Climate Change Effects on Shrimp Production in Bangladesh: Economic Insights for Declining Export Revenues

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Abstract

Shrimp, often called to as the "white gold" of Bangladesh, ranks as the second most exported product after ready-made garments. The shrimp industry is crucial for increasing national income, generating employment, and earning foreign currency for Bangladesh, but it is adversely affected by various climate-related factors. Applying unit root tests, co-integration, ordinary least squares (OLS) methods, and one-way ANOVA, the study evaluates how climate factors influence shrimp production and assesses whether foreign exchange earnings have significantly increased with the rise in shrimp production from 1990 to 2022. The results reveal that moderate humidity, greenhouse gas emissions, mean temperature, and rising Ganges water levels positively affect shrimp production, with greenhouse gas emissions, mean temperature, and water level increases showing significant results at the 1 percent level of significance. Conversely, precipitation and areas affected by flooding have adverse effects on shrimp production, also significant at the 1 percent level. Additionally, despite the rise in shrimp production, export earnings have not increased significantly, although they have a long-run association. The research identifies several factors contributing to the decline in export revenue, including limited product variety, high production costs, global economic downturns, decreased global demand, rising domestic consumption, trade barriers, inadequate export subsidies, dishonest trading practices, lack of quality control, reliance on extensive farming, the Covid-19 pandemic, devaluation of domestic currency, and inefficient supply chain management. This study proposes key strategies to enhance shrimp export revenues, including diversifying into value-added shrimp products, increasing the production of vannamei shrimp, integrating modern technologies, ensuring the availability of healthy fingerlings, adopting semi-intensive farming practices, improving supply chain management, modernizing processing facilities, boosting incentives for exporters, and maintaining political stability.

KeyWords: *Climate Change; Shrimp Production; Export Revenue.*

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1. Introduction

Bangladesh is one of the most vulnerable countries to climate change, with its impacts anticipated to significantly disrupt ecosystems and increase pressure on livelihoods and food supplies, particularly in the fisheries and aquaculture sectors (*IPCC, 2007*). Because of shrimp's high export value, it is referred to as "white gold" in the Bangladeshi economy (*Islam, 2008*). In Bangladesh, the shrimp industry plays a vital role in the economy, contributing significantly to domestic livelihoods and export earnings. But this sector is increasingly vulnerable to the adverse effects of climate change, including rising temperatures, fluctuating water levels, and humidity, extreme weather events, greenhouse gas emissions, and so on. These environmental disruptions not only threaten shrimp production but also have profound economic insights, particularly concerning Bangladesh's recently declined export revenues. Shrimp resources play a vital role in increasing national income, creating employment, and earning foreign currency for Bangladesh, while also developing as a significant industry. After the garment sector, the shrimp industry holds the second most significant contribution to the country's export trade. Shrimp accounts for nearly 70 percent of the frozen fish and fish products exported from Bangladesh. During the 2020-2021 period, Bangladesh's shrimp exports reached US$ 383.16 million, positioning the country as the ninth largest player in the global shrimp market. The area dedicated to shrimp farming ranged from 180,000 to 185,000 hectares, with 59 percent of the shrimp exported to the European Union (EU) market (*Statistical Yearbook Bangladesh, 2022*). About 2 million people are directly or indirectly engaged in the fishing profession in the shrimp industry, including activities such as fishing, aquaculture, processing, export trade, and other fish-related supportive work (*Bangladesh Economic Review, 2022*) .

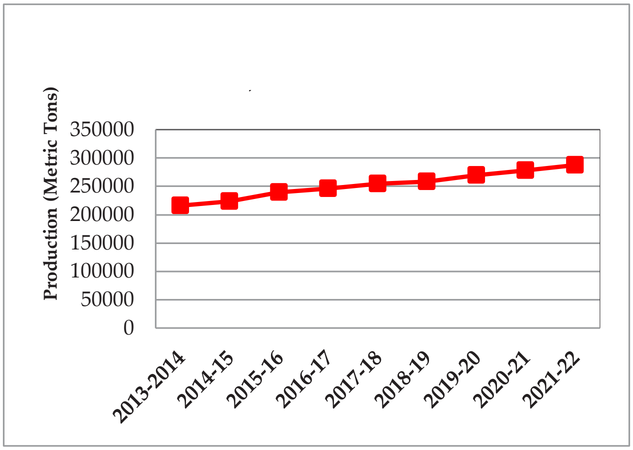

Figure 1. Shrimp Production (Metric Tons) from 2013-2022.

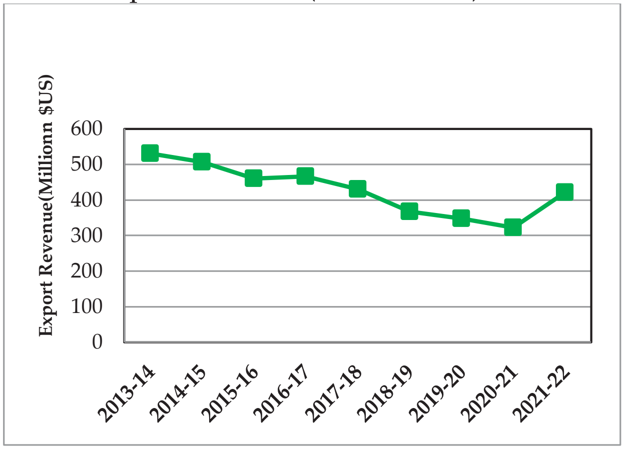

Figure 2. Shrimp Export Revenue (millions$US) from 2013-2022.

Shrimp production and export earnings are economically interconnected, as higher production increases export potential, boosting foreign exchange reserves if other things remain constant. The more export demand leads to more domestic production, and if export earnings increase through export growth, the domestic economy will be positively impacted. Since climate change has great impacts on shrimp production in Bangladesh, the first part of the paper will discuss the effects of climate change factors on shrimp production. Although we know Bangladesh is a climate-vulnerable country in the world, the production trend of shrimp is upward from 2013 to 2022 (Figure 1). Therefore, the export earnings from shrimp should also be increased, and this is crucial for us, like other developing countries that export dependably. But we see the downward trend of export earnings

(Figure 2), and Bangladesh loses its position in export earnings compared to other countries than before. So the second part of the study will discuss which economic issues are responsible for this, though the production trend is upward in the last decade, and will suggest some suggestions on how we can increase export earnings with an increase in our domestic shrimp production.

