Ecological Indicators 155 (2023) 110992

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Nexus between trade, industrialization, and marine pollution: A quantile regression approach

Irfan Ullah [a,*], Florian Marcel Nuta [b], Dimen Levente [c,*], Bian Yiyu [a], Zhou Yihan [a], Chen Yi [a], Muhammad Haroon Shah [d], Rupesh Kumar [e]

[a] Reading Academy, Nanjing University of Information Science and Technology, Nanjing 210044, China
[b] Faculty of Economic Sciences and Business Administration, Danubius University of Galati, 800654, Romania
[c] Faculty of Computer Science and Engineering, 1 Decembrie 1918, University of Alba, Iulia 510009, Romania
[d] School of Business, Hohai University, Nanjing 210098, China
[e] Jindal Global Business School (JGBS), O P Jindal Global University, Sonipat 131001, Haryana, India

ARTICLE INFO

Keywords:
Trade
Industrialization
Heavy water pollution
Marine Pollutions
Time Series Analysis

ABSTRACT

In the recent decades, developing nations aim to industrialize and grow sustainably often ignoring the environmental consequences. However, few empirical studies have looked at the influence of industrialization-driven economic transition on marine pollution, in particular post trade openness. This paper analyzes the nexus between trade openness, industrialization, and marine pollution. The study uses time series data (1995–2022) and applies quantile regression to analyze the impact of trade openness and industrialization on marine pollution. The finding of this study suggested that trade openness and industrialization have a significant positive impact on marine pollution. Trade activities and rapid transition towards industrialization enforced large industrial inputs resulting marine pollution. In general, industrial wastewater contains heavy metals, organic compounds, and toxic chemicals, and causes marine pollution and disturb the marine life if not treated properly. Thus, improper waste management and mitigation leads to marine pollution. Therefore, implications of strategic policy that integrates trade, industrialization, and environmental is of prime concern and need to be address for effective marine pollution mitigation and control. To minimize the environmental effects of trade and industrial operations, developed and developing nations should promote sustainable industrial practices and enforced stricter regulations in international trade.

1. Introduction

The world has gradually adopted globalization in the last few decades, which brings substantial advancements in developed and developing countries through the efficient reallocation of scarce resources, particularly in international trade and industrial production (Narlikar, 2005). Globalization has benefited developed and developing nations due to their industrial production expansion and technological advancements, which contributed to economic growth, job creation, and living standards. Despite the positive aspect, industrial production expansion is the primary source of energy consumption and waste (Li et al., 2015; Sadorsky, 2014). Industrial waste includes various forms, such as solid waste, wastewater, hazardous materials, and air emissions. Industrial production expansion is considered the main factor of waste generation driven by domestic and international demand (Liu et al., 2022; Zhang et al., 2021). Global supply chains that operate across national borders can generate more waste due to their complexity and fragmentation (Barik, 2018; Misra and Pandey, 2005). Production in different stages may result in the generation of waste materials at various points in the supply chain, which can include unused materials, packaging waste, and end-of-life products. The management of industrial waste gets more complicated with international trade (Jacobs et al., 2022). It is possible for waste generated in one country to be transported or exported to another country for treatment or disposal (Mukherjee et al., 2004). A number of challenges may arise for waste management, including the logistics of waste transportation, the availability of proper treatment facilities, and the adherence to local environmental regulations. Industrial waste has influenced trade policies because of environmental concerns. Several countries have implemented stricter regulations regarding waste management and disposal. Trade flows may

* Corresponding authors.
E-mail addresses: irfanecon@nuist.edu.cn (I. Ullah), floriann@univ-danubius.ro (F.M. Nuta), ldimen@uab.ro (D. Levente).

https://doi.org/10.1016/j.ecolind.2023.110992
Received 27 June 2023; Received in revised form 20 August 2023; Accepted 10 September 2023
Available online 28 September 2023

be affected by these regulations by requiring specific waste management practices or restricting the import or export of waste materials (Ilankoon et al., 2018). Industries are adopting sustainable production practices to minimize waste and environmental concerns. It involves adopting cleaner technologies, reducing waste, and promoting circular economy principles (Sharma et al., 2023; Verma, 2014). The use of sustainable production practices can help reduce waste, maximize resource efficiency, and manage industrial waste responsibly.

Trade stimulates each section of the economy; especially the industrial section has dramatically expanded; in addition, the trade also expands the agriculture section, especially both in industrialized and non-industrialized nations. There has been a significant impact of industrialization on marine pollution. Industrial activities, particularly in manufacturing, transportation, energy production, and mining, have contributed to various forms of pollution in marine ecosystems (Mejjad et al., 2023). Since it is common for industrial processes to release chemical pollutants into the environment via various pathways, such as direct discharge into water bodies or runoff from industrial sites. Many types of chemicals include heavy metals, toxic substances, pesticides, and industrial effluents (Garg et al., 2022). The improper disposal of industrial waste can also contribute to marine pollution, mainly if it contains hazardous or non-biodegradable materials. It is possible for industrial activities, especially those in the oil and gas sector, to cause accidental spills of oils and chemicals into marine environments (Zhang et al., 2019). An oil spill can devastate marine ecosystems, destroying aquatic organisms, habitats, and the overall balance of an ecosystem (Kaiser, 2023; Kennish, 1991; Thakur and Koul, 2022). Besides contaminating water, chemical spills can also harm marine life. In marine ecosystems, eutrophication can be caused by industrial processes, including agriculture and wastewater discharge. The excessive use of fertile nutrients, such as nitrogen and phosphorus, can cause algal blooms and oxygen depletion, negatively affecting marine life (Koul et al., 2022). Infrastructure, like ports and coastal developments, is built with industrialization, which can destroy or alter habitats. Marine ecosystems can be negatively impacted when critical habitats like coral reefs, mangroves, and seagrass beds are lost (Fanning et al., 2021; Nagelkerken et al., 2002). Emissions of greenhouse gases from industrial activities, mainly burning fossil fuels, contribute to climate change. Climate change significantly impacts marine ecosystems, like sea level rise, rising sea temperatures, and ocean acidification (Guinotte & Fabry, 2008; Hoegh-Guldberg et al., 2007). In addition, these changes can hurt coral reefs, affect the distribution of marine species, and disrupt the delicate balance of marine ecosystems. Industrial activities are closely associated with plastic production, use, and disposal. It is possible to pollute marine environments with plastic due to improper waste management and insufficient recycling practices (Ambrières, 2019; Rajmohan et al., 2019). A significant threat to marine organisms and ecosystems arises when plastics are broken down into microplastics, which can be ingested or accumulate in food chains (Waring et al., 2018).

