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ARTICLE

Impact of Average Atmospheric Temperature on Rainbow Trout Production in South Africa: A Time Series Analysis Approach

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ABSTRACT

Climate change has various effects on the global food supply and the environment as a whole. Similarly, the production of fish like Rainbow Trout is affected by variation in the atmospheric temperature higher than 21°C, leading to fluctuations in yield. Therefore, this study sought to investigate the impact of average atmospheric temperature on Rainbow Trout production in South Africa using time series data spanning from 2000 to 2022. The unit root test, Johannsen cointegration test, and the Vector Error Correction model were employed to analyse the data. The results show that the change in average atmospheric temperature affects the production of Rainbow Trout. The correlation between average temperature and Rainbow Trout production is positive in the short-run and long-run. I Prolonged exposure to high temperature may lead to fish stress, migration and increased susceptibility to diseases which ultimately affects the economic viability of the sector in both the short-run and the long-run. In addition, the overall change in the atmospheric temperature has a negative effect on the production of the fish highlighting the need for climate change intervention to sustain fish production. The study recommends implementing strategies that reduce the impact of temperature changes on fish production to support both economic growth and food security.

Keywords: Rainbow Trout production; Average temperature; Unit root test; Vector Error Correction model

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1. Introduction

Fish is an important food source to various households and a significant contributor to economies across the globe. The consumption of fish offers nutritional benefits such as protein, calcium, vitamins and minerals which are important for human development [1]. Fish provides households with accessible proteins that support health and contribute to the development of sustainable local economies, food security and livelihoods of rural communities. Like agriculture, fisheries are vulnerable to climate change, which can affect water temperature, water levels and ecosystem dynamics potentially leading to losses in fish stocks and biodiversity [1, 2]. These climatic changes can disrupt fish reproductive cycles, increase water acidity, and spread diseases, and water availability for both fish and humanutilisation. In addition, temperatures above 21°C have negative effects on fish growth, causing higher mortality rates, reduced appetite, poor digestion and decreased antioxidant levels while temperature preference ranges from 10 to 15°C [3]. Fish species such as Rainbow Trout (Oncorhynchus mykiss) are invasive species commonly found in cold and oxygenated water [4]. These environmental conditions are crucial for the growth and reproduction of this fish. Although the Rainbow Trout has spread to various water bodies as an invasive species, temperature remains an important factor which influence its population density and production [5]. In addition, Rainbow Trout is highly popular in recreational fishing, and it has emerged as an economic-niche and popular fish in South Africa from the early 1890s [6]. Similarly, over ZAR 32 billion has been contributed by recreational fishing in the South African economy [7] suggesting that the industry plays an important role in supporting local livelihoods, promoting tourism and boosting economic development through job creation and business-related opportunities.Despite this, the rise in global warming has negatively affected the environmental conditions that support the reproduction of fish such as the Rainbow Trout, potentially threatening its habitats ultimately leading to declines in population. According to Kao et al. [2], climate change has affected lakes where fish catches are increasingly scarce decreasing oxygen levels and increasing toxicity of pollutants. This, in turn, affects the economic benefits, as a declining population can lead to low production in both commercial and aquaculture. Subsequently, the recreational fishing industry and local economies that rely on O. mykiss may also experience financial losses. Thus, adaptation strategies and effective environmental management are essential to sustain the economic contributions of Rainbow Trout fisheries.

The global production of fish has seen a decline due to several factors, including overfishing, unregulated fishing practices and climate change. For instance, overfishing has led to the depletion of fish stocks, ultimately affecting food security [8]. Similarly, unregulated fishing practices such as illegal, unreported and unregulated (IUU) fishing, exacerbates this problem causing a global concern on the sustainability of fishing resources [9]. In freshwater ecosystem, the rise in temperature, water pollution and invasion of other species further reduce fish stocks. For instance, polluted waters can cause the perishability of fish species while warmer waters may lead to migration leading to increased competition for resources and potential declines in native populations [10].

