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# IMPACT OF CLIMATE CHANGE ON RICE PRODUCTION IN AFRICAN COUNTRIES: A PANEL DATA ANALYSIS

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## ABSTRACT

Agriculture plays a key role in the overall economic and social wellbeing in Africa. Now, Africa appears to emerge as a key player in food production because there exists enormous unused land for cultivation. On the basis of availability of data, this study aims at investigating the impact of the climate change on rice production in the twenty-five African countries from 2002 to 2014 following a static panel data approach using World Bank and Food and Agricultural Organization (FAO) data. Considering $CO_2$ (Carbon Di Oxide) emissions as average precipitation in depth and temperature change as climate change indicators along with other control variables such as fertilizer consumption and use of pesticides, this study observes that these climate indicators have significant adverse impact in explaining variations in spatial and temporal change in rice production in African countries. It may be demonstrated from the empirical analysis that those climate variables like $CO_2$ emissions, pesticide use and temperature change are statistically significant at a 5 %, 10 % and 5 % levels, respectively. All the indicators have negative effects on rice production in African countries. The coefficients associated with these indicators are negative and statistically significant indicating that higher $CO_2$ emissions adversely affect rice production in Africa. Moreover, pesticides used per kg in production have an inverse relation with rice production in this continent. Further, temperature harms rice production in African countries. Temperature changes negatively affect rice production as indicated by its coefficient value being -199958.10. The results also demonstrate that adaptation of new rice seed varieties that are more tolerant to higher temperature will be more effective in response to climate change. The study suggests that there is need for enormous development in the agriculture sector, to reach the ultimate goal. In particular, development of irrigation system and large-scale funding by the government in African countries is required.


**Key words:** Rice Production, Climate Change, Static Panel Approach, Average Precipitation

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## INTRODUCTION

Among all the cereals, rice is the most important food grain in the world. During the last forty years, increasing population and the consequent consumption growth created a huge demand for cereals, in particular, rice at the global level. The growing competition for land use, water, energy and flourishing of fisheries, have adverse effects on food security in the economy. In any economy, food security is a key part of the food system. There are many challenges to achieving higher productivity of rice. In the future, the new challenges will include climate change and its consequences. However, the world can produce more food and can ensure that it is used more efficiently and equitably [1]. According to the 2020 Global Report on Food Crisis, an estimated 135 million people globally face hunger [2]. This acute level of hunger in the world increases due to lower food production. Lower food production is one of the main causes of food crisis. But climate changes and economic shocks are also responsible for food crisis. To resolve the food crisis as well as hunger level, it is necessary to increase food production. Despite the technological improvements such as improved crop varieties and irrigation systems, weather and climate are important factors, which play a significant role in agricultural productivity [3]. The impacts of climate change on agricultural food production are global concerns and, for that matter, climatic factors such as temperature, rainfall, atmospheric carbon dioxide, and solar radiation, among others, are closely linked to agricultural production, in particular, rice production.

The bulk of rice production occurs in the monsoon land of Asia, spreading from the Islamic Republic of Pakistan (now Pakistan) to Japan and covering countries that are densely populated and are major consumers of rice [4]. In addition to the projected adverse impacts of climate change on crop productivity, there will be serious consequences on food availability in the future. However, the potential impacts are not very clear at the regional level but there is a consensus that climate change could provoke food insecurity in regions currently vulnerable to hunger. Taking suitable actions like adaptation, fertilizer consumption, pesticides use and mitigation strategies may reduce the adverse effects of climate change on food production as well as food security in the world.

Even though the previous best continents of food production were Asia and America, Africa now appears as the new continent for food production. According to IRRI (International Rice Research Institute), Africa has the highest reserves of unused natural resources for food production, especially water and land, in the world [5]. With over 130 million hectares in inland valleys suitable for rice


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production, but only about 10 million hectares are currently being used, Africa's tremendous potential in agriculture remains untapped [5]. Rice production depends not only on the land but also many crucial factors like fertilizer consumption, pesticide use in crop production, climate change, cultivation strategy and labour forces used in agriculture.

**Rice production in Africa**

According to the World Development Report [6], agriculture is the main engine for overall economic growth, rural poverty reduction and food security in Africa [6]. The report emphasized that growth originating in agriculture is four times as effective in reducing poverty as growth originating outside of the agricultural sector.

A large number of food insecure people live in Africa (73 million), followed by 43 million people in Middle East countries [7]. An estimated 18.5 million people fall into food insecurity in Latin America and the Caribbean region [7]. Moreover, in Africa, rice is one of the main food commodities whose demand is rapidly growing, mainly driven by urbanization. In urban areas of Africa, the population is expected to increase from 38% in 2014 to 48% by 2030 [8]. Rice consumption in Africa is expected to increase rapidly [9,10]. Household consumption surveys reveal that urban consumers on lower incomes tend to spend a greater share of their total budget on rice than higher income household consumers [11]. However, a recent global trend in the rice industry shows that there is a growing import demand for food grains in Africa [12]. In 2006, Africa's global rice imports accounted for 32% of global imports [12]. In 2009, rice imports into sub-Saharan countries (SSA) translated into 9.68 million Mt (metric ton), worth more than $ 5 billion. Due to population growth (4% per annum), rising incomes and a shift in consumer preferences in favour of rice, especially in urban areas, the relative growth in demand for rice is faster in this region than anywhere in the world [13].

