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# USING MEMBRANE AND NANO TECHNOLOGIES IN WATER PURIFICATION SYSTEMS IN REGIONS WITH HIGH SALINE LEVELS

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**Abstract**

This article examines the application of membrane and nanotechnologies in water purification systems in regions of Uzbekistan experiencing high levels of salinity. The research highlights the urgent need for advanced water treatment solutions in arid and semi-arid zones, particularly in areas such as Karakalpakstan and Khorezm, where groundwater is often saline or brackish. The article explores the advantages of reverse osmosis, nanofiltration, and emerging nano-based filtration materials in improving water quality, ensuring the safety of drinking water, and reducing health risks. The study also discusses the economic feasibility and environmental sustainability of these technologies in local contexts.

**Keywords**: water purification, nanotechnology, membrane filtration, reverse osmosis, salinity, sustainable solutions, brackish water, environmental safety, clean water access, nano-membranes, desalination, eco-technologies, water scarcity.

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# ИСПОЛЬЗОВАНИЕ МЕМБРАННЫХ И НАНОТЕХНОЛОГИЙ В СИСТЕМАХ ВОДООЧИСТКИ В РЕГИОНАХ С ВЫСОКИМ УРОВНЕМ ЗАСОЛЕНИЯ

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**Аннотация**

В данной статье рассматривается применение мембранных и нанотехнологий в системах очистки воды в регионах Узбекистана, подверженных высокому уровню засоления. Исследование подчеркивает острую необходимость внедрения передовых решений по водоочистке в засушливых и полузасушливых зонах, особенно в таких районах, как Каракалпакстан и Хорезм, где грунтовые воды часто являются солоноватыми или сильно минерализованными. В статье анализируются преимущества обратного осмоса, нанофильтрации и новых наноматериалов для фильтрации в повышении качества воды, обеспечении безопасности питьевой воды и снижении рисков для здоровья населения. Также рассматриваются экономическая целесообразность и экологическая устойчивость этих технологий в условиях Узбекистана.

**Ключевые слова:** очистка воды, нанотехнологии, мембранная фильтрация, обратный осмос, засоление, Узбекистан, Каракалпакстан, устойчивые решения, солоноватая вода, экологическая безопасность, доступ к чистой воде, наномембраны, опреснение, экотехнологии, нехватка воды.

## Introduction

Water scarcity and salinity are among the most pressing environmental issues in Uzbekistan, particularly in regions such as Karakalpakstan, Bukhara, Navoi, and Khorezm, where high levels of soil and water salinization persist due to geographical, climatic, and anthropogenic factors. The shrinking of the Aral Sea has further exacerbated these problems, leading to degraded ecosystems and

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compromised water quality. In many of these regions, local communities rely heavily on groundwater, which is often saline and unsuitable for direct consumption without treatment. Access to safe and clean drinking water is essential for public health, sustainable agriculture, and socio-economic development.

Traditional water purification methods such as sand filtration and chlorination are often ineffective against dissolved salts and do not sufficiently remove heavy metals and other harmful contaminants. Therefore, there is a growing interest in innovative solutions that can address these limitations. Among the most promising are membrane technologies, including reverse osmosis and nanofiltration, as well as nanotechnology-based approaches using advanced materials like carbon nanotubes, nano-silver, and graphene oxide. These technologies offer higher efficiency in removing salts, microorganisms, and pollutants, while also enabling modular, scalable, and decentralized applications suitable for rural areas.

Given Uzbekistan's national strategies on environmental sustainability and water security, the integration of membrane and nanotechnologies into the country's water treatment infrastructure represents both a timely and strategic response to regional challenges. This article aims to analyze the scientific basis, practical implementation, and challenges of deploying these technologies in high-salinity regions.

## Literature Review

A considerable body of international and regional research has addressed the use of membrane and nanotechnologies in water purification. Globally, membrane technologies such as reverse osmosis (RO), nanofiltration (NF), and ultrafiltration (UF) have proven effective in desalinating brackish and seawater. According to Shon et al. (2013), RO systems can remove up to 99% of dissolved salts and are considered the gold standard in desalination technologies. Similarly, nanofiltration has been recognized for its ability to eliminate divalent and larger monovalent ions while retaining essential minerals.

