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An ARDL Study on Wastewater, Carbon Dioxide, and Blue Economy Impacts in Türkiye

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ABSTRACT

Pollution of water resources results in the degradation of aquatic ecosystems and poses a threat to the global Blue Economy. Water pollutants, especially in water source like oceans, seas, rivers, and lakes where aquaculture is prevalent, can lead to species alterations, reduced food quality, decreased tourism opportunities in coastal areas, reduced employment in the sector, and declining incomes. This study aims to capture the impact of municipal wastewater and carbon dioxide on income in Türkiye between 1994 and 2022 using the ARDL approach. It examines the relationship between municipal wastewater and carbon dioxide discharged into rivers, lakes, and seas, and the income generated from aquatic resources, with the objective of guiding Blue Economy policy actions. The results of the ARDL long-term estimates indicate that (i) wastewater discharged by municipalities and (ii) carbon dioxide have adverse effects on income derived from aquatic resources. In the long-term forecast, carbon dioxide is expected to cause supply shortages due to increasing pollution in seas and rivers, while in the short term, it affects resources in lakes. The findings also suggest a long-term decrease in product quantities due to wastewater in water sources. Based on these results, the study recommends changes in policies addressing factors that disrupt the aquatic ecosystem, and suggests that municipalities develop new methods to combat wastewater discharge.

Keywords: Blue economy, Wastewater, Water Pollution, Aquatic Ecosystem, Environmental Economics

JEL Classification: Q1, Q2, Q5

Türkiye'de Atıksu, Karbondioksit ve Mavi Ekonomi Etkileri Üzerine Bir ARDL Çalışması

ÖZ

Su kaynaklarındaki kirlenme su ekosisteminin bozulması ve küresel mavi ekonomiyi tehdit etmesiyle sonuçlanmaktadır. Su kirleticiler, özellikle su ürünlerinin bulunduğu okyanus, deniz, akarsu ve göl gibi su kaynaklarında bulunan türlerin değişimine, gıda kalitesinin azalmasına, kıyı bölgelerinde turizm imkânlarının daralmasına, sektördeki istihdamın azalmasına ve gelirlerde düşmeye yol açabilmektedir. Bu makale ARDL yaklaşımını kullanarak, Türkiye'deki 1994-2022 arasındaki verileri kullanarak belediyelerin atık suları ve karbondioksitin gelir üzerindeki etkisini yakalamayı amaçlamıştır. Mavi Ekonomi politika eylemlerine yön vermek için belediyelerin akarsu, göl ve denize deşarj ettiği atık su ve karbondioksit ile su ürünlerinden elde edilen gelirlerin arasındaki ilişkiyi incelemeyi amaçlamaktadır. ARDL uzun vadeli tahminlerinin sonuçları (i) belediyelerin deşarj ettiği atık suyun ve (ii) karbondioksitin su ürünlerinden elde edilen gelirlerde olumsuz etkileri olduğunu göstermektedir. Uzun dönemli tahminde karbondioksit, deniz ve akarsularda kirlenme artışı nedeniyle ürün temininde sıkıntı yaşanacağı, kısa dönemde göldeki su ürünlerinde etkili olduğu görülmüştür. Sudaki atık su nedeniyle uzun dönemde ürün miktarında azalma olacağını da göstermektedir. Sonuçlara dayanarak, su ekosistemini bozan unsurlarla ilgili politikalarda değişiklik gerektiğini önermektedir. Belediyelerin atık suyla mücadele etmesinde yeni yöntemler geliştirilmesi önerilmektedir.

Anahtar Kelimeler: Mavi Ekonomi, Atık Su, Su Kirliliği, Su Ekosistemi, Çevre Ekonomisi

JEL Sınıflandırması: Q1, Q2, Q5

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1. INTRODUCTION

Due to climate change, water resources are diminishing, and vital issues are emerging (Ritchie et al. 2024; Stringer et al. 2006). The global Blue Economy is confronted with numerous challenges, including overfishing, environmental pollution, the impacts of climate change, and the acidification of oceans (Lockerbie et al. 2024). Of the Earth's total water resources, which amount to roughly 1.4 billion km³, only about 2.5% is freshwater. Additionally, 30% of this freshwater is groundwater, while 97% of the Earth's water is saltwater (FAO, 2024). The increase in water pollution affects human health, food security, and the economy (Lu et al. 2015). Water pollution creates issues for the Blue Economy, including degradation of the aquatic ecosystem and challenges in food supply (Boelee et al. 2019; Russ et al. 2022; Troell et al. 2023; Turhan 2021). Wastewater, which is seen as an obstacle to sustainability within the Blue Economy, adversely affects food supply, employment, the tourism economy, and import-export volumes (Cochard 2017; Okuku et al. 2022; Reopanichkul et al. 2010; Satumanatpan and Pollnac 2017).