In response to this growing demand, total rice production in SSA has gradually increased. In the past, this increase was mainly attributed to the expansion of harvested areas [14], although recently, it has been attributed to increased yield [15]. In that context, the study pointed out that the relative contribution of yield to the increase in total production rose to 71% with the high yield growth rate at 108 kg $ha^{-1}$ per year during the period 2007 to 2012, which was equivalent to that achieved by Asian countries during the Green Revolution period [16]. In Figure 1, it is shown that the harvest area increased gradually in Africa in past years.

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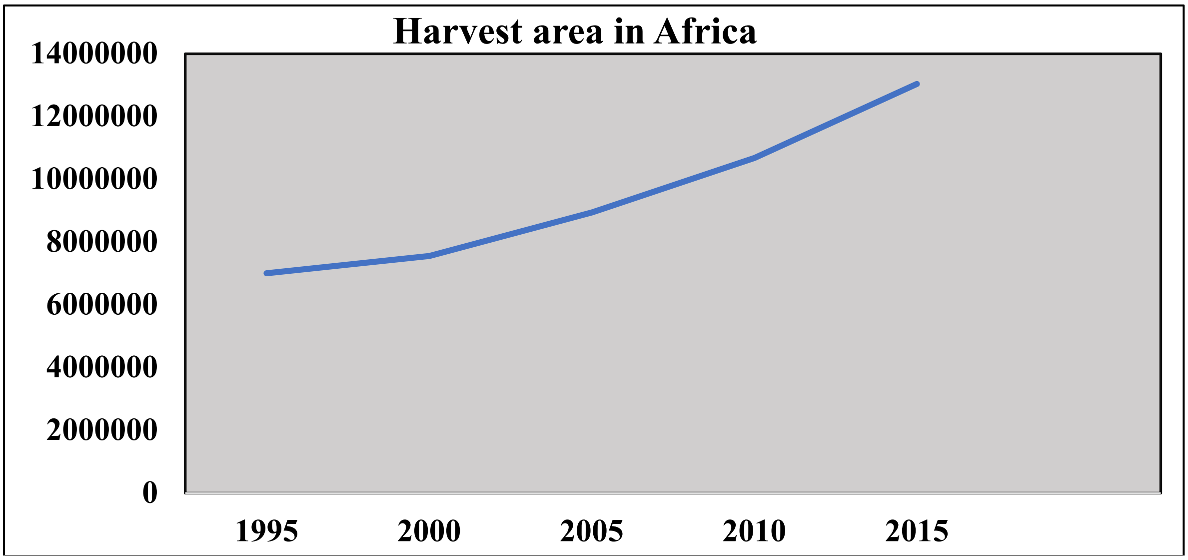


**Figure 1: Harvest area in Africa from 1995 – 2015**

Note: Vertical axis (y axis) measures harvest area of land (in hector) and Horizontal axis (x axis) measures as time (year)

Source: FAOSTAT, 2020 [33]

**Rice production, Food security, and Climate change**

In the last few decades, air temperatures have been warming in most of the major cereal cropping regions around the world [17]. According to global studies, estimated results showed that rice yields in West and Central Africa would slightly decline and those in East and Southern Africa would slightly increase with climate change [17,18].

Agriculture plays a key role in the overall economic and social wellbeing in Africa. Though the share of agriculture in both Gross Domestic Product (GDP) and employment has declined over time, the pace of decline in its share in employment has been much slower than that of GDP [19]. Statistics from the World Bank indicate that agriculture contribution to GDP has gone down from 20.5% in 1990 in Africa to 15.1 % in 2015, as shown in Figure 2. It is estimated that agriculture is Africa's largest economic sector, representing 15% of the continent's total GDP, or more than $100 billion annually. Unemployment rate in agricultural sector gradually decreased during the period 1990-2015 in African countries, ranging between 54% and 60 % (in Figure 3).

