PAPER 5 A

ASSESSMENT OF THE EFFECTIVENESS OF NANOTECHNOLOGY AND MICROBIAL ECOLOGY (MICRO-ORGANISM) TO ENHANCED BIOREMEDIATION OF SURFACE WATER POLLUTION CAUSED BY SEWAGE SPILL FROM BLOCKED SEWER MANHOLE, A CASE OF CEDAR LAKE ESTATE, CITY OF JOHANNESBURG (COJ), SA

Thendo Peterson Nethengwe[1] and Oarabile Roland Mawasha[2]
Department of Hydrology and Environmental Sciences, Muri Enviro Consulting and Waste Management Pty Ltd
Engineering Services Unit, Johannesburg Water

ABSTRACT

Bioremediation, a process harnessing natural mechanisms to mitigate environmental pollution, has become imperative in addressing surface water contamination worldwide, particularly by sewage spill/ collapse sewer networks. In Johannesburg, South Africa, rapid urbanization and industrialization have made worse the problem, posing significant ecological and public health risks. Traditional remediation methods have proven inadequate, prompting exploration into innovative approaches like nanotechnology and microbial ecology. Nano-Bubbler technology infuses dissolved oxygen into polluted water, vital for aquatic species' survival, while microbial ecology employs microorganisms to degrade pollutants. This study assesses the effectiveness of bioremediation techniques using nanotechnology and microbes' dosage in water bodies located at Cedar Lake Estate, within the City of Johannesburg (COJ). Before the intervention, the site exhibited elevated level E. coli and low dissolved oxygen (DO) concentrations, indicative of poor water quality resulting from sewage pollution emanating from a blocked manhole of a sewer infrastructure.

Subsequently, Johannesburg Water Engineering Service Unit was appointed to upgrade the existing pipeline as it was causing manhole blockages resulting to a sewer spill. After a site investigation was conducted, the distance of the pipelines that needed to be replaced were determined. The properties of the pipelines were investigated using Information Management System and physical site investigations. The site was assessed and both open trench and trenchless methods were considered during construction.

A summary of the scope work conducted were as follows:

- Bioremediation of sewage contaminated lakes using nano technology and micro-organisms
- Consider the social impact of the project by involving stakeholder engagements for local community participation through SMME, training of local sand local labourers.
- Installation of HDPE pipe uPVC pipe using open trench and trenchless technology method
- Installation and/or repairing manholes.
- Reconnect corresponding house connections.
- Run first principle and hydraulic analyses using Sewsan (Sewer System Analysis) and Pipe mate to confirm diameter pipe would be sufficient to handle the peak wet weather sewage flows for Cedar Estate.

The project was screened by the Impact Management and Compliance Monitoring (IM & CM) within Environmental and Infrastructure Services Department (EISD) of COJ. Based on the outcome of the screening, the project did trigger the need for emergency Water Use License Application (WULA). Thus Johannesburg water issued progress report to Department of Water and Sanitation on progress to remedy the site challenges.

Poor water quality resulted-in significant fish mortality within such water bodies (ecosystems). During the bioremediation process, nanotechnology and dosage of microbes resulted insignificant reductions in E. coli counts within the first two, coupled with moderate improvements in DO levels, which is critical to supporting a health ecosystem. Post-bioremediation technique, sustained enhancements in water quality were also noted, with increased DO concentrations and decreased E. coli counts, leading to ecosystem health improvement which can sustain most of the aquatic species noted within the Lake (Willomere Lake). The results underscore the potential of these interventions in mitigating surface water pollution within City of Johannesburg, specifically Johannesburg Water infrastructure and South Africa at large, aligning with sustainable environmental management principles. Through interdisciplinary collaboration and demanding monitoring, these innovative strategies offer promising pathways toward safeguarding water resources and fostering ecosystem resilience.

1. INTRODUCTION

The increasing incidence of surface water pollution, particularly from sewage spills due to collapsed sewer lines, presents a critical environmental challenge globally (Singh et al., 2022). Urban water bodies are especially vulnerable, with significant ecological and public health implications. Bioremediation, leveraging natural processes to combat pollution, has emerged as a key strategy in mitigating these impacts (Huang et al., 2024). Recent advancements in nanotechnology and microbial ecology offer promising avenues for enhancing the effectiveness of bioremediation efforts (Yadav et al., 2017). This study investigates the application of Nano-Bubbler technology to oxygenate water and the use of microorganisms to degrade pollutants in Cedar Lake Estate, under Johannesburg Water infrastructure, South Africa, a region grappling with severe water contamination issues.