Moreover, policymakers, researchers, and the Bangladeshi economy would benefit greatly from this study since it reveals insight into how climate change affects shrimp production, a significant export industry. It facilitates formulating of economic policies, initiatives for sustainable growth, and well-informed decision-making by policymakers. Addressing knowledge gaps and developing multidisciplinary research on climate adaptation are beneficial to researchers. In terms of the economy, the study defends export earnings, keeps employment in at-risk areas alive, and keeps Bangladesh competitive in international trade by outlining methods to lessen the hazards associated with climate change. This paper aims to analyze the effects of climate change on shrimp production in Bangladesh and explore the economic insights of declining export revenues. The study uses secondary annual time series data from 1990 to 2022, which are analyzed using statistical and econometric techniques. The second section of the paper discusses the review of literature, while the third section presents the theoretical framework. The fourth section discusses the materials and methods, and the fifth section examines the results and discussion. The final section includes the concluding remarks and limitations of the study.

2. Literature Review

Rimi et al.(2013) examined the effects of climate change on shrimp production in the Shyamnagar area of Satkhira District, Bangladesh. Their study integrated social surveys, historical climate data, and shrimp production statistics. From 2001 to 2010, shrimp production showed a positive correlation with both average maximum temperature and average relative humidity, whereas it had an inverse correlation with average rainfall. However, no notable direct relationship was identified between shrimp production and minimum temperature. Findings from 1980 to 2009 revealed a significant decline in annual average maximum temperature, while the annual average minimum temperature showed an increasing trend. Notably, the maximum temperature decreased during the post-monsoon period but increased in winter. Additionally, relative humidity trends showed a significant increase across all seasons, with monsoon inundation depths exceeding 180 cm and dropping below 30 cm in the dry season, creating conditions unsuitable for shrimp cultivation. *Islam et al.(2016*) investigated the impacts of climate change on shrimp farming in the southwestern coastal region of Bangladesh, where around 80-90 percent of the population is engaged in the industry. The study found that 60 percent of farmers observed significant changes in weather over the past five years, with high temperatures identified as the primary challenge. Issues such as reduced growth, production loss, and increased disease susceptibility in shrimp were attributed to low rainfall. Notably, 80 percent of farmers reported that shrimp displayed signs of disease, including body deformities and skin lesions. *Islam et al. (2018)* identified that fluctuations in climatic factors significantly contribute to the degradation of water quality, leading to water scarcity and harm to the structural integrity of ponds. Their research highlighted that excessive rainfall, coastal flooding, and extreme weather events negatively affect shrimp production. These adverse effects of climate change can lead to increased disease prevalence and mortality among shrimp, resulting in reduced yields and the escape of shrimp due to water flow. To mitigate the effects of declining water quality, shrimp farmers often resort to exchanging tidal water. *Aziz et al.(2018)* investigated the impact of climate variations on shrimp growth at a shrimp farm in Kedah, India, focusing on the species *Penaeus Vannamei*. Using MANOVA and regression analysis, the study examined how climate influenced shrimp productivity and assessed the role of the feed conversion ratio in relation to the mean body weight across different climate seasons. The findings indicated that the dry season is more favorable for shrimp growth and production due to more stable temperatures. The shrimp exhibited higher survival and growth rates during the dry season, with increased harvest yield, higher average body weight, and a lower feed conversion ratio compared to the wet season. *Kais & Islam (2017)* studied the impacts of climate change and resilience at the lower end of the shrimp commodity chain in Bangladesh, focusing on variables such as sea-level rise, salinity, temperature, riverbank erosion, and extreme weather events. They found that increased rainfall disrupts shrimp ecosystems by causing water turbidity, leading to food shortages that hinder shrimp growth. Turbid water also results in breathing difficulties and loss of appetite in shrimp, further slowing their development. Heavy rainfall negatively affects shrimp physiology, raising mortality rates. Additionally, sharp rises in sea level can submerge low-lying shrimp farms, causing production losses, while higher air and water temperatures in summer severely impact shrimp metabolic activity due to overheating in ponds. *Khan et al.(2023*) examined the factors influencing shrimp export competitiveness across six nations: Bangladesh, China, India, Indonesia, Thailand, and Vietnam, using data from 1990 to 2019. The study employed the ARDL model to analyze the trends. Results indicate that each of these countries exhibited some level of shrimp export competitiveness during the period under review. However, China experienced a complete loss of its competitiveness after 2004. Meanwhile, Bangladesh's shrimp export competitiveness has slightly declined in recent years, in contrast to the steady growth seen in competitors like India, Indonesia, and Vietnam. According to *Rahman & Hossain (2009)*, in export markets, shrimp holds significant potential. Still, numerous challenges persist due to stricter quality standards, food safety regulations, and the emergence of technological and trade barriers in major markets like the USA and EU. However, addressing these challenges through improved aquaculture practices and enhancing export competitiveness are essential strategies for poverty reduction and contributing to Bangladesh's national development goals. *Fami (2019*) observed that the shrimp industry faces challenges due to competition, political conflicts, environmental disruptions, a lack of organizational growth, and price instability of essential raw materials in Bangladesh.

Based on the literature review, it is evident that most studies in the context of Bangladesh are region-specific. To the best of my knowledge, very few have focused on the entire country. Furthermore, no research has yet explored the economic implications of the recent decline in Bangladesh's export revenue. This study aims to address these gaps utilizing econometric and statistical methods.

3. Theoretical Framework

The first part of the paper will discuss the impacts of climate change on shrimp production. Using various well-established theories and empirical studies, we can take help to construct a strong theoretical framework for understanding the effects of climate change on shrimp production in Bangladesh. The Ricardian theory of climate and agriculture, which is one of the core theories of climate and agriculture, shows that climate elements such as temperature, humidity, and others have substantial effects on agricultural production *(Mendelsohn et al., 1994)*.

The ecological resilience theory discusses how various climate change factors, such as fluctuations in temperature, floods, and precipitation, affect ecosystems, including shrimp production. Moreover, this theory provides valuable insights for adaptation and recovery measures for these climate changes *(Holling, 1973)*. The sustainable livelihood theory provides crucial insights to know the effects of climate factors on the aqua farmers' livelihoods and aqua production. This theory also discusses the influence of some socio-economic factors on the sustainability of aqua farms. This hypothesis can be used to examine how the climate affects shrimp output and the livelihood of shrimp farmers *(Chambers & Conway, 1991)*. Additionally, fluctuations in temperature and humidity have an effect on fish metabolism and disease outbreaks. Although higher temperatures help fish growth, they manifest the growth of pathogens *(Boyd & Tucker, 1998)*.

