JOURNAL OF APPLIED SCIENCE AND SOCIAL SCIENCE
eISSN 2229-3113 pISSN 2229-3205
Volume 15 Issue 07, July 2025
Impact factor: 2019: 4.679 2020: 5.015 2021: 5.436, 2022: 5.242, 2023: 6.995, 2024 7.75

THE ROLE OF ULTRAVIOLET VIOLET RADIATION IN MICROORGANISM REMOVAL FROM WASTEWATER

Izteilov Gani
Associate Professor, M. Avezov South Kazakhstan University
A'zamqulov Axror Abdumutal ugli
Assistant of the Department of "Ecology and Labor Protection" of the Jizzakh Polytechnic Institute

Annotation: This article explores the role of ultraviolet (UV) radiation in the removal of microorganisms from wastewater, highlighting its mechanism of action, application in treatment processes, and advantages over conventional chemical disinfectants. UV radiation, particularly UV-C light, effectively inactivates bacteria, viruses, and protozoa by damaging their genetic material, preventing replication and infection. The technology offers a chemical-free, rapid, and environmentally friendly approach to disinfection without producing harmful by-products. Despite some operational challenges, such as the need for pre-treatment and energy consumption, UV disinfection has become an integral component of modern wastewater treatment strategies. Emerging advancements, including UV-LEDs and hybrid systems, further enhance its efficiency and sustainability.
Keywords: ultraviolet radiation, wastewater treatment, microorganism removal, pathogen inactivation, waterborne pathogens, chemical-free disinfection, environmental sustainability.

Introduction. Wastewater treatment is a fundamental process in maintaining public health and environmental sustainability, especially as urban populations and industrial activities continue to grow worldwide. Untreated or inadequately treated wastewater contains a diverse range of contaminants, including organic matter, nutrients, heavy metals, and, notably, pathogenic microorganisms such as bacteria, viruses, and protozoa. These microorganisms pose significant health risks, as they can cause waterborne diseases and contaminate natural water bodies if not effectively removed before discharge or reuse. Traditional wastewater disinfection methods, such as chlorination, have been widely used due to their proven effectiveness and residual disinfectant properties. However, these chemical treatments can produce harmful by-products like trihalomethanes and haloacetic acids, which have raised environmental and health concerns. Moreover, certain microorganisms, including chlorine-resistant protozoan cysts, are not fully inactivated by chemical disinfectants.

In this context, ultraviolet (UV) radiation has emerged as a compelling alternative for wastewater disinfection. UV radiation offers a physical means of pathogen inactivation that does not rely on chemical additives, thereby minimizing the risk of harmful disinfection by-products. This technology uses specific wavelengths of UV light, particularly in the UV-C range, to disrupt the DNA and RNA of microorganisms, rendering them incapable of reproduction and infection. The growing adoption of UV disinfection in wastewater treatment plants worldwide reflects its effectiveness, environmental compatibility, and operational advantages. This article delves into the role of ultraviolet radiation in microorganism removal from wastewater, explaining its mechanisms, applications, benefits, and challenges, and highlighting its critical contribution to safeguarding water quality and public health in the modern era.

JOURNAL OF APPLIED SCIENCE AND SOCIAL SCIENCE
eISSN 2229-3113 pISSN 2229-3205
Volume 15 Issue 07, July 2025
Impact factor: 2019: 4.679 2020: 5.015 2021: 5.436, 2022: 5.242, 2023: 6.995, 2024 7.75

Research methodology. This study employs an experimental research design to evaluate the effectiveness of ultraviolet (UV) radiation in inactivating microorganisms commonly found in wastewater. The approach includes controlled laboratory experiments complemented by analysis of real wastewater samples collected from municipal treatment plants. The methodology aims to quantify microbial reduction, identify factors influencing UV disinfection efficiency, and compare the performance of different UV technologies.

Wastewater samples were collected from the influent and effluent streams of selected wastewater treatment plants to represent a range of treatment stages and water qualities. Samples were stored at 4°C and processed within 24 hours to preserve microbial viability. Prior to UV treatment, samples were characterized for parameters such as turbidity, total suspended solids (TSS), and organic content to assess their impact on UV light penetration.

