpha_{i0}^{0}) \quad \text{...(2)}$$

$$h_{it} = \left(\phi^1\right)\left(\Gamma\, \beta\alpha\varepsilon h_{it} + \chi_{it} + \varepsilon_{it}\right) \quad \text{...(3)}$$

where h_{i0} represents the initial Tax Revenue, X_{ui0} includes observable traits such as CCWA, GDP, INF, POP, and POL and represents unobserved taste dependency related to income. The estimation of the model involves simulation-based techniques due to the presence of serially dependent disturbances. The Heckman method (1981) can be employed to address this issue effectively.

3.6. Data Analysis and Results

Results will be presented using tables, figures, and descriptive statistics to provide insights into the impact of climate changes and weather abnormalities on tax revenue.

Data analysis will involve the application of statistical methods to estimate the coefficients and assess the significance of the relationships between variables.

3.7. Robustness Checks

Robustness checks will be performed to validate the results and assess the sensitivity of the findings to different model specifications.

3.8. Ethical Considerations

The research will adhere to ethical guidelines in data collection and analysis, respecting privacy, confidentiality, and the proper citation of data sources.

4. Data Results

This study focuses on tax revenue compliance in Rwanda, specifically examining the impact of climate changes and weather abnormalities. With an eye on enhancing our understanding of the intricate relationship between environmental factors and tax revenue, the research delves into how phenomena such as Climate Changes and weather abnormalities may influence the fiscal landscape in Rwanda. By scrutinizing the interplay of these variables, the study aims to provide valuable insights into the challenges and opportunities for tax revenue compliance in the face of evolving climatic conditions, contributing to a more comprehensive understanding of economic dynamics in the region.

4.1. Descriptive Statistics

In examining tax revenue compliance in Rwanda amidst climate changes and weather abnormalities, descriptive statistics reveal notable patterns. The mean tax revenue stands at 92,037 billion Rwf, with a standard error of 3.29. Precipitation averages at 98.43 mm, with a standard error of 4.03. Max temperature records a mean of 25.42°C, while GDP Current $ exhibits a mean of 7,760.13 with a substantial standard error of 565,113,414.8. Unemployment, exchange rate, and real interest rate demonstrate means of 840.78, 840,477,787.3, and 961,580,640.4, respectively. Exports and imports in current $ show mean values of 1,075,398,539 and 1,299,373,547, with standard errors of 764,387,218.8 and 876,980,770.6. These statistics, encompassing medians, minimums, maximums, sums, and year observations, provide a concise overview of the variables influencing tax revenue dynamics in Rwanda (Table 1).

Table 1: Descriptive Statistics of Data Variables on Tax and Combined Climate Changes and Weather Abnormalities (CCWA)

Variables	Mean	SE	Minimum	Maximum	Sum	Year Obs.
Tax Revenue (bn) Rwf	92037	3.289004158	0.986000001	3318107347	4.42E+09	16
Precipiation (mm)	98.43	4.030907623	1.011999965	4068224991	5.53E+09	16
Max Temerature (°C)	25.41833333	5.156260958	1.024000049	5177230923	7.13E+09	16
GDP Curent ($)	7760.125834	565113414.8	1.059999943	5671592572	7.76E+09	16
Unemployment	840.7778731	609950180.9	1.077999949	6121529488	8.4E+09	16
Exchange rate	840477787.3	609950180.9	1.077999949	6121529488	8.4E+09	16
Real interest rate	961580640.4	685864348.4	1.098999977	6881379762	9.62E+09	16
Exports Curent ($)	1075398539	764387218.8	1.118000031	7650671477	1.08E+10	16
Imports in curents ($)	1299373547	876980770.6	1.144000053	8690878328	1.3E+10	16