The impact of industrialization on marine plastic pollution has become a major environmental and economic concern. In recent years, plastic products have increased due to industrial production expansion. Over 8.3 billion tons of new plastic were produced between 1950 and 2015, half of which was produced after 2004 (Mortillaro, 2017). Although eutrophication, oil spills, heavy metal deposition, and solid waste disrupt Marine biota, plastic debris is responsible for 60 to 95 % of all Marine debris, from surface to deep-sea sediment (Guern, 2018). According to the Ocean Conservancy, 150 million tons (Mt) of plastic are seeping into the ocean (OECD, 2022). WWF report suggests that plastic waste in the global Marine environment will reach 300 Mt by 2030 (Sexton, 2019). The increasing demand for plastic materials in industrial society, and improper management of plastic waste, have led to the gradual accumulation of plastic in the Marine ecosystem, which has caused negative socio-economic impacts on the marine environment (Diggle and Walker, 2022).

Marine pollution is a serious issue that needs to be addressed. The wellbeing of both people and the world depends on the health of oceans and marine ecosystems. Pollution-induced degradation of marine ecosystems poses a serious threat to human health, ecosystem services, biodiversity, and sea-dependent economic activity. international trade openness enlarges the industrial production, sea shipment, resource extraction, manufacturing, and transportation operations have all increased. These procedures contribute to the production of waste and contaminants, some of which end up in the oceans and cause marine pollution. Therefore, it is worthwhile to explore the nexuses between trade openness, industrialization, and marine pollution in the world; this study may provide insight into how industrial activities and trade patterns contribute to marine pollution. Understanding marine environments is essential to develop effective strategies and policies for mitigation and prevention of further degradation. This paper sheds light on the specific phenomena through which industrial activities and international trade contribute to marine pollution. Firstly, it provides insights into the processes, drivers, and impacts of marine pollution arising from trade and industrialization, which can guide policymakers and stakeholders in formulating targeted interventions and policies to mitigate and prevent such pollution. Secondly, this study uses quantile regression techniques to better capture dynamics, heterogeneity, and outliers in time series data. The results obtained through this approach are more robust and insightful, enabling policy recommendations tailored to specific quantiles and time periods to be more effective. Thirdly, considering ocean pollution data at the global level, this study provides a global perspective on the issue. The problem of marine pollution affects all countries, regardless of their development level. It is necessary to understand the global scope of the issue to develop comprehensive policy recommendations that will address transboundary pollution, conservation efforts, and sustainable management of marine resources. Fourthly the study uses micro and macro plastic proxy variable that could help to capture more plastic pollution sources, distribution patterns, and ecosystem effects by including micro and macro plastic variables. This comprehensive approach can improve the study's accuracy and robustness in drawing meaningful conclusions and statistically significant inferences.

2. Literature review

Trade, industrialization, and pollution have been extensively discussed in the literature. However, less attention has been given to trade and marine pollution. This research attempts to identify the implications of international trade and industrialization on marine pollution. Hakimi and Hamdi (2016) and Shahbaz et al. (2013) reported that international trade increases the energy energy-intensive industries, which is a potential source of exponential growth in energy consumption, discharge of pollutants and environmental degradation, triggering the rise in the vulnerability of the ecosystem. Hakimi and Hamdi (2016) and Lopez (1997) pointed out that international trade stimulates foreign direct investment in energy-intensive activities, especially in manufacturing and transportation sectors, which discharge higher amounts of air pollution. Mignamissi et al. (2022) suggest that trade openness is a crucial factor in determining industrialization and economic growth in Africa. This implies that trade and industrialization is complements factor responsible for the pollution in the environment. However, these polluting effects are perceived as direct and indirect effects of trade, which promotes industrialization.

Sbia et al. (2014) found that Trade openness has led to the introduction of advanced and environmentally friendly technologies that place of out-of-date machines that burn fossil fuels and eventually emit air and water pollutants. Most efforts of previous studies were focused on the air pollutants, such as carbon dioxide and $PM_{2.5}$, produced by industrialization, which possibly simulated by international trade. However, few studies have considered other possible forms of pollution, including soil contamination and water pollution. Liu et al. (2022)

analyzed the relationship between plastic pollution and trade openness from 2000 to 2020. They used complex networks, regression analysis, and link prediction methods to establish the Global Plastic Waste Trade Network (GPWTN), which was a useful method for predicting the trend of trade and global pattern. Their finding indicated that plastic pollution had been disposed of in 21st century by both low- and high-income countries. Trade brings development and raises the income of most countries, despite the fact trade is also responsible for pollution in society. Many countries both in Asia, Africa, and Latin America gradually move towards free trade. These economies gain significant development goals however would bear a greater risk of plastic pollution. In addition, some developed countries such as “Germany, England, Singapore, Switzerland and USA” have established a relatively mature pollution recycling system which helped to alleviate the pollution problem.

Liu et al. (2022) studied the relationship between ocean pollution, trade and the marine fishery economy. They applied a simultaneous equation model for the analysis. They found that marine pollution has a negative effect on fisheries industries. They found that trade may affect marine pollution by increasing the demand for the increasing demand for aquatic products in the world market. In addition, the problem of overexploitation in the development of the economy led to serious pollution and adversely impacted trade growth. They suggested that environmentally friendly technology improved marine pollution and achieved low pollution production. Furthermore, they recommend that monitoring and management of marine pollution may reduce marine pollution. Wan et al. (2022) examined the influence of accidents on marine pollution and the relationship between trade and accidents. They reported that the frequency of container ship accidents has increased due to the global maritime trade, which is also one of the causes of marine pollution. In addition, they claimed that the number of containers increased post-trade liberalization in many countries, and the ratio of accidents also rose. Since the outbreak of COVID-19, the growth of the global economy has slowed down, and seaborne trade decreased to some extent. However, marine pollution did not decline. Sources of marine pollution resulting from the container ship accidents included heavy metal, plastic fibers, leaked fuel, HNSs and container box. Maritime trade is an indispensable part of global trade. The development of seaborne trade leads to more possibilities of container ship accidents. They suggest more safety measures to lower ocean container accidents. Yu et al. (2020) analyzed the evolution trend of heavy metal pollution in Fangcheng Bay, South China, since the 1970s. Metal concentration curves were plotted on three sediment cores of 210pb age, reflecting local urbanization and industrialization. The finding concluded that the accumulation of metal in Fangcheng Bay is mainly due to the rapid development of industrialization. Meanwhile, the growth rate of metal accumulation in the east and west of Fangcheng Bay is different, which primarily resulted in urbanization expansion in the east and west.