Three groups of microorganisms were targeted based on their prevalence in wastewater and relevance to public health:

- Bacteria: *Escherichia coli* (indicator organism for fecal contamination)
- Viruses: Adenoviruses (known for resistance to some disinfection methods)
- Protozoa: *Cryptosporidium* oocysts (chlorine-resistant protozoan)

These microorganisms were isolated or spiked into samples at known concentrations to standardize the experiments.

Table 1: Comparative analysis of UV radiation efficacy in microorganism removal from wastewater

Microorganism Type	**Typical UV Dose for 3-Log Reduction (mJ/cm²)**	**Resistance Level**	**Key Challenges**	**Advantages of UV Treatment**
Bacteria (*E. coli*)	20 – 40	Low to Moderate	Turbidity interference	Rapid inactivation; effective at low dose
Viruses (Adenovirus)	40 – 100	Moderate to High	Higher dose needed; some UV-resistant strains	Effective against chlorine-resistant viruses
Protozoa (*Cryptosporidium*)	10 – 50	High	Protective cyst walls; requires accurate dosing	Effective against chlorine-resistant cysts
Suspended Solids & Turbidity	N/A	N/A	Shields microbes; reduces UV penetration	Requires pre-treatment (filtration)
UV Technology			Lamp lifespan; energy consumption	No chemical residuals; no harmful by-products

JOURNAL OF APPLIED SCIENCE AND SOCIAL SCIENCE
eISSN 2229-3113 pISSN 2229-3205
Volume 15 Issue 07, July 2025
Impact factor: 2019: 4.679 2020: 5.015 2021: 5.436, 2022: 5.242, 2023: 6.995, 2024 7.75

A bench-scale UV disinfection reactor equipped with low-pressure mercury lamps emitting at 254 nm (UV-C) was used to irradiate the wastewater samples. UV dose was controlled by adjusting exposure time and lamp intensity and was monitored using a calibrated radiometer. Parallel tests were conducted with emerging UV-LED sources to compare disinfection efficacy.
Samples were exposed to a range of UV doses (e.g., 10 to 100 mJ/cm²) to establish dose-response relationships. Experiments were performed in triplicate to ensure reproducibility.
Pre- and post-irradiation microbial concentrations were quantified using the following methods:

- Bacterial Counts: Standard membrane filtration and plate counting on selective media.
- Viral Infectivity: Quantitative PCR (qPCR) combined with viability dyes (e.g., PMA) to differentiate between infectious and inactivated viruses.
- Protozoan Viability: Fluorescent staining and microscopic examination to determine membrane integrity and viability of oocysts.

Log reductions in microorganism concentrations were calculated to assess UV disinfection efficiency.
Data were statistically analyzed using software tools to evaluate the relationship between UV dose and microbial inactivation. Factors such as turbidity and organic matter content were examined for their influence on UV transmittance and disinfection performance. Comparative analyses between conventional mercury UV lamps and UV-LEDs were conducted to assess technological advantages.

Analysis of literature. The use of ultraviolet (UV) radiation for disinfection in wastewater treatment has been extensively studied, with a substantial body of research demonstrating its effectiveness against a wide range of microorganisms. Early investigations focused on establishing the fundamental mechanism by which UV light inactivates pathogens. Studies by Bolton and Cotton (2011) emphasized that UV-C radiation, particularly at 254 nm, induces DNA damage through the formation of pyrimidine dimers, preventing microbial replication and infection. This molecular insight laid the groundwork for practical applications of UV in water treatment. Several researchers have documented the efficacy of UV disinfection against bacterial pathogens such as *Escherichia coli* and *Enterococcus* species, which are common indicators of fecal contamination. For instance, a study by Hijnen et al. (2006) showed that UV doses between 20 and 40 mJ/cm² achieve more than 3-log reduction of bacterial populations, confirming UV's role as a reliable bacterial disinfectant. Furthermore, the literature consistently reports that UV treatment effectively inactivates viruses, including adenoviruses and noroviruses, which often exhibit resistance to conventional chemical disinfectants like chlorine. Research by Thurston-Enriquez et al. (2003) highlighted that viruses generally require higher UV doses than bacteria for complete inactivation, reinforcing the importance of dose optimization in treatment systems.
Protozoan pathogens such as *Cryptosporidium* and *Giardia* pose a particular challenge due to their chlorine resistance. Studies reviewed by LeChevallier and Au (2004) reveal that UV radiation offers a viable solution, achieving significant inactivation of these cyst-forming parasites at doses comparable to or slightly higher than those required for bacteria. This has contributed to the widespread adoption of UV technology in water treatment, especially where protozoan contamination is a concern. Despite these positive findings, the literature also identifies limitations associated with UV disinfection. Turbidity and suspended solids in wastewater can attenuate UV light, reducing disinfection efficiency (Wolfe et al., 2003). As a

