Mesopotamia Journal of Agriculture

https://magrj.uomosul.edu.iq

INFLUENCES OF ENVIRONMENTAL AND CLIMATE INDICATORS ON AQUACULTURE PRODUCTION IN COASTAL PROVINCES, VIETNAM

Nguyen M. N. Nam [1], **Nguyen P. Le** [2]

Department of Economics, Engineering Society and Business Organization, University of Tuscia, Rettorato, Via S.M. in Gradi n.4, 01100 Viterbo, Italy 1

Department of Agricultural Economics and Policy, Vietnam National University of Agriculture, Trau Quy commune, Gia Lam district, Hanoi, Vietnam 2

Article information
Article history:
Received: 26 /5 /2025
Accepted: 24 /9 /2025
Available: 30/9/2025

Keywords:
aquaculture, climate, coastal Vietnam, environment, influence.

DOI:
https://doi.org/10.33899/mja.2025.160772.1603

Correspondence Email:
nguyenphuongle.vnua@gmail.com

ABSTRACT

Aquaculture plays an important role in Vietnam's economic development, particularly in terms of export turnover and aquaculture producers' income. However, climate change and environmental pollution strongly impact Vietnam's aquaculture industry. In this paper, the panel data collected from eight provinces in the eight coastal provinces from 2014 to 2023 were employed. A fixed-effects model was applied to determine relationships between climate variables (temperature, rainfall, humidity, sea level rise, and sunshine hours) and environmental factors (dissolved oxygen, lead contamination, and ammonia) with aquaculture output. The results showed that factors such as dissolved oxygen, lead contamination, production area, humidity, and seawater level reveal strong relationships with aquaculture production at a statistically significant level. Meanwhile, the factors such as ammonia, rainfall, sunshine hours, and temperature did not have statistically significant correlations with aquaculture production. The findings highlighted the need for policymakers and other stakeholders to address climate resilience issues in planning, investment, and technological transformation for aquaculture development.

INTRODUCTION

Aquaculture has been one of the major sectors of the international economic strategy in terms of its contribution to the national economy, food security, and sustainable development, especially along the coast. According to the Food and Agriculture Organization (FAO, 2023), the contribution of aquaculture to world fish production has been steadily increasing: 130.9 million tons (58.6%) of the total annual global supply (223.2 million tons/year), but the question arises: to what extent is the sector developing sustainably to meet the growing demands of the emerging economic market in light of rapidly increasing world population and climate and environmental parameters change?

With more than 3,260 km of coastline, Vietnam forms one of the three largest aquaculture producers in the world (FAO, 2022). In 2022, the country's aquaculture production totaled nearly 5.2 million tons, representing more than 55% of total Vietnamese seafood production (General Statistics Office, 2023). The success was achieved thanks to the industrialization of aquaculture. Agricultural producers have increasingly adopted circular systems, automated feeding devices, water quality monitoring equipment, and disease management techniques to increase production efficiency and minimize environmental impacts (Nguyen *et al*., 2019). The innovative intensive farming systems in shrimp culture have been strengthened, particularly the integrated farming model that includes rice and shrimp. This integrated model has contributed positively to the social-environmental-economic efficiency (Nguyen *et al*., 2020). As a result, shrimp exports in 2022 reached over USD 4.3 billion (Vietnam Association of Seafood Exporters and Producers [VASEP], 2023). Not only shrimp, but the pangasius sector has also undergone significant restructuring. The progress of breeding, feed conversion ratios, and processing quality has enhanced Vietnam's competitiveness in the global markets. Pangasius exports amounted to USD 2.4 billion in 2022, mainly reaching China, the United States, and the European Union (VASEP, 2023). Together with producers' technological adaptation, the Vietnamese government's policies have promoted sustainable aquaculture practices consistent with international certifications such as the Aquaculture Stewardship Council and Global GAP (Ministry of Agriculture and Rural Development [MARD], 2021).

Despite the successes, Vietnam's aquaculture is facing many challenges. Environmental pollution and climate change have been considered significant threats to coastal aquaculture (Asian Development Bank, 2007). Numerous publications demonstrate how environmental factors such as land, soil, water quality (dissolved oxygen, ammonia, lead contamination), temperature, sunshine hours, and humidity significantly influence aquaculture productivity (Engle and Wossink, 2008; Yoo and Lee, 2016; Boyd and Tucker, 1992; Davidson *et al*., 2021).

Climate change, especially extreme weather events and sea level rise, has impacted aquaculture both in the short and long term. In the long term, climate change causes the reduction of wild seeds and rainfall and increases competition for freshwater. All these changes extensively influence aquaculture production, particularly in species growth, disease prevalence, and productivity. The impacts of climate change on aquaculture sustainability have recently attracted considerable attention from the scientific community, as aquaculture significantly contributes to global food security, nutrition, and socio-economic livelihoods (Yazdi & Shakouri, 2010; Lam *et al*., 2024). Further, climate change has the potential to amplify an increase in the likelihood of conflict and a reduction in the feasibility of maintaining current residence (Nosir, 2023). However, quantitative models are inadequately explaining the relationships between climate-related risks and poverty and assessing the farmers' coping strategies (Nofiu and Baharudin, 2024). Smart farming has emerged as one of the solutions to the challenges of climate change in aquaculture and agriculture (Noor *et al*., 2023; Kadem, 2025) .