Zheng et al. (2020) explored the relationship between economic growth and marine pollution in China’s coastal provinces and cities. They applied the nonlinear Markov switch model for data estimations. In addition, the change frequency is different in different regions; some regions have more ordinary changes, while others tend to be stable. Finally, the results conclude that marine pollution has significantly increased with economic growth. Schmid et al. (2021) critically analyzed marine debris and the presence of microplastics and large microplastics in the Adriatic region. The research considers both spatial and temporal trends and real data were also compared with estimated models. The results indicate that in the areas rivers, tourism, and conservation were the most affected. To conclude, the results of this study have extended the level of research conducted so far and clarified future approaches. Liu et al. (2022) used a simultaneous equation model to study the relationship between Marine environmental pollution, aquatic product trade and Marine fishery economy in China’s coastal areas from 2001 to 2020. In China’s coastal regions, it has been discovered that marine pollution in aquatic products impedes the marine fishery industry. In the long run, the rapid development of fishery economy and the increase of aquatic product trade are conducive to the improvement of Marine environmental pollution, while the rapid growth of Marine fishery economy. Therefore, the government should strengthen the protection of the Marine environment and moderately develop the trade of aquatic products in coastal areas. Some studies suggest that renewable energy is essential to reduce the environmental pollution such as Fareed, Z., & Pata, U. K. (2022); Rehman et al. (2021); Pata and Kartal (2023); Sharif et al (2023); Pata et al (2023); Pata et al. (2023); Kartal et al. (2023) and Adebayo et al. (2023). Overall, the previous studies mainly focus on marine pollution with different factors such as Zheng et al. (2020) examine economic growth and marine pollution, while Liu et al. (2022) analyzed the relationship between plastic pollution and trade openness. Yu et al. (2020) analyzed relationship metal pollution China ocean due to urbanization and industrialization. Schmid et al. (2021) examined marine pollution especially the presence of microplastics and large microplastics in the Adriatic region. Wan et al. (2022) examined the influence of accidents on marine pollution and the relationship between trade and accidents. The present study contributes the existing literature by analyzing both trade openness and industrialization effect on marine pollution. In addition, the quantile regression may provide more robust estimations as compared to the previous studies and help to suggest suitable policy recommendations.

3. Marin pollutions, industrialization, and global trade: a historical overview

This section provides stylized facts and responsible factors for marine pollution especially post trade liberalization era. The oil leakage pollution through cargo and tank transport has been the main responsible factor in ocean pollution for the last few decades. In addition, plastic pollution is also a major factor in ocean pollution. It is noted that plastic pollution and oil leakage pollution in ocean has significantly increased post trade liberalization in world ocean.

The effect of an oil spill is determined by factors such as the quantity of oil released, the type of oil spilled, for example, crude oil or refined products, the spill’s location, and its response efforts. The immediate effects of an oil spill include the coating of the water’s surface, drowning of marine life, and the loss of habitats such as coral reefs and marshes. Fig. 1 illustrates the growth in crude and other tanker trade, as well as oil spill amounts from 1970 to 2021. The figure demonstrates that oil leakage and trade growth are negatively correlated, making oil spill less in marine pollution from 1970 to 2018. The negative association reflects the measure and safety, which leads to the safe shipment of oil tankers from one country to another country. In addition, the downward trend of oil tanker leakages can be explained in two aspects: one for macro control of the world, including enforcement of laws and regulations, and another for progressive improvements, like grounding and unloading. The toxic components of the oil can directly affect marine organisms, causing physical harm, disruptions in their reproductive, respiratory problems and feeding behaviors. Birds, fish, and mammals are especially vulnerable to oil pollution. In addition, oil spills may have long-term ecological effects, altering the food chain and leading to population declines or even the extinction of certain species. To minimize oil spills and ocean pollution, prevention is essential. The essential measures should be taken to reduce the risk of oil spills and protect the marine environment, including stringent regulations, improved safety standards, routine infrastructure maintenance, and public education campaigns. To address marine pollution, particularly resulting from oil spills, a variety of legislations have been made, including “the intergovernmental Maritime Consultative Organizations have made laws to regulate transporting behavior on the sea, and they have signed the International Convention on Intervention in Oil Pollution Accidents on the High Sea and the International Convention on Civil Liability for Oil Pollution Damage. These efforts drastically decreased the stereotype of oil spills, modern vessels were adopted, oil unloading machines were installed, and laws were enforced to prevent spills.

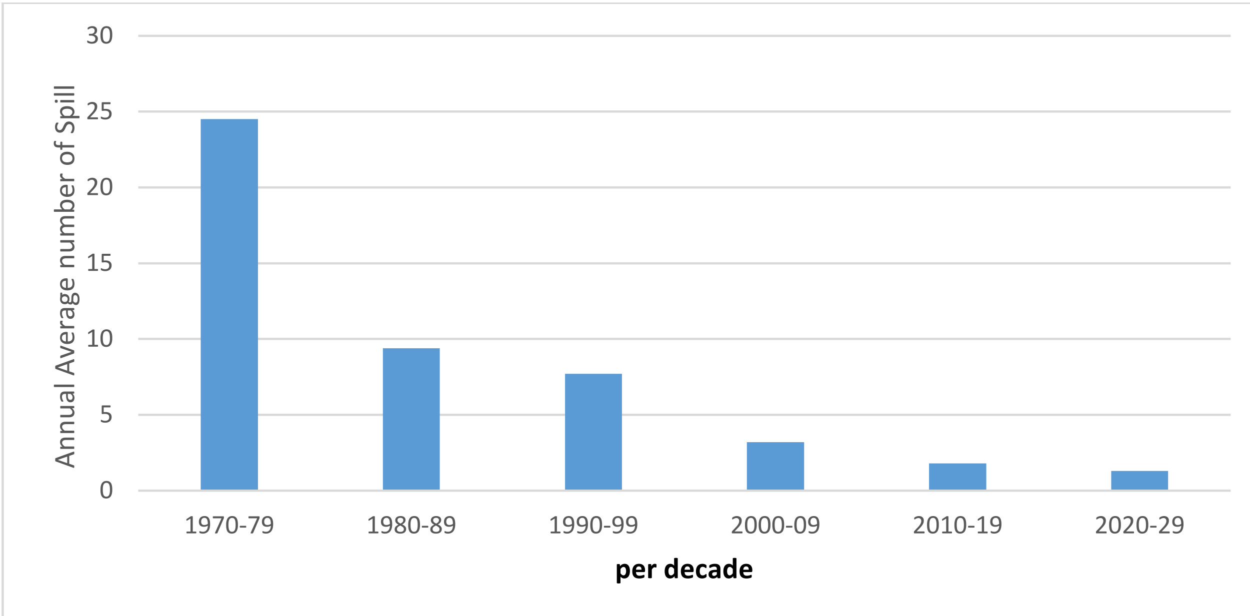

Fig. 1. Global Oil spills by decade: 1970–2022. Source: https://www.statista.com/.