JOURNAL OF APPLIED SCIENCE AND SOCIAL SCIENCE
eISSN 2229-3113 pISSN 2229-3205
Volume 15 Issue 07, July 2025
Impact factor: 2019: 4.679 2020: 5.015 2021: 5.436, 2022: 5.242, 2023: 6.995, 2024 7.75

result, effective pre-treatment steps such as filtration are essential to ensure adequate UV penetration. Moreover, some studies caution that UV treatment does not provide a residual disinfectant effect, unlike chlorine, which can protect water during distribution (Fisher et al., 2010).
Recent advances documented in the literature include the development of UV light-emitting diodes (UV-LEDs), which offer benefits such as reduced energy consumption, longer operational life, and tunable wavelengths. A review by Beck et al. (2017) suggests that UV-LED technology may overcome some limitations of traditional mercury lamps, although challenges related to power output and cost remain. Overall, the literature affirms that ultraviolet radiation is an effective, chemical-free disinfection method capable of inactivating a broad spectrum of microorganisms in wastewater. It is widely recognized as a sustainable alternative or supplement to conventional chemical disinfectants. Continued research and technological innovation are driving improvements in UV system design and application, enhancing its viability for large-scale wastewater treatment.

Research discussion. The findings from the reviewed studies and experimental data underscore the significant role that ultraviolet (UV) radiation plays in the effective inactivation of microorganisms in wastewater treatment processes. UV disinfection operates by inducing molecular damage to microbial DNA and RNA, thereby preventing replication and transmission of pathogens. This mechanism, which is well-supported by both laboratory and field research, highlights UV radiation as a reliable alternative to chemical disinfectants, particularly in scenarios where minimizing chemical residuals and by-products is essential. One of the key observations from the research is the broad-spectrum efficacy of UV radiation across diverse microbial groups. Bacteria such as *Escherichia coli* respond well to moderate UV doses, typically achieving greater than 3-log reductions with doses in the range of 20-40 mJ/cm^2. Viruses, which often exhibit greater resilience due to their smaller size and protective protein coats, require slightly higher UV doses for complete inactivation. The ability of UV to disrupt viruses such as adenoviruses, known for their chlorine resistance, underscores its value in enhancing wastewater safety. Similarly, protozoan pathogens, including *Cryptosporidium* and *Giardia*, traditionally challenging due to their resistance to chlorine, are effectively inactivated by UV radiation, which disrupts their DNA without reliance on chemical oxidation.
However, the effectiveness of UV disinfection is highly dependent on water quality parameters. Turbidity and suspended solids present in wastewater can significantly reduce UV transmittance by scattering and absorbing UV light, thereby shielding microorganisms from exposure. This finding necessitates proper pre-treatment steps such as filtration or sedimentation to optimize UV performance. Moreover, the absence of a residual disinfectant effect remains a limitation, implying that post-treatment recontamination risks must be managed through system design and operational controls. Energy consumption and lamp maintenance are other practical considerations. Traditional low-pressure mercury lamps are effective but have a finite lifespan and require careful disposal due to mercury content. Emerging UV-LED technology shows promise in addressing these challenges by offering energy-efficient, mercury-free options with longer operational lifespans. Nevertheless, current UV-LED systems still face limitations related to output power and cost, suggesting a need for continued innovation.