Aquaculture expansion is not only influenced by environmental factors and climate change, but it also negatively pollutes soil, air, and water. Several studies detail the negative effects of aquaculture production on the environment, such as greenhouse gas emissions (Froehlich *et al*., 2017; MacLeod *et al*., 2020), habitat destruction and modification (Richards and Friess, 2015; Primavera, 2006), antibiotic resistance proliferation (Cabello *et al*., 2013; Miranda *et al*., 2018), and nutrient pollution (Taranger *et al*., 2015) .

In Vietnam, several studies focused on investigating the impacts of climate change on aquaculture and farmers' mitigation (Johnson & Hung, 2020). Moreover, many other researchers explored the environmental damages caused by aquaculture (Nguyen, 2017; Luom *et al*., 2022). On the other hand, Nguyen *et al*. (2020) conducted a study on" impact of environmental pollution on aquaculture development" in Vietnam using households' survey data with a small sample and qualitative analysis to show that water pollution was one of the factors causing loss in aquaculture production. The research done by White (2017) also witnessed environmental impacts on aquaculture. However, this report investigated how fish farming waste components (nutrients, uneaten food, residues of disease or parasite treatment chemicals) affect wild fish species. The research that focused on analyzing the influences of environmental factors (dissolved oxygen, ammonia, lead contamination, temperature, sunshine hours, and humidity…) on aquaculture production based on panel data and quantitative analysis is uncommon .

The paper mainly aims to examine the impacts of environmental parameters (dissolved oxygen, ammonia, and lead contamination) and climate factors (area of production, rainfall, sea level, sunshine hours, temperature, and humidity) on aquaculture production in coastal areas of Vietnam. By doing so, some evidence-based policy recommendations for developing aquaculture in coastal areas of Vietnam in the context of climate change are provided.

MATERIALS AND METHODS

Study Site

This study examines Vietnam's coastal provinces during the ten years from 2014 to 2023, covering the vast country's coastline from the southern Mekong Delta to the northern Gulf of Tonkin. Quang Ninh, Hai Phong, and Nam Dinh in the North; Nghe An in the North-central region; Quang Nam and Ninh Thuan in the South-central region; Vung Tau in the Southeast region; and Ca Mau in the Mekong Delta are among the important aquaculture regions included in the study area. These provinces were chosen because they represent a variety of coastal ecosystems along Vietnam's coastlines and contribute substantially to the country's aquaculture output. The study area is ideally situated to investigate the effects of climate and environmental factors on aquaculture production because they have tropical monsoon climates with regional variations in temperature, rainfall, and humidity.

Data Collection

The empirical analysis is based on a dataset from 2014 to 2023. To guarantee the accuracy and completeness of the data, environmental and climate indicators were gathered from several reliable sources. The Statistical Yearbook of Vietnam, which offered standardized time-series measurements of important climatic variables, such as mean annual temperature, precipitation levels, and humidity indices across the study regions, was a primary data source. Specialized environmental parameters taken from the Annual Environment Statistics Reports, which provided comprehensive measurements of water quality indicators (dissolved oxygen, ammonia, and lead contamination), coastal pollution indices, and extreme weather events' frequency were added to these core datasets.

Data Analysis

A fixed-effects regression model is utilized to investigate the connection between aquaculture production and environmental and climate factors. The data's panel structure and the model's capacity to account for unobserved time-invariant heterogeneity across provinces served as the driving forces behind this decision. The fixed-effects model is specified as:

$$Y\_it = \beta\_0 + \beta\_1X\_1it + \beta\_2X\_2it + \ldots + \beta\_kX\_kit + \alpha\_i + u\_it$$

Where Y_it represents the logarithm of aquaculture production in province i at time t, X_1it to X_kit are our environmental and socio-economic variables, shown in Table (1), α_i captures the province-specific fixed effects, and u_it is the error term.

Table (1): Variable Description

Variable definition	Unit	Expected value
Dependent variable		
Prod_Total aquaculture production	Tons	+
Independent variables		
DO_Dissolved Oxygen	Mg/l	+
Pb_Lead Concentration	Mg/l	-
NH4_Amonia	Mg/l	-
Area_Production area	ha	+
Rain_Rainfall	mm	+
Water_Sea level	cm	+
Sun_Sunshine hours	hour	+
Humid_Humidity	%	-
Temp_Temperature	^{0}C	-

Before model estimation, comprehensive diagnostic tests were conducted to ensure the validity of our econometric approach. Variables were examined for multicollinearity using variance inflation factors (VIF), with values consistently below the conventional threshold, indicating no severe multicollinearity concerns. The Hausman test confirmed the appropriateness of fixed-effects over random-effects specification ($\chi^2 = 27.43$), validating our methodological choice. Additionally, we tested for heteroskedasticity using the modified Wald test and addressed detected issues through robust standard errors. By showing how changes in potentially controllable environmental factors correlate with changes in aquaculture outcomes, the model's results are suitable for policy-relevant analysis. This will create a strong empirical basis for management plans and policy recommendations that align with the principles of a sustainable economy.

RESULTS AND DISCUSSION

Overview of Aquaculture in Vietnam in the Context of Climate Change

Vietnam's fishery industry has contributed substantially to economic and social development while simultaneously enhancing the national position in a global market. The contributions of the aquaculture sector have been manifested in the expansion of cultivation areas, production output, substantial export value, and job creation for coastal laborers. The emergence of Vietnam's aquaculture has made the country one of Southeast Asia's most important agricultural producers in recent decades (FAO, 2023). Vietnam has transformed from a modest producer in the 1990s to one of the world's prominent aquaculture nations, with annual production exceeding 4.5 million tons (World Bank Aquaculture Report, 2023).