Fig. 2 illustrates the pathway by which plastic goes into the oceans all over the world, starting from primary production to marine plastic inputs. The amount of global plastic waste exceeds the amount of primary plastic production around the world, considering that it includes production from previous years. Every year 99.5 million tons of plastic waste is disposed of in the sea, but almost one third of this waste is mismanaged, causing 8 million tons of plastic waste to remain in the sea. It is noted that plastic pollutants found in surface waters, such as plastic bags and plastic bottles, are likely to be produced by people near the coast. Notwithstanding, it remains unclear whether there still exist unobservable plastic pollutants, like micro-plastic, or left accumulated in deep ocean. Plastic pollution poses a significant threat to marine life, therefore, further analysis of plastic waste, including its types and methods of data analysis is required.

Fig. 3 illustrate the relationship between micro or macro plastic and trade, both micro and macro plastic have almost the same trend with trade. In the period 1960 to 2020, the amount of micro- or macro-pollution showed a continuous rise. Meanwhile, after experiencing fluctuations, the trade volume has significantly increased from 2006 and thereafter decreased; this decreasing trend depicts the economic recession of 2008. This figure suggests important that both pollution and trade experienced a rising trend and international trade and the development of marine economy are main factors responsible for the plastic pollution in ocean. The trade openness policy in different countries promotes interactions of economics and technologies, which leads to aggravation of industrialization. However, tight measures and legislation for environmental pollution could significantly mitigate marine pollution. In the future, the number of micro or macro plastic and industrialization will continue to increase. It is indispensable for countries to pay more attention to decrease pollution in trade and environmental protection while pursuing marine economic development. Trade creates potential waste in world and Trade contribute 75 % of global waste volume in developed nations. In addition, trade with secondary materials for example waste and end-of-life products expanded from 4

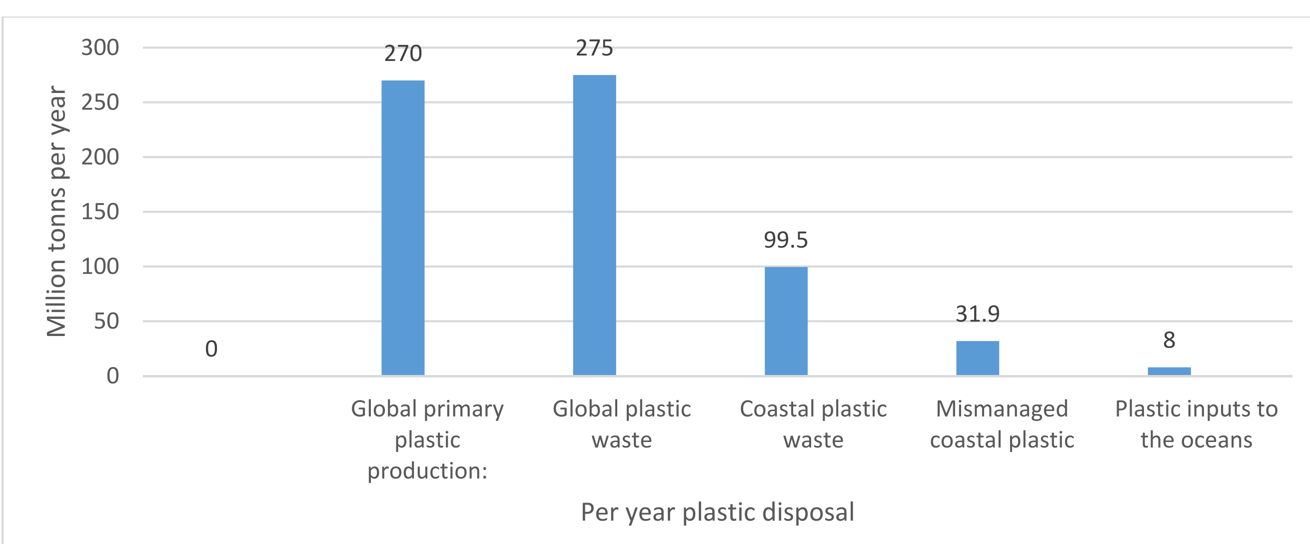

Fig. 2. Plastic enters the world’s oceans. Source: ourworldindata.org [Jambeck et al. (2015) and Eriksen et al. (2014)].

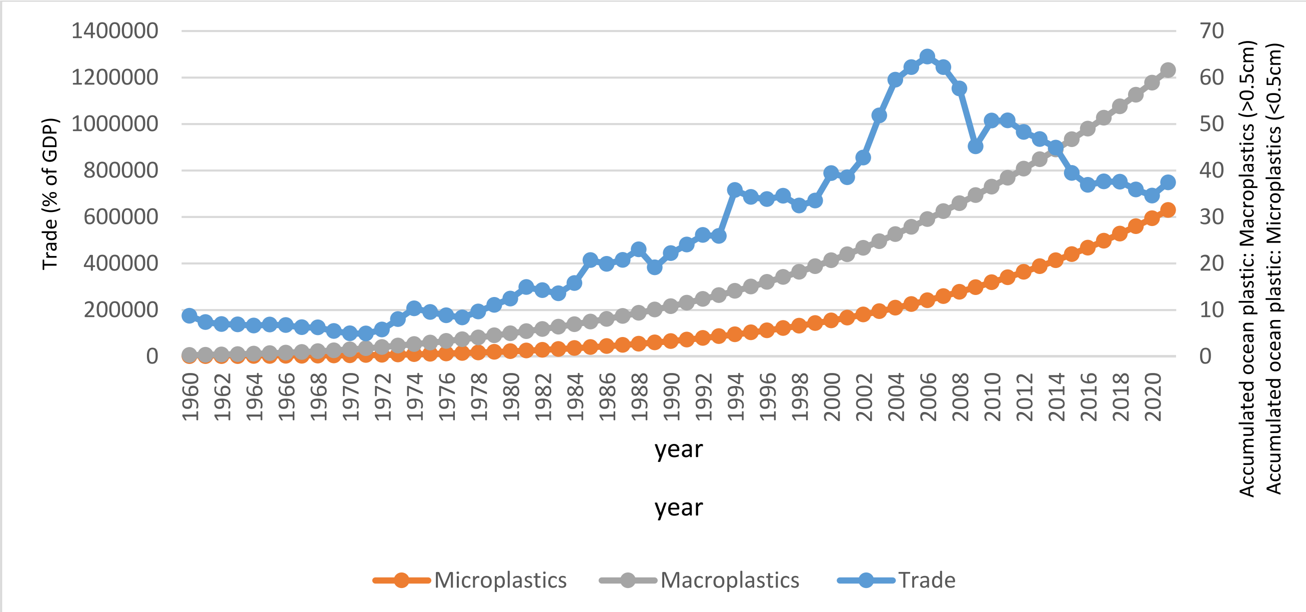

Fig. 3. Trade, Micro and Macro Plastic Trend [1960–2022]. Source: OurWorldinData.org [Jambeck et al. (2015) and Eriksen et al. (2014)].

million to 16 million tons during 1993—2001. According to the World Economic Forum, e-waste will treble to 120 million metric tons by 2050 from 54 million tons in 2022 if consumer behavior does not change.