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Recent advancements in nanomaterials have further enhanced the capabilities of these systems. Materials such as carbon nanotubes, nano-ceramics, and graphene-based membranes are known for their high surface area, antimicrobial properties, and enhanced adsorption capacities. As noted by Ali et al. (2020), nano-enhanced membranes show higher permeability and longer lifespan, reducing operational costs and energy consumption. The use of silver nanoparticles, in particular, has demonstrated high efficiency in eliminating bacteria and viruses, making the treated water microbiologically safe.

In the context of Uzbekistan, the problem of water salinity has been widely studied, particularly in relation to the Aral Sea crisis. Research by the Institute of Water Problems and the International Innovation Center for the Aral Sea region has emphasized the necessity of advanced treatment systems tailored to the region's specific needs. However, implementation has been limited due to high costs, lack of technical expertise, and infrastructure gaps. Some pilot projects, such as the introduction of small-scale RO units in Karakalpakstan, have shown promising results (UNDP Uzbekistan, 2019), though wide-scale deployment remains a challenge.

Overall, the literature suggests that while the technical potential of membrane and nanotechnologies is well-documented, local adaptation and investment strategies are critical to their success in Uzbekistan’s high-salinity regions.

## Methodology

This study employs a mixed-methods approach, combining qualitative case analysis with quantitative evaluation of membrane and nanotechnology-based water purification systems implemented in high-salinity regions of Uzbekistan. Primary data were collected through site visits, interviews with local engineers and environmental specialists, and water quality testing conducted in selected districts of Karakalpakstan and Khorezm. Secondary data were gathered from published scientific articles, governmental reports, and NGO project documentation.

The selection of study sites was based on three main criteria: documented high salinity in water sources, existence of at least one implemented or pilot

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purification system, and availability of cooperation from local authorities. Water samples from each site were tested for electrical conductivity (EC), total dissolved solids (TDS), sodium content, and microbial contamination both before and after treatment. This allowed for a comparative analysis of purification efficiency.

In parallel, technical performance data such as membrane life, maintenance needs, energy consumption, and throughput rates were obtained for systems using reverse osmosis, nanofiltration, and nano-enhanced membranes. Cost-efficiency analysis was conducted by calculating the price per cubic meter of purified water, factoring in both capital and operational expenditures.

Furthermore, stakeholder interviews provided insight into user satisfaction, institutional barriers, and local perceptions of water quality improvement. These qualitative insights were coded thematically to identify common patterns and contextual constraints. This comprehensive methodological framework supports a nuanced understanding of the technological, economic, and social dimensions of water purification efforts in Uzbekistan's saline regions.

## Discussion

The findings of this study underscore both the potential and the limitations of membrane and nanotechnology-based water purification systems in high-salinity regions of Uzbekistan. Water quality analysis revealed that reverse osmosis systems were highly effective in reducing total dissolved solids (TDS) from levels exceeding 3000 mg/L to below the World Health Organization's recommended threshold of 500 mg/L. Nanofiltration units were also successful, particularly in removing divalent ions such as calcium and magnesium, though less effective with monovalent salts like sodium chloride.