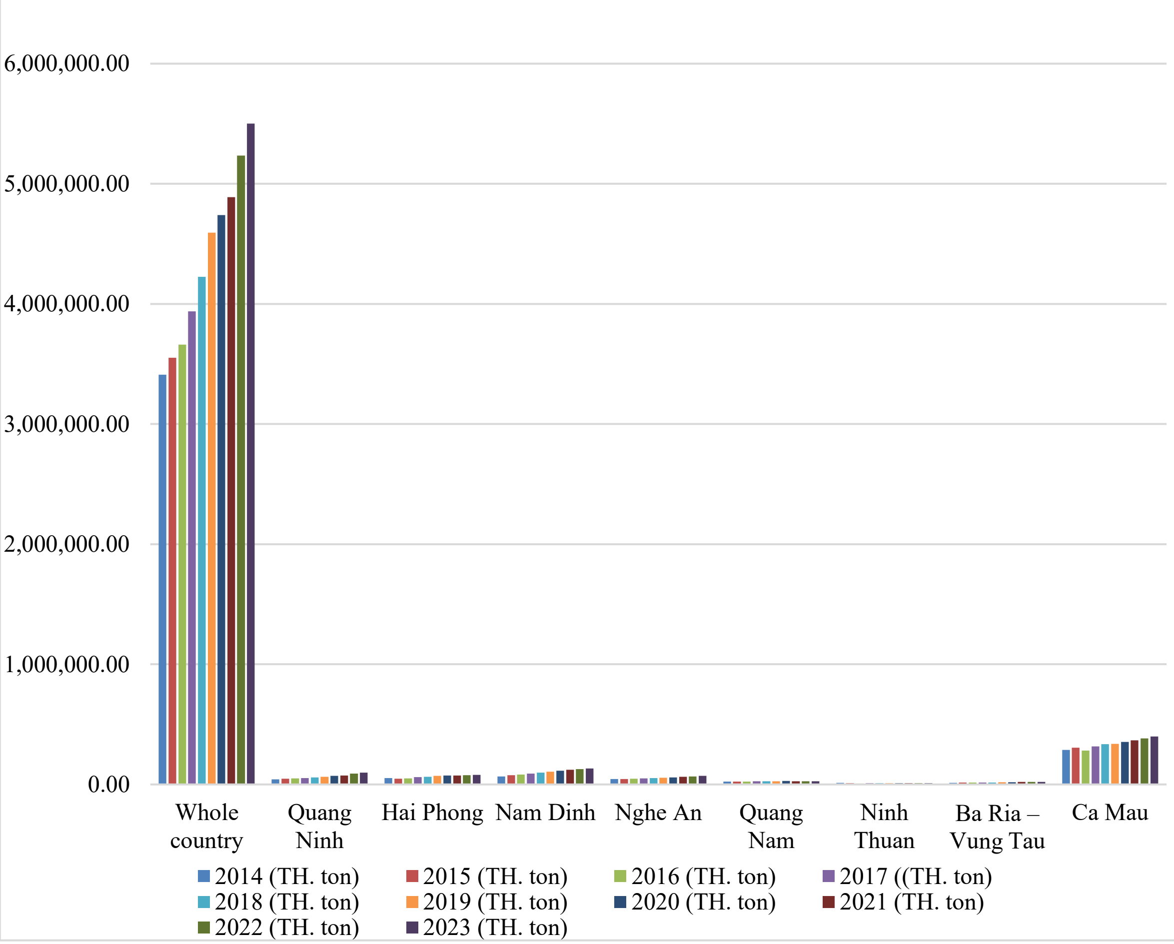
Over ten years (2014-2023), the aquaculture area increased at an average annual growth rate of 0.13%. Among the eight selected provinces, the aquaculture area expanded rapidly at a rate of 3.63% in Quang Ninh, followed by Quang Nam province with an increase of 1.89%, and Nghe An province with an increase of 0.95%. The remaining provinces experienced decreases in total aquaculture area Table (2). Looking at the whole country, the aquaculture area has expanded across all geographical regions with increasing offshore development. The expansion witnesses that the Vietnamese government has implemented effective policies and land use planning measures, especially converting ineffective rice land and other crops into aquaculture cultivation.

Table (2): Aquaculture Area of Vietnam

Location	2014 (TH.ha)	2015 (TH.ha)	2016 (TH.ha)	2017 (TH.ha)	2018 (TH.ha)	2019 (TH.ha)	2020 (TH.ha)	2021 (TH.ha)	2022 (TH.ha)	2023 (TH.ha)	Average growth rate (%)
Whole country	*1,048.9*	*1,054.5*	*1,066.6*	*1,100.6*	*1,118.0*	*1,138.0*	*1,118.3*	*1,089.5*	*1,097.7*	*1,061.3*	*100.13*
Quang Ninh	18.50	19.10	19.00	20.10	20.80	21.00	23.50	27.70	29.00	25.50	103.63
Hai Phong	12.60	12.00	12.20	13.00	13.30	12.60	11.70	10.70	11.00	8.90	96.21
Nam Dinh	15.80	16.00	15.40	15.40	15.20	15.50	15.80	14.40	14.80	14.50	99.05
Nghe An	20.20	20.60	20.70	21.10	21.40	21.40	21.50	19.00	19.70	22.00	100.95
Quang Nam	4.90	5.00	5.10	5.20	5.50	5.50	5.40	5.20	5.10	5.80	101.89
Ninh Thuan	1.30	1.20	0.90	1.20	1.20	1.10	1.00	1.00	1.00	0.80	94.75
Ba Ria – Vung Tau	7.00	6.90	6.80	6.90	6.90	6.80	6.80	6.70	6.50	6.60	99.35
Ca Mau	298.10	299.80	301.50	302.90	302.40	305.00	285.50	279.40	280.10	287.60	99.60