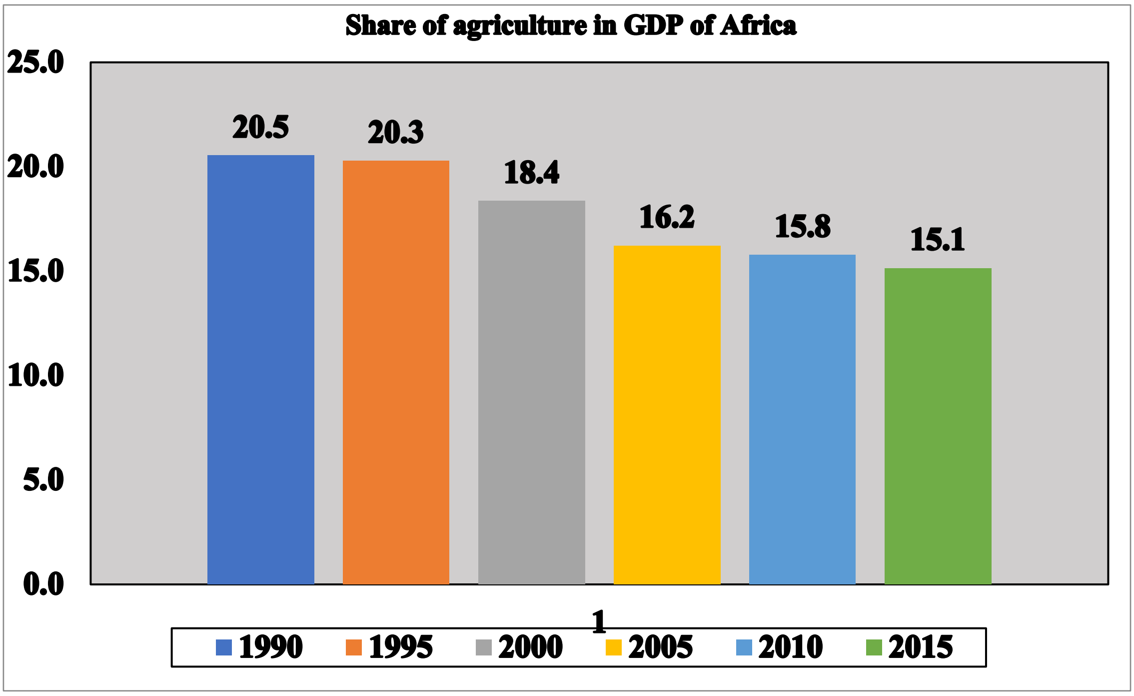


**Figure 2: Share of agriculture in GDP in Africa different period's time**

Note: Vertical axis (y axis) reflects as share of agriculture in GDP (%) and Horizontal axis (x axis) reflects as time (year)

Source: World Bank data, 2020

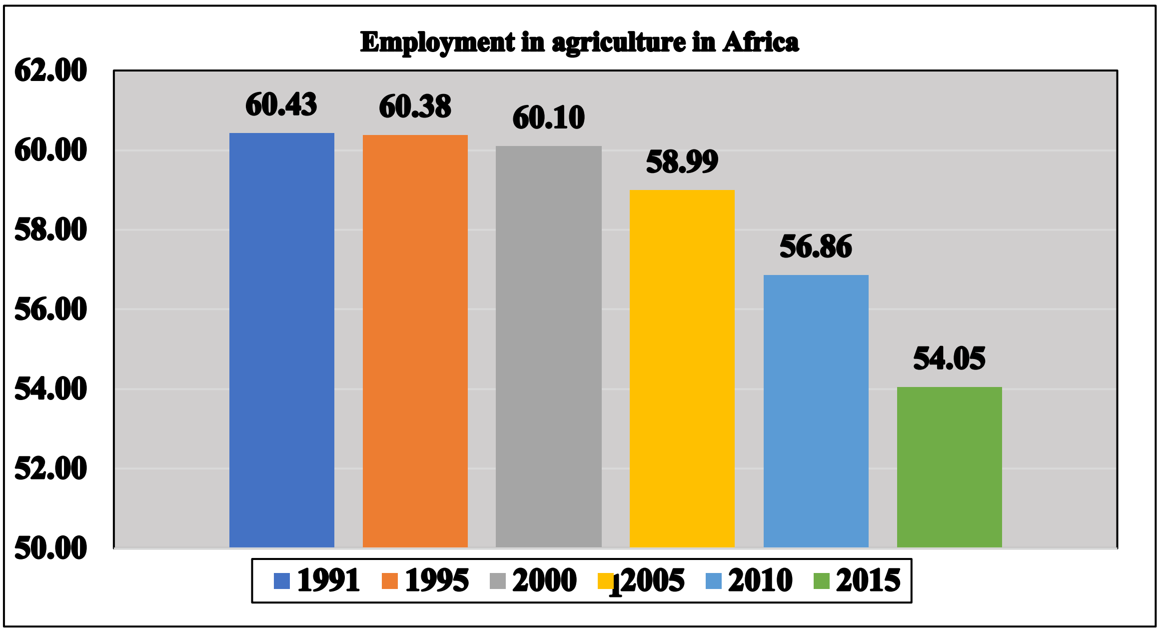


**Figure 3: Trend of employment in agriculture in Africa**

Note: Rate of unemployment in agriculture (%) measure in Vertical axis (y axis) and Horizontal axis (x axis) reflects as time (year)

Source: World Bank data, 2020

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Another climate change factor like the large emission of $CO_2$ has significant effects on agriculture. With abrupt changes in environmental conditions, the bad impacts on plant productivity are progressing in great intensities owing to the direct and indirect effects of abiotic stresses. Because of the continuous deforestation and excessive utilization of fossil fuels, the concentration of $CO_2$ has escalated from 280µmol$^{-1}$to 400µmol$^{-1}$ in the atmosphere. It is predicted that the $CO_2$ concentration will double, that is, up to 800 µmol$^{-1}$ at the end of the 21$^{st}$ century [20]. Emission of these dangerous gases, (particularly $CO_2$) is the main cause of the greenhouse effect and warmer average global temperatures [21]. On the other hand, the effects of climate change and environmental variation are mainly estimated by the number of stress spells, their impact on daily life, and damage to crops [4]. In developing countries, the agricultural yield is predominantly suffered due to adverse environmental conditions; therefore, high temperature and excess of $CO_2$ accumulation forced scientists to devise new strategies to cope with less predictable challenges [22].

Moreover, the gaps between regional rice consumption and production in SSA have continuously widened. The increasing dependency on rice imports has created an economic burden and food insecurity in SSA, and this insecurity became particularly apparent when food riots occurred in several major capitals during 2007–2008 [23]. Therefore, further increases in regional rice production remain an urgent priority to ensure food security in SSA.