The Blue Economy is largely concerned with aquaculture and fisheries (Narwal et al. 2024). The Blue Economy is an economic model that aims to promote the sustainable use of water resources such as oceans and seas, while achieving goals like economic growth, job creation, food security, and environmental health (Setiawan & Wahyudi, 2023). In other words, it seeks to protect the environment while contributing to the economy. Water resources provide protein for billions of people and generate economic income through aquaculture and fisheries (Erüz & Erol, 2019). At the same time, it creates employment opportunities, especially in coastal regions, through renewable energy, maritime transportation, tourism, and fisheries (Rolli et al., 2024). Maritime transportation and logistics serve as significant support for exports and imports, contributing to foreign exchange earnings as a sector (Hadjimichael, 2018). Additionally, the extraction of natural gas, oil, or various minerals from the sea depends on sustainable processes. Activities in coastal regions also stimulate hotels, recreation, transportation, and other commercial operations (Siswanto & Rosdaniah, 2023). Furthermore, while the Blue Economy strives for the continuity of aquatic ecosystems, it also combats climate change. Preserving ecosystems ensures the protection of biodiversity, the environment, and the long-term economy (Malik et al., 2020). Activities within the Blue Economy interact directly with natural resources, while industrial production and urban life pose risks of pollution and resource depletion. The release of diverse pollutants into aquatic environments damages the blue ecosystem. These pollutants include oil spills, wastewater, micro plastics, non-compliance in coastal shipping, air pollution, global warming, drought, and carbon dioxide (Denchak, M. 2023; Huang, Wei, & Wang 2024; Lincoln et al. 2022; Tom et al. 2021). Although environmental policies related to fisheries contribute to sustainable development (Hamaguchi & Thakur 2024; Osmundsen et al. 2020), they are not sufficient.

Seafood provides 20% of the animal protein consumed by over three billion people, and the sector employs around 500 million individuals worldwide. Additionally, oceans absorb roughly one-third of carbon dioxide produced by human activities (Arshad, Samat, & Lee 2022; FAO 2020). Industrialization-driven pollution and resource depletion are likely to hinder a country’s economic growth, with resource depletion rates accelerating as the population increases. Numerous researchers have explored how aquatic resources influence economic growth, investigating the link between water resources and economic development (Grealis et al. 2017; Kumar Sharma et al. 2024; Yilanci, Cutcu, & Cayir 2022; Zhang et al. 2022). Empirical studies have also investigated the relationship between aquatic resources and the economy (Eyüboğlu & Akmermer 2023; Garlock et al. 2024; Li, Li, & Li 2020; Ngarava et al. 2023; Pincinato 2021; Rehman et al. 2023). Most of this research emphasizes the economic value of fisheries and aquaculture. There are few studies demonstrating the economic impact of a deteriorated aquatic ecosystem due to water pollution. The increase in water pollution has societal, environmental, and economic impacts. From a societal perspective, its negative effects on public health pose a threat to future generations. Pollution can lead to an increase in waterborne diseases, the accumulation of heavy metals, and poisoning (Lu et al., 2015; Toufique & Belton, 2014). Additionally, reduced aquaculture production due to pollution will result in a decrease in food supply. Coastal pollution, combined with unemployment, may also trigger forced migration. From an environmental perspective, water ecosystems will deteriorate. Many plants and animals may become extinct or alter their natural characteristics. Along with the threat to natural habitats, it is anticipated that global oxygen levels will decline (Diaz & Rosenberg, 2008). The relationship between water pollution and climate change is one of the most extensively studied topics (Clarke et al., 2021; Fang et al., 2021; Ho et al., 2016; Islam et al., 2020; Khalid, 2022; Ngarava et al., 2023; Oyebola & Olatunde, 2019; Stringer et al., 2021). From an economic perspective, productivity in the fishing and aquaculture sectors may decline, leading to export losses (Heneghan et al., 2023; Liu et al., 2021). Coastal regions, in particular, will lose their appeal as tourism destinations. Water pollution may result in economic contraction across all areas where water is utilized (Adam, 2021; Dodds & Holmes, 2019). Sectors such as agricultural irrigation, beverages, plant-based products, and water sports will be indirectly affected.

Although Türkiye is rich in biodiversity with its seas, lakes, and rivers, fish consumption remains below the global average. The annual per capita consumption worldwide is 22 kg, while in Türkiye it is only 7.1 kg, with variations across regions. Additionally, high prices of fishery products in Türkiye affect consumption levels. In aquaculture production, China produced approximately 66 million metric tons in 2018, whereas Türkiye produced around 312,000 metric tons (FAO 2020). However, the increasing export levels over the years indicate that aquaculture production is growing in Türkiye (TEPGE 2023), contributing more significantly to the national economy. Environmental pollution and global warming pose a threat to Turkey's future, as they do worldwide. Water pollution has various causes, and the increase in water pollution will lead to both environmental and economic challenges. The fact that even aquaculture, which is essential for food supply, contributes to water contamination highlights the need for significant measures in this area (Bergheim, Schumann, and Brinker 2019; Malik et al. 2020; Wisnu, Karuniasa, & Moersidik 2019).

In the literature, the limited number of studies may not be sufficient to comprehensively address the Blue Economy. Notable studies in this field include Suluk (2022), which examines the Blue Economy and its status in Türkiye; Tutar (2013), which analyzes water resources; Kocaman et al. (2016), which explores the impact of pollution on the agricultural sector; and Bakkal & Bakkal (2024), which investigates the macroeconomic effects of water. Other relevant works include studies on the effects of water quality in the Gulf of Gemlik (Kocaman, Akın & Oğuzhan, 2016; Suluk, 2022; Teksoy, Katip & Nalbur, 2019; Tutar, Kılıç & Aytekin, 2012). However, the short- and long-term economic impacts of water pollution in Türkiye remain unexplored.