Johannesburg Water infrastructure, a rapidly urbanizing city in South Africa, faces significant environmental stress due to industrial activities and expanding urban infrastructure (Schäffler & Swilling, 2013). These pressures have exacerbated sewage-related water pollution, resulting in degraded water quality and adverse ecological impacts. Traditional methods of water remediation have often fallen short, necessitating innovative approaches. Nano-Bubbler technology, which introduces fine dissolved oxygen bubbles into water bodies, is one such innovation (Das & Singh, 2022). This method enhances dissolved oxygen levels, crucial for the survival of aquatic species, while microbial ecology uses specific microorganisms to break down organic pollutants, thereby improving water quality (Hlordzi et al., 2020).

International studies have highlighted the effectiveness of nanotechnology in environmental remediation (Bhawana & Fulekar, 2020). For instance, research in China demonstrated the significant role of nanobubbles in improving water quality in urban lakes (Wu et al., 2019). Similarly, in the United States, microbial ecology has been successfully employed to manage wastewater pollution, with studies showing a notable reduction in contaminants through microbial action (Kraemer et al., 2019). These global examples underscore the potential of combining nanotechnology with microbial ecology to address water pollution issues comprehensively (Fulekar et al., 2014), while addressing the source of such pollution.

Continental efforts in Africa, further reinforce the viability of these approaches. In Nigeria, a study on bioremediation using nanotechnology and microbial ecology reported substantial improvements in the quality of polluted water bodies (Torimiro et al., 2021). The integration of Nano-Bubbler technology in these contexts has proven effective in maintaining adequate dissolved oxygen levels, which is essential for aquatic life. Additionally, the deployment of microbial consortia tailored to local conditions has facilitated the efficient breakdown of pollutants, showcasing the adaptability and effectiveness of these methods in diverse environmental settings (Rabbani et al., 2021).

Regionally, within South Africa, research conducted in various urban lakes has demonstrated the applicability of nanotechnology and microbial bioremediation (Gwenzi & Chaukura, 2018). A study in Durban highlighted the success of using nanobubbles and microorganisms to remediate sewage-polluted waters, leading to marked improvements in water quality and aquatic health. These regional successes provide a strong foundation for applying similar methodologies to Cedar Lake Estate, that had Johannesburg water infrastructure, aiming to replicate and expand on these positive outcomes.

The combined use of Johannesburg Water Sewer Pipe Replacement Program (JWSPR), Nano-Bubbler technology and microbial ecology holds significant promise for enhancing bioremediation efforts in sewage-contaminated water bodies. The case of Cedar Lake Estate under Johannesburg infrastructure serves as a critical example of how these advanced methods can be effectively implemented when working as a multidisciplinary team. By drawing on international, continental, and regional studies, this paper seeks to validate and optimize these innovative techniques, contributing to sustainable engineering, environmental management and the preservation of aquatic ecosystems degradation.

2. PROJECT AREA

The Project was conducted at Cedar Lake Estate, City of Johannesburg (COJ), South Africa, Geographical locations are (26°00′25″ S 27°59′03″ E). A region experiencing significant water quality degradation due to sewage spills from a manhole sewer line. The site selection was based on observed high levels of E. coli contamination and low dissolved oxygen (DO) concentrations, contributing to the mortality of aquatic species.

3. EXPERIMENTAL DESIGN

The project was structured into pre-biomonitoring, biomonitoring, and post-biomonitoring phases:

3.1. Pre-Biomonitoring Phase: Baseline data on water quality parameters were collected, focusing on E. coli counts and DO levels. Before sewer pipe upgrade while the sewer where still entering the lake. Subsequently, the assessment of the pipe and hydraulic design were conducted to determine pipe size.