Studies examining the impact of climate change have been conducted in various parts of the world. For instance, Cheung et al., [11] investigated the impact of high temperatures on fish as a result of climate change. On one hand, Mendenhall et al., [12] focused on the risk of fish conflicts arising from climate change. On the other hand, Huang et al., [13] conducted a literature review on the impact of climate change on fish growth revealing that both freshwater and marine species are affected.. In the context of South Africa, Hara et al., [14] concluded that the impact of climate change on fisheries affects production leading to a loss of biodiversity. Scharsack and Franke [15] noted that unfavourable water temperatures contribute to infectious diseases, such as Viral Haemorrhagic Septicaemia Virus (VHSV), which leads to high mortality among Rainbow Trout fish. In South Africa, it was established by Shelton et al., [16] that Rainbow Trout expands in production during cooler seasons leading to a decrease during warmer temperature. This then prompts further research into adaptative strategies that could mitigate the diverse effects of climate change on fisheries.According to Maimela et al. [4], alien fish species often encounter natural migration barriers, but these barriers can be bypassed through human actions, such as the intentional stocking of upstream areas. This is particularly concerning in the upper Blyde River, where Trout stocking continues due to its designation as a Trout angling area. Conversely, areas with remaining populations of E. treurensis have avoided the introduction of alien fish species because they are designated as natural heritage sites. The distinction between areas where Trout fishing is permitted and those where it is prohibited has helped reduce potential conflicts between Trout fishing and conservation efforts, unlike in other parts of the country. Therefore, it is crucial to maintain the conservation status of these alien-free areas through regular monitoring to ensure they remain free of alien fish species, thus protecting the endemic and range-restricted minnows that inhabit the system. This is because for various households, fish like Rainbow Trout serves as a source of food[14]. Given this information, the next section focuses on the material and methods used in the study.

2. Material and methods

2.1 Descriptive statistics

The analysis of the impact of average atmospheric temperature on Rainbow Trout production was conducted using secondary time series data from South Africa spanning from 2000–2022, which accounts 23 observations. Times series analysis typically requires a minimum of 10 observations to be considered suitable for analysis. The data for the average atmospheric temperature (°C) was sourced from World Bank Climate Knowledge Portal whereas the Rainbow Trout production data (in tons) was obtained from FAOFish Stat database. Diagnostic tests such as the Augmented Dickey-Fuller (ADF) test were employed to test for the unit root. The Johansen cointegration test was used to analyse the cointegration between atmospheric temperature and Rainbow Trout production. To determine the relationship between average atmospheric temperature and Rainbow Trout production in South Africa, the study employed the Vector Error Correction Model. The next subsections explain the models used in this study.

2.2 Testing for unit root

The central measures of tendency from the descriptive statistics were used to describe the average atmospheric temperature and the production of Rainbow Trout in South African freshwaters. These measures included the mean, standard deviation, minimum and maximum values.

Augmented Dickey-Fuller (ADF) test

The unit root test is essential for testing the stationarity among the dependent and independent variables. According to Guo[17], a unit root, characterised by a non-stationarity time series implies that the overall mean and the variance are not constant over time. Therefore, the time series data that is stationary suggest that the mean and the variance will not change over time. In this study, a stationary series will have a constant mean and variance which is crucial for reliable results where data is tested to analyse relationships between two or more variables.

The ADF is a common unit root test which is used to check whether a given time-series is stationary or non-stationary. This test was first established by Dickey and Fuller in 1979 to demonstrate the existence of unit root with the primary emphasis of testing the null hypothesis that φ=1. In the equation

$$Y_i = \varphi Y_i + \ U_i \tag{1}$$

Therefore, the hypotheses are given as:

H0: Time series data encompasses a unit root (φ = 1)

H1: Time series data is stationary (φ < 1)

The conditions are that if the data does not have a unit root problem, the null hypothesis will be rejected.