According to the threshold theory, climate factors like irregular precipitation patterns and high temperatures can reduce shrimp metabolism, increase disease outbreaks, and reduce water quality. This idea suggests that agricultural crop production declines considerably beyond certain climate thresholds *(Schlenker & Roberts, 2009)*. The ecological system theory discusses the relationship between organisms and their environments. This theory can be utilized to analyze how climate factors like water levels and water quality, impacted by climate change, affect shrimp production and growth. This theory also helps us to understand the dynamics between shrimp farming and the surrounding ecosystem, offering insights into how water level fluctuations affect shrimp habitats and yields *(Bronfenbrenner, 1979)*.

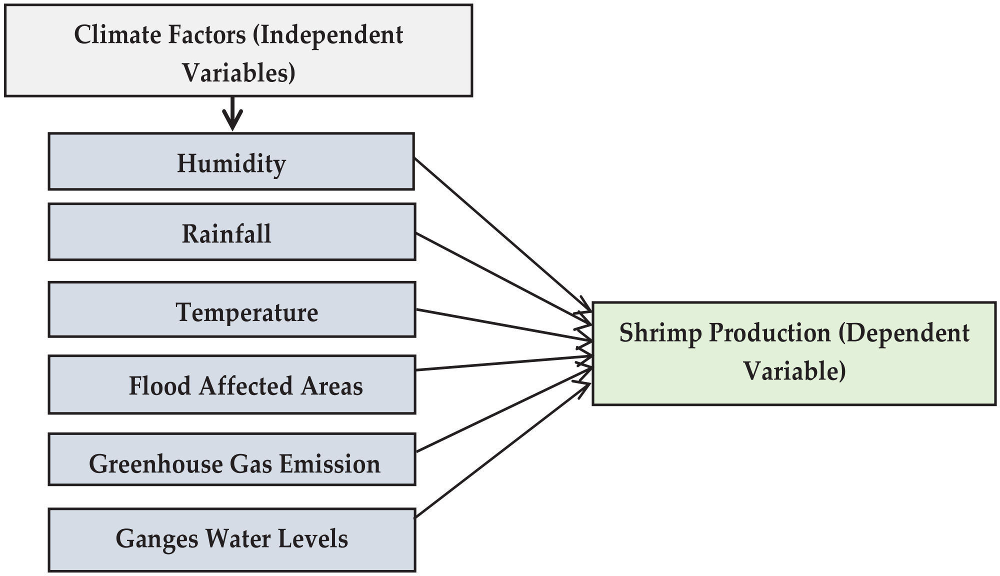

Figure 3. Framework for the Effects of Climate Factors on Shrimp Production.

Based on the above well-established theories, we can relate our analysis to analyze the effects of climate factors on shrimp production in Bangladesh. Humidity influences water evaporation, ventilation, and salinity changes, which are crucial for shrimp farming. Temperature affects shrimp metabolism, growth rates, disease susceptibility, and mortality. Precipitation patterns play a key role in maintaining pond ecosystem, water levels, and salinity balance. Flood-affected areas disrupt shrimp farm infrastructure and lead to stock losses and greenhouse gas emission influences on water warming. Lastly, Ganges water levels impact coastal shrimp production by regulating water salinity and transferring nutrients. This framework is shown in Figure 3.

The second part of the research discusses the economic insights for declining export revenue. The decrease in export earnings in spite of the increase in shrimp production can be explained by several theories. According to price transmission and terms of trade theory, a reduction of global prices of a commodity because of oversupply or trade barriers can decrease the export revenue of a country *(Krugman & Obstfeld, 2000)*. Elasticity of demand theory explains that for inelastic demand, a decrease in the price of a commodity can impact export earnings *(Nicholson & Snyder, 2012)*. Bangladesh's market share may be diminished by international competition from nations like Vietnam and India, while market access may be restricted by non-tariff barriers (NTBs) *(Baldwin, 2000)*. According to these theories, some reasons for diminishing export revenue include worldwide economic downturns and the COVID-19 pandemic, limited product variety, decreased global demand, trade restrictions, and high production costs. These factors are shown in Figure 4.

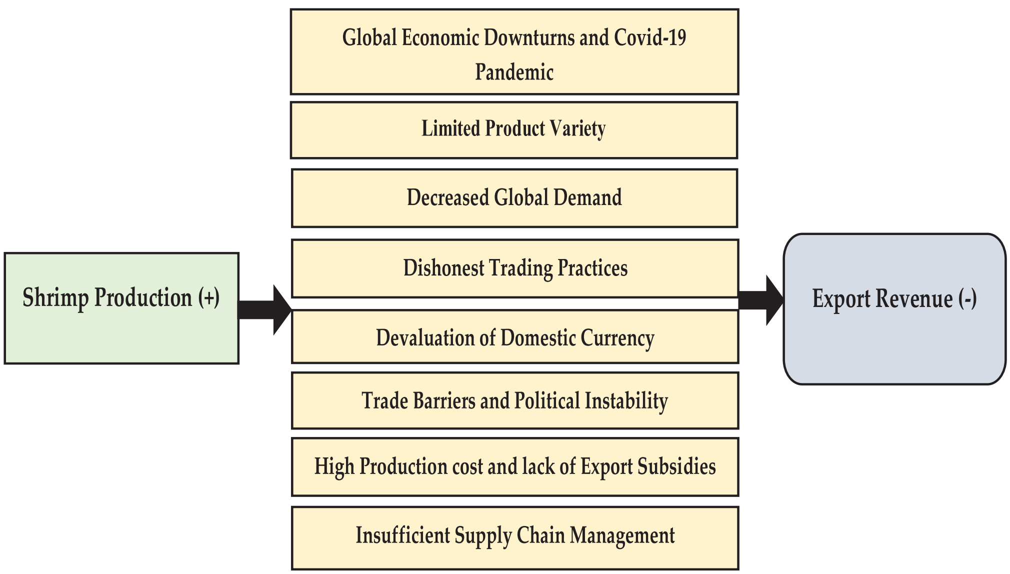

Figure 4. Framework for Declining Export Revenues.

4. Materials and Methods

4.1. Data Collection

This study employs annual time series data from 1990 to 2022, collected from various reliable secondary sources. The annual time series data of mean temperature (in degrees celsius) and precipitation (in millimeters) are sourced from the *Climate Change Knowledge Portal* (*2022*). Data on greenhouse gas (in per capita ton) emissions are obtained from the CO_2 country profile for Bangladesh by Hannah Ritchie and Max Roser (*Hannah et al., 2020*).