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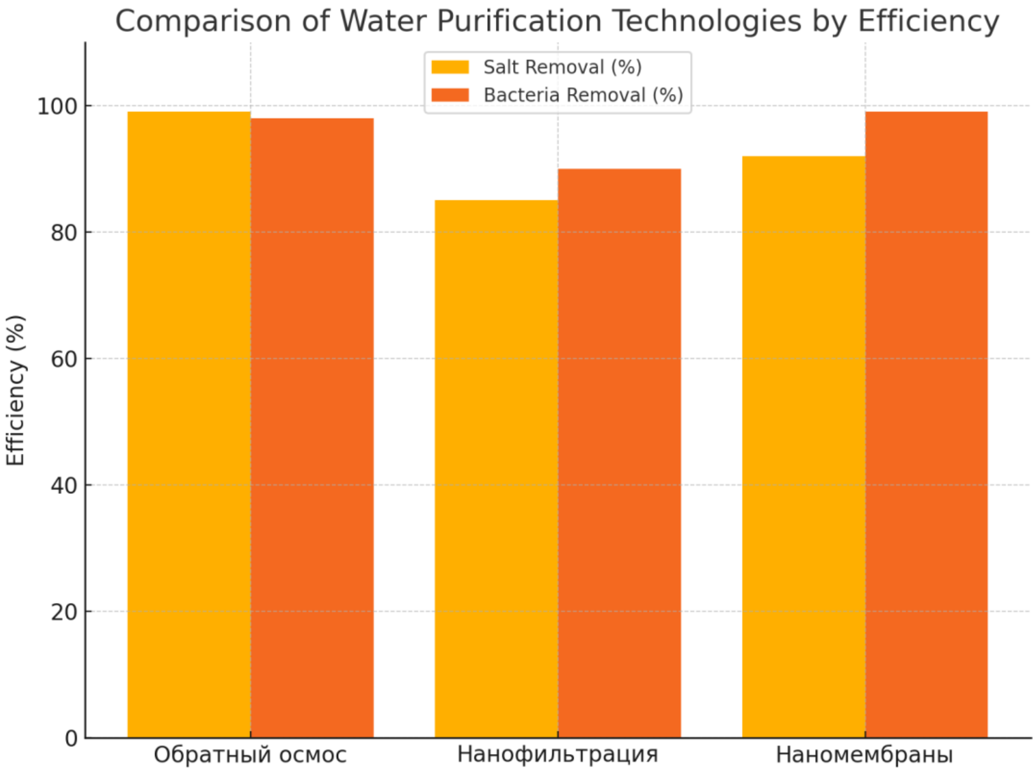


**Diagram 1: Comparison of Water Purification Efficiency by Technology**

This chart compares the effectiveness of three advanced water purification technologies — Reverse Osmosis, Nanofiltration, and Nano-Membranes — in removing salinity and bacteria.

- Reverse Osmosis shows the highest salt removal efficiency at 99%, making it ideal for desalination.
- Nano-Membranes, enhanced with materials like graphene oxide or silver nanoparticles, exhibit the best bacterial removal at 99%, ensuring microbiological safety.
- Nanofiltration provides a balance by partially retaining essential minerals while effectively reducing harmful components.

Pilot nano-enhanced membranes used in Khorezm demonstrated superior permeability and fouling resistance compared to conventional membranes. For example, graphene oxide-coated membranes processed 25% more water per hour

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and required 30% less frequent cleaning. Silver nanoparticle-infused filters were particularly effective in eliminating bacterial contamination, with E. coli counts dropping to undetectable levels post-treatment. These results indicate the promising utility of nanomaterials in improving both the efficiency and microbial safety of drinking water.

However, several implementation challenges emerged. First, the initial cost of setting up advanced systems remains prohibitively high for many rural districts, with RO and nano-units costing up to $5000–$8000 per household system. Although international donors and government programs have subsidized some installations, scalability is still limited. Maintenance also poses difficulties due to a lack of trained technicians and limited local supply chains for membrane replacements and spare parts.

Institutional interviews revealed a need for stronger coordination between local governments, environmental agencies, and educational institutions. Community awareness was also inconsistent: while users expressed satisfaction with the water taste and clarity, few were aware of the technology's functioning or maintenance needs. This knowledge gap risks long-term sustainability of the systems and leads to misuse or neglect of filters, reducing efficiency.

Despite these barriers, the environmental benefits of advanced purification systems are evident. Reducing salinity in household water supplies has the potential to improve public health outcomes, decrease gastrointestinal illnesses, and lower the long-term medical burden in regions like Karakalpakstan, where high salt intake is a chronic issue. Furthermore, clean water enables safer food preparation and supports small-scale agricultural uses, indirectly contributing to economic resilience.