Fig. 4 demonstrates a graphical relationship between the world's overall micro and macro-plastic waste polluted in the ocean and industrialization from 1960 to 2020. The graphical trend between plastic pollution and industrialization suggests a positive association. The plastic pollution in the oceans has increased dramatically over the last 20 years; A total of 8.3 billion tons of new plastic were aggregated in 2015, with half of it produced since 2004 (Mortillaro, 2017). Plastic is widely producing the industry due to its growing demand in modern society. However, it is essential, multifunctional, corrosion-resistant, durable materials in ocean. Plastic is used in many forms in industries including packaging, construction, and transportation. Many industrial wastes, such as packaging, household items, and fishing related items, are likely to be carried by the current and deposited in the ocean, which leads to serious plastic pollution. In addition, there is a slight difference in the trend of micro and macro plastic, and macro plastic are comparatively dump in less amount. The modern society has keen concern for environmental protection initiatives. The amount of macro-

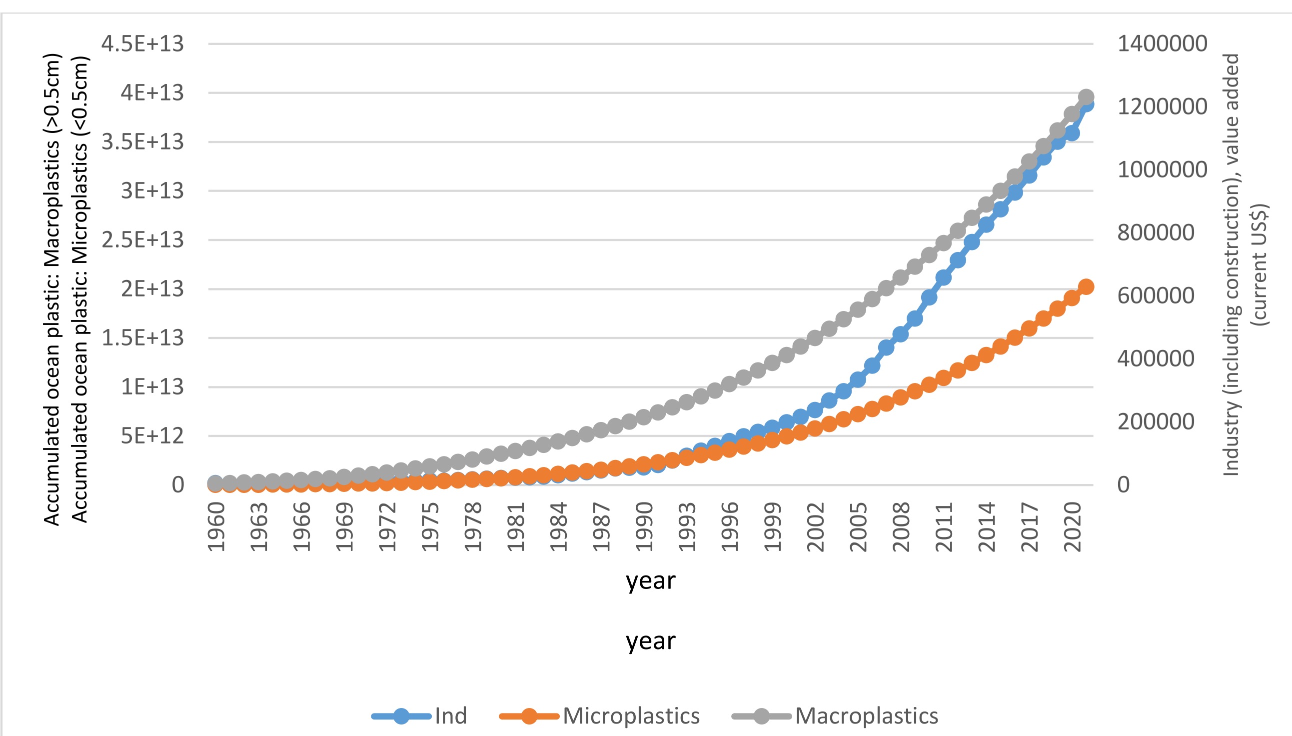

Fig. 4. Industrial production, Micro and Macro plastic historical trend. Source: OurWorldinData.org [Jambeck et al. (2015) and Eriksen et al. (2014)].

plastic waste can be reduced significantly when the government implements policies to dispose of plastic waste. However, dealing with micro- plastic waste is more complicated. Micro-plastics are simply polymer materials that are usually invisible. Industrialization production disposes of microplastic in the ocean and most of them between 2 mm and 5 mm. Due to their small size, they are quickly released into the environment during the production process. It is more challenging to deal with microplastic waste than microplastic waste. Over the last few years, more countries have realized the need to deal with microplastic waste, and many more scientific governance policies have been implemented.

4. Research methodology adopted

4.1. Quantile regression model

Marine pollution (MP) is the dependent variable, while trade, industrialization (Ind) and population (pop) are the independent variables. We applied quantile regression, Quantile regression uses absolute deviations that are weighted to get conditional quantile variables (Koenker & Bassett 1978; Koenker & Hallock, 2001). The conventional applies a single conditional mean value for estimation, while quantile regression, however, utilizes different weights for estimation. The quantile regression follows the conventional regression framework by utilizing symmetric weights of median such as 0.1, 0.2…0.9. In comparison to OLS, Quantile regression provides more diversified estimates since it does not have to explain only the main dependent variable. It estimates the dependent variable at any given point (Zietz et al. 2008). Moreover, quantile regression allows for the empirical analysis of factors such as industrialization, population effects, marine pollution, and trade openness. Quantile regression is preferred over traditional regression techniques, such as ordinary least squares (OLS), are susceptible to outliers, which may provide misleading results. Quantile regression, on the other hand, is robust against outliers because it estimates conditional quantiles rather than to the conditional mean. This a useful method especially with data containing extreme values. Quantile regression estimates multiple quantiles, which provides a more comprehensive results for the relationship between independent and dependent across the entire data set. This is helpful when the data distribution is asymmetrical. In many real-world situations, the variance of the independent variable across different levels of the predictor variables may not be constant. Quantile regression can provide estimations even if the heteroscedasticity exists in the data, this implies that quantile regression provides robust estimations if the data has heigh level of dispersion.