Median humidity data (in percentages) is retrieved from the *Climate Information Management System (2024*). Data on flood-affected areas and Ganges water level rises are collected from the *Bangladesh Water Development Board (2022*). In this paper, the Ganges water level rise variable is included because the vast coastal plains of the lower Ganges-Brahmaputra delta play a crucial role in supporting natural shrimp aquaculture, especially in the southeast region of Bangladesh. Ten stations (Kalaroa, Benarpota, Protapnagar, Basantapar, Kaikhali, Tala Magura, Chandkhali, Elarchari, Kobadak Forest, and Shakra) are taken into account to measure the water level rise in the Ganges Delta. The average water level rise for each year is then calculated based on the water levels recorded at the ten stations. Data on domestic shrimp production (in million tons) and export revenue (in million USD) are sourced from *Statistical Yearbook Bangladesh (2022*).

4.2. Model Specification

This research examines six climate change factors in Bangladesh, including humidity, greenhouse gas emissions, rainfall, average temperatures, Ganges water level increases, and flood-affected areas. The analysis employs a log-log model by applying logarithms to independent and dependent variables. This technique helps manage nonlinearity, stabilizes heteroskedasticity, improves data interpretation, simplifies intricate relationships, handles multiplicative effects, reduces skewness, and enhances the residuals distribution for regression. Additionally, it allows for analyzing percentage changes in variables across different domains. The model under consideration is as follows:

$$LNSHRIMP_t = \alpha_0 + \alpha_1 LNHUMDTY + \alpha_2 LNGREG + \alpha_3 LNPCIPT + \alpha_4 LNTEMPR + \alpha_5 LNGWLAL + \alpha_6 LNFLOOD + U_t \ldots\ldots\ldots\ldots\ldots (i)$$

Where, LNSHRIMP = Log of shrimp production, LNHUMDTY = Log of median humidity, LNPCIPT = Log of precipitation, LNTEMPR = Log of mean temperature, LNGWLAL = Log of Ganges water level rise, LNGREG= Log of greenhouse gas emissions, and LNFLOOD = Log of flood-affected areas.

4.3. Econometric and Statistical Methods

We used augmented *Dickey & Fuller (1979*) and *Phillips & Perron (1988*) tests in Eviews (version 11) software to examine the stationarity of the variables. An interesting point to note is that all the variables are stationary at their level. Given this, the ordinary least squares (OLS) method is the most suitable approach for analysis. Using SPSS software, the planned comparison method is applied to analyze significant differences between shrimp export revenues (in million $US) and domestic shrimp production (in metric tons) (both the variables are normally distributed) over the past 33 years. Shrimp production is categorized into five groups: Group 1 (27,000–81,000), Group 2 (81,000–135,000), Group 3 (135,000–189,000), Group 4 (189,000–243,000), and Group 5 (243,000–290,000). A one-way ANOVA (analysis of variance) is then used to assess whether there are statistically significant differences in shrimp export earnings and production across these groups. Johansen (1991) co-integration test is applied to check the long-run association between shrimp production and its export earnings. Finally, different types of diagnostic tests, namely normality, serial correlation, heteroskedasticity, multicollinearity, and cusum and cusum square tests, are applied to check the classical linear regression model's assumptions.

5. Results and Discussion

5.1. Descriptive Statistics

The mean, median, maximum, and minimum values for every variable are shown in Table 1, along with the descriptive statistics for the variables from 1990 to 2022.

Table 1
Descriptive statistics

	LNSHRIMP	LNHUMDTY	LNGREG	LNPCIPT	LNTEMPR	LNGWLAL	LNFLOOD
Mean	11.64	4.32	0.21	7.67	3.24	7.04	10.05
Median	11.76	4.31	0.16	7.67	3.25	6.97	10.37
Max	12.57	4.39	0.48	7.89	3.28	7.50	11.51
Min	10.22	4.27	0.03	7.44	3.28	6.77	6.04
Obs.	33	33	33	33	33	33	33

Source: Eviews software based on annual time series data (1990-2022).

5.2. Unit Root Test

To evaluate the stationarity of the variables, we employed the augmented *Dickey & Fuller (1979*) and *Phillips & Perron (1988*) unit root tests. The results, presented in Tables 2 and 3, show that the tests are performed twice: initially on the variables in their original form and then on their first differences. These tests are conducted using two specifications: intercept, and intercept with trend. The findings from both tests confirm that all variables are stationary at the level and first difference.

Table 2
Augmented Dickey-Fuller (ADF) unit root test

	Level		First Difference	
Variables	Intercept	Intercept and Trend	Intercept	Intercept and Trend
LNSHRIMP	0.00***	0.04**	0.21	0.01**
LNHUMDTY	0.00***	0.00***	0.00***	0.00***
LNGREG	0.99	0.65	0.00***	0.00***
LNPCIPT	0.00***	0.00***	0.00***	0.00***
LNTEMPR	0.02**	0.10*	0.00***	0.00***
LNGWLAL	0.41	0.03**	0.00***	0.00***
LNFLOOD	0.00***	0.00***	0.00***	0.03**

Source: Eviews software based on annual time series data (1990-2022). Notes: *** P<0.01, **P<0.05, *P<0.10.

Table 3
Phillips-Perron (PP) unit root test

	Level		First Difference	
Variables	Intercept	Intercept and Trend	Intercept	Intercept and Trend
LNSHRIMP	0.00***	0.78	0.00***	0.00***
LNHUMDTY	0.00***	0.00***	0.00***	0.00***
LNGREG	0.99	0.03**	0.00***	0.00***
LNPCIPT	0.00***	0.00***	0.00***	0.00***
LNTEMPR	0.03**	0.11	0.00***	0.00***
LNGWLAL	0.39	0.30	0.00***	0.00***
LNFLOOD	0.00***	0.00***	0.00***	0.00***

Source: Eviews software based on annual time series data (1990-2022). Notes: *** P<0.01, **P<0.05, *P<0.10.