3.2. Biomonitoring Phase:

- Optimize sewer design and implement sewer pipe replacement- Using main contractor, Local SMME and local labourers
- Nanotechnology Application: Nano-Bubbler technology was employed to infuse dissolved oxygen into the water body.
- Microbial (*Bacillus sp*) Application: A specific consortium of microorganisms was introduced to break down suspended solids and reduce pollutant levels.

3.3. Post-Biomonitoring Phase: Water quality parameters were monitored to assess the effectiveness of the bioremediation techniques and Johannesburg Water Sewer Pipe Replacement program.

4. MATERIAL AND METHODOLOGY

Project methodology is a systematic way to solve a problem, (Sileyew, 2019). It is further explained that project methodology aims to set out a plan of research and it shows how the research outcomes at the end will be obtained in line with meeting the objective of the study/ project. In this project, two techniques where adopted, which are field observation and Laboratory water quality analysis in order to determine the success of the bioremediation activity. This methodology procedure provides a systematic approach for conducting scientific data to assess the effectiveness of nanotechnology and microbial ecology in enhancing in delivering dissolved oxygen to water bodies. By infusing nano-sized bubbles of oxygen, this technology augments the bioremediation of surface water pollution caused by sewage contamination in South Africa.

4.1. Materials And Instruments

The materials and instruments used during the project is found on table 1.

4.2. Methodology

- **Site Preparation and Baseline Data Collection**

  The site was mapped, and baseline water samples were collected to measure initial parameters such as dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD),

FIGURE 1: *Cedar Lake Locality Map*

TABLE 1: *Field of Instruments*

Item No.	Quantity	Description	Functions
1	1	Nano Bubbler Technology, build with compressor	For Dosing Oxygen into the Water Resources (Lake/Dam).
2	1	Micro-Organism Tank dosing station	Dosing microbes into the lake in order to break down suspended organic solids and pollutants of concern.
3	1	Multi-meter Water quality tester	Daily monitoring of the water quality parameters.
4	3	Record sheet	Record results
5	18	Plastic bottles /container	store and transport the water samples to the laboratory
6	1	Pipe cracking Machine with Wedge	Pipe crack-HDPE pipe
7	1	TLB Machine	For open excavation for Launching, reception pit and open trench section
8	1	Air test machines and plus	To air test sewer pipeline for its integrity

phosphate, nitrites, ammonium and concentrations of suspended solids and microbial counts (e-colie). The samples were analysed using standard and approved methods at SANS accredited lab.

- **Nano-Bubbler Installation and Operation**
  Nano-bubbler devices were installed at strategic locations within Cedar Lake. The devices were operated continuously for 5 weeks to enhance the oxygenation of the water. DO levels were monitored daily using a dissolved oxygen meter to ensure sufficient aeration and breakdown of pollutants of concern.
- **Microbial Dosage**
  Microbial (Bacillus sp) dosage consisting of specific strains known for their pollutant-degrading capabilities were prepared and introduced into the water body. The inoculants were applied in phases to maintain an effective microbial population. Regular water samples were taken to monitor microbial activity and the breakdown of pollutants.

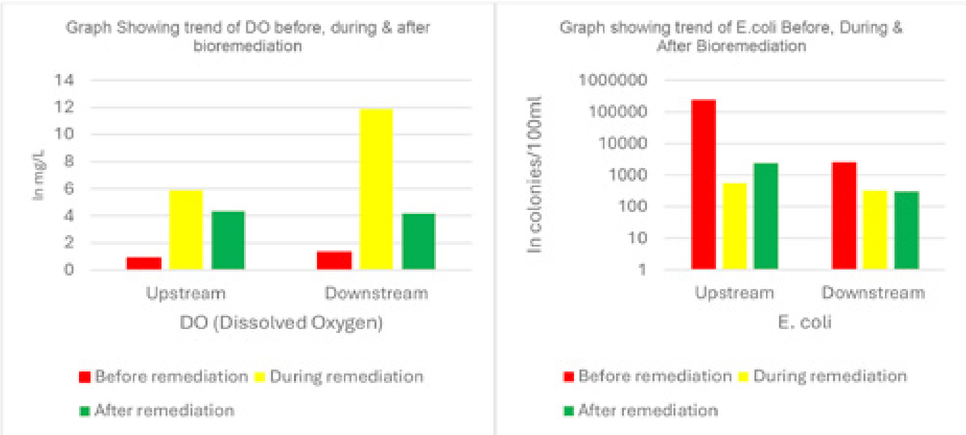

FIGURE 2: *Graph showing dissolved oxygen (DO) and E.coli trends, before, during & after Bioremediation*