Previous studies have provided various socio-economic and biophysical constraints for rice yields in SSA. It is generally agreed that inadequate fertilizer input and poor soil fertility are major limiting factors to the production of not only rice but also other crops in SSA [24].

**Role of temperature on rice production**

According to the international panel on climate change (IPCC, 2014) there have been more negative impacts of climate change on crop and terrestrial production than positive impacts [20]. If local temperature increases by $1^0$C then it negatively impacts the yields of crops such as rice, maize and wheat, and it hampers agricultural systems and production. These scarcities of food grains such as rice, maize and wheat may trigger restrictive trade policies such as quantitative restriction of exports, safeguard or anti-dumping measures and high tariff rates that ensure the food security of a nation.

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Rice is a tropical cereal and its growth is highly sensitive below $15^0$C temperatures. But extreme temperatures are also destructive to plant growth. The life cycle of a rice plant can be complete under temperatures showed in Table 1. The effect of temperature on growth of rice plants was reviewed concerning germination, early growth, rooting, tillering, and the critical temperature common for different physiological plant properties that were 0–$3^0$ C, 15–$18^0$C, 30–$33^0$ C, and 45–$48^0$ C, respectively. The low temperatures in early growth stages retard the development of seedling and dry matter production [25]. Generally, rice is adversely affected by high temperatures in the lower elevations of the tropics and by lower temperatures in the temperate regions. At different times during the life cycle, a rice plant is differentially sensitive to temperature stress. Hence, the critically low and high temperatures, normally below $20^0$C and above $30^0$C, vary from one growth stage to another.

The climate change indicators have been briefly described as average from 2002 - 2014 in Table 2. Herewith, is also mentioned the average rice production during the stipulated period. Among the top five rice production countries are Egypt, Madagascar, Guinea, Tanzania, and Mali. However, the highest average rice production is noticed in Egypt and the lowest in Mauritius and it is shown in Table 2. On fertilizer consumption measures, the number of plant nutrients used per unit of arable land and the fertilizer products cover nitrogenous, potash, and phosphate fertilizers (including ground rock phosphate). From the calculation it is also noticed that the average fertilizer consumption is highest in Egypt. It should be noticed that average fertilizer consumption is second highest in Mauritius and its value represents 268.35 kg per hector arable land but average rice production is lowest among the African countries. Average $CO_2$ emission is highest in south Africa and its value is 454781.3 (kt) as shown in Table 2. Therefore, it must be explained that the high value of $CO_2$ emission has bad an effect on rice production. Another climate change indicator like average precipitation in depth (mm per year) is lowest in Egypt (51 mm) but the result is ambiguous. This is the highest in Mauritius and the value indicates 2041 (mm/year). In that context, the average precipitation value is not effective in this regard because of absurd results in the case of rice production.

## LITERATURE REVIEW

There are lots of reviews; most of them describe the impact of climate change on crop production. Empirical research has analysed the change in production due to climate variables in Bulgaria during 20th century by using multiple regression models and also stated that crop yields are affected by variations in climatic factors


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such as air temperature and precipitation, and the frequency and severity of extreme events like droughts, floods, hurricanes, windstorms and hail [26].

Manneh *et al.* [27] observed that climate change has a negative impact on African agriculture through extreme temperatures, frequent flooding, and droughts, and increased salinity of water supplies used for irrigation. Bulk poverty and high dependency on rain-fed agriculture in Africa present the region more vulnerable to climate change-induced disasters than other regions of the world. These climate change factors have crucial effects on rice production in Africa.

Ngaira's [28] concerns about climate change are global and real as all communities try to get adapted to the challenges of their local climate; they are today sensitive to its variations. Climate changes are crucial in Africa for economic development because their backbone is agriculture. The study stated that the effects of climate change may include reduced agricultural land use due to submergence of coastal regions and increased aridity in the tropical high agricultural potential regions; there will be increased incidences of farm pests and diseases, over cultivation, food insecurity and poverty mainly in tropical regions. As a result, Africa will face serious challenges in its endeavour to adapt to new mechanisms of food production for sustainable development.

Guan *et al.* [29] described that persistent drought has negatively impacted agricultural production systems, with rice production being among the worst hit systems since the crop is more sensitive to droughts than other crops in SSA countries. Rice production is largely grown under the rainfed area, but scattered in vulnerable draught areas in SSA region. Due to this situation, rice yields reduce significantly even under mild drought.

According to Li *et al.* [30], climate factors play a pivotal role in rice production and it leads to global food security in future. In that context, 13 rice models were evaluated against multi-year experimental yield data at four sites with diverse climatic conditions in Asia. The study examined whether different modelling approaches on uncertainties of production to field measured yields. The results depicted that the uncertainty raised in the continent and rice production is highly sensitive to changes in temperature and $CO_2$ concentration.

Tsujimoto *et al.* [31] conducted a study based on agronomic nitrogen use efficiency in rice production in sub–Saharan African countries. They discussed the improvement of nutrient efficiency which is important for increasing both fertilizer use and rice yield in SSA countries. Experimental results suggest agronomic

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nitrogen use efficiency can be improved by addressing spatial variations in soil-related factors such as phosphorous, sulphur, zinc, and silica deficiencies and iron toxicity in both irrigated and rainfed production systems.