5.3. Estimated Results of Ordinary Least Squares (OLS)

The estimated equation is:

$$LNSHRIMP = -28.69 + 2.26\,LNHUMDTY + 2.61\,LNGREG - 1.80\,LNPCIPT + 10.58\,LNTEMPR + 1.03\,LNGWLAL - 0.22\,LNFLOOD$$

The study applied an ordinary least squares (OLS) method to derive its findings. It is gratifying that all of the variables in my regression analysis, except for humidity, are significant at the 1 percent significance level. First of all, the results indicate that moderate humidity (60 -80 percent) level (LNHUMDTY) is positively associated with domestic shrimp production (LNSHRIMP), though this relationship is not statistically significant (*Rimi et al., 2013*). The coefficient for humidity is 2.26, suggesting that a 1 percent rise in humidity corresponds to a 2.26 percent increase in shrimp production (Table 4). High humidity may reduce ventilation and oxygen levels in water, stressing fish, while low humidity can cause rapid evaporation, affecting water parameters like pH and salinity, potentially harming the fish. Maintain humidity between 60-80 percent inhibits the development of mold, mildew, and fungi by regulating moisture levels. Shrimp are highly responsive to environmental fluctuations. Steady humidity levels help maintains a balanced system, lowering stress and supporting improved growth and well-being. *(Go Green. Aquaponics, 2024; Wisaiprom et al., 2018*). Table 4 illustrates that greenhouse gas emissions (LNGREG) have positive impacts on shrimp production (LNSHRIMP), and it is significant at the 1 percent level of significance (*Hiditomo, et al., 2020; Huang et al., 2024*). The coefficient of greenhouse gas emissions is 2.61; a 1 percent rise in greenhouse gas emissions leads to a 2.61 percent increase in shrimp production. Shrimp farming has a considerable effect on the environment, particularly by contributing to greenhouse gas emissions, including carbon dioxide (CO_2), a primary factor in global warming. For each kilogram of shrimp produced, based on a yield of 8 tons per hectare annually, around 10 kilograms of carbon dioxide (CO_2) are emitted (*Tansakul, 2024*). Table 4 shows that precipitation (LNPCIPT) has a negative and significant impact on shrimp (LNSHRIMP) production (*Khan et al., 2024; Rimi et al., 2013*). A 1 percent rise in precipitation results in a 1.80 percent decrease in shrimp production. Excessive rainfall has both direct and indirect effects on shrimp production. Intense rainfall causes rapid alterations in the physical and chemical properties of shrimp ponds. Following the heavy rainfall, a series of reactions is triggered within the pond's ecosystem. Excessive rainfall during the shrimp breeding season poses various challenges for farmers. Heavy rains can cause a significant drop in water temperature, which reduces shrimp feed intake and slows their activity (Buike, 2018). The combination of cooler water and reduced oxygen (O_2) levels at the pond's bottom stresses the shrimp and weakens their immune systems. Additionally, changes in water parameters like pH and salinity disrupt shrimp growth by reducing phytoplankton and beneficial bacteria. The amplified sound of rain further stresses the shrimp, ultimately increasing the risk of diseases and mortality in the breeding ponds. Shrimp production (LNSHRIMP) is positively and significantly (*Wayban et al., 1995*) impacted by mean temperatures (LNTEMPR), as seen in Table 4. Shrimp yield rises by 10.58 percent for every 1 percent increase in mean temperature, according to results from ordinary least squares (OLS). It means that mean temperature plays a very crucial role for shrimp production. Moderate temperature is significant for shrimp production. Since shrimp are poikilothermic animals, any rise or fall in the temperature of their aquatic environment will notably impact their body metabolism and alter their susceptibility or resistance to diseases (*Pradhan & Dash, 2021*).The ideal temperature for shrimp farming is between 28°C and 32°C. In winter, a sharp drop in water temperature reduces the shrimp's appetite and their ability to digest food. On the other hand, high temperatures have detrimental effects on shrimp’s growth, feeding, and production. According to *Limsuwan & Ching (2012*), shrimp feed consumption increased by 36.5 percent at 33°C compared to 29°C, although growth remained similar at both temperatures. However, survival rates were lower at 33°C, likely due to declining water quality. Higher levels of ammonia-nitrogen and nitrite-nitrogen were observed at this temperature, resulting in a higher feed conversion ratio (FCR) due to lower survival. Additionally, when feed was limited to 3 percent of body weight at 33°C, growth rates decreased, suggesting that shrimp required more feed to achieve normal growth at this higher temperature. We found a positive and significant impact of the Ganges water level rise (LNGWLAL) on shrimp production (LNSHRIMP). According to our findings, a 1 percent rise in the Ganges water level results in a 1.03 percent increase in shrimp production, and it is significant at the 1 percent level of significance. Rising water levels in rivers like the Ganges can transport additional nutrients to shrimp farming regions, particularly in estuaries, stimulating phytoplankton growth and boosting shrimp production. Additionally, increased water flow helps to dilute pollutants, improving water quality and creating healthier conditions for shrimp farming, reducing disease risks. Water exchange due to rising water levels is essential for maintaining optimal water quality. It helps prevent the accumulation of excessive ammonia and aids shrimp in coping with stressful phases of their life cycle, such as disease outbreaks and harvesting. It is advisable to perform a daily water exchange of 10 to 30 percent. Finally, our findings indicate that the flood-affected area (LNFLOOD) has a significant negative effect *(Ahmed & Diana, 2015;*

Muralidhar et al., 2012; Pradhan & Dash,2021) on shrimp production (LNSHRIMP). According to our outcomes, a 1 percent increase in the flood-affected area leads to a 0.22 percent decline in shrimp production, which is significant at the 1 percent level. Extended flooding frequently leads to physical harm to shrimp farming operations. During such floods, it is challenging for farmers to prevent shrimp from escaping, and they struggle to reinforce their low, narrow dikes. Additionally, floods create opportunities for predatory and wild fish to enter shrimp farms, potentially introducing diseases and parasites. The water quality in shrimp farms can also deteriorate due to coastal flooding, which introduces land-based pollutants (*Ahmed & Diana, 2015*).

Table 4
Results of Ordinary Least Squares (OLS)
Dependent variable: LNSHRIMP

Variables	OLS			
	Coefficient	**Std. error**	**t-statistics**	**Prob.**
C	-28.69	12.88	-2.23	0.03**
LNHUMDTY	2.26	1.73	1.30	0.21
LNGREG	2.61	0.71	3.69	0.00***
LNPCIPT	-1.80	0.43	-4.16	0.00***
LNTEMPR	10.58	3.33	3.18	0.00***
LNGWLAL	1.03	0.35	2.96	0.00***
LNFLOOD	-0.22	0.05	-4.02	0.00***
R^2=0.89, **F-Statistic** = 33.95, **Prob (F-Statistic)** = 0.00, **Durbin-Watson Stat** = 1.38				

Source: Eviews software based on annual time series data (1990-2022). Notes: *** P<0.01, **P<0.05, *P<0.10.