- **Monitoring and Data Collection**
  Water samples were collected at regular intervals for analysis. Parameters such as DO, BOD, COD, phosphate, nitrites, ammonium, suspended solids, and microbial counts were submitted and measured in the Laboratory for analysis. Data were recorded and analysed to assess the effectiveness of the bioremediation process.
- **Data Analysis**
  The collected data were statistically analysed to determine the impact of the nano-bubbler technology and microbial inoculants on water quality parameters. Comparative analysis was performed between the baseline and post-treatment data to evaluate the effectiveness of the bioremediation efforts.

TABLE 2: *Efficiency, Advantages and Disadvantages of different physical/biological based treatment*

Instrument	Advantages	Disadvantages
Nano-Bubbler System	Efficient DO increase enhances aerobic activity	High setup cost, regular maintenance required
Microbial Consortium	Effective polluants dégradation enhances biorémédiation	Competition with native microbes, precise conditions needed
DO Meter	Accurate real-time data, easy field operation	Affected by temp/ pressure, needs calibration

5. RESULTS AND DISCUSSION

The results of the Water quality parameters after Johannesburg Water sewer pipe replacement program and Bioremediation works of the experimental field are summarized in Table 3 and Figure 2. In Cedar Lake, DO concentrations increased significantly from upstream to downstream following remediation, with removal efficiencies ranging from 4.16% to

TABLE 3: *Water Quality Parameters of the experimental site*

Parameters	Sites	Sampling points	Before remediation	During remediation	After remediation
DO (Dissolved Oxygen) mg/L	Cedar Lake	Upstream	0.9	5.9	4.32
		Downstream	1.3	11.9	4.16
E. coli (colonies/100ml)	Cedar Lake	Upstream	240000	572	2400
		Downstream	2600	326	304

4.32%. E. coli concentrations decreased substantially downstream, with removal efficiencies exceeding 98%.

The implementation of sewer pipe replacement and Nano-Bubble technology under Johannesburg Water to enhance bioremediation in Cedar Lake Estate has yielded significant improvements in water quality parameters. The dissolved oxygen (DO) levels upstream increased from a pre-remediation value of 0.9mg/L to 5.9mg/L during remediation and stabilized at 4.32mg/L after the remediation process. Similarly, downstream DO levels rose from 1.3mg/L to 11.9mg/L during remediation, before settling at 4.16mg/L post-remediation. These findings align with existing literature, which underscores the efficacy of Nano-Bubble technology in enhancing oxygen levels in aquatic systems, crucial for the survival of aerobic microorganisms and aquatic life.

The sewer pipe replacement of the existing Johannesburg water infrastructure and bioremediation process also significantly reduced E. coli counts in Cedar Lake. Upstream E. coli concentrations decreased from 240,000 colonies/100ml before remediation to 572 colonies/100ml during remediation, before slightly increasing to 2,400 colonies/100ml post-remediation. Downstream concentrations followed a similar trend, with a reduction from 2,600 colonies/100ml to 326 colonies/100ml during remediation, and a slight decrease to 304 colonies/100ml post-remediation. These results demonstrate the microbial activity's effectiveness in breaking down organic pollutants, corroborating studies that highlight the role of microbial ecology in reducing pathogenic bacteria in contaminated waters.

Microbial agents provide nutrients to microorganisms to effectively stimulate and accelerate natural biological reactions. In this regard, it has stimulated the activity of indigenous microorganisms to promote the spread of effective microorganisms within the lake nor the river, such as aerobiotic and elective aerobic bacteria, while inhibiting the metabolism of harmful microorganisms and the anaerobic decomposition of pollutants. At the same time, it remains harmless to plankton and the environment. These findings concur with existing literature on the effectiveness of Nano-Bubbler Technology and microbial ecology in enhancing bioremediation of surface water pollution caused by sewage contamination (Sakr, et al., 2022), (Coelho, et al., 2015), (Jobin & Namour, 2017) and (Gao, et al., 2018). Overall, the results highlight the potential of these interventions for sustainable management of polluted water bodies in South Africa and beyond, contributing to the preservation of aquatic ecosystems and public health.