The relationship between X and Y variables can be established by employing the following model:

$$Y_t = b_0 + a_0 X_t \sum m_j = 1\ a_j X_{t-j} + \sum n_i = 1 b_i Y_{t-i} + u_t \tag{2}$$

$$X_t = c_0 + d_0 Y_t \sum n_j = 1\ c_j Y_{t-j} + \sum m_i = 1 d_i Y_{t-i} + v_t \tag{3}$$

Where the error terms of the model are represented by u_t and v_t. The relationship between X and Y can be determined by testing the null hypothesis that $a_j = d_j = 0$ for all $j\ \ (j = 0,\ 1 \ldots m)$ as opposed to the alternative hypothesis that $a_j \neq 0$ and $dj\ \neq 0$ for some j.

2.3 Johansen cointegration test

The Johansen cointegration test was employed to analyse the cointegration between average atmospheric temperature and Rainbow Trout production. The Johansen cointegration test plays a pivotal role in understanding the relationship between variables in time series data. Using the residuals which is the error term of the regression equation, the least-squares regression equation and the eigenvalues of data transformation, the Johansen cointegration test gives an estimate for all cointegrating vectors within the context of unit root analysis[18]. Similarly, the Johansen cointegration test in this study was preferred because it can identify several cointegrating vectors in multiple time series data.

2.4 Vector Error Correction model (VECM)

In this study, the aim was to explore the impact of average atmospheric temperature on Rainbow Trout production. To achieve this, the Vector Error Correction model was used. The VECM assists in analysing the dynamics between the variables in the dataset in the short-run and the equilibrium relationship between these variables in the long-run. In addition, the VECM model is used to test the relationship among non-stationary time series data that are cointegrated by capturing both the long-run and short-run dynamics of the variables tested.The model is illustrated as:

$$\Delta LTROUT = \beta_0 + \beta_1 \Delta TEMPERATURE_{t-1} + \beta_2 \Delta XTROUT_{t-1} + \epsilon_t \quad (4)$$

Where ΔL represents the variation in the natural logarithm of TROUT. While β_0 represent the fixed value and $\beta_1 \beta_2$ are the parameters. TROUT and TEMPERATURE represents the Rainbow Trout production and average atmospheric temperature. The next section includes the discussion on the results of the study.

3. Results

3.1 Descriptive statistics

Table 1 shows the descriptive results of the average temperature and the Rainbow Trout production. The average production of Rainbow Trout in tons was 1280.587 as presented in **Table 1**. The median production was 1250.00 tons, indicating that half of the production values were below this tons and half were above. The highest recorded production of rainbow trout was 1750.00 tons. While the lowest recorded production was 949.00 tons. The standard deviation of the average production was 252.742, showing relatively low variability of production in the study area.

The average temperature across the dataset was 18.384°C with the median temperature of 18.410°C as presented in **Table 1**. The highest recorded temperature was 19.490°C while the lowest recorded temperature was 17.550°C. The variability or spread of temperatures around the mean was 18.410°C. The average temperature was relatively stable with a low standard deviation of 0.463.

Table 1. Descriptive statistics results.

Properties	Rainbow trout production (Tons)	Average atmospheric temperature (°C)
Mean	1280.587	18.384
Median	1250.000	18.410
Maximum	1750.000	19.490
Minimum	949.000	17.550
Standard deviation	252.742	0.463

Source: Own computation.

3.2 Average temperature vs Rainbow Trout production

Figure 1 shows the graphical relationship between average temperature (°C) and Rainbow Trout production (Tons) spanning from 2000 to 2022. Between 2000 to 2005, the production of Rainbow Trout experienced fluctuations, reaching a peak in 2003. However, from 2004 to 2005, production declined as temperatures rose above an average of 19.5°C. This potential correlation may be influenced by the rising temperatures. From the year 2010 to 2015, as temperatures declined, production of Rainbow Trout increased suggesting a favourable climate. In recent years (2016 to 2022), both average temperature and Rainbow Trout production has shown fluctuations. Despite these variations in average temperature and Rainbow Trout production in South Africa, there is a trend where periods of lower temperatures promote more production of the fish and higher temperatures pose a risk to production. This suggests that climate variability influences production of fish species such as Rainbow Trout in South Africa. The following section discussed the results in greater detail.

