

On the Problem of Wastewater Formation, Disposal, Treatment, and Discharge

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Abstract:

The article examines the theoretical and applied aspects of wastewater generation, drainage, treatment, and discharge into water bodies under conditions of increasing anthropogenic pressure on aquatic ecosystems. It provides a systematic analysis of wastewater generation sources, their quantitative and qualitative characteristics, modern transportation and treatment technologies, and environmental requirements for discharging treated water into water bodies. The study substantiates the need to implement integrated water management solutions based on the principles of a circular economy and sustainable development. Particular attention is paid to the application of best available technologies, the digitalization of monitoring processes, and the minimization of environmental risks.

Keywords: Wastewater, Sewerage, Wastewater Treatment, Permissible Discharge Standard, Environmental Safety, Sustainable Development, Circular Economy.

Introduction

Wastewater management is a critical element of sustainable development, as it affects the state of water ecosystems, public health, and resource conservation. According to UN/WHO data, only **56% of domestic wastewater in the world undergoes safe treatment** at a level that meets the criteria of SDG Target 6.3 (The share of wastewater that has undergone hazardous treatment). Annual wastewater generation worldwide is estimated at approximately **359.4×10⁹ m³/year**, with only about **52% of the total volume** actually undergoing treatment [1]. The problem is exacerbated by the fact that even in

developed countries, a significant portion of wastewater is not treated to the required environmental standards [2]. A number of studies indicate that up to **80% of wastewater in the world may be discharged into the environment without sufficient treatment**. In the context of globalization, urbanization, and industrialization, the pressure on surface and underground water resources is increasing, requiring the improvement of drainage and wastewater treatment systems. According to United Nations data, a significant portion of the wastewater generated worldwide is discharged into the environment without sufficient treatment, leading to the degradation of ecosystems and the deterioration of drinking water quality. According to World Health Organization estimates, the pollution of water sources remains one of the causes of the spread of infectious diseases, especially in developing regions [3]. The purpose of this article is to form a comprehensive scientific approach to researching the conditions for the formation, transportation, treatment, and discharge of wastewater, taking into account modern technological and environmental requirements.

Materials and Methods

The study was conducted based on a comprehensive analysis of scientific publications, statistical data from international organizations, and regulatory documents in the field of wastewater disposal and treatment. The results of modern scientific research dedicated to wastewater management issues were used as an information base [4], [5], [6], [7].

Theoretical foundations of wastewater formation. The formation of wastewater is a complex multi-factor process determined by the nature of economic activity, water consumption levels, population density, and natural-climatic conditions. Depending on the source of formation, wastewater is classified as follows:

- Domestic wastewater is formed in residential and public buildings;
- Industrial wastewater is formed as a result of technological processes;
- Surface (rainfall) wastewater is formed as a result of atmospheric precipitation;
- Agricultural wastewater is associated with irrigation, animal husbandry, and agro-industrial processing.

The qualitative composition of wastewater is characterized by indicators of biochemical oxygen consumption (BCP), chemical oxygen consumption (CHP), the concentration of suspended matter, biogenic elements (nitrogen, phosphorus), heavy metals, and pathogenic microflora. Quantitative parameters are determined by water consumption norms, technological production modes, and water conservation levels [8], [9], [10].

Organization of wastewater disposal systems. Sewerage systems are divided into centralized and decentralized. In engineering practice, three main sewage schemes are used: separate; general-melting; and semi-separate.

The choice of scheme is determined by urban planning conditions, economic factors, and environmental requirements. The design of drainage networks is based on hydraulic calculations that ensure self-flow or pressure transportation. Minimizing groundwater infiltration and preventing emergency discharges is of significant importance. Modern trends include the implementation of automated control systems, flow rate and quality control sensors, and the use of energy-efficient pumping equipment [11].

Formulas and cleaning efficiency indicators.

Coefficient of removal of contaminants. The primary indicator of wastewater treatment efficiency is the removal of contaminants (η).

Formula for the pollution removal factor:

$$\eta = \frac{C_{BX} - C_{BbIX}}{C_{BX}} \times 100\%$$

where: C_{input} is the concentration of the pollutant at the inlet of the treatment plant (mg/l);

- C_{output} - the concentration of pollutant at the outlet after purification (mg/l);
- η - cleaning efficiency, %.

In an alternative form (without interest):

$$\eta = \frac{C_{BX} - C_{B\text{Ы}X}}{C_{BX}}$$

Modern technologies for wastewater treatment. Wastewater treatment is carried out according to a multi-stage technological scheme that includes:

Mechanical cleaning. It provides for the removal of large and suspended particles through grates, sand traps, and primary settling tanks. Efficiency reaches 50–70% for suspended substances.

Biological purification. It is based on the microbiological oxidation processes of organic substances under aerobic and anaerobic conditions. The most common are aeration tanks with active sludge, biofilters, and bioreactors. The kinetics of biochemical oxidation are described by the Mono equation:

$$\mu = \mu_{max} \frac{S}{K_s + S}$$

K_s Where: μ is the specific growth rate of microorganisms, S is the substrate concentration, and is the saturation constant [12].

Physicochemical methods. Includes coagulation, flocculation, flotation, sorption, and ozonization. These methods are used to remove hard-to-oxidize and toxic compounds.

Membrane technologies. The use of ultrafiltration and reverse osmosis ensures a high degree of purification and the possibility of water reuse in technological cycles.