Parkes *et al.* [32] showed in their study climate variability is highly sensitive to crop yields. They highlighted in their model the importance of weather dataset consistency throughout the design and application of statistical weather-yield models. Finally, the approach would provide a more accurate picture of the uncertainty in estimates of the exposure of agriculture to climate risks, policy and management recommendations about how to improve the elasticity of smallholder farming to extreme weather and climate change.

The very limited numbers of studies, all with different models, do not yield a consistent or comprehensive estimate of climate change impact on rice in Africa. Many research studies were focused on the impact of climate change on total agricultural products. No study has discussed in particular the impact of climate change on rice production in Africa. Therefore, an enormous research gap is presented in that sector. Here, presents a new study covering more countries and indicating the impact of more factors like fertilizer consumption, uses of pesticides in agriculture, $CO_2$ emissions, and average precipitation in-depth. The objectives of this study are to find out the climate change impacts on future rice production in Africa and explore the causes of impacts in a static panel model.

## MATERIALS AND METHODS

This study was carried out by static panel data analysis under the fixed effect (FE) model. For the estimation of coefficients of the variables in the static panel regression model, the study used the Eviews 7 software. The study intended to find out the impact of climate change on rice production in twenty-five African countries from 2002 to 2014 following a static panel approach.

### Data

This study covers 25 major rice producing countries of the African continent, namely: Algeria, Burkina Faso, Burundi, Cate d'Ivoire, Egypt, Ethiopia, Gambia, Ghana, Guinea, Kenya, Madagascar, Malawi, Mali, Mauritius, Morocco, Mozambique, Niger, Rwanda, Senegal, South Africa, Togo, Uganda, United Republic of Tanzania, Zambia and Zimbabwe, depending on the availability of data. Data on rice production(tonnes) were recollected from FAOSTAT (Food and Agriculture Organization Corporate Statistical Database) [33]. The period covered was 2002-2014. The total number of observations in the static panel with a fixed-effect model was 325. The data on country-wise $CO_2$ emissions (kt) for the period 2002-2014 were collected from the World Bank database. The data on fertilizer consumption (kilograms per hectare of arable land) were collected from the current World Bank database [19]. Average precipitation in depth (mm per year) that is, average rain fall data were taken from the World Bank database, The data on pesticide (total kg/ha) use in agriculture in Africa were drawn from FAOSTAT [33]. The temperature change figures for the period 2002–2014 were taken from FAOSTAT [33]. Agricultural land data as percentages of total land falls on the World Bank database [19].

Short descriptive statistics for all the variables as well as climate change factors used in the regression analyses over the entire study period are summarized in Table 3. One important observation is that in selected twenty-five African countries, average precipitation has no variability (World Bank database). The table represents the maximum, minimum, and standard deviation values of rice production, average precipitation, $CO_2$ emissions, and fertilizer consumption, respectively of selected countries from 2002 to 2014.

**Static panel data method**

In the context of the impact of climate change on rice yield or production in African countries, the research study considered the static panel data approach with a fixed-effect model. Usually, two types of the model like fixed effect (FE) and random effect (RE) are used in the panel regression. In the present study, FE model are suitable because there arises a correlation between regressors and time invariant. So, it implies that the intercept term varies across the countries and intercept of the countries does not vary over time. In this regard, the study also used a specification test like the Wu Hausman [34] test to decide which model was suitable for research study. The Fixed effect and Random effect methods used in panel data analysis differ on the assumptions whether $\alpha_i$ is correlated with $x_{it}$ (Fixed effect) or uncorrelated with $x_{it}$ (Random effect). In the generalized model the fixed effects approach takes $\alpha_i$ to be a group specific constant term in the regression model. The random effect approach specifies that $\alpha_i$ is a group specific disturbance, similar to $v_{it}$ except that for each group there is but a single draw that enters the regression identically in each period.

Moreover, the study also used a normality test to specify the data set is well modelled and the given data set has followed the normal distribution. In this context, study applied the Jarque-Bera [35] test for normality of the data and goodness of fit.

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The static panel regression used for the given study as follows-

$$Yit = \alpha + \beta_1 \mathbf{x_{1it}} + \boldsymbol{\beta_2} \mathbf{x_{2it}} + \boldsymbol{\beta_3} \mathbf{x_{3it}} + \boldsymbol{\beta_4} \mathbf{x_{4it}} + \boldsymbol{\beta_5} \mathbf{x_{5it}} + \boldsymbol{\beta_6} \mathbf{x_{6it}} + \mathbf{v_{it}} \quad (1)$$

Where,
$Y_{it}$: Rice production of the $i^{th}$ country in the $t^{th}$ year.
α: constant term.
$X_{1it}$: The fertilizer consumption vectors of the $i^{th}$ country in the $t^{th}$ year.
$X_{2it}$: $CO_2$ emissions vectors of the $i^{th}$ country in the $t^{th}$ year.
$X_{3it}$: Pesticides use vectors of the $i^{th}$ country are in the $t^{th}$ year.
$X_{4it}$: Agricultural land use vectors of the $i^{th}$ country are in the $t^{th}$ year.
$X_{5it}$: Average precipitation in depth vectors of the $i^{th}$ country in the $t^{th}$ year.
$X_{6it}$: The temperature change vectors of the $i^{th}$ country are in the $t^{th}$ year.
$v_{it}$ : The error terms. And $V_{it} \tilde{} N(0, \sigma^2)$
i= 1, 2, 3, ……………………………, 25.
t= 2002, 2003, ………………., 2014.