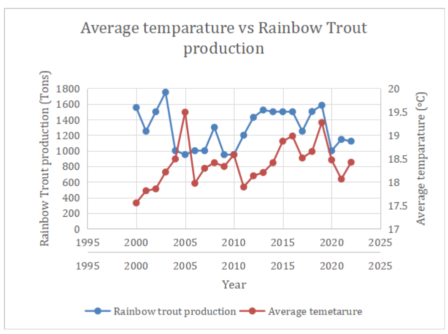

Figure 1. Average temperature vs Rainbow Trout production.

Source: Own computation.

4. Discussion

4.1 Augmented Dickey Fuller

To assess the stationarity of the data set, the study utilised the Augmented Dickey Fuller (ADF) unit root test. This test as presented in **Table 2**, involves rejecting the null hypothesis of unit root at a 5% level of significance. Stationarity is determined based on the ADF test by comparing the test statistics to the critical values. If the test statistics is greater than the critical values, the null hypothesis is rejected indicating that the time series is stationary. Conversely, if the test statistics is less negative than the critical value, the time series has a unit root. Therefore, if the p-value is less than the chosen significance level i.e., 5%, the null hypothesis is rejected, and it is concluded that the time series exhibit stationarity. Therefore, the results showed that at level, the data was stationary at 1% and 5% for both variables.

Table 2. Augmented Dickey Fuller.

Average temperature				
Test statistics	1% critical value	5% critical value	10% critical value	McKinnon approximate p-value
−3.004349	−3.769597	−3.004861	−2.642242	0.0500
Rainbow Trout production				
Test statistics	1% critical value	5% critical value	10% critical value	McKinnon approximate p-value
−3.692834	−3.769597	−3.004861	−2.642242	0.0118

Source: Own computation.

Based on the results from **Table 2**, the value of the test statistics was less than the critical value at 1% and 5% for the variable "average temperature". However, it was significant at 10% level. Additionally, the results showed that the test statistics of the variable Rainbow Trout production was greater than the critical value at 5% and 10%. Based on the 5% level of significance, it can be concluded that time series was stationary on Rainbow Trout production and non-stationary on average atmospheric temperature variable. These results agree with the findings of Borgwardt et al.,[19] who suggested that high water temperature leads to habitat loss.

4.2 Johansen cointegration test

To determine the long-run relationship between average atmospheric temperature and Rainbow Trout production in South Africa, the Johansen cointegration test was employed. The results as indicated in **Table 3**, illustrate the cointegration test using both Trace and Max-Eigen statistics. The condition of the Johansen cointegration test is that the null hypothesis should be rejected if the Trace statistics or Max-Eigen statistics is higher than the 0.05 critical value. Based on the results, it is evident that the Trace statistics was greater than the critical value at 5%, therefore the null hypothesis was rejected with a rank of 0 at 5% level.

The Max-Eigen statistics test revealed a 1 cointegration relationship between average atmospheric temperature and Rainbow Trout production at a 5% level of significance as shown in **Table 3**. Thus, the results of both the Trace statistics and Max-Eigen statistics implied that there is a log-run relationship between these two variables. This suggests that as temperature increases in the long run, Rainbow Trout production will decrease. Consequently, the Vector Error Correction Model (VECM) was employed to test the long run relationship. The results concur with the arguments of Andrew et al.,[20] who attested that climate change has a negative effect on the growth, survival and reproduction of Rainbow Trout suggesting a need for long term intervention in fish production and climate change.

