ENVIRONMENTAL AND HEALTH IMPACTS OF TECHNOGENIC AND MICROBIOLOGICAL POLLUTION IN THE MAILUU-SUU RIVER BASIN, KYRGYZSTAN: A COMPREHENSIVE ASSESSMENT FOR SUSTAINABLE WATER MANAGEMENT

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Abstract
The Mailuu-Suu River in Kyrgyzstan, a critical water resource in a region historically impacted by uranium mining, faces severe environmental and public health challenges due to technogenic and microbiological pollution. This review synthesizes findings from microbiological analyses of water quality, assessments of radionuclide and trace element contamination, and their combined effects on human health and ecosystems. Microbiological studies reveal elevated levels of lactose-positive Escherichia coli (LPC), exceeding sanitary norms by 2–4 times, indicative of fecal contamination from untreated sewage and industrial discharges. Concurrently, technogenic pollution assessments identify concentrations of uranium (U), selenium (Se), and heavy metals (Al, Fe, Mn, Hg, Pb, Cd) far exceeding Maximum Permissible Concentrations (MPCs), linked to legacy uranium tailings and waste dumps. Health data correlate poor water quality with increased morbidity, including acute intestinal infections, respiratory diseases, and cancer, particularly in downstream communities like Kok-Tash. Vegetation and soil analyses further highlight the unsuitability of floodplain areas for agriculture due to radionuclide accumulation. This review underscores the urgent need for a multidisciplinary water protection program, integrating regular monitoring, advanced treatment technologies, and transboundary cooperation to mitigate pollution and safeguard sustainable development in the Mailuu-Suu region.

Keywords: Mailuu-Suu River, microbiological quality, technogenic pollution, radionuclides, Kyrgyzstan

ВЛИЯНИЕ ТЕХНОГЕННОГО И МИКРОБИОЛОГИЧЕСКОГО ЗАГРЯЗНЕНИЯ НА ОКРУЖАЮЩУЮ СРЕДУ И ЗДОРОВЬЕ В БАССЕЙНЕ РЕКИ МАЙЛУУ-СУУ, КЫРГЫЗСТАН: КОМПЛЕКСНАЯ ОЦЕНКА ДЛЯ УСТОЙЧИВОГО УПРАВЛЕНИЯ ВОДНЫМИ РЕСУРСАМИ

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Аннотация
Река Майлуу-Суу в Кыргызстане, критически важный водный ресурс в регионе, исторически подверженном влиянию добычи урана, сталкивается с серьезными проблемами окружающей среды и общественного здравоохранения из-за техногенного и микробиологического загрязнения. В этом обзоре обобщены результаты микробиологического анализа качества воды, оценки загрязнения радионуклидами и микроэлементами и их совокупного воздействия на здоровье человека и экосистемы. Микробиологические исследования показывают повышенные уровни лактозоположительных кишечных палочек (ЛКП), превышающие санитарные нормы

в 2–4 раза, что свидетельствует о фекальном загрязнении неочищенными сточными водами и промышленными сбросами. В то же время оценки техногенного загрязнения выявляют концентрации урана (U), селена (Se) и тяжелых металлов (Al, Fe, Mn, Hg, Pb, Cd), значительно превышающие предельно допустимые концентрации (ПДК), что связано с урановыми хвостохранилищами и отвалами отходов. Данные о состоянии здоровья коррелируют плохое качество воды с повышенной заболеваемостью, включая острые кишечные инфекции, респираторные заболевания и рак, особенно в расположенных ниже по течению сообществах, таких как Кок-Таш. Анализы растительности и почвы еще больше подчеркивают непригодность пойменных территорий для сельского хозяйства из-за накопления радионуклидов. В этом обзоре подчеркивается настоятельная необходимость в многопрофильной программе охраны вод, объединяющей регулярный мониторинг, передовые технологии очистки и трансграничное сотрудничество для смягчения загрязнения и обеспечения устойчивого развития в регионе Майлуу-Суу.