In the static panel model, rice production is considered as the dependent variable. Climatic factors that may affect agricultural production are represented by $CO_2$ emissions, average precipitation in-depth, and temperature change, as independent variables. Other explanatory variables are considered as fertilizer consumption, pesticides used and agricultural land used in agriculture.

## RESULTS AND DISCUSSION

### Hausman test results

According to the Hausman test results, FE method is more suitable than the RE method in the model. The Chi-square test statistic value being 51.196 is statistically significant at a 1% level, that is, the FE method is appropriate for the research model. In the context of the Wu Hausman test, the empirical results have been shown below in Table 4.

### Result of normality test

Jarque-Bera normality test is used for normality of the data. According to the estimated results the given data set follows the normal distribution. This test results have also assured the normality errors at 1 percent level and is depicted in Figure 4.

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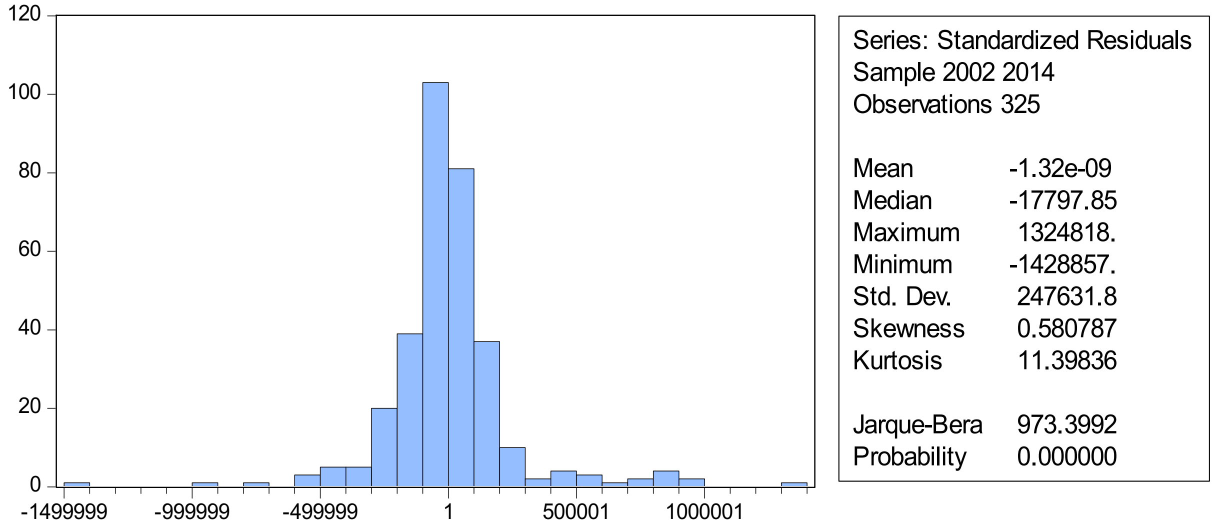


**Figure 4: Normality test result**

Hence, this research study has presented the empirical results on static panel analysis in Table 5. The empirical results depict that climate changes variables are highly significant in explain variation in rice production across the major rice production. However, the value of $R^2$ is also indicated by the high value of 0.97. The results show that the three explanatory variables are statistically significant in explaining the variation in rice production across the twenty-five African economies over the period 2002 to 2014. That is, the independent variables in the model namely $CO_2$ emissions, pesticide use and temperature change together explain about 97% of the variation in rice production across the twenty-five African economies over the period 2002 to 2014. F-statistic is also significant at a 1% level which indicates that the model is a good fit.

To describe empirical results in details, first, the climate changes indicators such as $CO_2$ emissions, pesticide use and temperature change are statistically significant at a 5 %, 10 % and 5 % levels, respectively. All the indicators are negatively related to the rice production. The result on $CO_2$ emission has an adverse effect on rice production in African countries. One can thus conclude that the pesticides used per kg in production is inversely related to rice production across the selected twenty-five African countries during the period 2002 to 2014. Extreme weather especially high temperature has greater threat on rice production in African countries. In that context, as per the estimation of agricultural land, average precipitation and fertilizer consumption have no significant effect on rice production. Fertilizer has a positive effect on rice production but it is insignificant in the statistical estimation.


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## CONCLUSION

Global climate change is not a new phenomenon. The effect of climate change poses many threats, one such important consequence is bringing about changes in the quantity of rice productivity. Rice production in Africa faces severe challenges from climate change. This study has investigated the impact of climate change on rice production during 2002-2014 in African countries by applying static panel data model. The results show that the rise in annual temperature changes will negatively affect rice production in African countries and this is a hindrance to food security in Africa. This is also negatively impacting employment in Africa. Only adaptation of new rice seed varieties that are more tolerant to higher temperatures, increasing government investment in agricultural research, and developing proper adaptation programs or policies, will be necessary to effectively respond to climate change.

