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POLLUTION PROCESSES IN MARINE ECOSYSTEMS

H.T.Mammadli, O.Salamov

Azerbaijan University of Architecture and Construction, Baku, Azerbaijan

memmedlihussein@gmail.com

Abstract: Marine ecosystems represent one of the most valuable components of the Earth's environment, providing essential ecological services such as climate regulation, nutrient cycling, biodiversity conservation, and food resources for millions of people. Despite their importance, these ecosystems are increasingly threatened by pollution originating from industrial activities, urban wastewater, agricultural runoff, maritime transport, and improper waste disposal. Contaminants including plastic debris, microplastics, petroleum products, heavy metals, and toxic chemicals negatively affect water quality, marine habitats, and aquatic organisms. This paper investigates the major processes responsible for marine pollution, evaluates their impacts on ecosystem structure and biological diversity, and discusses their long-term environmental consequences. Furthermore, it reviews modern pollution control measures, sustainable marine management practices, and international initiatives designed to protect marine environments. The findings highlight that reducing marine pollution requires coordinated global action, advanced environmental monitoring, effective legislation, and greater public awareness to ensure the sustainable use of marine resources.

Keywords: marine ecosystems, marine pollution, plastic pollution, microplastics, oil contamination, biodiversity, environmental management, ocean conservation

1.Introduction

Seas and oceans cover approximately 71% of the Earth's surface and represent one of the main components of the global ecological system. They play an essential role in regulating atmospheric carbon dioxide, producing oxygen, and maintaining climate balance. In addition, marine ecosystems provide food, energy resources, and economic opportunities for millions of people worldwide. Sectors such as fisheries, tourism, and maritime transportation are directly dependent on ocean resources.

In recent decades, the amount of waste entering marine environments has increased rapidly as a result of intensified human activity. Industrial enterprises, oil extraction, shipping, agriculture, and domestic waste are considered the primary causes of marine pollution. In particular, plastic waste and oil spills pose serious threats to marine ecosystems. Scientists estimate that millions of tons of waste enter oceans every year, and the rate of pollution continues to grow [1].

Marine pollution negatively affects not only water quality but also biodiversity, fisheries, and human health. The entry of microplastics into the food chain and the bioaccumulation of toxic substances create long-term ecological problems. At the same time, polluted marine waters may contribute to the spread of various diseases among humans. Therefore, the protection of marine ecosystems has become one of the major global environmental priorities.

The purpose of this article is to investigate pollution processes in marine ecosystems, analyze their major sources and consequences, and evaluate modern approaches used to address these problems. The article examines ecological, economic, and social aspects of marine pollution. In addition, international environmental programs and scientific research findings are discussed. The main objective is to demonstrate the importance of protecting marine ecosystems on a scientific basis [2].

1.1 Main sources of pollution in marine ecosystems

Marine pollution is caused by various anthropogenic activities. One of the most widespread sources of pollution is industrial waste. Heavy metals, chemical compounds, and toxic substances discharged from factories and industrial plants enter water bodies and threaten marine organisms. Substances such as mercury, lead, and cadmium accumulate in aquatic organisms and negatively affect their development. These toxic materials may also enter the human body through the food chain.

Oil extraction and transportation accidents are among the most dangerous forms of marine pollution. Oil spills weaken oxygen exchange on the water surface and seriously damage marine life. Birds and fish species are particularly vulnerable to oil contamination. Oil-covered birds lose their ability to fly and often die shortly afterward. Furthermore, petroleum products remain in marine environments for a long time, making ecosystem recovery more difficult.

Plastic waste has become a global problem for oceans in the modern era. Every year, millions of tons of plastic waste enter seas and oceans, and most of this material does not decompose for decades. Over time, plastics break down into microplastic particles that are consumed by marine organisms. Fish, sea turtles, and other animals often mistake plastic debris for food. As a result, their digestive systems become damaged, leading to increased mortality rates.

Fertilizers and pesticides used in agriculture are transported into marine environments through rivers. Consequently, eutrophication occurs, leading to oxygen depletion in water bodies. This process creates so-called “dead zones” where marine organisms cannot survive. In recent years, the number of such zones has increased significantly in different parts of the world’s oceans [3-5].

Table 1. Main sources of marine pollution and their effects

Source of pollution	Main pollutants	Ecological effects
Industrial waste	Heavy metals, chemicals	Poisoning of marine organisms
Oil spills	Oil and petroleum products	Oxygen depletion, biodiversity loss
Plastic waste	Plastics and microplastics	Food chain contamination
Agriculture	Fertilizers, pesticides	Eutrophication and dead zones
Domestic waste	Sewage and wastewater	Decline in water quality

As shown in the table, marine pollution originates from different sources, each causing specific negative impacts on ecosystems. Plastic waste and oil pollution are particularly dangerous because they create long-term environmental problems. Solving these issues requires both technological and legal measures. Governments and international organizations must cooperate to reduce pollution levels and protect marine environments.