This study investigates the environmental and economic impacts of water pollution in Türkiye. To fill this gap in the literature, this study examines the relationship between wastewater discharged by municipalities into lakes, rivers, and seas where fish and aquaculture are cultivated; carbon dioxide levels; and the income generated from fishery and aquaculture activities in Türkiye. The structure of the article is as follows: Initially, it provides an overview of the Blue Economy concept and examines how the aquatic ecosystem influences food supply, employment, and economic outcomes. Second, a review of the literature on factors disrupting the aquatic ecosystem, including studies examining the relationship between water pollution and the economy, is provided. Third, using the ARDL model, the study analyzes the relationship between municipal wastewater, carbon dioxide levels, aquaculture and fishing production, and the income generated from water resources in Türkiye from 1996 to 2022. Research findings confirm the long-term impacts of water pollution on Turkey's water resources. As supported by previous studies, the deterioration of aquatic ecosystems has detrimental effects on society, the environment, and the economy.

2. LITERATURE REVIEW

Nutrients found in aquatic ecosystems are essential for alleviating hunger, malnutrition, and poverty. The sector’s strength is further illustrated by the employment of over 61 million people globally. At the same time, studies highlight the importance of the Blue Economy (FAO, 2024). The fact that certain water bodies are shared by multiple countries underscores the importance of global policies (Preisner, Neverova-Dziopak, & Kowalewski 2020). The environmental damage caused by wastewater is frequently discussed in the literature. Many studies focus on the impact of nuclear wastewater or polluted water on fisheries. However, there is a lack of research on the impact of wastewater discharged into rivers, seas, or lakes on income.

Russ et al. (2022) investigated the global economic cost of water pollution and its impact on GDP. Their findings show that declining water quality reduces economic growth in 17 countries (Russ et al. 2022). Another study found that increased carbon dioxide levels contribute to ocean acidification, leading to ecosystem degradation (Doney et al. 2009). Additionally, water pollution leads to an increase in harmful substances in aquatic products such as oysters, which poses a health risk (Fiori et al. 2024). Since the consumption of health-threatening aquatic products is likely to decrease, this also leads to economic drawbacks.

We know that climate change negatively affects all aspects of life. Some researchers have studied the impact of climate change on fish productivity. For example, it has been noted that climate change alters marine ecosystems and may adversely affect the fishing trade. It was also found that workers in this sector face livelihood challenges (Ho et al. 2016). Fish output and carbon dioxide emissions are negatively correlated, according to an empirical study looking at how climate change affects marine fish production. Additionally, increased wind had a positive effect, while increased sunlight had a negative effect on fish production (Begum et al. 2022).

Bakun & Weeks identified that the accumulation of greenhouse gases in water bodies harms both ecosystems and sardine populations (Bakun and Weeks 2004). A study in the Eastern Tropical Pacific Ocean found that rising temperatures cause changes in fish species and lead fish to migrate to colder waters (Clarke et al. 2021). Consequently, there will be regional shifts in aquaculture production and, subsequently, economic changes. In Türkiye, sea surface temperatures have also been rising. For instance, in the Black Sea—a region with a high density of marine life—the temperature increased from 15.1°C in the 1970s to 16.3°C in the 2020s (MGM 2024).

More research in this area has been conducted recently as a result of the Blue Economy's increased attention. Studies examining the impact of water pollution on fish and other marine products have also started to appear in the literature (Alsaleh 2024). In economics, research is being conducted to measure the economic effects of water pollution. Hamaguchi (2024) examined the impact of water polluted by industry on both fishery resources and R&D-based growth. Like some other studies in this field, it has shown the adverse effects of Individual Transferable Quotas (ITQs) established to reduce the risk of resource depletion (Hamaguchi and Thakur 2024). Thus, systems intended to increase production also contribute to water pollution.

Similarly, we can say that aquaculture also increases water pollution and harms the aquatic ecosystem. For example, Alsaleh (2024) found that aquaculture negatively impacts seawater quality in the EU Region. The findings reveal the adverse effects of waste and chemicals released into the water during aquaculture (Alsaleh 2024). Toufique and Belton stressed that the desire to improve food supply sources and the falling prices for fisheries goods are the main drivers of the growth in aquaculture. According to their study, the increase in aquaculture in developing countries can actually pose a threat to their economies (Toufique and Belton 2014).

A study conducted in Sub-Saharan Africa found that greenhouse gas emissions negatively impact aquaculture (Ngarava et al. 2023). Some studies also suggest that aquaculture has the potential to adapt to climate change (Oyebola and Olatunde 2019). Researching the economic implications of aquaculture's adaptation to climate change could be necessary for future studies. Nuclear waste, one of the water pollutants, also negatively impacts the aquatic ecosystem. A study examining the effects of discharging nuclear wastewater into Japanese waters found that demand for aquatic products would decrease in the short term, while both demand and the value added by industries would decrease in the long term (Wu, Zhang, and Feng 2023). In the Chinese economy, it has been discussed that wastewater discharged into water resources could lead to water scarcity. Recommendations emphasize the importance of investments in wastewater treatment (Liu et al. 2021). Another study in China found that industrial firms' wastewater leads to high pollution levels in coastal provinces (Chen & Chen 2021).

Teodosiu et al., who investigated the environmental impacts of municipal wastewater discharge, examined wastewater discharged by a municipality in Romania. The findings discussed the risks posed to water bodies by components that cause eutrophication and other pollutants in wastewater (Teodosiu et al. 2016). Similar to this, a research conducted in Thailand looked at how seven wastewater treatment plants in a town affected the ecosystem. This study discussed efficiency-enhancing practices, such as collecting wastewater and converting it into electricity for companies (Limphitakphong, Pharino, & Kanchanapiya 2016). A study in India highlighted the importance of sanitation investments in wastewater discharge to water resources, suggesting that countries with stronger economies are better equipped to manage wastewater (Schellenberg et al. 2020). A study in Pakistan examined the economic impact of water pollution on water resources and provided recommendations (Khalid 2019). Water pollution resulting from untreated wastewater discharge adversely affects not only the aquatic ecosystem but also agriculture and dietary habits. Estimates of water scarcity in 40 countries from 1995 to 2010 concluded that new strategies are needed for managing wastewater flows (Yang et al. 2024).