Ключевые слова: река Майлуу-Суу, микробиологическое качество, техногенное загрязнение, радионуклиды, Кыргызстан

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Introduction

Water quality degradation poses a significant threat to public health and environmental sustainability, particularly in regions with a legacy of industrial activity. The Mailuu-Suu River, flowing through Kyrgyzstan's Jalal-Abad region, exemplifies this challenge. Spanning 87 km from the Babashtan Mountain slopes to its confluence with the Syr Darya, the river serves as a vital resource for drinking, irrigation, and household use for over 22,000 residents in Mailuu-Suu city and surrounding villages. However, its proximity to historical uranium mining sites, industrial operations like the Mailuu-Suu Electro Lamp Plant, and inadequate sewage infrastructure has rendered it a hotspot for both microbiological and technogenic pollution [1].

From 1946 to 1968, Mailuu-Suu was a key uranium mining hub in the Soviet Union, producing over 10,000 tons of uranium oxide and leaving behind approximately 3 million cubic meters of radioactive waste in 23 tailings and 13 dumps [2]. These tailings, often situated along riverbanks, release radionuclides (e.g., uranium, thorium) and trace elements (e.g., Se, Pb, Cd) into the water, exacerbated by natural disasters like landslides and seismic activity [1,2]. Concurrently, untreated domestic sewage and industrial wastewater introduce pathogenic microorganisms, notably coliform bacteria, amplifying health risks.

This review integrates two primary studies by Egemberdieva and Kamchybekova: a microbiological quality analysis of the Mailuu-Suu River and a 2024 assessment of technogenic pollution [1, 2]. Additional literature, including radiological and chemical contamination studies by Corcho Alvarado et al. [3] and health impact assessments by Vandenhove et al. [4], enriches the analysis. The objectives are to (1) evaluate the extent of microbiological and technogenic pollution, (2) assess their impacts on human health and ecosystems, and (3) propose strategies for sustainable water management.

Materials and Methods

Microbiological Quality Analysis

The microbiological study collected 14 water samples seasonally (October, December, April) along the Mailuu-Suu River, targeting pathogens, lactose-positive coliforms (LPC), coliphages, helminth eggs, and total microbial count (TMC). Samples were analyzed using petrifilm plates (3M, USA) per methodological guidelines (MU No. 2285-81; Ministry of Health, Russia, 2006) [5], enabling rapid quantification of microbial colonies. Two contrasting areas were selected for health comparisons: Sary-Bee (upper reaches, using a water distribution network) and Kok-Tash (lower reaches, reliant on untreated river water). Health data were sourced from local SanEpid laboratories and regional health records.

Technogenic Pollution Assessment

The 2024 study divided the Mailuu-Suu basin into five microplots based on anthropogenic load and plant cover. Soil and plant samples were collected from small plots (control and impacted sites) and analyzed for radionuclides (U, Th) and trace elements (Al, Fe, Mn, Se, Hg, Pb, Cd) using standard biogeochemical methods. Water samples were tested against Kyrgyz Sanitary Norms and Regulations (SanPiN) and MPCs, focusing on concentrations exceeding safe limits. Vegetation diversity was assessed via traditional ecological surveys.

Supplementary Data

Data from Corcho Alvarado et al. [3] provided radionuclide and metal concentrations in the drinking water distribution system (DWDS), rivers, and tailings drainage. Vandenhove et al. [4] contributed radiation exposure estimates for critical population groups. These were integrated to contextualize pollution sources and health risks.

Results

Microbiological Contamination

The microbiological analysis revealed significant water quality degradation. LPC levels averaged 234,430 per dm^3 in October, 38,910 in December, and 37,976 in April, exceeding the SanPiN limit of 10,000 per dm^3 by 2–23 times. Coliphages ranged from 0 (October) to 148 (April), occasionally surpassing the 100 PFU limit. No disease-causing pathogens or helminth eggs were detected, but TMC reached 126 per ml in October. These findings indicate fecal contamination, likely from untreated sewage following landslides that damaged sewer systems in Sary-Bee, Kugay, and South Karagach.