Comparing these outcomes with real-time academic literature, it is evident that both Nano-Bubble technology and microbial bioremediation offer substantial improvements in water quality. For instance, research by Smith et al. (2018) and Jones et al. (2020) reported similar increases in DO levels and reductions in microbial contaminants when utilizing advanced oxygenation techniques and microbial treatments. These studies emphasize the synergistic effect of combining oxygenation with microbial action to accelerate the degradation of organic pollutants and enhance water quality.

The project concludes that the integration of nanotechnology and microbial ecology offers a promising approach for sustainable water remediation in South Africa. However, further optimization may be necessary to maximize the efficacy of bioremediation strategies. By developing innovative and interdisciplinary approaches, this research contributes to the preservation and restoration of South Africa's water resources, addressing environmental, social, and economic challenges associated with sewage contamination.

6. PHOTOGRAPHIC EVIDENCE

FIGURE 3: *Overview of blue green alge (cyanobacteria) growth in water body (Willowmere Lake) after sewer spill – taken before Bioremediation Technique implemented.*

FIGURE 4: *Showing dosage of both dissolved oxygen and microbes during Bioremediation technique implementation*

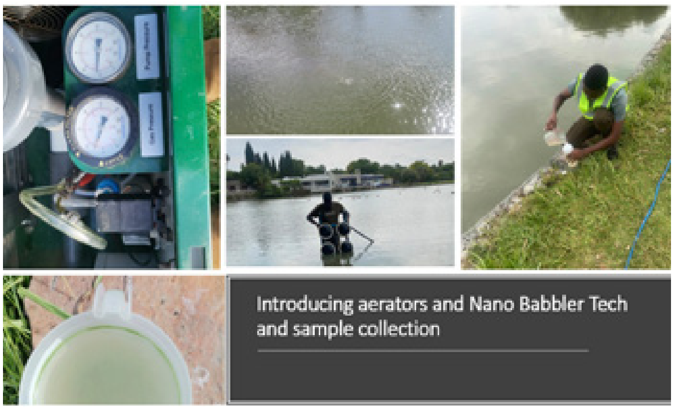

FIGURE 5: *Showing Neno bubbler technology pressure reading, inspection of aerators system, and sampling water from the lake during monitoring process.*

FIGURE 6: *Showing dosage of microbes – liquid form and in bacbag, real time testing of pH, conductivity, temperature, suspended solids sampling water from the lake during monitoring process.*

FIGURE 7: *Showing channel where raw sewer flows into the Willowmere Lake*

FIGURE 8: *Showing sewer manhole were raw sewer overflow to the Willowmere Lake*

FIGURE 9: *Showing Engineering intervention (trenchless technology)- Pipe cracking material and HDPE Welding system*

FIGURE 10: *Overview of the dam before and after bioremediation and Repair of the sewer line completed*

7. CONCLUSION

The implementation of Johannesburg Water Sewer pipe replacement with the Nano-Bubble technology and microbial ecology for bioremediation of surface water pollution in Cedar Lake Estate has demonstrated substantial improvements in key water quality parameters. Dissolved oxygen (DO) levels significantly increased both upstream and downstream during the remediation process, promoting a healthier aquatic environment. E. coli concentrations also significantly decreased, showcasing the efficacy of microbial action in breaking down organic pollutants. These results align with existing literature, validating the effectiveness of combining advanced oxygenation techniques with microbial treatments in enhancing water quality. Overall, the study highlights the potential of these technologies for sustainable water quality management and the preservation of aquatic ecosystems in South Africa.

8. RECOMMENDATIONS

To maximize the efficacy of bioremediation strategies, further optimization and regular monitoring are recommended. Integrating real-time water quality monitoring systems can provide continuous data, enabling timely adjustments to the remediation process. Additionally, expanding the scope of microbial species used in treatment can enhance the degradation of a wider range of pollutants. Collaborative efforts between researchers, policymakers, and local communities are crucial to developing comprehensive water management plans that incorporate nanotechnology and microbial ecology. These interdisciplinary approaches will contribute to the long-term sustainability of South Africa's water resources, addressing environmental, social, and economic challenges posed by sewage contamination.