Moreover, precipitation in depth is positively related with rice production but in some country, it gives opposite result like in Egypt, that is , lower rain falls but highest rice production. Here, we also noticed that higher average rain falls in Mauritius but lower rice production. There should be more investments in irrigation schemes that help in mitigating rainfall variations, by ensuring steady water supply for the crops.$CO_2$ (Carbon di Oxides) emissions and pesticides use in rice cultivation inversely impact rice production in Africa.

This study has prescribed that it is necessary to take some initiatives to reduce the harmful effect of climate changes on rice production. However, rice production is also related to the food security of the economy. In this regard, efficient and fruitful use of land, water supply, etcetera are crucial for rural agriculture in African region. However, it is also required to development of agricultural infrastructure, rainwater harvest and rain water storage program. Therefore, high investment in the agriculture is utmost important in African agriculture.


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**Table 1: Rice plant growth stages**

| Growth Stages | Critical temperature (⁰C) | | |
|---|---|---|---|
| | **Low** | **High** | **Optimum** |
| Germination | 16-19 | 45 | 18-40 |
| Seedling emergence | 12 | 35 | 25-30 |
| Rooting | 16 | 35 | 25-31 |
| Leaf elongation | 7-12 | 45 | 31 |
| Tillering | 9-16 | 33 | 25-31 |
| Initiation of panicle primordial | 15 | - | - |
| Panicle differentiation | 15-20 | 30 | - |
| Anthesis | 22 | 35-36 | 33 |
| Ripening | 12-18 | >30 | 20-29 |

Source: Yoshida (1978) [25]

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**Table 2: Descriptive statistics on rice production and climate change indicators in African countries during 2002–2014**

| Countries | Average rice production (tonnes) | Average precipitation in depth (mm per year) | Average CO2 emissions (kt) | Average Fertilizer consumption (kg / ha of arable land) |
|---|---|---|---|---|
| Algeria | 351 | 89 | 113044 | 15.35563 |
| Burkina Faso | 186747.2 | 748 | 1836.885 | 11.24112 |
| Burundi | 68674.46 | 1274 | 226.7898 | 3.870066 |
| CÃ´te d'Ivoire | 1000832 | 1348 | 7668.261 | 26.46308 |
| Egypt | 6020938 | 51 | 186040.7 | 588.0535 |
| Ethiopia | 59455.62 | 848 | 6904.397 | 17.23511 |
| Gambia | 44063.69 | 836 | 373.4698 | 6.755408 |
| Ghana | 368196.4 | 1187 | 9705.985 | 16.06017 |
| Guinea | 1522844 | 1651 | 2190.891 | 1.476138 |
| Kenya | 72780.08 | 630 | 10667.3 | 34.38852 |
| Madagascar | 3734001 | 1513 | 2064.803 | 3.147595 |
| Malawi | 101742.5 | 1181 | 1023.093 | 32.65093 |
| Mali | 1379089 | 282 | 979.6532 | 27.28377 |
| Mauritius | 259.6154 | 2041 | 3633.715 | 268.3568 |
| Morocco | 37397 | 346 | 51022.64 | 57.77455 |
| Mozambique | 141254.4 | 1032 | 2908.777 | 5.213496 |
| Niger | 74013.38 | 151 | 1124.359 | 0.497225 |
| Rwanda | 64892.85 | 1212 | 611.2607 | 4.672907 |
| Senegal | 357993 | 686 | 6263.518 | 8.316679 |
| South Africa | 3030.692 | 495 | 454781.3 | 58.48044 |
| Togo | 109404.2 | 1168 | 1953.665 | 6.984998 |
| Uganda | 179979.5 | 1180 | 3186.059 | 1.747214 |
| United Republic of Tanzania | 1625064 | 1071 | 6825.697 | 6.698771 |
| Zambia | 30656.38 | 1020 | 2706.528 | 34.22829 |
| Zimbabwe | 654.4615 | 657 | 9647.313 | 27.20799 |

Sources: World Bank, FAOSTAT



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**Table 3: Descriptive statistics of the study variables (2002 to 2014)**