The study most closely aligned with the purpose of this research was conducted in Karachi, where an average of 1,000 gallons of municipal wastewater is discharged into the sea daily. According to reports, coastal habitats and marine fisheries are both declining. Although Pakistan's fishing industry is relatively small, it significantly contributes to the national economy, and wastewater discharge is expected to negatively impact its annual growth rate (Abro, Panhwar, & Wahid 2021).

As seen, the literature is rich in studies on water pollutants, particularly within the natural sciences. However, there are fewer studies that explore the economic impact of the damage caused by pollutants to the aquatic ecosystem. No study was found that aligns precisely with the purpose of this research. The results of this study are expected to make a substantial contribution to the body of knowledge regarding the Blue Economy.

3. RESEARCH METHODOLOGY

3.1. Data

This study utilizes time series data from Türkiye covering the years 1994 to 2022. The Turkish Statistical Institute (TUIK), formerly known as (DIE), and Climate Watch provided the data. The variables included in the model are wastewater discharged into seas, rivers, and lakes, carbon dioxide emissions, aquaculture production, and income generated from aquaculture. All variables have been transformed into their natural logarithms. Table 1 gives a description of the data. Figure 1 displays the variables' time series graphs.

Table 1: Descriptions of Variables

Variables	Code	Description	Source
Sea waste	SW	Annual amount of wastewater discharged into the sea	TUİK
Lake waste	LW	Annual amount of wastewater discharged into lakes	TUİK
Stream waste	STW	Annual amount of wastewater discharged into rivers	TUİK
Carbon dioxide	COEM	CO₂ emissions per capita (metric tons)	Climate Watch
Aqua product	AP	Quantity of products obtained from fishing and aquaculture	DİE, TUİK
Income	IN	Income generated from fishing and aquaculture	DİE, TUİK

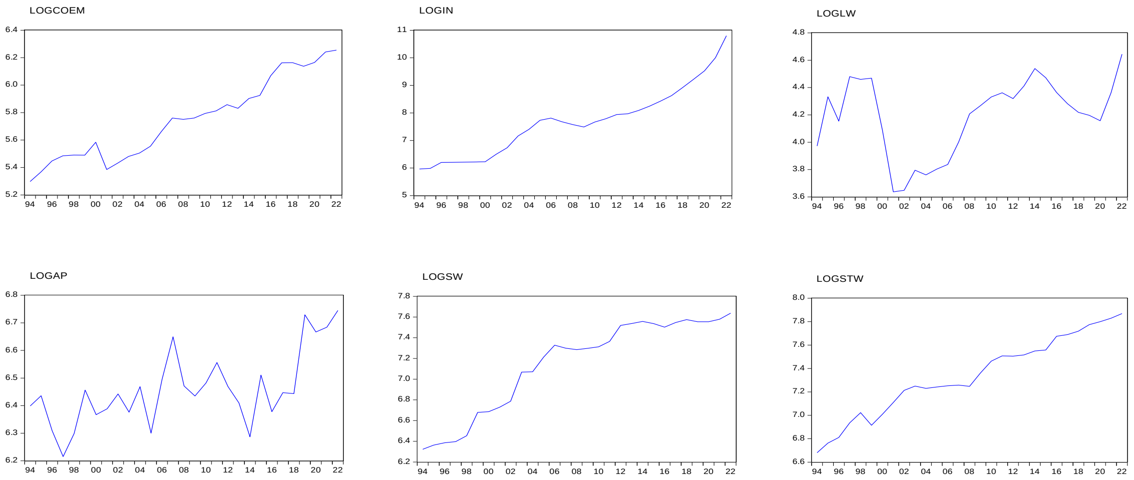

Figure 1: Trends in Data Series

In this study, aquaculture income is used as the dependent variable, while carbon dioxide emissions, wastewater discharged into the sea, lakes, and rivers, and the quantity of aquaculture production are used as independent variables. According to Figure 1, which shows the trends of the variables, carbon dioxide emissions have shown a steady increase over the years. It is noteworthy that income from aquaculture has risen rapidly since 2014. the quantity of aquaculture production has fluctuated over the years, with irregular increases and decreases, and shows a sharp rise after 2016. The amount of wastewater discharged into the sea and rivers has continuously increased over time, while in lakes, the amount of discharged wastewater was lower between 2000 and 2006.

In this study, the time series ARDL model (Pesaran, Shin, & Smith 2001) was employed and evaluated using EViews 10. The dependent and independent variables' short- and long-term relationships were investigated. An economics researcher's go-to time series model is the ARDL model (Bentzen & Engsted 2001; Hassan and Mohamed 2024; Kumar Sharma et al. 2024; Shrestha and Bhatta 2018). Both short-term and long-term coefficients are computed concurrently by ARDL. Regardless of residual correlation, endogeneity among variables can be managed using the ARDL approach (Daly et al. 2024; Setiawan & Wahyudi 2023). For small sample sizes, as in this study, ARDL provides accurate and consistent results (Li et al. 2022). However, this method also has some limitations. Since the ARDL technique limited to addresses one level of relationship, it does not allow for multiple correlations. It also assumes that the regression is linear. The choice of variables and the most appropriate lag lengths in the ARDL model can significantly affect the performance of the model (Şanlı et al. 2023). The robustness of the ARDL test results can be tested by examining scatter plots and residual plots, using tests such as the Ramsey RESET, CUSUM and CUSUM squares, DOLS or FOLMS test to test the linearity assumption and to provide robustness checks (Nkoro & Uko 2016).