2.Experimental Section

2.1 Ecological and social consequences of marine pollution

Marine pollution causes serious damage to biodiversity. Chemical substances and toxic waste disrupt the life processes of fish, coral reefs, and other marine organisms. Many species experience population decline, while some face the risk of extinction. Coral reefs are especially sensitive to pollution and rising temperatures. The destruction of coral ecosystems leads to major changes in ocean biodiversity and ecological balance.

Microplastics entering the food chain also pose significant risks to human health. Research indicates that microplastic particles found in seafood may create toxic effects within the human body. These substances may negatively affect the hormonal and immune systems. In addition, microplastics often carry toxic chemicals on their surfaces, increasing their harmful effects. Recent studies have even identified microplastic particles in human blood and tissues.

Oil pollution severely affects coastal ecosystems as well. Mangrove forests, wetlands, and habitats of coastal birds are destroyed due to oil contamination. As a result, ecological balance is disrupted and natural recovery processes become weaker. Coastal communities also face economic difficulties caused by environmental degradation. Fishing and tourism revenues decrease, while unemployment rates may increase in affected regions [6].

From an economic perspective, marine pollution negatively impacts fisheries and tourism industries. Polluted coastlines reduce tourism income, while declining fish populations threaten food security. Moreover, governments are forced to spend large financial resources on pollution cleanup and environmental restoration. Therefore, protecting marine ecosystems is important not only environmentally but also economically and socially.

Table 2. Some global consequences of marine pollution

Problem	Approximate Indicator	Area of Impact
Plastic waste entering oceans	8–10 million tons annually	Biodiversity and food chains
Number of dead zones	More than 400	Ocean ecosystems
Oil spills	Thousands of tons per year	Coastal regions
Spread of microplastics	Present in almost all oceans	Human health and marine life

This table demonstrates that marine pollution is no longer a local issue but a global environmental problem. The rapid increase in plastic waste and the expansion of dead zones pose serious threats to ecosystem sustainability. The current situation requires stricter international measures and stronger environmental policies. Otherwise, a significant portion of marine resources may be endangered in the future [7].

3.Result and Discussion

3.1 Methods of preventing marine pollution

To protect marine ecosystems, waste management systems must first be improved. Many countries have introduced restrictions on single-use plastic products in order to reduce plastic pollution. Waste separation and recycling processes can significantly decrease the amount of plastic entering marine environments. Public awareness campaigns also help encourage environmentally responsible behavior among people.

Strengthening safety standards during oil extraction and transportation is another important measure. Modern monitoring systems and satellite technologies make it possible to detect oil spills at early stages. In emergency situations, advanced cleanup technologies can prevent pollution from spreading further. International maritime organizations continue to develop stricter regulations for oil transportation and marine safety.

The development of wastewater treatment technologies also plays an essential role in reducing marine pollution. Biological and chemical treatment methods help reduce the amount of toxic substances entering seas and oceans. Modern filtration systems can remove certain amounts of microplastics from wastewater before it reaches marine environments. Many developed countries are implementing innovative technologies for complete wastewater purification.

International cooperation is of great importance in preventing marine pollution. The United Nations Convention on the Law of the Sea and other international agreements aim to protect oceans and marine biodiversity. Cooperation between countries through data exchange and joint monitoring systems improves pollution management. Furthermore, supporting scientific research contributes to the development of new environmental solutions [8].

Artificial intelligence and digital technologies are increasingly used in modern environmental monitoring systems. Satellite data analysis helps identify pollution sources and predict high-risk zones. AI-based models can estimate ocean currents and forecast the spread of pollutants in advance. These technologies are expected to play a major role in the protection of marine ecosystems in the future.

4. Conclusion

Marine ecosystem pollution is considered one of the major global environmental problems of the modern world. Industrial waste, oil spills, plastics, and chemical substances reduce the quality of marine environments and cause serious damage to biodiversity. Pollution processes

create not only ecological but also economic and social problems. Solving these issues requires coordinated action by governments and international organizations.

The analysis presented in this article demonstrates that effective waste management, modern purification technologies, and stronger international cooperation are essential for preventing marine pollution. Reducing plastic waste and preventing oil spills should remain among the primary environmental priorities. At the same time, environmental education and public awareness campaigns play a significant role in reducing pollution.

In the future, strengthening environmental policies, implementing sustainable development strategies, and increasing public ecological awareness will be crucial for protecting marine ecosystems. Only comprehensive and scientifically based approaches can ensure the sustainability of marine environments. International cooperation and innovative technologies will continue to play a central role in this process.

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