| Countries | Rice production | | | Average Precipitation | | | $CO_2$ emissions | | | Fertilizer Consumption | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max | Min | SD | Max | Min | SD | Max | Min | SD | Max | Min | SD |
| Algeria | 425 | 300 | 42.5 | 89 | 89 | 0 | 145400.2 | 88510.3 | 17707 | 24.6 | 6.0 | 6.2 |
| Burkina Faso | 347501 | 68916 | 102730.5 | 748 | 748 | 0 | 3058.2 | 1004.7 | 700.6 | 15.8 | 0.4 | 4.0 |
| Burundi | 91415 | 41454 | 11888.6 | 1274 | 1274 | 0 | 440.0 | 154.0 | 76.0 | 10.2 | 0.3 | 3.0 |
| CÃ´te d'Ivoire | 2053520 | 606310 | 518172.3 | 1348 | 1348 | 0 | 11045 | 5460.1 | 1706.6 | 42.3 | 15.3 | 8.0 |
| Egypt | 7253373 | 4329503 | 740492.8 | 51 | 51 | 0 | 217163.4 | 127193.6 | 29385 | 709.6 | 432.5 | 84.6 |
| Ethiopia | 131821 | 11244 | 47691.9 | 848 | 848 | 0 | 11598.7 | 4521.4 | 2189.7 | 26.1 | 5.7 | 6.7 |
| Gambia | 99890 | 11395 | 26381.7 | 836 | 836 | 0 | 513.3 | 289.6 | 76.5 | 10.8 | 0.4 | 3.6 |
| Ghana | 604000 | 185340 | 139260 | 1187 | 1187 | 0 | 14620.3 | 7422.0 | 2557.5 | 34.7 | 3.7 | 8.2 |
| Guinea | 2053359 | 1088669 | 324582.2 | 1651 | 1651 | 0 | 2779.5 | 1804.1 | 333.0 | 3.5 | 0.6 | 0.9 |
| Kenya | 946141 | 21881 | 37573.7 | 631 | 631 | 0 | 14286.6 | 6754.6 | 2497.9 | 43.5 | 27.3 | 5.0 |
| Madagascar | 4737965 | 2603965 | 682775 | 1513 | 1513 | 0 | 3116.9 | 1235.7 | 573.2 | 5.5 | 2.0 | 1.1 |
| Malawi | 135988 | 41270 | 29008.1 | 1181 | 1181 | 0 | 1276.1 | 850.7 | 146.6 | 41.7 | 24.6 | 4.6 |
| Mali | 2166830 | 693203 | 516595.5 | 282 | 282 | 0 | 1411.7 | 806.7 | 154.7 | 52.0 | 6.0 | 13.6 |
| Mauritius | 1186 | 0 | 386.7 | 2041 | 2041 | 0 | 4228.0 | 2885.9 | 422.1 | 352.1 | 163.2 | 48.2 |
| Morocco | 69554 | 16900 | 14370.4 | 346 | 346 | 0 | 62731.3 | 37561.0 | 8162.1 | 66.7 | 41.0 | 7.0 |
| Mozambique | 271402 | 64634 | 67128.4 | 1032 | 1032 | 0 | 8426.7 | 1587.8 | 1792.8 | 8.1 | 0.7 | 3.0 |
| Niger | 103941 | 56221 | 15952.2 | 151 | 151 | 0 | 2126.8 | 700.3 | 525.3 | 0.9 | 0.1 | 0.2 |
| Rwanda | 93746 | 20976 | 21859.6 | 1212 | 1212 | 0 | 839.7 | 520.7 | 112.6 | 12.6 | 0.0 | 4.2 |
| Senegal | 604043 | 172395 | 153099.2 | 686 | 686 | 0 | 8855.8 | 4730.4 | 1694.0 | 12.7 | 2.1 | 3.9 |
| South Africa | 3067 | 3000 | 25.6 | 495 | 495 | 0 | 489771.9 | 356637.8 | 40908.8 | 65.0 | 47.3 | 4.5 |
| Togo | 260418 | 62048 | 55391.9 | 1168 | 1168 | 0 | 2658.5 | 1221.1 | 645.7 | 20.9 | 0.0 | 5.1 |
| Uganda | 237000 | 120000 | 42301.3 | 1180 | 1180 | 0 | 5229.1 | 1558.4 | 1236.0 | 2.9 | 0.9 | 0.5 |
| United Republic of Tanzania | 2650120 | 984615 | 604675.2 | 1071 | 1071 | 0 | 11562.0 | 3589.9 | 2592.1 | 11.2 | 3.6 | 2.2 |
| Zambia | 51656 | 13337 | 16263.4 | 1020 | 1020 | 0 | 4503.0 | 1928.8 | 828.4 | 50.4 | 25.6 | 9.2 |
| Zimbabwe | 700 | 598 | 38.2 | 657 | 657 | 0 | 12020.4 | 5603.1 | 1935.2 | 40.0 | 18.2 | 6.7 |

Sources: World Bank, FAOSTAT


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### Table- 4: Hausman test results

| Test cross-section random effects | | | |
|---|---|---|---|
| **Test summary** | **Chi-Sq. Statistic** | **Chi-Sq. d.f** | **p-value** |
| Cross section random | 51.196 | 6 | 0.0000 |

| Test cross-section random effects test comparisons | | | | |
|---|---|---|---|---|
| **Variables** | **Fixed effects** | **Random effects** | **Var (Diff.)** | **p-value** |
| Fertilizer Consumption | -499.64 | 1717.89 | 154109.98 | 0.0000 |
| Agricultural land (% of land area) | 31200.91 | 11062.47 | 20622791.23 | 0.0000 |
| Pesticides | 952.69 | 11742.04 | -208915546.17 | 0.3798 |
| Temperature Change | -115432.61 | 121568.81 | -62315194.57 | 0.4370 |

Source: own calculation

### Table 5: Static Panel results in African countries during 2002–2014

| Variables | Co-eff. | S E | t-Stat | p- Value |
|---|---|---|---|---|
| Constant | 1082195 | 82357.99 | 13.14 | 0.00* |
| CO2Emissions | -4.48 | 1.57 | -2.85 | 0.01* |
| Pesticides | -63709.23 | 39441.48 | -1.62 | 0.10*** |
| Temperature Change | -199958.10 | 70376.48 | -2.84 | 0.01* |
| No. of Observations | 325 | | | |
| Log Likelihood | -4498.79 | | | |
| Durbin-Watson Statistics | 0.75 | | | |
| F-test | 222.48 | | | 0.00* |
| Adjusted $R^2$ | 0.96 | | | |
| $R^2$ | 0.97 | | | |
| * Significant at 1% level, *** significant at 10% level | | | | |

Source: World Bank, FAO database


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