3.2. Econometric Modeling

The ARDL model is used to evaluate relationships in a stepwise manner. It first investigates the possibility of a long-term link between the research variables. Every lagged dependent variable in the autoregressive (AR) model is regarded as an independent variable. The model takes into account a single variable that is assessed using the dependent variable's (lagged) value from the prior year (Pesaran et al. 2001). The quantity of independent variables that show up with multiple lags is known as the distributed lag (DL) component. Because the impact of the independent variables is dispersed over multiple time periods, it is known as a distributed lag (Eren 2023).

The Autoregressive Distributed Lag model in time series data analysis is made up of two parts: (i) the dependent variable is correlated with its prior (lagged) value through the autoregressive component (AR); (ii) the independent variable influences the dependent variable with varying lags through the distributed lag component (DL). The limits test is used in this work to investigate the long-term association between IN, COEM, AP, SW, STW, and LW. The lower limit and the upper bound are the two categories of crucial values used in the bounds test. I (0) variables utilize the lower limit critical values, and I (1) variables use the upper bound critical values (Pesaran et al. 2001).

The modeling of the impact of wastewater discharge, aquaculture production, and carbon dioxide emissions on income derived from aquaculture is conducted as follows:

$$IN_t = \beta_0 + \beta_1 STW + \beta_2 SW + \beta_2 LW + \beta_3 AP + \beta_5 COEM + \varepsilon_t \tag{1}$$

The formula that is obtained after taking the logarithm of the variables:

$$lIN_t = \beta_0 + \beta_1 lSTW_t + \beta_2 lSW_t + \beta_3 lLW_t + \beta_4 lAP_t + \beta_5 lCOEM_t + \varepsilon_t \qquad (2)$$

Variables COEMt is the logarithm of the amount of carbon dioxide at year t, APt is the logarithm of the amount of product obtained from the waters in year t, LWt is the logarithm of wastewater discharged into the lake in year t, SWt is the logarithm of wastewater discharged into the sea in year t, and STWt is the logarithm of wastewater discharged into the river in year t. Also, Ɛt is the degradation term at time t.

It is possible to estimate the ARDL model's long-run coefficient. The long-run cointegration of the ARDL equation is expressed as follows:

$$\Delta lnIN_t = \alpha_0 + \sum_{i=0}^{p} \Delta\alpha_1 lIN_{t-k} + \sum_{i=0}^{p} \Delta\alpha_2 lSTW_{t-k} + \sum_{i=0}^{p} \Delta\alpha_3 lSW_{t-k} + \sum_{i=0}^{p} \Delta\alpha_4 lLW_{t-k} + \sum_{i=0}^{p} \Delta\alpha_5 lAP_{t-k} + \sum_{i=0}^{p} \Delta\alpha_6 lCOEM_{t-k} + \beta_1 lIN_{t-1} + \beta_2 lSTW_{t-1} + \beta_3 lSW_{t-1} + \beta_4 lLW_{t-1} + \beta_5 lAP_{t-1} + \beta_6 lCOEM_{t-1} + ECT_{t-1} + \varepsilon_t$$

(3)

p is the number of lags, Δ is the first difference, ECTt-1 is the error correction term, εt is the error term, α0 is the constant, α1 is the coefficient of the short-term variables, and β1 is the coefficient of the long-term variables.

If the calculated F-statistic exceeds the upper bound, the null hypothesis of no cointegration is rejected, confirming evidence of a long-term cointegration relationship among the variables. If the calculated F-statistic is below the lower bound, indicating no long-term relationship among the variables, we fail to reject the null hypothesis of no cointegration.

$H_0 = \beta_0 = \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$ There is no cointegration among the variables. Stated differently, it is impossible to deny the existence of cointegration.

$H1 = \beta_0 \neq \beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq 0$ The variables exhibit cointegration. This indicates that it is impossible to deny the presence of cointegration.

4. EMPIRICAL FINDINGS

4.1. Descriptive Statistics

The raw annual time series data for the 29-year period from 1994 to 2022 is included in the summary statistics. It's crucial to summarize the raw data while discussing data processing because using unprocessed data can produce inconsistent and erroneous findings. The results provide an overview of all variables' descriptive summaries. This table shows the mean, median, maximum, minimum values, skewness, and kurtosis statistics. According to the table, IN has the highest mean (10.7) among the variables, while AP has the lowest mean (3.6). All variables show consistent performance, as evidenced by the fact that their standard deviations are smaller than their mean values. Furthermore, the skewness values fall within the range of +1 and -1. AP, STW, and LW have long left-tail distributions (negative skewness), whereas COEM, IN, and SW have long right-tail distributions (positive skewness), according to the skewness results. The data are regularly distributed, according to the Jarque-Bera results. A normal distribution is also supported by the probability values.