A promising direction is the implementation of membrane bioreactors and anaerobic plants with biogas production, which increases the energy efficiency of treatment plants. Modern membrane technologies (MBR) ensure the removal of up to 95-99% of pollutants.

Normative requirements for wastewater discharge. The discharge of treated wastewater into water bodies is permitted provided that permissible discharge standards and maximum permissible concentrations of pollutants are met.

Environmental regulation is aimed at preventing: the eutrophication of water bodies; the accumulation of toxic substances in bottom sediments; and the deterioration of the sanitary and hygienic condition of water bodies [13].

Control is carried out through laboratory analysis, automated monitoring stations, and environmental audits.

In modern conditions, the concept of "Zero Liquid Discharge" is becoming increasingly widespread, which involves minimizing or completely eliminating the discharge of liquid waste into the environment.

Environmental and socio-economic aspects. Insufficient treatment of wastewater leads to the accumulation of nutrients (nitrogen, phosphorus) and organic pollutants in water bodies, causing esterification, a decrease in dissolved oxygen levels, and the destruction of biodiversity. Inefficient treatment systems lead to the spread of diseases, increased drinking water costs, and losses in fisheries and agriculture.

Inefficient drainage and wastewater treatment systems lead to the degradation of aquatic ecosystems, a decrease in biodiversity, and economic losses.

Integrated wastewater management must be based on: implementing the best available technologies; digitalizing monitoring processes; economic mechanisms to stimulate resource conservation; and improving the regulatory and legal framework [14].

The integration of sustainable development principles and the circular economy allows for treating wastewater as a source of secondary resources—water, energy, and nutrients [15].

Results

The analysis of modern wastewater management systems demonstrated that the efficiency of wastewater treatment largely depends on the combination of mechanical, biological, physicochemical, and membrane technologies. The reviewed studies and international statistical reports indicate that conventional mechanical treatment removes approximately 50–70% of suspended solids, while biological treatment systems significantly reduce biochemical oxygen demand and organic pollutants.

Advanced membrane technologies, particularly membrane bioreactors (MBR), were identified as the most effective methods, ensuring pollutant removal rates of up to 95–99%.

The study also revealed that increasing urbanization and industrialization have substantially intensified the volume of wastewater generation worldwide. Statistical data from international organizations confirmed that nearly half of global wastewater is still discharged without adequate treatment, creating serious environmental risks for surface and groundwater resources. In many developing regions, insufficient infrastructure, outdated treatment facilities, and weak environmental monitoring systems remain major barriers to effective wastewater management.

The analysis further demonstrated that integrated wastewater treatment systems combining biological and membrane technologies provide higher environmental and economic efficiency compared to traditional systems. The implementation of automated monitoring stations, digital control systems, and energy-efficient pumping equipment improves operational reliability and minimizes accidental pollutant discharge. In addition, the application of the “Zero Liquid Discharge” concept contributes to reducing liquid waste emissions and increasing the reuse of treated water in industrial and agricultural sectors.

The obtained results confirm that sustainable wastewater management requires not only technological modernization but also the integration of environmental regulations, economic mechanisms, and resource-saving approaches. Wastewater should increasingly be considered as a secondary resource containing reusable water, nutrients, and energy potential.

Discussion

The findings of this study highlight the growing importance of integrated wastewater management in ensuring environmental safety and sustainable development. The results demonstrate that modern wastewater treatment technologies can significantly improve water quality and reduce the negative impact of anthropogenic activities on aquatic ecosystems. In particular, membrane bioreactors and advanced biological treatment systems showed the highest treatment efficiency, supporting the conclusions of previous international studies on innovative wastewater technologies .

At the same time, the analysis revealed that many countries continue to face serious challenges related to insufficient treatment infrastructure and increasing wastewater generation caused by urbanization, industrial growth, and population expansion. The discharge of untreated or partially treated wastewater contributes to eutrophication, biodiversity loss, and the spread of waterborne diseases. These environmental and public health risks are especially critical in developing regions where monitoring systems and treatment capacities remain limited.

The study also emphasizes that technological solutions alone are insufficient for solving wastewater problems. Effective wastewater management requires comprehensive regulatory frameworks, digital monitoring systems, economic incentives for resource conservation, and stronger environmental control mechanisms. The integration of circular economy principles allows wastewater to be transformed from an environmental burden into a valuable source of reusable water, energy, and nutrients.

Furthermore, the implementation of automated monitoring technologies and smart wastewater management systems can improve operational efficiency and support real-time environmental assessment. Such approaches contribute to minimizing ecological risks and increasing the sustainability of urban water infrastructure. Therefore, future wastewater management strategies should combine engineering innovation, environmental protection measures, and sustainable resource management principles to achieve long-term ecological and socio-economic stability.

Conclusion

The formation, drainage, treatment, and discharge of wastewater are interconnected elements of a unified water management system. A scientifically grounded approach to their organization involves

a comprehensive combination of engineering, environmental, and economic solutions. Increasing the efficiency of treatment plants, implementing innovative technologies, and improving regulatory frameworks are key conditions for ensuring environmental safety and sustainable water use.

Integrated wastewater management requires a combination of engineering precision, environmental control, and strategic planning. Statistical data confirm that a significant portion of wastewater in the world is not treated at the proper level, creating serious environmental and socio-economic risks. The proposed innovative approaches and recommendations are aimed at increasing the efficiency of treatment systems, reducing the burden on ecosystems, and sustainable water resource management.

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