Source: Nzabirinda Etienne,2024

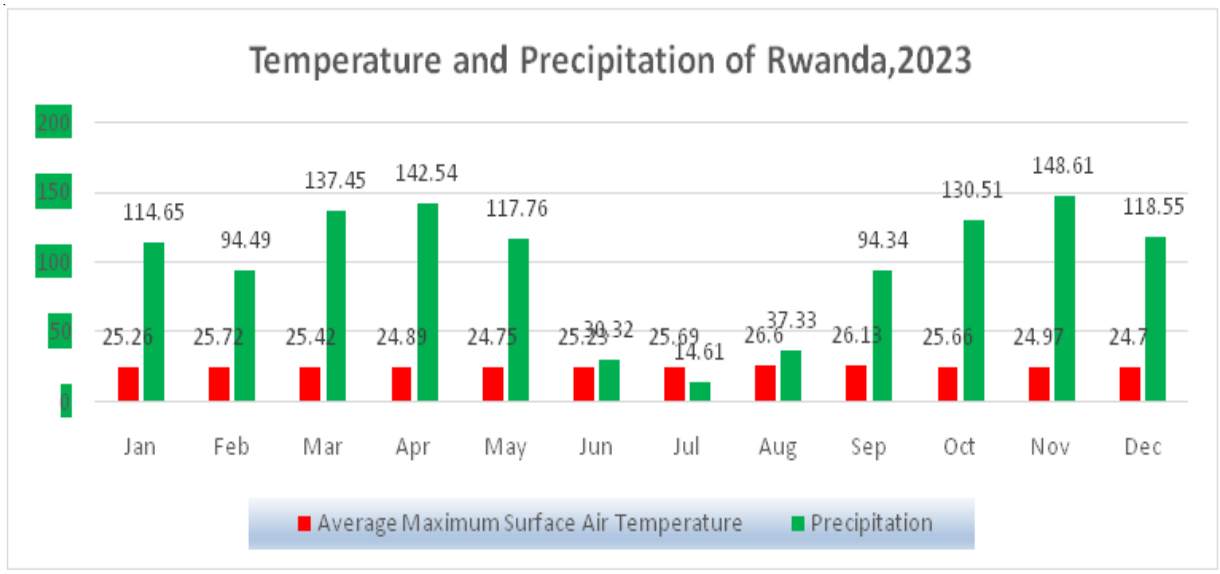
4.2 Objective 1

To examine the historical trends of tax revenue in Rwanda over a specific period and identify any significant fluctuations that might be associated with climate changes and weather abnormalities.

The provided data, showcasing the Average Maximum Surface Air Temperature in Rwanda across different months, offers valuable insights into the potential impact of climate changes and weather abnormalities on tax revenue compliance (Figure 1). The impact of climate changes and weather abnormalities on tax revenue compliance in Rwanda is intricately linked to the country's distinctive rainfall patterns and temperature variations. Rwanda, characterized by diverse topography and proximity to large water bodies, experiences significant temporal and spatial variations in rainfall. The two main rainy seasons, occurring around March to May and October to December, play a crucial role in shaping the country's climate dynamics. However, this temporal variability has given rise to extreme weather events, including the floods of the 1997/98 El-Niño phenomena and frequent droughts. These events have profound socio-economic implications for Rwanda.

In terms of temperature, Rwanda exhibits contrasting patterns across different regions. The eastern low-lying areas and Bugarama Valley record the warmest annual average temperatures, ranging between 20-24°C, while the central plateau and highlands experience cooler temperatures, ranging from 17.5-19°C and less than 17°C, respectively. Despite these regional variations, temperatures in Rwanda show minimal fluctuations throughout the year.

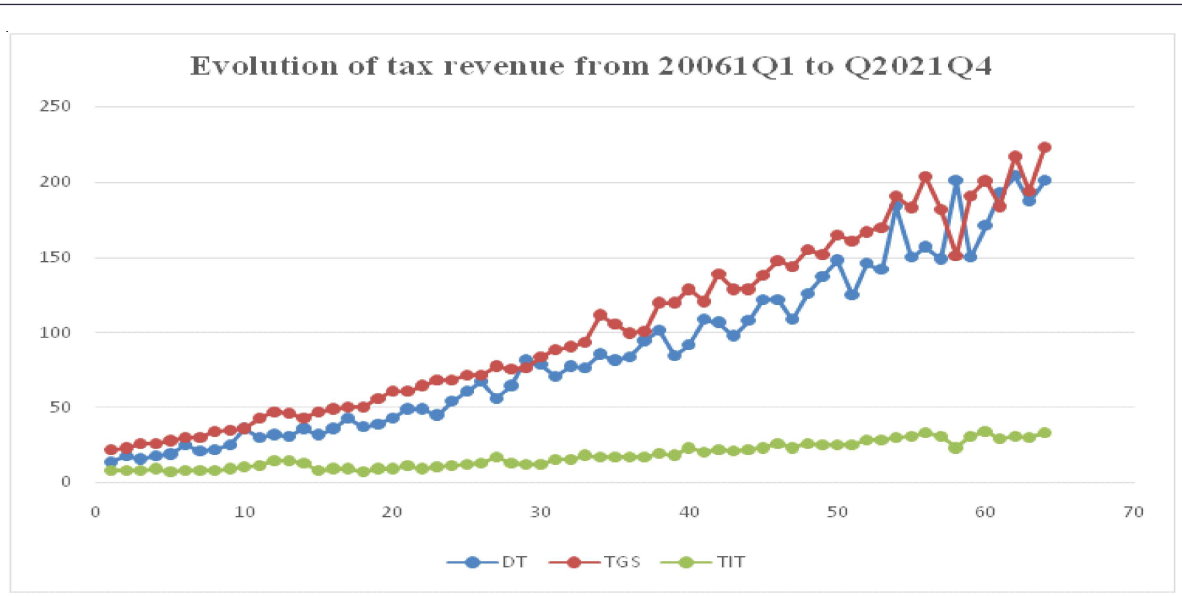
The country's rainfall pattern follows a bimodal distribution, primarily influenced by the Inter-Tropical Convergence Zone (ITCZ). The ITCZ's movement corresponds to the annual progression of the sun, crossing the equator in March and September each year, leading to distinct maximum rainfall seasons. These seasons occur over March, April, and May (MAM) and in September, October, November, and December (SOND).