An unconditional quantile in the case of Quantile regression, is generalized to a conditional quantile for covariates. Quantile regression generalizes an unconditional quantile into a conditional quantile. This study uses a linear model as follows:

MP = f (Trade, Ind, Pop)

Under the least square model, the summation of squared residual variates is given as follows:

$$\min_{\{b_n\}_{n=0}^{m}} \sum_i \left(y_i - \sum_{n=0}^{m} b_n x_{n,i} \right)^2$$

Where y_i represents the dependent variable for data set i and n shows the independent variable, while b_n indicates the element of estimation of the regression model. Therefore, quantile regression minimizes the weighted sum of absolute deviations (Zietz et al., 2008).

$$\min_{\{b_n\}_{n=0}^{m}} \sum_i \left| y_i - \sum_{n=0}^{m} b_n x_{n,i} \right| w_i$$

In the above function, w_i represents the weight which can be defined as

$$w_i = 2a$$

In case the residual variable is restricted to be positive, then the i th observation will be given as

$$w_i = 2 - 2a$$

Moreover, the distribution residual for i th variable is negative or zero, and q is the quantile variable with a value lying between 0 and 1 and provides the estimated or predicted value. Carpenter et al. (1999) suggest that bootstrapping method is used to estimate conventional errors based on quantile regression coefficients. According to Rogers (1993), bootstrapping is less volatile than heteroskedasticity compared to standard error estimation. Nevertheless, this method does not provide information on spatial correlation in the data. The different quantile estimates obtained would be used to give robust estimates useful in understanding the correlation between marine pollution and other underlying factors such as industrialization, population, and trade. The data is extracted from the World Bank, marine pollution data is retrieved from the OECD database.

5. Results and discussions

In this section, we present the results and discussion of this study. The study applied Quantile regression as main estimation method. The results can be split into two sub sections one is baseline results and baseline results and then robustness test.

5.1. Baseline results

This section provides results obtained from the model. The bassline results mainly focus on the quantile regression coefficients. Before proceeding baseline estimations, we first estimate the descriptive statistics. It is essential to use descriptive statistics, which provide a detailed breakdown of the data, such as mean, standard deviation, and dispersion. In addition, Kurtosis measures dispersed the data, while skewness estimate the degree of symmetry between the data. The outcomes are reported in Table 1.

Table 1 presents descriptive statistics; the mean value is suggested that Maine pollution has comparatively highest value among the other variables, while industrial production has lower mean value. The standard deviation presents the deviations from the mean value, the higher standard deviation implies more dispersion and it's expected that the variable coefficient may not provide accurate information. The skewness and kurtosis estimate the symmetrical property of the data and acceptable rage is (±2), our findings of skewedness suggest that all variables lie in the acceptable range. In addition, the dataset is properly tailed because all variables lie within the "rule of thumb" range. Skewness and kurtosis together reveal the model's goodness of fit. Table 2 demonstrates the different combinations among the variables which present the correlation between the existing variables. A strong correlation in the dataset leads to multicollinearity, which is considered one of the main statistical issues in estimation. In addition, in presence of multicollinearity the empirical results are biased. Since industrialization has been adopted by many developed and developing nations, particularly post trade liberalization. However, industrialization

Table 1
Descriptive statistics of variables.

Statistical test	IND	P	POP	T
Mean	1.614	100,473	6.780	53.382
Median	1.633	936,700	6.767	54.438
Maximum	2.723	186,050	7.849	60.738
Minimum	8.687	403,300	5.717	43.091
Std. Dev.	5.973	444,685	6.532	5.3885
Skewness	0.042	0.385	0.028	−0.5235
Kurtosis	1.565	1.945	1.792	2.1147
Jarque-Bera	2.323	1.918	1.646	2.1150
Probability	0.313	0.383	0.439	0.3473

Table 2
Correlation between variables.

	IND	P	POP	T
IND	1			
P	0.954	1		
POP	0.962	0.991	1	
T	0.689	0.563	0.655	1

All coefficients are estimated at 5 percent level of significance.

provides jobs, economic growth, and development for the societies in the world. Most of the past studies have confirmed that industrialization has been responsible for environmental pollution. Industrialization is essential in modern society, and many researchers suggest that heavy industry generates a tremendous impact on the environment. The relationship between industrial development, energy consumption and economic growth was largely investigated and suggested that environmental degradation mainly arises due to industrialization (Al-Mulali et al., 2016; Apergis and Ozturk, 2015; Ongan, and Özdemir, 2019; Shahbaz et al., 2013). Industrialization also influenced the explosive growth of urban areas as the labor force agglomerated in industrialized regions and increased in numbers population in urban life (Akinsola et al., 2022; Atack et al., 2022). This steady increase in the world population puts more pressure on environmental quality, decisively contributing to pollution. The urban population is the biggest contributor of plastic waste to the ocean.

Table 3 presents the detailed results of the quantile regression. The quantile has been distributed into different rage such as (10–90). The results indicate that population has positive and significant effect on marine pollution in most of the quantiles, which indicates that population increase generates more marine pollution, particularly the plastic use and dispose in the ocean have been significantly increased. The results are in line with previous research, such as Xu and Zhang (2022). The results are slightly different for industrialization. The first two quantiles (10–20) suggest that industrial growth shows a negative effect on marine pollution, but the coefficients are insignificant. However, the results are significant only for the last six quantiles (40–90), confirming the previous results of Pan et al. (2022). This implies that industrialization leads to higher level of marine pollution. Industrial processes generate heavy metals, solvents, pesticides, and other toxic chemicals. Chemical spills or improper disposal that can pollute rivers, lakes, and oceans, which adversely affect marine life and disrupt ecosystems. Industrialization increased plastic consumption. Industries produce packaging, microplastics, and plastic products. Plastic waste takes centuries to dissolve, causing ingestion, entanglement, and habitat destruction. Trade openness is a positive and significant contributor to marine pollution in all quantiles (10–90); however, the coefficient sign of marine pollution is minor. Transport and shipping are major components of international trade. Fossil fuels are used in these ships, causing greenhouse gas emissions and air pollution. Furthermore, accidents such as oil spills and chemical leaks during transport may directly threaten marine ecosystems. Offshore oil drilling and oil transportation can result in oil spills, marine life can be adversely affected by oil leaks and spills. It causes long-term health and reproductive problems for ocean animals.

Table 3
Quantile Process Estimates [Dependent variable marine pollution].