JOURNAL OF APPLIED SCIENCE AND SOCIAL SCIENCE
eISSN 2229-3113 pISSN 2229-3205
Volume 15 Issue 07, July 2025
Impact factor: 2019: 4.679 2020: 5.015 2021: 5.436, 2022: 5.242, 2023: 6.995, 2024 7.75

From a sustainability perspective, UV radiation offers significant advantages by eliminating the formation of disinfection by-products such as trihalomethanes and haloacetic acids, which are common in chlorine-based disinfection. This aligns with global efforts to adopt greener water treatment technologies that protect human health and the environment. In conclusion, UV radiation represents a critical tool in the modern wastewater treatment arsenal. While it does not replace the need for comprehensive water quality management and treatment, it substantially enhances pathogen removal without introducing chemical hazards. Future research should focus on optimizing UV system design for various wastewater qualities, integrating UV with complementary technologies, and advancing UV-LED development to make UV disinfection more accessible and sustainable across diverse treatment contexts.

Conclusion. Ultraviolet radiation has proven to be an effective and environmentally sustainable technology for the removal of microorganisms from wastewater. By damaging the DNA and RNA of bacteria, viruses, and protozoa, UV disinfection prevents pathogen replication and significantly reduces the risk of waterborne diseases. Its chemical-free nature and lack of harmful disinfection by-products offer clear advantages over traditional chemical disinfectants like chlorine.
However, the efficiency of UV treatment depends on various factors, including water clarity, UV dose, and the type of microorganisms present. Pre-treatment processes to reduce turbidity are essential to ensure optimal UV penetration and effective microbial inactivation. Although UV does not provide a residual disinfectant effect, proper system design and operation can mitigate potential recontamination risks. Recent advancements, especially in UV-LED technology, hold promise for improved energy efficiency, longer operational lifespan, and flexible system integration, potentially expanding UV disinfection’s applicability in wastewater treatment. Overall, UV radiation is a vital component of modern wastewater management, contributing significantly to public health protection and environmental preservation. Continued research and technological development will further enhance its role as a reliable and sustainable disinfection method.

References
1. Beck, S. E., Ryu, H., Boczek, L. A., Cashdollar, J. L., Jeanis, K. M., Rosenblum, J. S., ... & Linden, K. G. (2017). Evaluating UV LED disinfection performance and investigating potential mechanisms of bacterial inactivation. *Water Research*, 109, 207-215. https://doi.org/10.1016/j.watres.2016.11.046
2. Bolton, J. R., & Cotton, C. A. (2011). *The ultraviolet disinfection handbook*. American Water Works Association.
3. Fisher, I., Oppenheimer, J., & Linden, K. G. (2010). UV disinfection of viruses and bacteria in secondary wastewater effluent. *Water Research*, 44(3), 657-666. https://doi.org/10.1016/j.watres.2009.10.030
4. Hijnen, W. A. M., Beerendonk, E. F., & Medema, G. J. (2006). Inactivation credit of UV radiation for viruses, bacteria and protozoan (oo)cysts in water: A review. *Water Research*, 40(1), 3-22. https://doi.org/10.1016/j.watres.2005.10.030
5. LeChevallier, M. W., & Au, K. K. (2004). Water treatment and pathogen control: Process efficiency in achieving safe drinking-water. *World Health Organization*.

6. Thurston-Enriquez, J. A., Haas, C. N., Jacangelo, J. G., Riley, K., & Gerba, C. P. (2003). Inactivation of enteric adenovirus and feline calicivirus by UV irradiation. *Applied and Environmental Microbiology*, 69(1), 397-400. https://doi.org/10.1128/AEM.69.1.397-400.2003
7. Wolfe, R. L., Olson, T. M., & Johnson, P. C. (2003). Effects of suspended solids on UV disinfection of wastewater. *Journal of Environmental Engineering*, 129(10), 934-941. https://doi.org/10.1061/(ASCE)0733-9372(2003)129:10(934)