Source: Nzabirinda Etienne,2024

Figure 1: Climate Changes and Weather Abnormalities

In assessing the trajectory of tax revenue compliance in Rwanda from 2006Q1 to 2021Q4, a comprehensive analysis of key revenue components, namely Domestic Tax (DT), Tax on Goods and Services (TGS), and Tax on International Trade and Transactions (TIT), reveals significant insights (Figure 2). The Domestic Tax revenue, depicting notable fluctuations, exhibits a pronounced upward trend, reflecting a robust growth in tax collection from within the country. This suggests effective domestic revenue mobilization efforts, possibly driven by expanding economic activities and enhanced compliance. Similarly, the Tax on Goods and Services category demonstrates temporal variability with a conspicuous ascending pattern, particularly since 2016. This observed trend signifies a substantial increase in tax revenue derived from goods and services, underscoring the sector's growing contribution to overall tax receipts. Furthermore, Tax on International Trade and Transactions showcases fluctuations with an overall ascending trajectory, indicating a potential expansion in tax collection related to international trade activities.



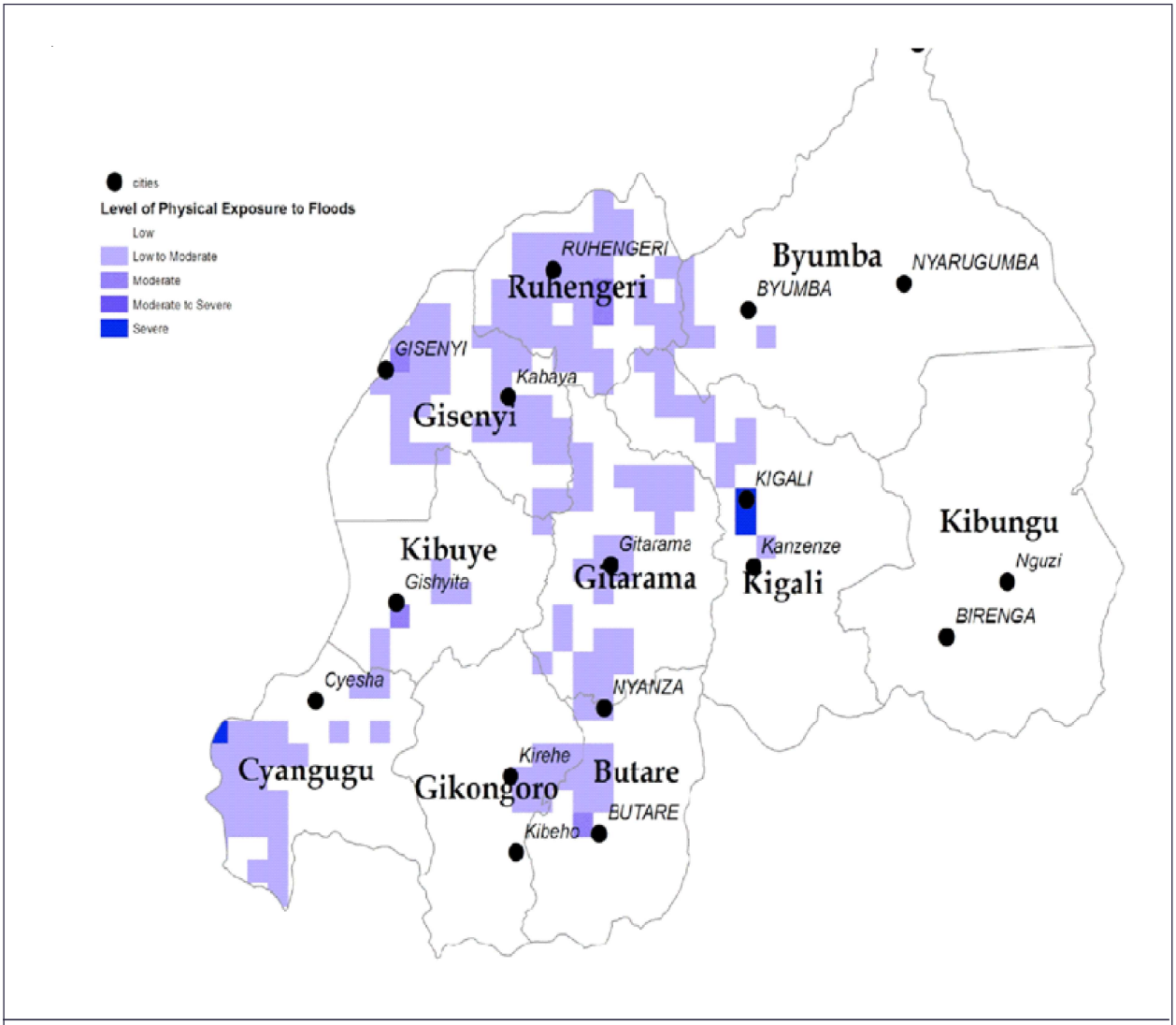
Source: Nzabirinda Etienne,2024

Figure 2: Evolution of Tax Revenue from 2006 Q1 to 2021 Q4

4.3. Objective 2

To assess the impact of climate changes and weather abnormalities on key economic sectors that contribute significantly to tax revenue, such as agriculture, tourism, energy, and infrastructure.

To assess the impact of climate changes and weather abnormalities on key economic sectors contributing significantly to tax revenue, such as agriculture, tourism, energy, and infrastructure, historical events provide valuable insights. Between 1999 and 2022, prolonged drought severely affected Bugesera, Umutara, and Mayaga regions, with similar drought effects observed in 2022. Predicting the economic costs of future events related to climate change is challenging due to the uncertainties in future projections. Climate models indicate an intensification of the hydrological cycle, with increased magnitude and frequency of intense precipitation events in the coming decades.



Source: Nzabirinda Etienne,2024

Figure 3: Illustrates the Location and Exposure to Floods in Rwanda