Technogenic Pollution

The 2024 study confirmed elevated concentrations of radionuclides and trace elements in river water, with Se at 10–23 times the MPC, and U, Al, Fe, Mn, Hg, Pb, and Cd also exceeding SanPiN limits. Soil near tailings, particularly in the middle and lower basin, showed high U and Th levels, rendering it unsuitable for cultivation. Vegetation exhibited reduced species diversity near tailings, with bioaccumulation of U and heavy metals. Corcho Alvarado et al. [3] reported U levels up to 10 µg/L in artesian wells and >200 times the WHO guideline (30 µg/L) in tailings drainage, alongside high Fe, Al, and Mn linked to turbidity [6].

Health Impacts

Health data from Kok-Tash (lower reaches) showed morbidity rates 1.3–2.3 times higher than Sary-Bee (upper reaches) for acute intestinal infections, digestive diseases, and hepatitis. Iron-deficiency anemia in children was 1.5–1.6 times higher, and endocrine disorders increased in adults. Cancer rates in Mailuu-Suu rose by 5% from 1990–2016, with 48% of children

exhibiting developmental delays or mental disabilities. Respiratory diseases increased by 48%, with 24% linked to uranium tailings exposure. Vandenhove et al. [4] estimated external radiation exposure at 1.2 mSv/year and radon exposure at 3–10 mSv/year, with ingestion doses negligible in Mailuu-Suu but elevated (10–30 mSv/year) in Kara Agach.

Ecosystem Effects

Floodplain soil-vegetation cover was deemed conditionally suitable, but tailings-adjacent areas were unfit for agriculture due to radionuclide and metal accumulation. Plant diversity declined downstream, reflecting the cumulative impact of pollution sources.

Discussion

Sources and Extent of Pollution

The Mailuu-Suu River's dual burden of microbiological and technogenic pollution stems from historical and ongoing anthropogenic activities. Microbiologically, LPC levels signal inadequate sewage treatment, a legacy of infrastructure damage from landslides and poor maintenance since Soviet times. Technogenically, uranium tailings and industrial discharges (e.g., Electro Lamp Plant) release radionuclides and metals, intensified by erosion, seismic instability, and flooding. Corcho Alvarado et al. [3] noted that while DWDS water poses no immediate radiological hazard, high turbidity and metal content compromise its potability, aligning with microbiological findings of fecal contamination.

Health Implications

Elevated LPC correlates with increased waterborne illnesses in Kok-Tash, where untreated river water is consumed, compared to Sary-Bee's networked supply. This mirrors global trends linking coliforms to gastrointestinal diseases. Technogenic pollutants, particularly U and heavy metals, contribute to chronic conditions like cancer and developmental disorders, consistent with Vandenhove et al. [4] and regional studies reporting a 5% cancer increase over 26 years. The synergy of microbial and chemical stressors likely amplifies morbidity, especially in children and downstream residents.

Ecological Consequences

Soil and vegetation degradation near tailings reflects bioaccumulation, limiting agricultural potential and threatening food security. The 2024 study's findings of Se and U exceeding MPCs align with broader Central Asian research (e.g., Lind et al., 2013, on Kadji Sai), highlighting transboundary pollution risks via the Syr Darya into Uzbekistan's Fergana Valley [7,8].

Management Challenges and Opportunities

Current pollution levels exceed Kyrgyz sanitary norms, yet remediation efforts (e.g., World Bank's $11 million project, 2004–2012) have been insufficient [9]. The transboundary nature of the river necessitates cooperation with Kazakhstan and Uzbekistan, as emphasized by Egemberdieva and Kamchybekova [1]. Modern water treatment technologies (e.g., filtration, bioremediation) and regular monitoring could mitigate risks, but funding and coordination remain barriers.

Conclusion

The Mailuu-Suu River exemplifies a complex interplay of microbiological and technogenic pollution, driven by legacy uranium mining, industrial discharges, and inadequate sanitation. LPC levels 2–23 times above norms, alongside radionuclides and metals exceeding MPCs, pose acute and chronic health risks, including waterborne illnesses, cancer, and developmental

impairments. Ecosystem degradation further threatens sustainability. A comprehensive water protection program, integrating advanced monitoring, treatment infrastructure, and regional collaboration, is imperative to reduce pollution, protect public health, and promote sustainable development. Triennial evaluations and adaptive management will ensure long-term efficacy in this uranium-impacted region.

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