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Addressing the global challenge of coastal sewage pollution

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Abstract :

Coastal environments, essential for about half of the world's population living near coastlines, face severe threats from human-induced activities such as intensified urbanization, aggressive development, and particularly, coastal sewage pollution. This type of pollution, comprising untreated sewage discharging nutrients, pathogens, heavy metals, microplastics, and organic compounds, significantly endangers these ecosystems. The issue of sewage in coastal areas is complex, influenced by factors like inadequate sewage systems, septic tanks, industrial and agricultural runoff, and natural processes like coastal erosion, further complicated by oceanic dynamics like tides and currents. A global statistic reveals that over 80 % of sewage enters the environment without treatment, contributing significantly to nitrogen pollution in coastal ecosystems. This pollution not only harms marine life and ecosystems through chemical contaminants and eutrophication, leading to hypoxic zones and biodiversity loss, but also affects human health through waterborne diseases and seafood contamination. Additionally, it has substantial economic repercussions, impacting tourism, recreation, and fisheries, and causing revenue and employment losses. Addressing this issue globally involves international agreements and national legislations, but their effectiveness is hindered by infrastructural disparities, particularly in developing countries. Thus, effective management requires a comprehensive approach including advanced treatment technologies, stringent regulations, regular monitoring, and international cooperation. The international scientific community plays a crucial role in fostering a collaborative and equitable response to this pressing environmental challenge.

Highlights

► Pollution of coastal waters by untreated or inadequately treated sewage. ► Over 80 % of sewage is discharged into the environment without treatment. ►Sewage pollution leads to biodiversity loss, eutrophication, and harmful algal blooms. ► This type of pollution also affects tourism, fisheries, and local economies. ► International collaboration is essential for effective sewage pollution management.

Keywords : Sewage, Pollution, Impacts, Wastewater treatment, Management

Coastal environments face increasing threats from human activities, with around half of the global population living within 150 kilometers of coastlines, leading to intensified urbanization and demographic pressures (UN-Habitat 2020). These pressures are exacerbated by factors such as aggressive urban development, excessive litter production, sand extraction, and notably, coastal sewage pollution (Doody 2013). Coastal sewage pollution, a critical and rapidly growing concern, involves the contamination of coastal waters by untreated or inadequately treated sewage, characterized by the discharge of nutrients, pathogens, heavy metals, microplastics, and organic compounds, posing significant risks to these fragile environments (Rangel-Buitrago 2019).

The United Nations Sustainable Development Goals (SDGs), have amplified global attention on the challenges of sewage pollution in coastal regions, as highlighted by two significant events. In 2023, the Gaza Strip experienced an environmental crisis, a stark reminder of the consequences of poor sewage management. The region's infrastructural damage and blockade led to over 130,000 cubic meters of untreated sewage being discharged daily into the Mediterranean Sea, causing an environmental disaster and a public health emergency. Families, lacking alternatives, used contaminated seawater for daily needs, increasing disease transmission, particularly among children. In another event in June 2023, a storm-induced burst pipe along the Fylde coast (UK) led to a major sewage spill contaminating several beaches. This incident exposed the fragility of coastal sewage systems against extreme weather, with delayed warnings exacerbating public health risks.

The entry of sewage into coastal regions is a complex issue influenced by both natural and anthropogenic factors (Callejas 2022). Municipal sewage systems, especially outdated or overburdened ones, contribute significantly by discharging untreated sewage directly into the sea (Figure 1). In areas without centralized sewage treatment, septic systems can also lead to nutrient and pathogen contamination in coastal waters, exacerbated in places with high groundwater levels or porous soils. Industrial activities near coastlines add to this pollution with their release of heavy metals, chemicals, and organic waste. Additionally, agricultural runoff, carrying fertilizers, pesticides, and animal waste, and urban stormwater runoff, especially during heavy rains, contribute pollutants including sewage to coastal areas. Combined sewer overflows in some cities release both stormwater and untreated sewage during heavy rainfall. Boat discharge and unregulated sewage discharges in areas with lenient regulations also contribute, while natural processes like coastal erosion and sediment resuspension can reintroduce trapped pollutants to coastal waters, further complicating this environmental challenge.

Urban wastewater represents a significant challenge for environmental management, yet it also offers an opportunity for sustainable resource use, particularly in developing countries. When treated effectively, wastewater can be transformed from a pollutant into a valuable resource, reducing the extraction pressure on natural water bodies and contributing to water security. The reclamation and reuse of treated wastewater for agricultural irrigation, industrial processes, and even as potable water through advanced treatment technologies can significantly alleviate the demand on freshwater resources. This approach not only mitigates the environmental impacts associated with untreated sewage discharge into coastal and other aquatic ecosystems but also supports water conservation and sustainability initiatives. The potential benefits are especially pertinent in developing regions, where water scarcity and inadequate sanitation infrastructure pose pressing challenges, highlighting the need for investment in treatment facilities and technologies that enable wastewater reuse.