Flood events, a consequence of these changes, pose threats to infrastructure, disrupting operations and causing damage (Figure 3). Critical infrastructure, like water treatment plants and roads, is particularly vulnerable, impacting health, livelihoods, and resulting in fatalities. The potential impacts are also influenced by socio-economic trends, such as population growth, urbanization, and increased asset values in flood-prone areas. Deforestation, loss of natural floodplain storage, and changes in climate further contribute to these impacts.

Recent events, like the significant rainfall in 2023 affecting Nyabihu and Rubavu districts, demonstrate the real and immediate consequences (Figure 4). The study estimates the direct effects of such events, considering factors like fatality costs, property loss, and displacement. For valuation, market prices are employed to assess the loss of crops/ yields, economic costs of fatalities, and Rwanda-specific data on house construction costs. This comprehensive analysis

Source: Nzabirinda Etienne,2024

Figure 4: Illustrates the Location and Exposure to Floods in Rwanda

aims to enhance our understanding of the potential economic repercussions of climate changes on vital sectors and, consequently, tax revenue in Rwanda.

4.4 Objective 3

To analyze the relationship between climate-induced events and fluctuations in tax revenue, taking into account potential time lags and nonlinear effects (Table 2).

Table 2: Illustrates Relationship Between Climate-Induced Events and Fluctuations in Tax Revenue

Variables	Coefficients	Standard Error	*t*-Stat	*p*-Value	Lower 95%
Intercept	-1979.049218	3424.931773	-0.5778361	0.581477717	-10077.72595
Precipitation	0.316893635	1.483256498	0.21364723	0.836911684	-3.190450651
Max Temperature	-73.51525186	95.42066849	-0.77043321	0.466244629	-299.1492787
GDP Curent $	-7.18282E-08	3.34319E-07	-0.21484898	0.836010236	-8.62368E-07
Unemployment	2732.380666	998.6900195	2.73596473	0.029087101	370.8540262
Exchange rate	2.806531945	4.217606674	0.66543236	0.527083976	-7.16652308
Real interest rate	11.69891245	12.13573069	0.96400561	0.367155926	-16.99753066
Exports Curent $	1.355E-06	6.01157E-07	2.25399137	0.058850619	-6.65077E-08
Imports in curents $	1.33539E-06	9.62964E-07	1.3867524	0.20807257	-9.41655E-07