Source: General Statistics Office of Vietnam

During the 2014-2023 period, total aquaculture output reached 43.74 million tons, with 2023 marking the highest annual output at 5.5 million tons, representing a 61% increase compared to 2014 and an average annual growth rate of 5.46%. The Red River delta provinces (Quang Ninh, Hai Phong, and Nam Dinh) recorded faster growth rates than other regions. However, Ca Mau remains the province contributing the largest share to the nation’s total aquaculture production Figure (1). Productivity has significantly improved in the period thanks to modern techniques, particularly in large-scale industrial and semi-industrial shrimp farming systems. Implementing closed-cycle industrial farming with minimal water exchange has yielded high economic returns as well as reduced environmental pollution in several Central coastal provinces.



Note: TH denotes thousand

Figure (1): Aquaculture production of Vietnam (*Source: General Statistics Office of Vietnam*)

Even though environmental pollution and climate change have increasingly occurred in the coastal regions of Vietnam, which accommodate 50% of the national population, possess abundant natural and human resources, and serve as a center for socio-economic activities, agricultural, industrial, and other economic activities generate wastes and emissions that negatively impact on aquatic environment in the coastal regions (Hoang, 2023). The Vietnamese case demonstrated that the coastal regions produce higher levels of solid waste than inland areas (Ministry of Natural Resources and Environment [MONRE], 2021).

The coastal surface water has experienced rising pollution due to multiple factors affecting the water environment, such as hydrological features, seasonal water flow variations, and contamination from industrial facilities, small-scale production operations, agricultural activities, and household wastewater discharge. These pollutants are transported via river systems to coastal zones, where concentrations of several contaminants have been reported to exceed permissible limits by 1.5 to 3 times. Although the overall quality of coastal seawater in Vietnam remains relatively good, with most parameters falling within the regulatory thresholds outlined in QCVN 10-MT: 2015/BTNMT, there are instances, particularly during the rainy season, when the influx of organic matter, ammonium (NH_4), total suspended solids

(TSS), and other pollutants from inland sources and offshore drift contribute to elevated marine environmental risk indices. In some areas, levels of NH_4, TSS, Fe, Coliform, and $P\text{-}PO_4^{3-}$ have exceeded the QCVN 10-MT: 2015/BTNMT limits (MONRE, 2021).

According to Pham *et al*. (2016), aquaculture productivity suffers negative effects from natural disasters (typhoons and floods) and various environmental stressors. In the South-Central provinces of Vietnam, sudden changes in pH resulted in mass mortality of shrimp and fish. Hoang and Tran (2020) found that rising temperatures, increased rainfall, sea level rise, and extreme weather events have collectively led to reductions in production areas, ecological diversity, and water quality, ultimately decreasing aquaculture output in the Northern coastal region.

Influences of Environmental and Climate Factors on Aquaculture Production

In the estimated model, the P-value = 0.000 indicates that the estimated model is statistically significant at the 99% confidence level. The overall R_squared value of 0.563 means that the independent variables can explain 56.3% of the dependent variable. The model results presented in Table (3) show that the coefficients of the variables align with theoretical expectations and are consistent with findings from previous studies presented in Table (1). Specifically, dissolved oxygen (DO), production area, and sunshine hours exhibit a positive effect on aquaculture production, whereas lead (Pb), ammonium (NH_4), humidity, and temperature demonstrate a negative influence. However, the associated p-values reveal that the variables NH_4, rainfall amount, sunshine hours, and temperature do not exhibit statistically significant effects.

Table (3): Results of the Model of Environmental and Climate Factors on Aquaculture Production

Model: Fixed-effects, using 80 observations				
Included 8 cross-sectional units				
Time-series length = 10				
Dependent variable: Ln-Prod				
Rsq: Within = 0.754		Between = 0.590		Overall = 0.563
Corr (u, j, xb) = 0.000			F(2.163)	= 348.02
			Prob>F	= 0.0000
	Coefficient	Std. error	t-ratio	p-value
Const	5.63429	7.47425	0.7538	0.4542
DO	0.100843	0.0270516	3.728	0.0005***
Pb	-6.1433	9.769312	-3.042	0.0036***
NH4	-0.0786781	0.0756094	-1.041	0.3026
Ln_Area	0.301919	0.137448	2.197	0.0323**
Ln_Rain	0.0841600	0.0733002	1.148	0.2559
Ln_Water	2.34806	0.896036	2.620	0.0113**
Ln_Sun	0.366278	0.238070	1.539	0.1297
Ln_Humid	-2.55707	0.780594	-3.276	0.0018***
Ln_Temp	-0.0755309	1.39920	-0.05398	0.9571

Dissolved Oxygen (DO)

The coefficient for DO is 0.100843 with a significant p-value (0.0005), indicating that a one percent increase in DO concentration correlated with a 0.1008% increase in aquaculture output. This means that DO plays a critical role in aquaculture production. This finding aligns with Boyd & Tucker (2021), who identified DO as a primary factor in intensive aquaculture farming. In Vietnam, Mutea *et al*. (2021) also found that DO fluctuations caused the yield variations in polyculture in the Mekong Delta. The variable's high statistical significance and narrow standard error (0.0270516) underscore this relationship's robustness, allowing researchers to conclude that investments in aeration technologies yield the highest returns among aquaculture interventions.