Upon reaching coastal areas, sewage undergoes distinct interactions with seawater, characterized by high levels of chlorides, dissolved salts, and influenced by dynamic ocean forces like waves, tides, and currents (Gierach et al., 2017). Tidal dynamics play a critical role in spreading and distributing sewage contaminants; high tides can dilute and disperse sewage, potentially reducing pollutant concentrations, while low tides may cause stagnation and concentration of contaminants in specific areas. Different ocean currents, such as longshore currents, rip currents, and gyres, significantly affect sewage movement. For instance, longshore currents transport sewage parallel to the coastline, impacting distant areas, while rip currents can carry sewage away from the shore, aiding in its dilution but also affecting water quality over larger distances. The volume of sewage discharged into the world's coastal areas is a significant environmental concern, particularly because a considerable portion remains untreated.

Globally, it is estimated that more than 80% of sewage is released into the environment without any treatment (WWAP 2017). This issue is especially severe in certain regions, such as the Caribbean, where the percentage of untreated sewage is notably higher. In terms of global nitrogen (N) pollution from anthropogenic sources in coastal ecosystems, the estimate stands at approximately 6.2 Tg (Tuholske et al., 2021). Analyzing the sources, about 63% (3.9 Tg) of this nitrogen originates from sewered systems. Septic systems contribute roughly 5% (0.3 Tg), while direct inputs account for 32% (2.0 Tg). Remarkably, nearly half of the nitrogen input into the oceans, approximately 46% or 2.8 Tg, is attributed to around 25 river basins. These basins are characterized by inputs from sewered, septic, and untreated wastewater (Tuholske et al., 2021). These basins are predominantly located in India, Korea, and China, but they are also found on other continents. A significant portion of this nitrogen load, specifically 11%, is attributed to a single source – the Chang Jiang (Yangtze) River in northern China (Tuholske et al., 2021).

The introduction of a variety of pollutants into the environment via coastal sewage presents a significant hazard (Halpern et al., 2008). Chemical contaminants, including pharmaceuticals, personal care products, heavy metals, and microplastics, are of major concern (Rangel-Buitrago et al., 2023). These substances negatively impact marine life by disrupting hormonal and reproductive systems and lead to the bioaccumulation of toxins in the food chain. Additionally, the discharge of nutrient-rich waters from sewage sources aggravates environmental challenges, particularly climate change. The high concentrations of nutrients, such as nitrogen, catalyze the release of nitrous oxide, a potent greenhouse gas, from coastal waters (Zhou et al., 2023). This phenomenon contributes to global warming, exacerbating issues like rising sea levels and increasing ocean acidity.

A cascade of ecological effects on marine ecosystems results from the influx of sewage pollution (Mekonnen et al., 2015). Eutrophication, characterized by excessive nutrient levels leading to abundant algal growth, is a primary outcome. This process disrupts aquatic ecosystems, often resulting in algal blooms that overshadow other vital marine plants and create hypoxic or 'dead zones,' areas inhospitable to most marine life. The decline in biodiversity is significant (Altieri et al., 2017). Harmful Algal Blooms (HABs) produce toxins harmful to a wide array of marine life, impacting food chains and overall ecosystem health. Additionally, the pollutants, such as nitrogen in sewage, threaten coral reefs, leading to bleaching and increased disease susceptibility, thus compromising the resilience of these diverse and productive ecosystems. Alterations in species composition also occur, with pollution-tolerant species replacing more sensitive ones, leading to a loss in biodiversity and disrupting the ecological equilibrium.

The sectors of waste treatment and waste management are witnessing significant growth, driven by the increasing recognition of the need to restore water quality and natural sites while also creating employment opportunities. The development of infrastructures dedicated to advanced sewage treatment, waste recycling, and pollution remediation is not only essential for environmental protection but also acts as a catalyst for economic development. By investing in these sectors, governments and private entities can stimulate job creation across various levels of skill, from engineering and technical roles to operational and maintenance positions. The economic benefits extend beyond employment, as cleaner water bodies and restored natural sites enhance tourism, recreational activities, and real estate values, contributing to the overall economic resilience and sustainability of communities.

The ramifications for human health due to sewage pollution in coastal areas are substantial, primarily through the spread of waterborne diseases and seafood contamination (Wear et al., 2021). Untreated sewage, harboring pathogens like bacteria, viruses, and parasites, poses significant health risks when it contaminates coastal waters. Those exposed to these polluted waters, through activities like swimming, fishing, or other recreations, face increased risks of gastrointestinal, dermatological, and respiratory conditions. The concern is heightened in regions heavily reliant on these waters for daily activities or recreation. Moreover, the accumulation of pollutants such as heavy metals, chemicals, and microbial contaminants in fish and shellfish raises serious health concerns. These include food poisoning and neurological disorders, with shellfish being particularly susceptible due to their tendency to concentrate higher pollutant levels. This not only poses direct health risks but also impacts the seafood industry, influencing global food safety standards and consumer trust.