Source: Nzabirinda Etienne,2024

Monitoring tax revenue compliance in Rwanda requires a keen eye on the intricate interplay between climate changes, weather abnormalities, and economic factors. An analysis employing a regression model reveals insights into the relationship between climate-induced events and tax revenue fluctuations, considering time lags and nonlinear effects. The baseline tax revenue, represented by the intercept, is negative but lacks statistical significance. While precipitation's coefficient is 0.3169, its high p-value suggests its impact on tax revenue might not be substantial. Max temperature, with

a coefficient of -73.5153 and a p-value of 0.4662, appears potentially insignificant. GDP Current $, indicated by a small coefficient of -7.18282E-08 and a p-value of 0.8360, may not be a robust predictor of tax revenue changes. However, the model identifies unemployment as a significant factor, with a coefficient of 2732.3807 and a low p-value of 0.0291. Exchange rate and real interest rate, though exhibiting coefficients of 2.8065 and 11.6989, respectively, may not be statistically significant. Notably, exports show borderline significance (coefficient 1.355E-06, p-value 0.0589), while imports lack significance (coefficient 1.33539E-06, p-value 0.2081) in predicting tax revenue fluctuations.

5. Conlusion and Policy Implications

5.1. Conclusion

This study offers valuable insights into the intricate relationship between climate changes, weather abnormalities, and tax revenue compliance in Rwanda. Historical trends in tax revenue reveal significant fluctuations, with the analysis pointing towards a robust upward trajectory in domestic tax collection and a notable increase in revenue from goods and services. The impact of climate changes and weather abnormalities on tax revenue is closely tied to the unique rainfall patterns and temperature variations in Rwanda.

Assessing the trajectory from 2006Q1 to 2021Q4 highlights the resilience of the domestic tax system, possibly fueled by expanding economic activities and improved compliance efforts. However, the study underscores the vulnerability of critical economic sectors, such as agriculture, tourism, energy, and infrastructure, to the adverse effects of climate changes and extreme weather events.

The analysis of climate-induced events, including floods and droughts, indicates potential threats to infrastructure, disrupting operations and causing economic damages. The study estimates the direct economic effects of such events, emphasizing the need for adaptive strategies and comprehensive planning to safeguard against the repercussions on vital sectors and, subsequently, tax revenue.

The regression model provides further insights, revealing that while some factors like precipitation may not have a substantial impact on tax revenue, unemployment emerges as a significant and statistically relevant variable. The model suggests that economic policies addressing unemployment may play a crucial role in maintaining tax revenue stability amid changing climatic conditions.

Finally, the study emphasizes the necessity of a holistic approach to monitoring tax revenue compliance, incorporating climate considerations and economic factors. The findings call for adaptive policies, diversification of revenue sources, and focused efforts to mitigate the impact of climate changes on key economic sectors. By addressing these challenges, Rwanda can fortify its fiscal resilience and ensure sustained economic growth.

5.2. Policy Implications

1. **Diversification of Revenue Sources**

   Given the susceptibility of tax revenue to climate-induced events, there is a need to diversify revenue sources. The reliance on specific sectors, such as agriculture and tourism, makes the revenue system vulnerable to climate-related fluctuations. Policy initiatives should explore opportunities for expanding revenue streams from more climate-resilient sectors, ensuring a more stable fiscal landscape.

2. **Investment in Climate-Resilient Infrastructure**

   Recognizing the threats posed by extreme weather events to critical infrastructure, policy interventions should prioritize investments in climate-resilient infrastructure. This includes reinforcing water treatment plants, roads, and other vital assets to withstand floods and other climate-related challenges. Such measures not only protect infrastructure but also contribute to sustained economic activities and tax revenue generation.

3. **Integrated Climate Adaptation Strategies**

   Policy frameworks should integrate climate adaptation strategies into economic planning. Considering the potential impact of climate changes on key economic sectors, including agriculture and energy, adopting proactive measures becomes crucial. This involves developing strategies that enhance the resilience of these sectors, minimizing disruptions and safeguarding their contribution to tax revenue.