Lead Concentration (Pb)

The coefficient for Pb is -6.1433 with a significant p-value (0.0036), showing a negative effect of Pb on aquaculture output. Similar to DO, it can be explained that an increase of lead concentration of one percent may cause a reduction of aquaculture production by 6.14 percent. This result is supported by prior findings by Authman *et al*. (2015) and Marsussen *et al*. (2007). However, most previous research conducted in Vietnam and the rest of the world did not directly show the quantitative relationships between Pb and aquaculture production. Most of them are convinced that a low level of Pb pollution caused adverse effects on fish and shrimp health and reproduction, then lowered productivity (Dave and Xiu, 1991; Devlin, 2006; Åkerblom *et al*., 2014; Tuan *et al*., 2021).

Production Area

The production area's coefficient in the model is 0.301587 with a statistically significant p-value (0.0337), indicating that a 1% increase in aquaculture area corresponds to a 0.3% increase in production. This result is relevant to Asche & Roll (2013), who found the relationships between production area and aquaculture output in Nordic aquaculture systems. Pham *et al*. (2016) indicated that medium-sized farms (from 2 to 5 hectares) achieved higher productivity per hectare than the larger farms due to more intensive management. This finding also supports Roy *et al*. (2002), who advocated for productivity intensification over spatial expansion in Vietnam.

Humidity

Humidity displays a heavy negative impact on aquaculture production, with a coefficient of -2.57708 and a highly significant p-value (0.0018). This result supports Balta *et al*. (2024)'s finding when they concluded that the higher humid was, the higher the pathogen proliferation rates were in tropical aquaculture settings. The coefficient is also associated with Maulu *et al*. (2019), who estimated significant economic losses from humidity because of disease outbreaks.

Sea level

The model shows a positive and significant effect of sea level on aquaculture production (coefficient is 2.34806, p is 0.0114). This result is supported by Wiyoto *et al*. (2022) when emphasizing the benefits of water depth stability for aquaculture, especially shrimp culture. However, the sea level's impact on aquaculture production must be interpreted carefully because moderate sea level rise may benefit in the short term. At the same time, it may damage infrastructure in the long term.

Non-significant Variables (Ammonia, Rainfall, Sunshine Hours, and Temperature): The fixed-effects model results did not show statistically significant influences of ammonia, rainfall, sunshine hours, and temperature on aquaculture output. Regarding temperature, this research result is supported by Nguyen (2015), who found that Vietnamese aquaculture mainly operates within optimal thermal ranges. The non-significance of the coefficients of the factors, especially ammonia (NH4), may be explained by good mitigating and managing practices of producers in the context of climate change (Mohamed *et al*., 2024; Vo *et al*., 2021). Moreover, Huynh and Nguyen (2019) indicated that in some coastal areas, NH4 in water was higher than the allowable threshold of 0.1 mg/L as prescribed by the Ministry of Natural Resources and Environment (standard QCVN 10-MT:2015/BTNMT). However, according to previous research, shrimp's tolerance to NH4 concentration in water is higher (Frías-Espericueta *et al*., 2000), so productivity is not strongly affected.

CONCLUSIONS

With an almost 5% GDP contribution, the aquaculture sector has been acknowledged as one of Vietnam's most important economic sectors. Aquaculture areas and production have grown in coastal regions and throughout the nation between 2014 and 2023. However, environmental pollution and climate change present many challenges for aquaculture. Aquaculture operations are impacted by climate change in several ways, including the farming environment, farming organization, infrastructure, and technical facilities. In the meantime, aquatic productivity and product quality are adversely impacted.

The relationship between environmental and climatic factors and coastal aquaculture production in Vietnam was examined using a fixed-effects model, identifying important productivity determinants. One of the key factors influencing aquaculture production is DO, whereas the most detrimental effect is Pb contamination. Production area and output have a positive correlation. Environmental factors, particularly humidity, also indicate significant effects, which exhibit a strong negative correlation. On the other hand, there was a noteworthy positive correlation with sea level. Notably, no statistically significant correlations existed between production and temperature, sunshine hours, rainfall, or ammonia.

These results offer evidence-based recommendations for operational management and policy formulation in Vietnam's coastal aquaculture industry. Significant productivity could result from giving DO management, Pb contamination prevention, ideal facility sizing, and humidity control measures top priority. Future studies should look into adaptive management techniques for the expected effects of climate change, especially concerning water levels and related environmental stressors, as well as possible synergistic effects between environmental parameters.

ACKNOWLEDGMENT

The authors express our deep thanks to Vietnam National University of Agriculture and the University of Tuscia for their spiritual encouragement in writing this paper.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

أثر المؤشرات البيئية والمناخية على إنتاج تربية الأحياء المائية في المناطق الساحلية في فيتنام

نجوين م. ن. نام 1، نجوين ب. لي2
قسم الاقتصاد والهندسة وإدارة الأعمال، جامعة توسيا، مبنى الإدارة، شارع سانتا ماريا إن جرادي رقم 4، فيتيربو 01100، إيطاليا 1
قسم الاقتصاد والسياسات الزراعية، الجامعة الوطنية للفنون الزراعية في فيتنام، قرية تراو كوي، منطقة جيا لام، هانوي، فيتنام 2