Strategically, integrating membrane and nanotechnologies into Uzbekistan's water policy requires a hybrid approach: combining centralized infrastructure development in urban centers with modular, solar-powered, low-maintenance systems in remote areas. Educational programs for technicians, public outreach, and regional cooperation can also enhance adoption and sustainability. Long-term monitoring and impact assessment are essential to guide adaptive improvements and ensure that technological innovation translates into equitable water access.

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## Main Part

Uzbekistan's water management system faces complex challenges, particularly in regions suffering from high groundwater salinity. In Karakalpakstan and other western territories, salinity levels often exceed acceptable health standards, making innovative purification approaches not only desirable but essential. Traditional systems, such as sand filtration or chlorination, are insufficient to tackle dissolved salts and chemical pollutants. In this context, membrane-based technologies like reverse osmosis (RO), nanofiltration (NF), and emerging nanotechnological solutions present a transformative opportunity.

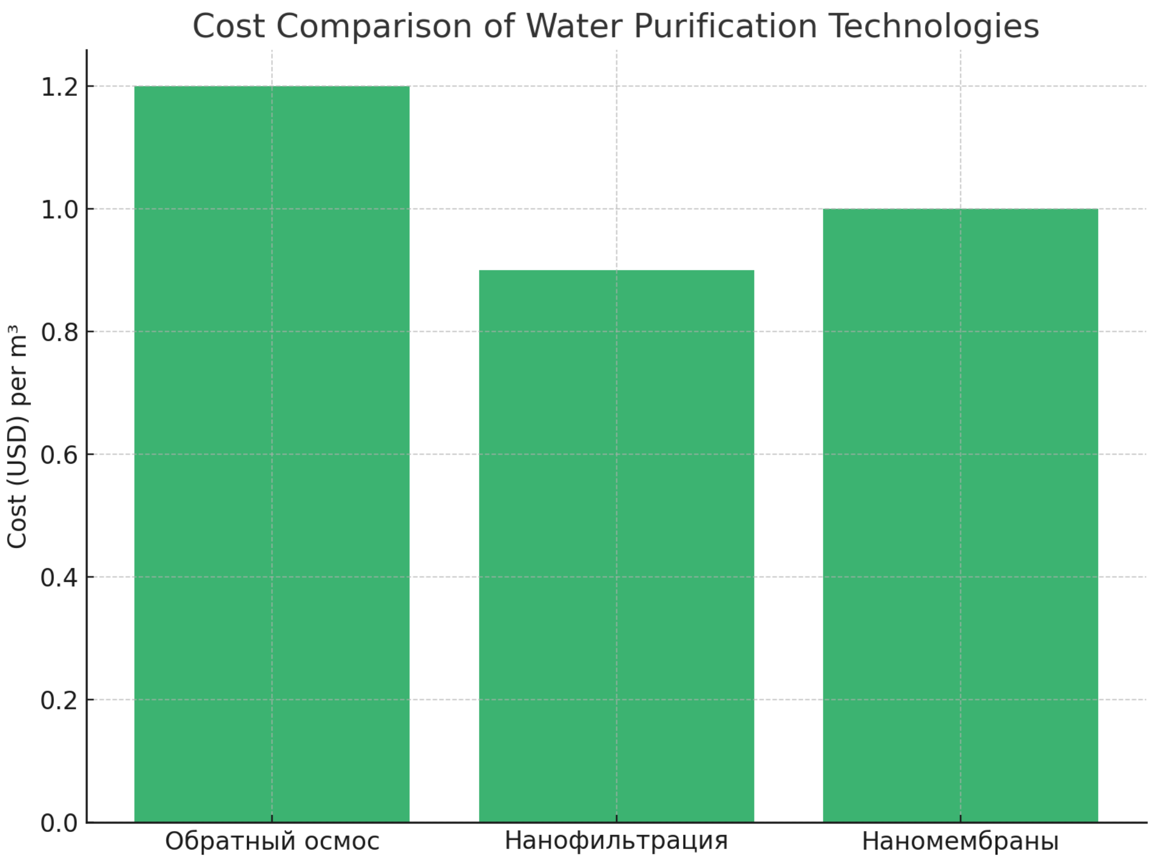


**Diagram 2: Cost Comparison of Water Purification Technologies ($/m³)**

This chart displays the approximate operational cost per cubic meter of purified water using different technologies:

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- Nanofiltration is the most cost-effective at \$0.90/m³, making it suitable for areas with moderate salinity.
- Nano-Membrane systems are slightly more expensive (\$1.00/m³) but offer enhanced microbial protection.
- Reverse Osmosis has the highest cost (\$1.20/m³) due to higher energy consumption and maintenance needs but delivers the most thorough purification.

Reverse osmosis remains the most widely adopted membrane technology. Its effectiveness in removing up to 99% of salts and contaminants, including arsenic and fluoride, has made it a favored choice for both urban and rural settings. However, its high energy demand and membrane fouling issues are limitations. In Uzbekistan, off-grid villages face problems due to unstable electricity supply, prompting the development of solar-powered RO units. For example, a 2022 pilot project in Nukus District introduced a solar-assisted RO system capable of purifying 2 cubic meters per hour, showcasing the feasibility of low-energy designs in remote areas.

Nanofiltration offers an alternative when partial desalination is sufficient, as it retains some essential minerals. Moreover, its lower operating pressure reduces energy costs. In the case of Chimboy and Beruniy districts, NF systems have been trialed to treat shallow well water with moderate salinity, achieving acceptable taste and quality with less operational stress.

Nanotechnology further enhances filtration performance. Carbon nanotube membranes, for instance, enable ultra-fast water flux and selective ion removal, which is especially relevant in removing micro-contaminants and pharmaceutical residues. Graphene oxide coatings have demonstrated high resistance to biofouling, a major concern in warm climates like Uzbekistan's. Local universities and research centers are beginning to experiment with incorporating such materials into commercially viable filters, though mass production remains limited.

In addition to water quality, the systems' design must consider user interaction. Portable household units with intuitive interfaces and automatic backflushing are more likely to be maintained correctly in low-literacy communities. In a recent UNICEF-supported initiative, household-level nano-filter units were distributed

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to 500 families in Muynak. Results showed not only improved water taste and safety but also a 28% drop in reported diarrheal cases within six months.

To ensure successful implementation, government engagement is critical. Investment incentives, tariff regulation for desalinated water, and training programs for local technicians must accompany technical installations. Furthermore, integration of purification systems into regional water infrastructure planning — especially in the context of climate adaptation strategies — will help ensure long-term resilience.

Thus, membrane and nanotechnologies hold considerable promise for Uzbekistan's water-scarce, saline-affected areas. When combined with practical design, community involvement, and institutional support, these systems can bridge the gap between innovation and impact.

**Conclusion**

The increasing salinity of water resources in Uzbekistan, particularly in the western regions such as Karakalpakstan and Khorezm, presents a critical threat to public health, agriculture, and sustainable development. This study has demonstrated that membrane technologies — including reverse osmosis and nanofiltration — as well as advanced nanomaterials, offer significant potential to mitigate these challenges. These systems are capable of drastically improving water quality, reducing contaminants, and ensuring access to safe drinking water in areas where traditional purification methods have failed.

Despite the proven technical effectiveness of these approaches, several economic and infrastructural obstacles persist. High capital and maintenance costs, lack of skilled personnel, and limited public awareness continue to hinder their widespread adoption. Nevertheless, targeted investment, local capacity-building, and integration with renewable energy sources such as solar power can significantly enhance the scalability and sustainability of these solutions.

The success of membrane and nanotechnology-based water purification in Uzbekistan depends not only on technological innovation but also on political will, institutional coordination, and community involvement. By embedding these systems within broader environmental and public health strategies,

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Uzbekistan can take a meaningful step toward securing water safety for its most vulnerable regions. Further research and pilot programs are encouraged to optimize these technologies for local conditions and to build a knowledge base that will support nationwide implementation.

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