4.3 Vector Error Correction Model (VECM)

Table 4 displays the results for the Vector Error Correction Model (VECM). The error correction term (0.094018) for D(TEMPERATURE) had a positive coefficient and was statistically significant at the 5% level, indicating adjustment towards long run equilibrium. The current period adjusts for the previous period's deviation from short run equilibrium at 9.4%. The sign and the value of the error correction term suggest a positive impact of average temperature on Rainbow Trout production in South Africa as argued by Shelton et al.,[16]. In the short run, a 1% change in D(TEMPERATURE) leads to a 168.0361 change in Rainbow Trout production. This means that, if average temperatures increase by 1°C, the Rainbow Trout production will decline by approximately 168 tons while holding other factors constant[21]. The value of the R-Square (0.4416) suggests that 44.16% of the variation

Table 3. Johansen cointegration test.

Hypothesised no. of CE (s)	Eigenvalue	Trace statistics	0.05 Critical value	Prob.**
None*	0.488192	21.81121	15.49471	0.0049
At most 1*	0.308452	7.745275	3.841465	0.0054

Hypothesised no. of CE (s)	Eigenvalue	Max-eigen statistics	0.05 Critical value	Prob.**
None*	0.488192	14.06594	14.26460	0.0537
At most 1*	0.308452	7.745275	3.841465	0.0054

Source: Own computation.

Table 4. Vector Error Correction Model.

Error correction	D(TEMPERATURE)	D(TROUT)
CointEq1	0.094018	0.001030
D(TEMPERATURE (−1))	−0.455693	−0.001077
D(TROUT (−1))	−168.0361	−0.007914
C	−23.43516	0.029640
R-Square	0.441610	0.681112
Adjusted R-square	0.242185	0.567224

Where the values in parathesis () and [ ] represent the standard errors and t-values respectively while the value without shows the coefficients.
Source: Own computation.

in atmospheric temperature is explained by the change in explanatory variable (Rainbow Trout production). In addition, about 68.1% of the variation in Rainbow Trout production in South Africa is explained by the variation in average atmospheric temperature.

5. Conclusion

The main aim of the study was to investigate the impact of average atmospheric temperature on the production of Rainbow Trout in South Africa. The initial analysis showed that both variables (TEMPERATURE and TROUT) had a unit root and were stationary at level. The study examined the short run and long run relationship between the Rainbow Trout production and the average atmospheric temperature, and the results showed that the variables have a relationship. The study further showed that the average atmospheric temperature influences the production of Rainbow Trout as indicated by the results of the Max-Eigen and trace statistics. In addition, there exists the short run and long run relationship between Rainbow Trout and average atmospheric temperature. Although Rainbow Trout is known as an invasive species, this fish plays a crucial role to the angling communities and some households as a source of protein. Similarly, various environmental factors such as water temperature, directly influence Trout production, and shifts in climate patterns may impact both the fish population and the livelihoods that depend on it. Additionally, these fish boost the recreational economy of South Africa suggesting a need for balanced conservation methods with sustainable management practices. The study recommends that mitigation strategies such as promoting sustainable water management, promoting awareness on the production of Rainbow Trout and reducing greenhouse emissions be put in place to reduce the impact of climate change on fish production particularly in inland freshwaters.

6. Limitations of the study

No study in South Africa specifically examined the relationship between Rainbow Trout production and average atmospheric temperature. This therefore advocates for more research to explore the potential effects of raising temperatures on Rainbow Trout. Understanding this relationship is vital for the development of effective management and conservation strategies as changes in temperature could affect native biodiversity.

Author Contributions

Conceptualisation, methodology, J.P.M.; formal analysis, J.P.M.; writing, J.P.M.; review and editing M.P.S.

Conflict of Interest

The authors declare no conflict of interest.

Institutional Review Board Statement

The study did not require ethical clearance since it used secondary time series data.

Informed Consent Statement

No informed consent was required for this study as it used public online available data.

Data Availability Statement

The Rainbow Trout data was obtained from FAO FISHSTAT which was downloaded from FAO website (https://www.fao.org/fishery/en/fishstat). Average temperature data was obtained from World Bank Climate Knowledge Portal (https://climateknowledgeportal.worldbank.org/).

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