الخلاصة

يلعب قطاع تربية الاحياء المائية دورًا هامًا في التنمية الاقتصادية في فيتنام، لا سيما من حيث حجم الصادرات ودخل منتجي الاحياء المائية. ومع ذلك، تتأثر صناعة تربية الاحياء المائية في فيتنام بشدة بتغيرات المناخ وتلوث البيئة. استخدمت هذه الدراسة بيانات لوحية تم جمعها من ثماني محافظات ساحلية في الفترة من 2014 إلى 2023. وقد تم تطبيق نموذج التأثير الثابت لتحديد العلاقة بين المتغيرات المناخية (درجة الحرارة، كمية الأمطار، الرطوبة، ارتفاع مستوى سطح البحر، عدد ساعات سطوع الشمس) والعوامل البيئية (الأكسجين الذائب، تلوث الرصاص، الأمونيا) وإنتاج تربية الاحياء المائية. أظهرت النتائج وجود علاقات قوية ذات دلالة إحصائية بين بعض العوامل، مثل الأكسجين الذائب، وتلوث الرصاص، والمساحة الإنتاجية، والرطوبة، ومستوى مياه البحر، وإنتاج تربية الاحياء المائية. بينما لم تظهر عوامل أخرى، مثل الأمونيا، وكمية الأمطار، وعدد ساعات سطوع الشمس، ودرجة الحرارة، أي ارتباطات ذات دلالة إحصائية مع إنتاج تربية الاحياء المائية. تسلط هذه النتائج الضوء على ضرورة أن يولي صانعو السياسات والجهات المعنية الأخرى اهتمامًا كبيرًا لقضايا التكيف مع تغير المناخ في تخطيط وتطوير قطاع تربية الاحياء المائية، وفي الاستثمار والتحول التكنولوجي اللازمين لذلك.

الكلمات المفتاحية: تربية الاحياء المائية، المناخ، المناطق الساحلية في فيتنام، البيئة، التأثير

REFERENCES

Åkerblom, S., Bignert, A., Meili, M., Sonesten, L., & Sundbom, M. (2014). Half a century of changing mercury levels in Swedish freshwater fish. *Ambio*, *43*(Suppl 1), 91-103. https://doi.org/10.1007/s13280-014-0564-1

Asche, F., & Roll, K. H. (2013). Determinants of inefficiency in Norwegian salmon aquaculture. *Aquaculture Economics & Management,* 17(3), 300-321. https://doi.org/10.1080/13657305.2013.812154

Asian Development Bank. (2007). Climate change in Southeast Asia: Focused actions on the frontlines of climate change. *Asian Development Bank*. https://www.adb.org/sites/default/files/publication/27474/climate-change-sea.pdf

Authman, M. M., Zaki, M. S., Khallaf, E. A., & Abbas, H. H. (2015). Use of fish as bio-indicator of the effects of heavy metals pollution. *Journal of Aquaculture*

Research & Development, 6(4), 1-13. https://doi.org/10.4172/2155-9546.1000328

Balta, I., Lemon, J., Murnane, C., Pet, I., Vintila, T., McCleery, D., ... & Corcionivoschi, N. (2024). The One Health aspect of climate events with impact on foodborne pathogens transmission. *One Health*, *19*, 100926. https://doi.org/10.1016/j.onehlt.2024.100926.

Boyd, C. E., & Tucker, C. S. (2012). *Pond aquaculture water quality management*. Springer Science & Business Media. http:/Pond aquaculture water.pdf

Boyd, C. E., & Tucker, C. S. (2021). Water quality and pond soil analyses for aquaculture. *Alabama Agricultural Experiment Station*, Auburn University.

Cabello, F. C., Godfrey, H. P., Tomova, A., Ivanova, L., Dölz, H., Millanao, A., & Buschmann, A. H. (2013). Antimicrobial use in aquaculture re-examined: Its relevance to antimicrobial resistance and animal and human health. *Environmental Microbiology*, 15(7), 1917-1942. https://doi.org/10.1111/1462-2920.12134

Cassou, E., Tran, D. N., Nguyen, T. H., Dinh, T. X., Nguyen, C. V., Cao, B. T., ... & Ru, J. (2017). An overview of agricultural pollution in Vietnam: Summary Report. *Prepared for the World Bank*. https://www.sidalc.net/search/Record/dig-okr-1098629242/Description

Dang, H.D. (2020). Sustainability of the rice-shrimp farming system in Mekong Delta, Vietnam: a climate adaptive model. *Journal of Economics and Development*, *22*(1), 21-45. https://doi.org/10.1108/JED-08-2019-0027

Dave, G., & Xiu, R. (1991). Toxicity of mercury, copper, nickel, lead, and cobalt to embryos and larvae of zebrafish, Brachydanio rerio. *Archives of Environmental Contamination and Toxicology*, *21*(1), 126-134. https://doi.org/10.1007/BF01055567

Davidson, J., Good, C., Welsh, C., & Summerfelt, S. T. (2021). Comparing the effects of high vs. low nitrate on the health, performance, and welfare of juvenile rainbow trout Oncorhynchus mykiss within water recirculating aquaculture systems. *Aquacultural Engineering*, 59, 30-40. https://doi.org/10.1016/j.aquaeng.2014.01.003

Devlin. E.W. (2006). Acute toxicity, uptake and histopathology of aqueous methyl mercury to fathead minnow embryos. *Ecotoxicology, 15*, 97-110. https://doi.org/10.1007/s10646-005-0051-3

Engle, C., & Wossink, A. (2008). "Economics of aquaculture better management practices", in Tucker C.S. & Hargreaves, J.A (Eds), *Environmental Best Management Practices for Aquaculture*. Blackwell Publishing. http://ndl.ethernet.edu.et/bitstream/123456789/23305/1/36%202008.pdf

FAO. (2022). The state of world fisheries and aquaculture 2022. Towards blue transformation. *Food and Agriculture Organization of the United Nations*. https://doi.org/10.4060/cc0461en

FAO. (2023). The state of world fisheries and aquaculture 2023. *Food and Agriculture Organization of the United Nations*. http:/The state of world fisheries and aquaculture.pdf

Froehlich, H. E., Runge, C. A., Gentry, R. R., Gaines, S. D., & Halpern, B. S. (2017). Comparative terrestrial feed and land use of an aquaculture-dominant world.