5.4. Co-integration Analysis of Export Revenue and Shrimp Production

To examine the long-run association between shrimp production and its export earnings, it is necessary to run a co-integration test. Before running the *Johansen (1991)* co-integration test, it is important to select the lag length and check the integration order of the variables. In our analysis, the integration order of both the variables is I(1), and a lag length of 1 is selected according to the *Akaike (1973)* information criterion (AIC). In Table 5, the max-eigen value and trace statistic represent that there is one co-integrating equation at a 5 percent significance level, depicting a long-term co-integrated relationship between shrimp production and export earnings.

Table 5
Johansen Co-integration Test
Unrestricted Co-integration Rank Test (Trace)

Hypothesizes No. of CE(s)	Eigen-value	Trace statistic	0.05 critical value	Prob.**
None	0.3289	17.0688	18.3977	0.07
At most 1*	0.1407	4.7030	3.8414	0.03

Source: Eviews software on the basis of annual time series data (1990-2022). **Notes:** **P<0.05.

Table 6
Unrestricted Co-integration Rank Test (Maximum Eigen-value)

Hypothesizes No. of CE(s)	Eigen value	Max-Eigen Statistic	0.05 critical value	Prob.**
None	0.3289	12.3657	17.1476	0.22
At most 1*	0.1407	4.7030	3.8414	0.03

Source: Eviews software on the basis of annual time series data (1990-2022). **Notes:** **P<0.05.

5.5. Relationship between Export Revenue and Shrimp Production Using ANOVA

The ANOVA (analysis of variance) test shows that there are significant differences among the five groups, as the p-value is less than the 5 percent level of significance. The F-value is 22.37 and the p-value is 0.00 (Appendix A). The contrast values for the null hypothesis (H_0: assuming equal variances) and the alternative hypothesis (H_a: not assuming equal variances) are 109.31, with t-statistics of 0.99 and 1.08, respectively (Appendix B). Both p-values are higher than the 5 percent significance level, suggesting there are no statistically significant differences in average shrimp export earnings between group five (243,000–290,000) and the other four groups (27,000–81,000, 81,000–135,000, 135,000–189,000, and 189,000–243,000). As a result, export earnings do not significantly increase across the five shrimp production groups. That is, despite the increase in shrimp production, foreign earnings have not increased significantly. Figure 5 illustrates these results.

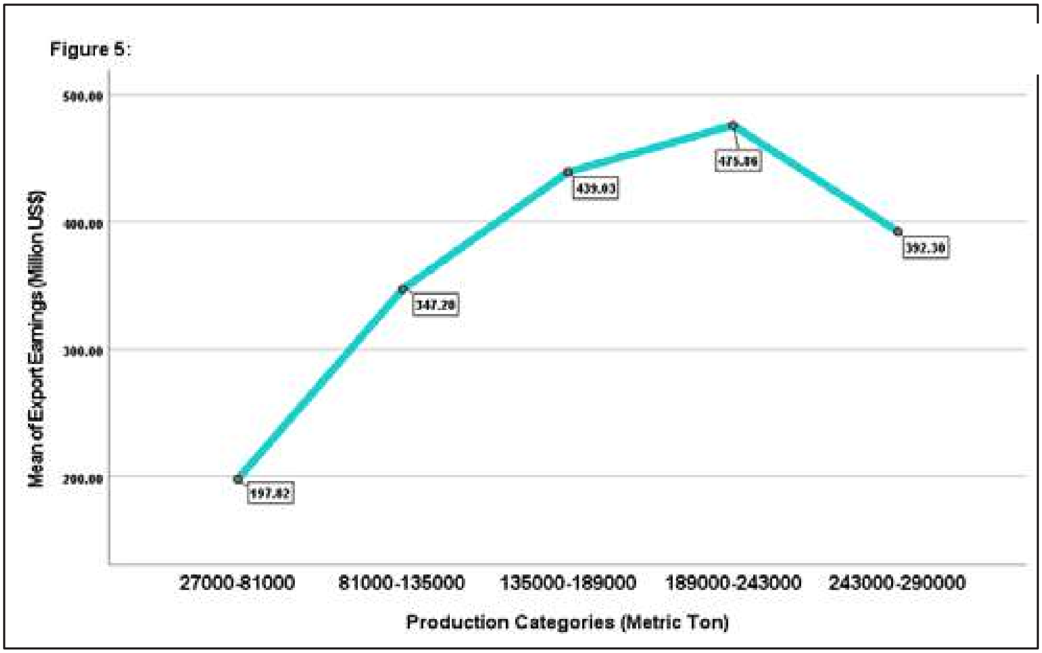

Figure 5. Export Earnings (Million US$) for Five Shrimp Production (Metric Ton) Categories (1990-2022).

Shrimp is one of the key sectors contributing to foreign exchange earnings in the country. At one point, it was the second-largest export product. Moreover, shrimp exports have been declining steadily in recent times. Bangladesh's native varieties, *Galda* and *Bagda*, are losing their foothold in the international market due to many economic and non-economic factors. According to government data, shrimp exports have decreased by at least 3,000 tons annually over the past five years. During the fiscal years 2021-2022 and 2022-2023, frozen shrimp export earnings were US$40.72 crore and US$30.02 crore, respectively. The growth rate of frozen shrimp export earnings turned negative in 2022-2023, declining by 26.27 percent, which was a 23.84 percent increase in 2021-2022 (*The Prothom Alo,2023*).

The primary markets for Bangladeshi shrimp are Europe, the United States, Japan, Russia, and China. Exporters note that shrimp exports to Europe, one of the largest markets for frozen shrimp, have declined due to the global economic recession. A range of factors have negatively impacted exports, resulting in a significant drop in prices in international markets, including reduced global demand, worldwide economic recession, global price competition, trade barriers and lack of export subsidies, limited product varieties, low productive methods, increase in domestic demand, inefficient supply chains, the COVID-19 pandemic, the Ukraine-Russia war, the Israel-Palestine crisis, lack of quality and dishonesty in trading, political instability, and so on. The Russia-Ukraine war has mainly led to a decline in shrimp demand in two significant markets for Bangladeshi shrimp: the European Union and the United States. In fiscal year 2023, the price of Bangladeshi shrimp fell by 24 percent due to the prolonged impact of the Russia-Ukraine war on global markets. Eighty-five percent of shrimp exports from Bangladesh are sent to European countries, while the remaining 15 percent is exported to the US, Japan, and other nations (*The Financial Express,2024*).