Table 2: Descriptive Statistics

	lIN	**lCOEM**	**lAP**	**lSW**	**lSTW**	**lLW**
Mean	7.667227	5.750572	4.192177	6.459149	7.142785	7.336033
Median	7.679212	5.759845	4.266840	6.443544	7.298768	7.257421
Maximum	10.79916	6.254694	4.644025	6.745010	7.637437	7.868823
Minimum	5.966008	5.297817	3.636823	6.215128	6.322407	6.680238
Std. Dev.	1.250248	0.294389	0.277778	0.133158	0.450497	0.338799
Skewness	0.552129	0.283991	-0.581314	0.579734	-0.675439	-0.193371
Kurtosis	2.857729	1.820693	2.300722	2.856687	1.938699	2.052397
Jarque-Bera	1.497883	2.070319	2.224175	1.649259	3.566071	1.265754
Probablity	0.472867	0.355170	0.328872	0.438397	0.168127	0.531062
Sum	222.3496	166.7666	121.5731	187.3153	207.1408	212.7450
Sum Sq. Dev.	43.76737	2.426612	2.160497	0.496471	5.682530	3.213979

IN, income, COEM, carbon dioxide, AP, aqua production, SW, wastewater in the sea, STW wastewater in the river, LW, wastewater in the lake.

4.2. Unit Root and Cointegration Results

The stationarity of the variables must be established prior to testing the ARDL model. With a constant mean, variance, and auto covariance at different lags, stationarity suggests that the series converges to a specific value over time. A time series is referred to as stationary if it lacks a unit root and is thought to have constant variance, covariance, and mean. To check for stationarity, a number of techniques and assessments have been created. The ADF (Augmented Dickey-Fuller) and PP (Phillips-Perron) tests, two of the most widely utilized techniques, were used in this investigation. The alternative hypothesis verifies that there isn't a unit root in both tests, although the null hypothesis suggests that there is. Stated differently, the data is stationary and the null hypothesis is rejected if the variable's t-statistic is greater than the crucial t-value. The data is non-stationary if the null hypothesis cannot be rejected.

Table 3 shows the integration levels at the level (I (0)) and first difference (I (1)) levels. The results indicate that all variables are non-stationary at level, so the null hypothesis H0 cannot be rejected, confirming the presence of unit roots in the variables. After taking the first differences of the variables, the same tests were conducted again. The results rejected the null hypothesis H0 and accepted the alternative hypothesis H1, indicating that the variables are stationary. According to the results, the STW and AP variables are stationary at level (I (0)), while all variables are stationary at the first difference (I (1)). Therefore, the presence of both level and first-difference stationary variables allows us to proceed with the ARDL test for further analysis.

Table 3: Variables' Unit Root Test Results

	Variables	**ADF**		**PP**	
		Intercept	Trend and intercept	Intercept	Trend and intercept
Level	AP	-2.1	-3.4	-2.1	-3.4
	COEM	-0.2	-2.2	-0.1	-2.2
	SW	-1.7	-0.9	-1.9	-0.9
	LW	-1.3	-5.4**	-1.6	-1.6
	STW	-1.2	-3.7*	-2.1	-4.3**
	IN	1.3	-0.3	1.9	-0.0
1st difference	AP	-7.0**	-7.1**	-8.9**	-10.9**
	COEM	-5.6*	-5.5*	-5.6**	-5.8**
	SW	-4.8**	-5.3**	-4.8**	-5.3**
	LW	-2.4	-4.2**	-4.2**	-4.2**
	STW	-5.0**	-4.9**	-5.9**	-6.0**
	IN	-5.2***	-5.6***	5.2***	-5.5***

*Null Hypothesis: There is a unit root in the variable. The Phillips-Perron Unit Root Test (PP) and the Augmented Dickey-Fuller Unit Root Test (ADF). ***, **, and * at the statistical significance levels of 1%, 5%, and 10%, respectively.*

The findings of the ADF and PP unit root tests may be deceptive because they are not designed to take structural breakdowns into consideration. Consequently, the Zivot-Andrews (ZA) unit root test was also used, which takes into account structural breakdowns in the variables (Zivot & Andrews 2002). There was no structural fracture discovered. The t-statistic's absolute value was below all critical values for every variable. Since the unit roots of the variables are non-stationary, the null hypothesis H_0 was accepted for all variables. The same tests were run again after the initial differences between the variables were determined. The alternative hypothesis H_1 is accepted and the null hypothesis H_0 is rejected based on the data, which show that the first differences of all variables are stationary.

We examined the long-term cointegration between the variables after verifying the data's stationarity. The long-term relationship was shown using an ARDL technique and a limits test at the 10% significance level. The ARDL (Auto-regressive Distributed Lag) method was developed by M. Hashem Pesaran, Yongcheol Shin, and Richard J. Smith (2001). When the independent and dependent variables are stationary at the level or first difference, the ARDL approach can be used. The general model is used as the starting point for the ARDL model, and then a cointegration test is examined using an error correction term model (Pesaran et al. 2001).

To illustrate the long-term association, an ARDL technique was used with a limits test at the 10% significance level. A long-term cointegration between the variables is demonstrated by the F-statistic results, which reveal a value of 11.12913 that is higher than the critical values at 10%, 5%, 2.5%, and 1%. According to the test results, the F-value (5.90601) is greater than the upper bound value (6.04) and corresponds to a statistical significance level of 1%. Therefore, it is possible to reject the null hypothesis (H_0) and accept the alternative hypothesis (H_1). According to the F-bounds test result, the model is symmetrically/linearly cointegrated at the 1% significance level (Table 4). As a result, we can say that the variables have long-term cointegration. Aquaculture production, carbon dioxide emissions, and wastewater released into rivers, lakes, and seas are all correlated over the long term with income from aquaculture (IN).