4. **Inclusive Economic Growth Policies**

   The observed upward trend in domestic tax collection suggests effective mobilization efforts. To sustain this growth amidst climate challenges, policies fostering inclusive economic growth should be emphasized. Supporting small

and medium enterprises (SMEs) and promoting diversified economic activities can contribute to a more resilient tax base less vulnerable to the shocks induced by climate changes.

5. **Unemployment Mitigation Strategies**

   The regression analysis highlights the significance of unemployment in influencing tax revenue fluctuations. Recognizing the significant impact of unemployment on tax revenue, policies aimed at reducing unemployment rates should be prioritized. Skill development programs, targeted job creation initiatives, and support for small and medium enterprises could contribute to economic stability and increased tax revenue.

6. **Continuous Monitoring and Adaptation**

   Given the dynamic nature of climate changes and their potential impact on tax revenue, a continuous monitoring and adaptation approach is crucial. Establishing a dedicated unit for climate and tax revenue monitoring can provide real-time insights, enabling timely policy adjustments. Regular assessments of climate patterns and their implications on economic sectors should inform adaptive strategies.

7. **International Collaboration on Trade Policies**

   Fluctuations in Tax on International Trade and Transactions (TIT) emphasize the need for international collaboration. Engaging in discussions and agreements with trading partners can contribute to stable international trade activities, reducing the impact of external economic factors on tax revenue. Bilateral or regional partnerships can address challenges arising from global economic uncertainties.

8. **Research and Development for Climate-Resilient Agriculture**

   Agriculture, a significant contributor to tax revenue, is highly sensitive to climate changes. Policies should encourage research and development initiatives aimed at promoting climate-resilient agricultural practices. This includes the introduction of drought-resistant crops, efficient water management, and sustainable agricultural methods to minimize the economic impact of climate-induced events.

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Appendix

A. Monthly Climatology of Average Maximum Surface Temperature & Precipitation of Rwanda

Rwanda, characterized by a tropical climate and a hilly landscape, is divided into four primary climatic regions: eastern plains, central plateau, highlands, and regions around Lake Kivu. Each region experiences distinct rainfall and temperature patterns. The eastern plains receive annual rainfall between 700 mm and 1,100 mm, with temperatures ranging from 20°C to 22°C. The central plateau enjoys rainfall between 1,100 mm and 1,300 mm, with temperatures of 18°C to 20°C. The highlands, including the Congo-Nile Ridge and volcanic chains of Birunga, experience annual rainfall between 1,300 mm and 1,600 mm, with temperatures ranging from 10°C to 18°C. Regions around Lake Kivu and Bugarama plains receive annual rainfall between 1,200 mm and 1,500 mm, with temperatures of 18°C to 22°C.

Rwanda has four climatic seasons, including the long rainy season (March to May), short rainy season (September to November), long dry season (June to August), and short dry season (December to February). The country's vulnerability to climate change is exacerbated by increased seasonal variability and potential long-term climate shifts. This poses risks to food security and the agricultural sector, as a significant portion of the country's agriculture relies on rain-fed methods practiced by smallholder farmers.

Analyzing data from the World Bank Group's Climate Change Knowledge Portal for the latest climatology (1991–2020), Rwanda has a mean annual temperature of 19.1°C, with monthly temperatures ranging between 18.8°C (July) and 19.8°C (September). The mean annual precipitation is 1,177.6 mm, with significant rainfall occurring from September to May. The geospatial variation of observed average annual precipitation and temperature across Rwanda is depicted in the analysis.

Month	Average Minimum Surface Air Temperature	Average Mean Surface Air Temperature	Average Maximum Surface Air Temperature	Precipitation
Jan	12.95	19.08	25.26	114.65
Feb	13.25	19.46	25.72	94.49
Mar	13.38	19.38	25.42	137.45
Apr	13.59	19.22	24.89	142.54
May	13.52	19.11	24.75	117.76
Jun	12.43	18.81	25.23	30.32
Jul	11.57	18.6	25.69	14.61
Aug	12.84	19.7	26.6	37.33
Sep	13.17	19.62	26.13	94.34
Oct	13.3	19.45	25.66	130.51
Nov	13.37	19.14	24.97	148.61
Dec	13.1	18.88	24.7	118.55

B. Data from Q1 2006 to Q4 2021, Expressed in Rwandan Francs and Measured in Billions

Periods	Domestic Tax (DT)	Tax on Goods and Services (TGS)	Tax on INTL Trade and Transaction (TITT)	Total Tax Revenue (TR)	NGDP
2006Q1	14	22	8	44	401
2006Q2	18	23	8	49	451
2006Q3	16	26	8	50	479

Appendix (Cont.)