	Quantile	Coefficient	Std. Error	t-Statistic	Prob.
C	0.100	−16.388	1.667	−9.830	0.000
	0.200	−16.387	2.128	−7.700	0.000
	0.300	−14.938	2.139	−6.981	0.000
	0.400	−11.645	1.188	−9.800	0.000
	0.500	−11.300	1.176	−9.608	0.000
	0.600	−11.115	1.189	−9.350	0.000
	0.700	−10.096	1.102	−9.161	0.000
	0.800	−7.8242	1.437	−5.441	0.000
	0.900	−7.7819	1.549	−5.023	0.000
IND	0.100	−9.490	8.480	−1.118	0.265
	0.200	−8.245	1.083	−0.764	0.445
	0.300	3.813	1.134	0.336	0.737
	0.400	2.194	5.995	3.664	0.000
	0.500	2.345	6.111	3.833	0.000
	0.600	2.954	9.385	3.145	0.002
	0.700	3.784	7.160	5.286	0.000
	0.800	4.684	5.835	8.024	0.000
	0.900	5.131	4.661	11.010	0.000
POP	0.100	1.451	1.429	10.175	0.000
	0.200	1.458	1.820	7.973	0.000
	0.300	1.332	1.839	7.239	0.000
	0.400	1.058	1.049	10.040	0.000
	0.500	1.014	1.040	9.737	0.000
	0.600	9.985	1.060	9.438	0.000
	0.700	9.060	1.033	8.807	0.000
	0.800	6.805	1.452	4.689	0.000
	0.900	6.849	1.604	4.301	0.000
T	0.100	0.017	0.002	8.155	0.000
	0.200	0.017	0.002	6.487	0.000
	0.300	0.018	0.002	6.378	0.000
	0.400	0.021	0.002	8.782	0.000
	0.500	0.024	0.003	8.792	0.000
	0.600	0.023	0.003	7.079	0.000
	0.700	0.026	0.005	4.775	0.000
	0.800	0.041	0.011	3.688	0.000
	0.900	0.037	0.012	2.862	0.005

5.2. Diagnostic Test

Table 4 represents the diagnostic tests applied to check the accuracy of the results. Diagnostic tests are often used to investigate the accuracy, precision, and predictions of the sample population. We use two types of diagnostic test such as Quantile Slope Equality Test and Symmetric Quantiles Test. The Quantile Slope Equality Test (QSET) determines - whether the relationship between two variables is the same or different across distribution quantiles. It is a nonparametric technique for comparing slopes or gradients at different points in distribution. The Symmetric Quantiles Test measures the variables' symmetric properties among the different quantiles. The Wald test is used for the robustness of the baseline findings; the Wald test outcomes coefficient value is 48.538 which is statistically significant. This indicates that the results are accurate, and results can be used for the policy recommendation.

5.3. Robustness Test

In addition, this study employs robustness tests, which show the stability of model and reliability of baseline model. Granger causality is a statistical technique used to forecast time series. Instead, it is used to study causal relationships and variable temporal dynamics. The Granger causality technique is applied for the robustness check. Granger causality is a statistical technique used to forecast time series. Granger causality provides causation between variables; in causality usually a variable usually uses the past value to predict the future value. For example, if X Granger causes Y, it means that the variation in Y is cause by X. There is a possibility of unidirectional, bidirectional and no causality.

Table 5 represents the outcomes of Granger Causality in different quantiles. The causality test has been performed in different quantile under the auto-regressive framework. The regression under var framework median-regression consider $\tau = 0.10, 0.20, \ldots 0.90$ in different

Table 4
Diagnostic Test of baseline results.

Quantile Slope Equality Test	Chi-Sq. Statistic	Symmetric Quantiles Test	Chi-Sq. Statistic
Wald Test	48.538 (0.000)	Wald Test	6.1349 (0.189)

Table 5
Granger causality in quantiles (subsampling p-values).

Causality Direction		ΔInd to ΔP			ΔP to ΔInd		
	Quantile	ΔInd_{-1}	ΔInd_{-2}	ΔInd_{-3}	ΔP_{-1}	ΔP_{-2}	ΔP_{-3}
Ind to P	0.10	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0324**
	0.20	0.0052*	0.0119*	0.0052*	0.0000*	0.0000*	0.0000*
	0.30	0.38693	0.29515	0.39293	0.0000*	0.0000*	0.0000*
	0.40	0.06549***	0.0679***	0.0575**	0.0000*	0.0000*	0.0000*
	0.50	0.46647	0.63979	0.81968	0.0000*	0.0000*	0.0004*
	0.60	0.00128*	0.0009*	0.00796*	0.0000*	0.0000*	0.0029*
	0.70	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0032*
	0.80	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0005*
	0.90	0.06376***	0.02378**	0.0272**	0.0000*	0.0000*	0.0000*
Causality Direction		ΔT to ΔP				ΔP to ΔT	
	Quantile	ΔT_{-1}	ΔT_{-2}	ΔT_{-3}	ΔP_{-1}	ΔP_{-2}	ΔP_{-3}
	0.10	0.0000*	0.0000*	0.0000*	0.0324**	0.07128	0.12154
	0.20	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
	0.30	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
	0.40	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
	0.50	0.0000*	0.0000*	0.0000*	0.0000*	0.0002*	0.0004*
	0.60	0.0000*	0.0000*	0.0000*	0.0020*	0.0004*	0.0019*
	0.70	0.0000*	0.0000*	0.0000*	0.0021*	0.0030*	0.0037*
	0.80	0.0000*	0.0000*	0.0000*	0.0001*	0.0001*	0.0002*
	0.90	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
Causality Direction		ΔInd to T				ΔT to ΔInd	
	Quantile	ΔInd_{-1}	ΔInd_{-2}	ΔInd_{-3}	ΔT_{-1}	ΔT_{-2}	ΔT_{-3}
	0.10	0.0000*	0.0004*	0.0397**	0.00000	0.0000*	0.0000*
	0.20	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
	0.30	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
	0.40	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
	0.50	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
	0.60	0.0002*	0.0001*	0.0016*	0.0000*	0.0000*	0.0000*
	0.70	0.0009*	0.0006*	0.0021*	0.0000*	0.0000*	0.0000*
	0.80	0.0003*	0.0004*	0.0005*	0.0000*	0.0000*	0.0000*
	0.90	0.0002*	0.0001*	0.0000*	0.0000*	0.0000*	0.0000*
Causality Direction		ΔPop to ΔP			ΔP to ΔPop		
	Quantile	ΔPop_{-1}	ΔPop_{-2}	ΔPop_{-3}	ΔP_{-1}	ΔP_{-2}	ΔP_{-1}
	0.10	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
	0.20	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
	0.30	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
	0.40	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
	0.50	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
	0.60	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
	0.70	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
	0.80	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
	0.90	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
Causality Direction		ΔInd to ΔP			ΔP to ΔInd		
	Quantile	ΔInd_{-1}	ΔInd_{-2}	ΔInd_{-3}	ΔPop_{-1}	ΔPop_{-2}	ΔPop_{-3}
	0.10	0.0000*	0.0000*	0.00000	0.0000*	0.0000*	0.0000*
	0.20	0.0000*	0.0000*	0.00520	0.0000*	0.0000*	0.0000*
	0.30	0.0000*	0.0000*	0.39293	0.0000*	0.0000*	0.0000*
	0.40	0.0000*	0.0000*	0.05756	0.15650	0.0000*	0.0000*
	0.50	0.0000*	0.0000*	0.81968	0.0647***	0.0000*	0.0000*
	0.60	0.0000*	0.0000*	0.00796	0.0014*	0.0000*	0.0000*
	0.70	0.0000*	0.0000*	0.00000	0.0005*	0.0000*	0.0000*
	0.80	0.0000*	0.0000*	0.0000*	0.20172	0.0000*	0.0000*
	0.90	0.0000*	0.0000*	0.02723**	0.0000*	0.0000*	0.0000*
Causality Direction		ΔT to ΔPop			ΔPop to T		
	Quantile	ΔT_{-1}	ΔT_{-2}	ΔT_{-3}	ΔPop_{-1}	ΔPop_{-2}	ΔPop_{-3}
	0.10	0.0397**	0.0000*	0.0000*	0.03971	0.15614	0.24949
	0.20	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
	0.30	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
	0.40	0.15650	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
	0.50	0.0647***	0.0000*	0.0000*	0.0006*	0.0029*	0.0033*