Coastal sewage pollution exerts a considerable toll on the economic and social fabric of coastal communities, primarily through its negative effects on tourism, recreation, fisheries, and aquaculture (Rangel-Buitrago 2019). Beach closures and a decline in water quality, direct consequences of pollution, significantly deter tourism and recreational activities (Islam et al., 2018). Coastal areas, often prized for their natural beauty and recreational opportunities, suffer a loss of visitor numbers and revenue when beaches are deemed unsafe for swimming, fishing, or other water-based activities. This downturn not only impacts local businesses and employment dependent on tourist spending but also diminishes the recreational value of these natural resources for residents.

In addition, the contamination and ecological disruption caused by sewage pollution have a profound impact on commercial fisheries and aquaculture (Altieri et al., 2017). The accumulation of toxins and pathogens in marine life leads to fish kills and reduced yields, directly affecting the livelihoods of fishermen and aquaculture operators. It also undermines consumer confidence in seafood safety, leading to market declines and economic losses. Furthermore, these impacts can extend beyond immediate coastal areas, affecting regional and even global seafood markets.

Coastal sewage pollution is addressed globally through a combination of international agreements, regional protocols, and national legislations, albeit with varying degrees of effectiveness across different regions (Malik et al., 2015). On an international level, agreements such as the United Nations Convention on the Law of the Sea (UNCLOS) establish general guidelines for marine environmental protection, including pollution control measures. Specific regional agreements, such as the Mediterranean Action Plan under the Barcelona Convention and the Helsinki Convention for the Baltic Sea, set more targeted standards for sewage discharge and treatment to protect marine ecosystems. Nationally, countries implement their own environmental laws to regulate sewage pollution. For example, the United States enforces the Clean Water Act, which oversees the discharge of pollutants into waters, while the European Union upholds directives like the Urban Wastewater Treatment Directive, mandating standards for urban wastewater treatment and discharge. These laws typically specify minimum requirements for sewage treatment, such as secondary and tertiary treatments, to remove organic materials, suspended solids, and nutrients like nitrogen and phosphorus.

On 26 October 2022, the Commission revised the 1991 Directive in line with the results of an evaluation and based on an extensive impact assessment, adapting it to the newest standards. By 2040 the new rules plan to (i) save almost EUR 3 billion per year across the EU, (ii) reduce greenhouse gas emissions by over 60% compared to 1990, (iii) decrease water pollution by more than 365 thousand tonnes, & (iv) cut microplastics emissions by 9%. In addition, the EU Mission "Restore our Ocean and Waters" aims to protect and restore the health of EU ocean and waters through research and innovation, citizen engagement, and blue investments. For its first term (2 years), the mission funded 20 projects to restore the EU seas (117 million Euros).

The effectiveness of these regulations is also dependent on the monitoring and enforcement mechanisms in place (Williams and Micallef 2009). Regular testing of sewage effluents and coastal water quality, combined with penalties for non-compliance, are essential for ensuring adherence to standards. However, the challenge is more acute in developing countries, where limited infrastructure and funding impede effective sewage management. International aid and development projects are thus crucial in these regions. Additionally, specific regulations may target pollutants of concern, like heavy metals, pharmaceuticals, or microplastics, setting limits on their presence in wastewater discharges. The role of non-governmental organizations (NGOs) and public awareness campaigns cannot be understated; they are pivotal in advocating for stronger regulations, better enforcement, and educating the public about the consequences of sewage pollution. Overall, while there are concerted efforts to control coastal sewage pollution through various regulations, the global disparity in infrastructure and enforcement highlights the need for continued and enhanced efforts to safeguard marine environments.

Effective management of coastal sewage pollution necessitates a comprehensive, multi-faceted strategy that includes upgrading and expanding sewage treatment facilities with advanced processes like tertiary treatment, strict enforcement of regulations on sewage discharge, and the adoption of innovative technologies such as membrane bioreactors and constructed wetlands (Williams and Micallef 2009). Key to this approach is also regular monitoring and research on the effects of sewage on marine ecosystems and public health. Additionally, community engagement and education play a critical role in raising awareness about proper waste disposal and the impacts of sewage pollution. Integrated Coastal Zone Management (ICZM) approaches, reducing pollutants at the source, and international collaboration, particularly in aiding developing countries to build and manage sewage infrastructure, are essential components of this comprehensive strategy.

The effective implementation of coastal sewage management strategies faces significant obstacles, particularly in developing countries where limited resources pose substantial challenges. These barriers underscore the critical need for a global reassessment of current practices and policies in coastal sewage management, informed by scientific research and environmental analysis. It is vital for the international scientific community to acknowledge and proactively engage in addressing these complexities. A concerted effort is required to support nations facing resource limitations, ensuring that the global response to coastal sewage pollution is both collaborative and equitable.

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Figure 1. A deteriorating sewage system discharges polluted water into the Caribbean Sea off the coast of Colombia. This situation poses risks to both the ecological balance of the shoreline and human health. The lack of maintenance and apparent abandonment of the sewage infrastructure indicate a neglect of environmental management in the area.