The limited variety of products, high production costs of *Galda* and *Bagda* shrimp, worldwide economic crisis, and intense global market competition have resulted in low export revenues for Bangladesh. Bangladesh primarily exports two types of shrimp: *Bagda* and *Galda*. However, the production costs for both are significantly high. Despite the growing global demand for shrimp, Bangladesh’s export earnings from this sector are declining. This is due to the decreasing demand for *Bagda* and *Galda* shrimp compared to *Vannamei* (Whiteleg shrimp) shrimp. The hybrid *Vannamei* shrimp is highly productive and much cheaper. Its lower production cost allows countries producing *Vannamei* shrimp to export to foreign markets at competitive prices. As a result of the global economic crisis, the demand for *Vannamei* shrimp has been steadily increasing. A survey shows that *Vannamei* shrimp holds 78 percent of the global market share, while *Bagda* shrimp has dropped to just 11 percent (*Haque, 2024*). Currently, *Bagda* shrimp is US$2 per pound more expensive than *Vannamei*. Due to economic challenges, buyers are cutting costs, further reducing the demand for our shrimp. The market share for *Galda* shrimp is even smaller, at only 6 percent. Countries like India, Vietnam, and Thailand have already seen tremendous success with this hybrid species, thanks to its high yield and low cost. In the last fiscal year, India's frozen *Bagda* shrimp exports increased by 55.41 percent, reaching US$320 million. In contrast, Bangladesh's frozen shrimp exports declined by

26.27 percent, dropping from US$407.2 million to US$300 million. According to the internationally recognized trade and economic database, OEC World, global shrimp exports amounted to US$22.03 billion in 2021. Ecuador was the top exporter, accounting for 23.9 percent of the total, followed by India with 23.5 percent, Vietnam with 10 percent, Indonesia with nearly 7 percent, and Argentina with 5 percent. That year, Bangladesh's share in global shrimp exports was just 1.5 percent (*The Prothom Alo, 2023*).

Some economists argue that the rise in domestic consumption is also a key factor contributing to the decline in export revenue in Bangladesh. According to the Department of Fisheries, domestic demand for *Bagda* and *Galda* shrimp has increased, resulting in a decrease in exports of these local varieties. A chief scientific officer of the fisheries department explained that with the increase in purchasing power in the country, our internal shrimp production has grown, and there is a growing preference among consumers for shrimp. Consequently, local consumers are buying more of these varieties. As a result, exports have slightly declined since we focused on fulfilling local demand before exporting (*Fayaz, 2024*).

Khulna, one of the largest shrimp-producing regions in Bangladesh, exports a substantial amount of shrimp annually; however, due to declining global demand, its export volume has significantly decreased. According to the Bangladesh frozen foods exporters association (BFFEA), due to decreased global demand and lower prices, fish exports from the Khulna region during the first five months of the 2023-24 fiscal year (July-November) amounted to 11,391.62 metric tons, valued at Taka 1,140 crore. In the same period of the 2022–23 fiscal years, exports were 13,890.62 metric tons, worth Taka 1,522 crore. This represents a decline of nearly Taka 382 crore in export revenue in just five months. Similarly, in the first five months of the 2023–24 fiscal years, *Bagda* and *Galda* shrimp exports totaled 7,741 metric tons, valued at Taka 946 crore. During the same period in 2022–23, shrimp exports amounted to 10,043 metric tons, worth Taka 1,478 crore. This marks a decrease of Taka 532 crore in shrimp exports within five months of 2023 (*Chowdhury, 2024)*).

Trade barriers and export subsidies also play a significant role in influencing export revenue for developing countries like Bangladesh. The loss of tariff preferences and the end of export subsidies could put considerable strain on Bangladeshi shrimp exporters. After Bangladesh graduates from LDC (Least Developed Countries) status, shrimp exports to the European Union and the United Kingdom will face tariff hikes of 0.52 percent and 0.46 percent, respectively (*The Daily Star, 2024*). Due to dishonesty in trade practices and poor product quality, many foreign buyers have rejected their shipments. The chairman of the fisheries department at the University of Dhaka stated that due to the actions of some dishonest traders, exported products are being returned from Europe and other countries (*Safwan, 2023*). Despite significant growth in the volume and value of prawn and shrimp markets over the years, Bangladesh has encountered challenges in upholding quality standards (*Alam & Pokrant, 2009*). In recent years, Bangladesh has faced growing criticism for adding substances like silicone, gum, water, and rice starch to black tiger shrimp, which make up 71.4 percent of the country's shrimp exports. Informal middlemen often engage in these practices to artificially inflate the shrimp's size and weight, aiming to sell them at higher prices internationally. This has damaged the reputation of Bangladeshi shrimp products, leading to a decline in export volumes. Bangladesh still primarily relies on extensive farming, which produces lower yields compared to semi-intensive farming methods. At present, 98 percent of shrimp is produced through extensive farming, which has a lower yield per hectare due to low stocking density, while only 2 percent comes from semi-intensive methods (*Ahmed & Ali, 2022*).

The COVID-19 pandemic caused a significant drop in Bangladesh's shrimp exports due to several factors. Global demand declined as importing countries faced economic slowdowns, restaurant closures, and disruptions in the food service industry. Supply chain issues, such as port closures and transportation restrictions, made it challenging to ship shrimp on time. Shortages of labor in shrimp farming and processing, along with rising logistics costs, led to slower production and a decline in profitability.

Additionally, maintaining quality standards became a challenge, leading to potential rejections of shipments, all contributing to the decrease in export volume. Finally, a significant factor behind the declining export volume is the inefficiency of the supply chain. In Bangladesh, the shrimp supply chain involves multiple intermediaries who often neglect quality control and proper storage during transport. Poor post-harvest management and a lengthy informal supply chain reduce the shrimp's quality when it reaches markets, often forcing it to be sold at lower prices (*Ahmed & Ali, 2022*). Devaluation of Bangladeshi currency against the US dollar can enhance market competition for Bangladeshi shrimp in the global market. If the export volume doesn’t increase proportionally, it can reduce export earnings. Moreover, this devaluation of domestic currency can increase the import prices of inputs (e.g., fishmeal, broodstock, aerators), which can decline export earnings.