Proceedings of the National Academy of Sciences, *114*(21), 5295-5300. https://doi.org/10.1073/pnas.1801692115

Frias-Espericueta, M. G., Harfush-Melendez, M., & Páez-Osuna, F. (2000). Effects of ammonia on mortality and feeding of postlarvae shrimp Litopenaeus vannamei. *Bulletin of Environmental Contamination & Toxicology*, *65*(1). https://link.springer.com/article/10.1007/s0012800100

General Statistics Office. (2023). Statistical Yearbook of Vietnam 2023. *Statistical Publishing House*. https://www.nso.gov.vn/wp-content/uploads/2024/07/NG-TCTK-2023_Final.pdf

Hoang, Nhat Thong. (2023). Environmental quality of coastal marine areas of Vietnam 2022-2023. *Ministry of Natural Resources and Environment*. https://tapchimoitruong.vn/uploads/pdf/092023/TA2-2023_63df32af.pdf

Hoang, N.K., & Tran, T.T.H. (2020). The assessment of sea–level rise impacts due to climate change on aquaculture areas in the North and Central Coast in Vietnam. *Journal of Hydrometeorology*, *715*, 68-77. https://doi.org/10.36335/VNJHM.2020(715).68-77

Huynh M. K. & Nguyen V. D. (2019). Study on total ammonium (NH4+-N) and ammonia (NH3-N) in water for shrimp breeding production in Ninh Thuan. http:/tomgiongdongthanh.vn/vi/news

Johnson, A., & Hung, P. Q. (2020). Impacts of climate change on aquaculture in Vietnam: a review of local knowledge. *Aquac. Asia Mag.*, 8-14. https://enaca.org/enclosure/?id=1089

Kadem, R. R. (2025). Level Application of growers to smart farming techniques to confront climate change. *Mesopotamia Journal of Agriculture*, *53*(1), 92-103. https://doi.org/10.33899/Mja.2025.161212.1613

Lam, P. T., Tinh, P. H., Isaac-Lam, M. F., & Dien, N. T. (2024). Economic losses and damages in aquaculture production caused by extreme weather events: an empirical assessment at the household scale in Quang Ngai province, Vietnam. *Journal of Environmental Studies and Sciences*, 1-17. https://doi.org/10.1007/s13412-024-00993-3

Luom T. Thanh, Huy B. Le, Quang M. Dinh, Hoan X. Nguyen, Hiep T. Dang, Thanh M. Le, Ngoc T. H. Dang (2022). Pollution by wastewater from aquaculture in some coastal zone in the Mekong Delta, Vietnam. *AACL Bioflux*, 15(3), 1520-1530. http://www.bioflux.com.ro/aacl

MacLeod, M. J., Hasan, M. R., Robb, D. H. F., & Mamun-Ur-Rashid, M. (2020). Quantifying greenhouse gas emissions from global aquaculture. *Scientific Reports*, *10*(1), 11679. https://doi.org/10.1038/s41598-020-68231-8

Marcussen, H., Holm, P. E., Ha, L. T., & Dalsgaard, A. (2007). Food safety aspects of toxic element accumulation in fish from wastewater-fed ponds in Hanoi, Vietnam. *Tropical Medicine & International Health*, *12*(s2), 34-39. https://doi.org/10.1111/j.1365-3156.2007.01939.x

MARD (Ministry of Agriculture and Rural Development). (2021). National aquaculture development strategy to 2030, vision to 2045. Ministry of Agriculture and Rural Development, Vietnam. https://chinhphu.vn/?pageid=27160&docid=202798&tagid=6&type=1

Maulu, S., Munganga, B. P., Hasimuna, O. J., Haambiya, L. H., & Seemani, B. (2019). A review of the science and technology developments in Zambia's aquaculture industry. *J Aquac Res Development*, *10*(567), 2. https://doi.org/10.4172/2155-9546.1000567

Miranda, C. D., Godoy, F. A., & Lee, M. R. (2018). Current status of the use of antibiotics and the antimicrobial resistance in the Chilean salmon farms. *Frontiers in Microbiology*, 9, 1284. https://doi.org/10.3389/fmicb.2018.01284

Mohamed R., de Cruz, C. R., & Prapti, D. R. (2024). The importance of ammonia removal process in aquaculture systems—towards improving malaysian aquaculture production. *Advances in Agricultural and Food Research Journal*, *5*(1). https://doi.org/10.36877/aafrj.a0000492.