Periods	Domestic Tax (DT)	Tax on Goods and Services (TGS)	Tax on INTL Trade and Transaction (TITT)	Total Tax Revenue (TR)	NGDP
2006Q4	18	26	9	52	499
2007Q1	19	28	7	54	506
2007Q2	25	30	8	63	547
2007Q3	21	30	8	59	573
2007Q4	22	34	8	63	599
2008Q1	25	35	9	68	607
2008Q2	36	36	10	82	687
2008Q3	30	43	11	84	749
2008Q4	32	47	14	94	788
2009Q1	31	46	14	91	786
2009Q2	36	43	13	92	774
2009Q3	32	47	8	87	808
2009Q4	36	49	9	94	855
2010Q1	43	50	9	101	853
2010Q2	37	50	7	94	857
2010Q3	39	56	9	104	905
2010Q4	43	61	9	113	955
2011Q1	49	61	11	121	963
2011Q2	49	65	9	123	999
2011Q3	45	69	10	124	1,074
2011Q4	54	69	11	134	1,095
2012Q1	61	72	12	145	1,114
2012Q2	68	72	13	153	1,143
2012Q3	56	78	17	151	1,209
2012Q4	65	76	13	154	1,234
2013Q1	82	77	12	172	1,213
2013Q2	79	84	12	175	1,252
2013Q3	71	89	15	175	1,261
2013Q4	78	91	15	185	1,328
2014Q1	77	94	18	189	1,355

Appendix (Cont.)

Periods	Domestic Tax (DT)	Tax on Goods and Services (TGS)	Tax on INTL Trade and Transaction (TITT)	Total Tax Revenue (TR)	NGDP
2014Q2	86	112	17	215	1,394
2014Q3	82	106	17	205	1,437
2014Q4	84	100	17	201	1,435
2015Q1	95	101	17	212	1,464
2015Q2	102	120	19	240	1,500
2015Q3	85	120	18	224	1,567
2015Q4	92	129	23	244	1,616
2016Q1	109	121	20	250	1,659
2016Q2	107	139	22	269	1,710
2016Q3	98	129	21	248	1,696
2016Q4	108	129	22	259	1,777
2017Q1	122	138	23	283	1,845
2017Q2	122	148	26	296	1,917
2017Q3	109	144	23	276	1,944
2017Q4	126	155	26	306	1,988
2018Q1	137	152	25	314	2,026
2018Q2	148	165	25	338	2,057
2018Q3	125	161	25	311	2,081
2018Q4	146	167	28	342	2,139
2019Q1	142	170	28	340	2,154
2019Q2	184	191	30	405	2,349
2019Q3	150	183	31	365	2,356
2019Q4	157	204	33	394	2,455
2020Q1	149	182	31	362	2,408
2020Q2	201	151	23	374	2,175
2020Q3	150	191	31	372	2,452
2020Q4	171	201	34	406	2,572
2021Q1	193	184	29	405	2,588
2021Q2	204	217	31	453	2,668
2021Q3	187	194	30	411	2,758
2021Q4	201	223	33	458	2,931

Appendix (Cont.)

Data Description

GDP: Gross Domestic Product.

DT: Direct Tax

Direct Tax comprises Pay as You Earn (PAYE), Taxes on Corporations & Enterprises, and Property Tax on Vehicles.

TGS: Taxes on Goods and Services

Taxes on Goods and Services include Value Added Tax (VAT), Excise Duty, Road Fund, Mining Royalties, and Strategic Reserves Levy.

TIT: Taxes on International Trade

Taxes on International Trade encompass Import Duty, Other Customs Revenues, Infrastructure Development Levy, and other regular taxes.

C. Tax revenue and Combined Climate Changes and Weather Abnormalities (CCWA)

During the study period, tax revenue dynamics in Rwanda exhibited variations across different quarters. The fourth quarter of 2020 saw a notable increase in tax revenue, reaching 406 billion Rwf, which continued into the first quarter of 2021 with a similar level. This growth is accompanied by an uptick in various tax categories, including Domestic Tax (DT), Tax on Goods and Services (TGS), and Tax on International Trade and Transactions (TITT). Interestingly, the second quarter of 2020 showed a dip in tax revenue, potentially reflecting the initial impacts of the global pandemic. The data also highlights fluctuations in temperature and precipitation, emphasizing the potential influence of climate factors on tax revenue compliance. Understanding these patterns is essential for devising effective strategies to navigate the complex interplay between climate changes, weather abnormalities, and fiscal performance in Rwanda