To boost foreign exchange earnings and enhance competitiveness in the shrimp industry, it is crucial to diversify production beyond frozen shrimp by introducing value-added products. Increasing the cultivation of *vannamei* shrimp, which has high global demand and adopting modern technologies can significantly raise production levels. Additionally, ensuring the supply of healthy shrimp fingerlings and moving away from traditional extensive farming methods will lead to more sustainable and efficient shrimp farming. Tackling the issue of middlemen who inflate the price of shrimp feed through syndicates is also essential. Upgrading processing plants to meet international standards, along with increasing incentives for exporters and efficient supply chain management, will further strengthen Bangladesh’s shrimp industry on the global stage. Last but not least, maintaining political stability is essential for fostering investor confidence and creating a favorable environment for sustained growth in the shrimp sector.

5.6. Residual Diagnostics Tests

The results of normality, heteroskedasticity, and serial correlation tests are presented in Table 6.

Table 6
Diagnostic tests' results

Test	OLS		Conclusion
	Prob.	Level of significance	
Normality (JB test)	0.80	0.05	Residuals are normally distributed
Breusch-Godfrey Serial Correlation LM Test	0.31	0.05	No serial correlation exists
Breusch-Pagan Godfrey heteroskedasticity test	0.40	0.05	Homoskedasticity exists

Source: Eviews software based on annual time series data (1990-2022).

5.7. Multicollinearity Test

The Variance Inflation Factor (VIF) quantifies the extent of multicollinearity in regression analysis. It is a statistical measure that reflects how much the variance of a regression coefficient is amplified due to the presence of collinear relationships among predictors. If centered VIF is between 1 and 10, multicollinearity does not exit. Based on our findings, the centered VIF values for all variables range between 1 and 10 (Appendix C), indicating the absence of multicollinearity in the model.

5.8. Cusum Test and Cusum Square Test

The Cusum and Cusum Square test statistics, as proposed by *Brown et al.(1975*), were applied to evaluate the stability of the model at a 5 percent significance level. Since the Cusum statistic stays within the critical boundaries at this significance level, the results indicate that the model is stable. The analysis also reveals that the coefficients are consistent and statistically significant.

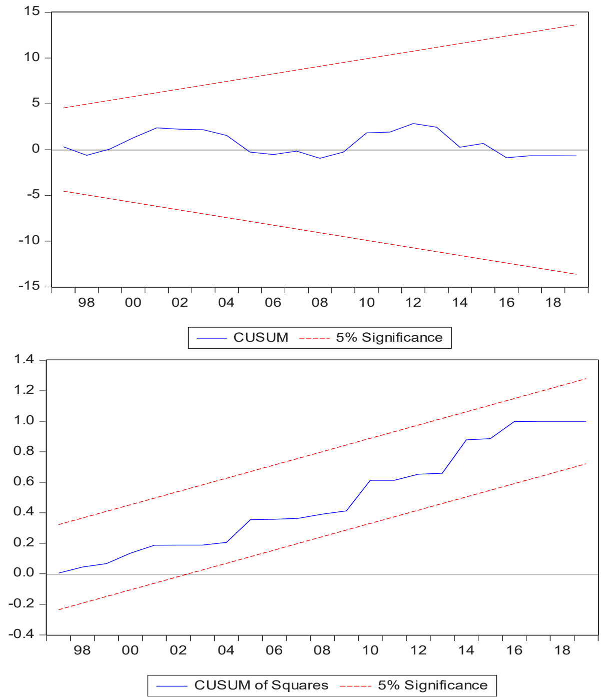

Figure 6. Cusum and Cusum square test.

6. Conclusion

This research offers an in-depth exploration of how climate change affects shrimp production in Bangladesh, alongside the economic consequences tied to reduced export revenues. A vital aspect of the study is its use of advanced econometric and statistical approaches to analyze the impacts of climate change on shrimp production and explore whether foreign exchange earnings have significantly increased with the rise in shrimp production from 1990 to 2022. The findings indicate that factors such as moderate humidity, greenhouse gas emissions, average temperature, and the rising Ganges water levels have a positive impact on shrimp production. Among these, greenhouse gases, temperature, and water levels show significant results at a 1 percent significance level. On the contrary, rainfall and flood-affected areas are found to have adverse effects, which are also significant at the 1 percent level. Furthermore, export earnings have not increased significantly despite a rise in shrimp production, although there was a long-run association between shrimp production and its export earnings. The study highlights numerous reasons for the decline in export revenues, including limited product diversification, high production costs, global economic recessions, falling international demand, increasing domestic consumption, trade restrictions, insufficient export incentives, fraudulent trade practices, lack of quality standards, reliance on extensive farming, disruptions caused by the Covid-19 pandemic, the Ukraine-Russia war, the Israel-Palestine conflict, devaluation of domestic currency, and poor supply chain management. The study recommends several strategies to boost shrimp export revenues, including expanding into value-added shrimp products, enhancing *vannamei* shrimp production, incorporating advanced technologies, ensuring the supply of healthy fingerlings, transitioning to semi-intensive farming practices, addressing price hikes caused by mediator syndicates, upgrading processing facilities, improving supply chain management, providing more incentives for exporters, and ensuring political stability. Lastly, water salinity and area under shrimp production are the crucial factors in shrimp production, and we made an effort to incorporate this variable into our model. However, while some regional salinity data were available for specific years, comprehensive data on Bangladesh's salinity from 1990 to 2022 could not be found, which is a limitation of our study.

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APPENDICES

Appendix A: ANOVA

Export Earnings	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	320377.61	4	80094.40	22.37	0.00
Within Groups	100234.35	28	3579.80		
Total	420611.96	32			

Source: SPSS software based on secondary data (1999-2022).

Appendix B: Contrast tests

Variable	Hypotheses	Contrast	Value of Contrast	**t**	Sig. (2-tailed)
Export Earnings	Assume equal variances	1	109.31	0.99	0.33
	Does not assume equal variances	1	109.31	1.08	0.31

Source: SPSS software based on secondary data (1999-2022).

Appendix C: Variance Inflation Factors (VIF)

Variable	Coefficient Variance	Uncentered VIF	Centered VIF
C	165.87	76580.86	NA
LNHUMDTY	3.01	25933.73	1.25
LNGREG	0.50	10.84	2.86
LNPCIPT	0.19	5086.30	1.38
LNTEMPR	11.09	53941.17	1.14
LNGWLAL	0.12	2777.64	2.75
LNFLOOD	0.00	136.29	1.70

Source: Eviews software based on annual time series data (1990-2022).