Table 4: Results of the Co-Integration Test

Co-integration test	**Value**	***K***
F-statistics	11.12913	
Significance	At 1(0)	At 1(1)
At 10%	2.508	3.763
At 5%	3.037	4.443
At 1%	4.257	6.04

4.3. Long-Term and Short-Term Estimates of the ARDL Model

Finding the ideal lag duration is the first stage in the ARDL modeling procedure. The model with the lowest value among information criteria like AIC, SIC, and HQ is chosen at this point after the variables are evaluated with various lag combinations (Liew 2004). Since the data in the model are annual, the optimal lag length was determined to be 2, and the most suitable model was identified as ARDL (1,0,1,0,1,0). Twenty-eight observations remained after deducting the maximum lag duration. Following that, the ARDL model's short- and long-term estimates were assessed. The independent variables' short- and long-term regression analyses on aquaculture revenue are displayed in Table 5.

Table 5 presents the short- and long-term regression estimation analysis, demonstrating that wastewater discharged into water bodies, carbon dioxide emissions, and aquaculture production have a long-term effect on income generated from these products. According to the results, the amount of wastewater discharged into lakes and the quantity of aquaculture production have no effect in the long term. Wastewater discharged into the sea has a negative effect on income at a significance level of 1%, with a coefficient of -1.09. A 1% increase in wastewater discharged into rivers also has a negative effect with a coefficient of -0.89. At the 10% significance level, a 1% increase in wastewater discharged into lakes has a negative effect of -0.26. Additionally, a 1% increase in carbon dioxide emissions has a negative effect with a coefficient of -0.84 at the 5% significance level.

Table 5: ARDL Model Estimation in The Short and Long Term (1, 0, 1, 0, 1, 0)

Variables	**Coefficient**	**Std. error**	**t-statistics**	**Probab.**
Long-run				
lnLW	-0.269019*	0.141265	-1.904363	0.0721
lnAP	-0.276269	0.245799	-1.123962	0.2750
lnSW	-1.091966***	0.310900	-3.512277	0.0023
lnSTW	-0.894106***	0.284355	3.144334	0.0053
lnCOEM	-0.847774**	0.386675	-2.192473	0.0410
C	3.013025	2.420475	1.244808	0.2283
Short-run				
D(lnLW)	-0.269019**	0.106894	-2.516696	0.0210
D(lnSW)	0.313955	0.250258	1.254527	0.2249
C	3.013025	0.312845	9.631061	0.0000
CointEq(-1)*	0.379242	0.041293	9.184068	0.0000
R^2	0.994563			
Adjusted R-squared	0.992274			

Probably (F-statistic)	0.000000

*The significance levels for 1%, 5%, and 10% are indicated by the symbols ***, **, and *, respectively.*

Aquaculture was found to be negatively impacted in the near term by the quantity of wastewater released into lakes. A 1% increase in wastewater released into lakes results in a 0.26% decrease in income at a 5% significance level.

The estimation results show a p-value of 0.0000 and an error correction term coefficient of 0.37. This coefficient is statistically significant because the p-value is less than 0.05. Furthermore, the "C" coefficient is positive and statistically significant. Aquaculture was found to be negatively impacted in the near term by the quantity of wastewater released into lakes.

Table 6: Model Diagnostic Tests

Type of tests	***F*-statistics**	**Probab.**	**Comment**
Breusch-Godfrey Serial Correlation LM Test	3.048195	0.0739	No serial correlation exists
Heteroscedasticity Test: Breusch-Pagan-Godfrey	1.572216	0.770	No heteroscedasticity exists
Normality test	2.898307	0.9327	Residuals are normally distributed
Cumulative Sum of Recursive Residuals (CUSUM) Test	Stable		The ARDL model is stable
Cumulative Sum of Square Recursive Residuals (CUSUM square) Test	Stable		The ARDL model is stable

The ARDL model was subjected to the CUSUM and CUSUM-SQ tests. It is evident from looking at Figure 2 that the model does not have any structural breaks. Over time, both tests stay within the 5% significance level, demonstrating the ARDL model's stability. The blue line is seen to remain inside the 5% significance level, which is represented by the red line.

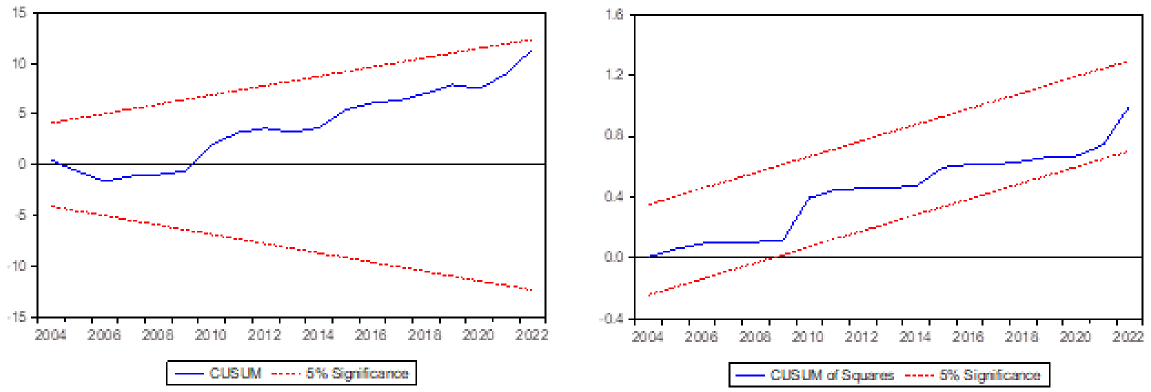

Figure 2: CUSUM and CUSUM of squares

Lastly, the estimated parameters of the ARDL approach were validated using the Fully Modified Ordinary Least Squares (FMOLS) method. According to the FMOLS estimated results, there is a negative and significant correlation between the amount of aquaculture production, the amount of wastewater released into rivers and the sea, and the revenue from aquaculture.