(*continued on next page*)

Table 5 (*continued*)

Causality Direction		ΔInd to ΔP			ΔP to ΔInd		
	Quantile	ΔInd_{-1}	ΔInd_{-2}	ΔInd_{-3}	ΔP_{-1}	ΔP_{-2}	ΔP_{-3}
	0.60	0.00137*	0.0000*	0.0000*	0.0016*	0.0016*	0.0031*
	0.70	0.00052*	0.0000*	0.0000*	0.0021*	0.0036*	0.0035*
	0.80	0.20172	0.0000*	0.0000*	0.0048*	0.0014*	0.0041*
	0.90	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*

***, **,*, denote signicance at the 10, 5 and 1 % levels, respectively; For $\tau \in [0.10, \ldots 0.90]$.

quantiles. The first part of the table represent vectors shows the causality outcomes between marine pollution and industrialization; the outcomes suggest that a causality running from industrialization to marine pollution in all quantiles expect 3rd and 5th quantile which indicates that industrialization. While causality running from marine pollution to industrialization in all quantiles. This indicates that except in few quantiles' industrialization leads to marine pollution. In addition, industrialization and trade quantile causality results indicates bivariate causality in all quantiles at 1 percent level of significance. The results indicate causality from trade to industrialization in all quantiles at 1 percent level of significance, however causality from industrialization from to trade are week and only few quantiles for example 2nd to 5th quantile is significant at percent level. Population also suggests a bivariate granger causality in all quantiles, which suggest population also causes the marine pollution and one of the important factors contributing to the marine pollution. Linear regression is applied as the second robustness test in Table 6; marine pollution is taken as independent variables, while industrial production, population and trade openness are independent variables in the model. The linear estimations suggest that population is positive and significantly related to marine pollution, which implies that with the increase in population marine pollution will increase. Industrial production and trade also have positive and significant effects on marine pollution, this implies that with industrial expansion and trade, marine pollution increases. The linear regression estimations are in line with baseline results. These results validate the baseline quantile regression, suggesting that industrialization and trade are the main factors responsible for marine pollution. However, the direct effect of trade on marine pollution is minor, but the indirect impact of trade via industrialization is more substantial.

6. Conclusion and policy implications

Marine economies significantly grow over the past few decades due to globalization and trade. There are some environmental concerns, like marine pollution, which arise from industrialization. Thus, our study primarily examines the relationship between marine pollution, trade openness, and industrialization. The finding of this study suggests that both trade openness and industrialization raise marine pollution, especially plastic pollution. In addition to industrialization's dependency on marine resources, the marine transportation sector significantly contributes to ocean pollution. The results also indicate that industrialization contributes comparatively more pollution than trade openness.

The study concluded that to prevent and control marine pollution, countries should increase cooperation and coordination, especially in the marine economy. The study concluded that to prevent and control marine pollution, countries should increase cooperation and coordination, especially in the marine economy. Based on findings of the study the following policy recommendations are suggested for both developed and developing nations. Firstly, marine pollution is a significant issue that needs to be addressed; both developed and developing economies should enhance green technological innovation in the export industry to improve marine ecosystem. There is need of investments based on standards like resource intensity, output efficiency, and environmental impact. Meanwhile, the enterprise should focus on energy conservation and adopt emission reduction policies to foster marine sustainable development. Secondly, all trading nations must adopt appropriate trade policies, including legislation, a combination of mandatory and guiding measures and the establishment of reasonable and practical regulations for environmental protection. Third, there is a need to control key industrial pollution sources and effective measures should be adopted to eliminate untreated industrial wastewater directly dump into the sea. It is also important to adopt advanced technologies and clean production processes, which could help to reduce the amount of industrial waste and mitigate marine pollution. This study has still some limitations. First, the study uses world-level data to examine the relationship between trade openness, industrialization, and marine pollution. However, some countries are more industrialized than others, so future studies may conduct separate analyses for industrialized and non-industrialized nations. Secondly, this study applied time series data, but future studies may use panel and cross countries data for analysis. Third, this study applied quantile regression method; future studies may use advance model or method to obtain more robust outcomes. Fourthly the research might cover a specific period 1995–2022, and long-term trends or gradual changes in the relationship between trade, industrialization, and marine pollution could be overlooked in future studies depending on the availability of data. The study is limited to Quantile regression application for the analysis; future studies may apply more advanced techniques specifically that offer long term and short-term effect of trade and industrialization effect on marine pollution. The study uses limited number of control variables the choice of control variable can be expanded in future studies.

Table 6
Dependent Variable: P.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	−9452291	5682884.	−16.63292	0.000
POP	4,251,775	254272.0	16.72	0.000
IND	1.697	4.219	3.805	0.001
T	17844.6	1759.836	10.140	0.000
R-squared	0.995	F-statistic		1402.873
Adjusted R-squared	0.995	Durbin-Watson stat		1.028
Prob(F-statistic)	0.000			23.892

Funding

Not available.

CRediT authorship contribution statement

Irfan Ullah: Conceptualization, Supervision and Proofreading. **Florian Marcel Nuta:** Conceptualization, Writing – review & editing. **Dimen Levente:** Funding acquisition, Writing – review & editing. **Bian Yiyu:** Writing – original draft. **Zhou Yihan:** Writing – original draft. **Chen Yi:** Writing – original draft. **Muhammad Haroon Shah:** Data curation, Formal analysis. **Rupesh Kumar:** Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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