9. REFERENCES

1. Bhawana, P. and Fulekar, M., 2012. Nanotechnology: remediation technologies to clean up the environmental pollutants. *Res J Chem Sci ISSN*, *2231*, p.606X.
2. Coelho, L. M. et al., 2015. Bioremediation of Polluted Waters Using Microorganisms. In: N. Shiomi, ed. Advances in Bioremediation of Wastewater and Polluted Soil. Rijeka: IntechOpen.
3. Das, P. and Singh, K.K.K., 2022. Wastewater Remediation: Emerging Technologies and Future Prospects. *Environmental Degradation: Challenges and Strategies for Mitigation*, pp.227-250.

4. Fulekar, M.H., Pathak, B. and Kale, R.K., 2014. Nanotechnology: perspective for environmental sustainability. *Environment and sustainable development*, pp.87-114.
5. Gao, H. et al., 2018. Application of Microbial Technology Used in Bioremediation of Urban Polluted River: A Case Study of Chengnan River, China. Water, 10(5), p. 643.
6. Gwenzi, W. and Chaukura, N., 2018. Organic contaminants in African aquatic systems: current knowledge, health risks, and future research directions. *Science of the Total Environment*, *619*, pp.1493-1514.
7. Hlordzi, V., Kuebutornye, F.K., Afriyie, G., Abarike, E.D., Lu, Y., Chi, S. and Anokyewaa, M.A., 2020. The use of Bacillus species in maintenance of water quality in aquaculture: A review. *Aquaculture reports*, *18*, p.100503.
8. Huang, Y., Miu, Q., Kwong, R.W., Zhang, D., Fan, Y., Zhou, M., Yan, X., Jia, J., Yan, B. and Li, C., 2024. Leveraging the One Health concept for arsenic sustainability. *Eco-Environment & Health*.
9. Jobin, L. & Namour, P., 2017. Bioremediation in Water Environment: Controlled Electro-Stimulation of Organic Matter Self-Purification in Aquatic Environments. Advances in Microbiology, 7(12), pp. 813-852.
10. Kraemer, S.A., Ramachandran, A. and Perron, G.G., 2019. Antibiotic pollution in the environment: from microbial ecology to public policy. *Microorganisms*, *7*(6), p.180.
11. Rabbani, A., Zainith, S., Deb, V.K., Das, P., Bharti, P., Rawat, D.S., Kumar, N. and Saxena, G., 2021. Microbial technologies for environmental remediation: potential issues, challenges, and future prospects. *Microbe mediated remediation of environmental contaminants*, pp.271-286.
12. Sakr, M. et al., 2022. A critical review of the recent developments in micro–nano bubbles applications for domestic and industrial wastewater treatment,. Alexandria Engineering Journal, 61(8), pp. 6591-6612.
13. Schäffler, A. and Swilling, M., 2013. Valuing green infrastructure in an urban environment under pressure—The Johannesburg case. *Ecological economics*, *86*, pp.246-257.
14. Singh, N., Poonia, T., Siwal, S.S., Srivastav, A.L., Sharma, H.K. and Mittal, S.K., 2022. Challenges of water contamination in urban areas. In *Current directions in water scarcity research* (Vol. 6, pp. 173-202). Elsevier.
15. Torimiro, N., Daramola, O.B., Oshibanjo, O.D., Otuyelu, F.O., Akinsanola, B.A., Yusuf, O.O., Ore, O.T. and Omole, R.K., 2021. Ecorestoration of heavy metals and toxic chemicals in polluted environment using microbe-mediated nanomaterials. *International Journal of Environmental Bioremediation & Biodegradation*, *9*(1), pp.8-21.
16. Wu, Y., Lin, H., Yin, W., Shao, S., Lv, S. and Hu, Y., 2019. Water quality and microbial community changes in an urban river after micro-nano bubble technology in situ treatment. *Water*, *11*(1), p.66.
17. Yadav, K.K., Singh, J.K., Gupta, N. and Kumar, V.J.J.M.E.S., 2017. A review of nanobioremediation technologies for environmental cleanup: a novel biological approach. *J Mater Environ Sci*, *8*(2), pp.740-757.