MONRE (Ministry of Natural Resources and Environment). (2021). National state of environment report 2021. Ministry of Natural Resources and Environment, Vietnam. https:/vea.mae.gov.vn/Data/files/2023/03/20230217.pdf

Mutea, F.G.; Nelson, H.K.; Au, H.V.; Huynh, T.G.; Vu, U.N. (2021). Assessment of water quality for aquaculture in Hau River, Mekong Delta, Vietnam using multivariate statistical analysis. *Water*, *13*(22), 3307. https://doi.org/10.3390/w13223307

Nguyen, T. H. (2015). The optimal temperature ranges for Vietnamese aquaculture species. *Vietnam Journal of Science and Technology*, 53(4), 422-438. https://eprints.qut.edu.au/86693/4/Phuc_Nguyen_Trong_Hong_Thesis.pdf

Nguyen, T. A. T., Nguyen, K. A. T., & Jolly, C. (2019). Is super-intensification the solution to shrimp production and export sustainability? *Sustainability*, *11*(19), 5277. https://doi.org/10.3390/su11195277

Nguyen, T.Q.H., Nguyen, P. T., Nguyen, M. K., Nguyen, C.M. (2020). A study of the current situation and the socio-environmental efficiency of rice production model combined with giant freshwater prawn in Thoi Binh District, Ca Mau Province. *Journal of Science and Technology in Irrigation and Environment*, 68(2020), 19-27. http:/A Study of The Current Situation.pdf

Nofiu, B.N. & Baharudin, S. A. (2024). The vulnerability of smallholder farmers to flooding, poverty, and coping strategies: a systematic review. *Mesopotamia Journal of Agriculture*, 52(2), 1-13. https://doi.org/10.33899/MJA.2024.149253.011424

Noor, A. A, Al-Hiyali, A. D. K, & Muhammed, K. H.M. (2023). An analysis of the impact of some socio-economic variables in regulating the cultivation and marketing of the rice crop in Iraq. *Iraqi Journal of Agricultural Sciences*, *54*(1), 317-329. https://doi.org/10.36103/ijas.v54i1.1704

Nosir, W. (2023). Climate change: consequences on Iraq's environment. *Mesopotamia Journal of Agriculture*, 51(2), 131-146. https://doi.org/10.33899/MAGRJ.2023.140391.1243

Pham, Q. T., Bui, D. H., Bui, D.P.H. (2016). Factors influencing aquaculture productivity in coastal South, Vietnam. *Journal of Economic Research*, 2(453), 56-64. http:/Factors influencing aquaculture productivity.pdf

Primavera, J. H. (2006). Overcoming the impacts of aquaculture on the coastal zone. *Ocean & Coastal Management*, 49(9-10), 531-545. https://doi.org/10.1016/j.ocecoaman.2006.06.018

Richards, D. R., & Friess, D. A. (2015). Rates and drivers of mangrove deforestation in Southeast Asia, 2000-2012. *Sustainability Science*, 113(2), 344-349. https://doi.org/10.1073/pnas.1510272113

Roy, A. K., Sahoo, K. N., Saradhi, K. P., & Saha, G. S. (2002). Farm size and aquaculture productivity relationship. *Asian Fisheries Science*, 15(2002), 129-134. https://doi.org/10.33997/j.afs.2002.15.2.004

Taranger, G. L., Karlsen, Ø., Bannister, R. J., Glover, K. A., Husa, V., Karlsbakk, E., ... & Svåsand, T. (2015). Risk assessment of the environmental impact of Norwegian Atlantic salmon farming. *ICES Journal of Marine Science*, *72*(3), 997-1021. https://doi.org/10.1093/icesjms/fsu132

Tuan N. V., Thuan TT. T., Nga N. T., Chi N. Q., Tram L. N., Le T. L., Thao N. T. (2021). Effects of lead on structures of zebrafish intestine and oocytes. *Journal of Entomology and Zoology Studies,* 9(2), 127-129. https://www.entomoljournal.com/archives/2021/vol9issue2/PartB/9-2-152-915.pdf

VASEP (Vietnam Association of Seafood Exporters and Producers). (2023). Vietnam seafood export report 2022. Vietnam Association of Seafood Exporters and Producers. https://seafood.vasep.com.vn/

Vo, T. T. E., Ko, H., Huh, J. H., & Park, N. (2021). Overview of solar energy for aquaculture: The potential and future trends. *Energies*, *14*(21), 6923. https://doi.org/10.3390/en14216923

White, P. (2017). Aquaculture pollution: An overview of issues with a focus on China, Vietnam, and the Philippines. *Food and Agriculture Organization*. http:/Aquaculture pollution.org

Wiyoto, W., Hendriana, A., Siskandar, R., Mashita, N., Mahendra, T., Cahyo, A.D., Arzi, J.R.A., Aulia, S.S., & Ekasari, J. (2022). Analysis of water and sediment quality in Pacific white leg shrimp Litopenaeus vannamei culture with different sediment redox potential. *Jurnal Akuakultur Indonesia*, 21(1), 59-67. https://doi.org/10.19027/jai.21.1.59-67

World Bank. (2023). World Bank Aquaculture Report 2023. *World Bank Group*. World Bank Aquaculture Report.pdf

Yazdi, S. K., & Shakouri, B. (2010). The effects of climate change on aquaculture. International. *Journal of Environmental Science and Development*, 1(5), 378-382. https://doi.org/10.7763/IJESD.2010.V1.73

Yoo, G. Y., & Lee, J. Y. (2016). The effect of feeding frequency, water temperature, and stocking density on the growth of river puffer Takifugu obscurus reared in a zero-exchange water system. *Fisheries and Aquatic Sciences*, *19*(1), 23. https://doi.org/10.1186/s41240-016-0024-x