Periods	Domestic Tax (DT)	Tax on goods and services (TGS)	Tax on INTL Trade and Transaction (TITT)	Total Tax Revenue (TR)	Nominal GDP	Average Minimum Surface Air Temp.	Average Mean Surface Air Temp.	Average Maximum Surface Air Temp.	Precipitation
2019Q1	142	170	28	340	2,154	12.95	19.08	25.26	114.65
2019Q2	184	191	30	405	2,349	13.25	19.46	25.72	94.49
2019Q3	150	183	31	365	2,356	13.38	19.38	25.42	137.45
2019Q4	157	204	33	394	2,455	13.59	19.22	24.89	142.54
2020Q1	149	182	31	362	2,408	13.52	19.11	24.75	117.76
2020Q2	201	151	23	374	2,175	12.43	18.81	25.23	30.32
2020Q3	150	191	31	372	2,452	11.57	18.6	25.69	14.61
2020Q4	171	201	34	406	2,572	12.84	19.7	26.6	37.33
2021Q1	193	184	29	405	2,588	13.17	19.62	26.13	94.34
2021Q2	204	217	31	453	2,668	13.3	19.45	25.66	130.51
2021Q3	187	194	30	411	2,758	13.37	19.14	24.97	148.61
2021Q4	201	223	33	458	2,931	13.1	18.88	24.7	118.55

Appendix (Cont.)

D. Tax revenue , Combined Climate Changes and Weather Abnormalities (CCWA) and Control Variables

Year	Tax Revenue (bn) Rwf	Precipitation	Max Temp.	GDP Curent ($)	Unemployment	Exchange Rate	Real Interest rate	Exports Curent ($)	Imports Curent ($)
2006	1830	114.65	25.26	3318107347	0.986000001	551.710333	13.082296	361305562	741573974.6
2007	2225	94.49	25.72	4068224991	1.011999965	546.955	2.717995	556349242.6	907851651.4
2008	2831	137.45	25.42	5177230923	1.024000049	546.848653	1.5650819	583912881.2	1363945823
2009	3223	142.54	24.89	5671592572	1.059999943	568.281327	8.937107	588300195.7	1500227088
2010	3570	117.76	24.75	6121529488	1.077999949	583.130907	13.389101	657968905.4	1625273159
2011	4131	30.32	25.23	6881379762	1.098999977	600.30652	8.8387896	871553115	1862866719
2012	4700	14.61	25.69	7650671477	1.118000031	614.295142	11.440964	918133646.2	2185172892
2013	5054	37.33	26.6	7815975294	1.15199995	646.635975	14.243493	1055111376	2283504166
2014	5621	94.34	26.13	8234762201	1.169999957	682.437795	11.96079	1142634538	2474496577
2015	6147	130.51	25.66	8539424910	1.148000002	719.859556	16.765604	1130492668	2731456245
2016	6842	148.61	24.97	8690878328	1.144000053	787.251522	11.674084	1340967912	2961879399
2017	7694	118.55	24.7	9252834120	1.136999965	831.55434	8.3342076	1899457438	3067026411
2018	8303	114.65	25.26	9642440646	1.110999942	861.093412	17.669414	2034370488	3342050932
2019	9314	94.49	25.72	1.0356E+10	1.09800005	899.350509	13.707402	2258781198	3741294412
2020	9607	137.45	25.42	1.0184E+10	1.485000014	943.278048	9.0113486	1966296256	3648739820
2021	10945	142.54	24.89	1.107E+10	1.606999993	988.624807	13.074957	2110469007	3851166792

The tax revenue in Rwanda has shown an upward trend over the years, increasing from 1830 billion Rwf in 2006 to 10945 billion Rwf in 2021. The precipitation and maximum temperature exhibit fluctuations, indicating variations in weather conditions. GDP has steadily risen, reaching 11070356519 current dollars in 2021. Unemployment rates and exchange rates have experienced changes, potentially influencing fiscal dynamics. Real interest rates have fluctuated, possibly impacting economic activities. Exports and imports have increased, reflecting international trade growth. The intricate interplay of these factors highlights the complexity of understanding the impact of climate changes and weather abnormalities on tax revenue compliance in Rwanda

Cite this article as: Nzabirinda Etienne (2024). Does Climate Change Impact Tax Revenue? Lesson from Rwanda. *International Journal of Management Research and Economics.* 4(2), 69-85. doi: 10.51483/IJMRE.4.2.2024.69-85.