Table 7: FMOLS Estimation Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
lnCOEM	-0.733176	0.799420	-0.917136	0.4011
lnSW	-1.294500***	0.248683	-5.205414	0.0035
lnSTW	-4.817150***	0.792075	6.081681	0.0017
lnLW	-0.242902	0.192470	-1.262025	0.2626
lnAP	2.230743**	0.577340	3.863827	0.0118
C	-27.36650***	2.975451	-9.197427	0.0003

*The significance levels at 10%, 5%, and 1% are shown by the symbols *, **, and ***, respectively. The t-statistics are indicated by the values in parenthesis.*

5. DISCUSSION AND CONCLUSION

Coastal countries enjoy a significant advantage over inland nations due to their proximity to seas and oceans. The sustainability of economic activities in water resources such as sea and ocean is the Blue Economy. Türkiye, with its 8,333 km coastline, numerous rivers flowing into the sea, and diverse aquatic life in its natural lakes, is well-positioned to pursue the objectives and practices of the Blue Economy. Furthermore, Türkiye ranks among the top 10 countries in fish farming (FAO, 2020).

However, wastewater discharged by municipalities is harming aquatic ecosystems, leading to health, food security, and economic problems. This study investigates the impact of municipal wastewater, carbon dioxide levels, and aquatic product quantities on revenue in Türkiye's water bodies. The findings indicate that wastewater, a major obstacle to sustainability in the Blue Economy, has short-term and long-term effects on food supply, employment, tourism economies, and import-export volumes. Employing an ARDL approach, the study analyzed data spanning from 1996 to 2022 to examine the long-term and short-term impacts of wastewater, carbon dioxide, and aquatic product quantities on revenue. One limitation of the study is the reliance on municipal wastewater data from the Turkish Statistical Institute (TÜİK), which may not account for wastewater from unregistered municipalities, potentially underestimating the total discharge. Despite this limitation, the results are significant. Another limitation is the exclusive focus on wastewater and carbon dioxide, excluding other water pollutants such as solid waste and industrial waste. There is no data available on the quantities of solid waste identified at the annual level. Since data prior to 2000 could not be accessed for industrial waste within the determined date range, it was not included in the model. On the other hand, it is intended to draw attention to the increase in wastewater quantities, especially by municipalities. Additionally, this study focuses solely on the amount of polluted water and carbon dioxide affecting the aquatic ecosystem within the context of the Blue Economy. Future research exploring the impact of climate change on Türkiye's economy could provide a broader perspective.

Long-term results show a negative impact on revenue, with coefficients of -0.26 for lakes, -1.09 for seas, and -0.89 for rivers. Similarly, carbon dioxide levels have a negative impact with coefficients of -0.84, and production quantity has a negative coefficient of -0.27. Short-term forecasts indicate that only wastewater in lakes reduces revenue.

Based on these findings, it can be concluded that municipal wastewater and carbon dioxide discharged into Türkiye's seas, rivers, and lakes will decrease revenue from aquatic products (Almafrachi, Gümüş, & Çorak Öcal 2024). The decline in revenue will lead to economic contraction and job losses. Moreover, increasing pollution in coastal regions will negatively impact both the tourism economy and the quality of life in these areas. Additionally, the decrease in aquatic products and the consumption of unhealthy species pose significant risks (Heneghan et al. 2023; Motivarash et al. 2024; Pandion et al. 2022). Beyond municipal wastewater, other pollutants and global warming necessitate new measures for Türkiye's Blue Economy (Cheung, Palacios-Abrantes, & Roberts 2024).

All countries are striving to reduce increasing water pollution. However, for various reasons, the desired outcomes have not yet been achieved. Some countries' efforts in this regard are noteworthy. Germany, for instance, enforces strict measures in controlling and recycling industrial waste (Erişen, D., 2019; Frank, 1998). Similarly, Denmark has implemented measures to tackle water pollution caused by agriculture (Marc, 2014). In the Netherlands, practices aimed at preserving water quality are actively applied (ABECE, 2024). These efforts reflect societal and industrial commitments across countries. Initiatives such as raising public awareness, keeping coastal areas clean, establishing waste collection centers, and implementing waste segregation are being carried out. On the other hand, wastewater treatment plants remain one of the most commonly applied solutions. Measures such as controlling and recycling industrial waste, enforcing mandatory regulations on water resources, reducing microplastics, pharmaceutical residues, and agricultural chemicals, minimizing waste in aquaculture, and protecting water bodies are being taken (Inyinbor et al., 2018; Okuku et al., 2022; Singh, 2019; Thyagaraju, 2016).

The findings of this research also offer several policy implications. First and foremost, it is essential for the government and the aquaculture sector to collaborate with all stakeholders, including NGOs, aquaculture producers, and public and private sectors, to implement consistent policies to combat the deterioration of the aquatic ecosystem (UNCTAD, 2018). Evaluating successful practices from other countries in the context of Türkiye is also crucial. Furthermore, it would be beneficial for the government to develop more projects, applications, and strategies to invest in the Blue Economy.

Research and Publication Ethics Statement

This study was conducted in compliance with the principles of scientific research and publication ethics.

Conflict of Interest Statement

There are no conflicts of interest associated with this study, either from the authors or from third parties.

Data availability

Upon reasonable request, the corresponding author can provide access to the datasets used and/or analyzed in this study.

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