

DAVID IKUMI

Unlocking wastewater: How resource recovery from treatment plants can confront water and sanitation challenges



As South Africa contends with an escalating water and sanitation crisis, Prof David Ikumi promotes innovation through research and academic mentorship. He views wastewater not as something to discard, but as a valuable source of energy, nutrients, and reusable water.

Article by Jorisna Bonthuys.

Ikumi explains, "Wastewater is no longer just something to treat – it is a platform for water security, energy recovery, and nutrient circularity."

To advance this perspective in practice, Ikumi – a full professor in the Department of Civil Engineering at the University of Cape Town (UCT) – provides academic mentorship on wastewater and environmental systems to his students.

Highlighting the real-world impact of this approach, he says, "Wastewater treatment plants represent a great opportunity within the framework of the circular economy." Ikumi's commitment to this belief has, over the years, propelled him from a high school science project on a polluted river to recognition as an expert in bioengineering models for wastewater treatment plants.

A personal journey

Ikumi's journey into the world of water began in Nairobi, Kenya, where he was born and raised. As a high school learner participating in a national science congress, he tackled projects that focused on pollution in the Nairobi River. "This was probably where my water journey started," he recalls.

His older cousin, Myra, who was living in Pretoria, suggested he study in South Africa. Motivated by this idea, Ikumi was eager to explore his education options. He moved to Pretoria to obtain a South African matric certificate. A year later, he was admitted to UCT's civil engineering programme.

Initially, Ikumi's ambition was to become a structural engineer, building bridges, high-rise buildings, and dams. However, during his first year, he met Prof George Ekama, who later became his



David Ikumi is a professor in the Department of Civil Engineering at the University of Cape Town.

supervisor and mentor in wastewater studies. "Prof Ekama was full of energy and incredibly knowledgeable about wastewater in particular," Ikumi recalls. "He reignited my passion for water because of how he taught his classes and by being passionate about the topic."

After graduating, Ikumi worked briefly at a marine engineering firm. Despite this, he kept feeling drawn back to academics. One day, Ikumi showed up unannounced at Ekama's office and expressed his interest in wastewater research, asking whether he could study under the expert. Ekama responded enthusiastically and they discussed his options. This encounter paved the way for Ikumi to start a Master's degree at the start of the next academic year.

"Prof Ekama was part of a very exciting research group which was at the forefront of wastewater-related research," Ikumi says. "At the time, UCT's Water Research Group included experts like Prof Ekama, Prof Mark Wentzel, and Prof Richard Loewenthal.

"They were leading in research about wastewater. For example, the group developed a system to remove nitrogen and phosphorus from wastewater. This process, called the 'UCT process', is now used worldwide, including in South Africa. It is a configuration used to remove organics and nutrients from the wastewater using biological treatment, via growth of mixed cultures of microorganisms in wastewater treatment reactors."

Unfortunately, Ikumi's study plans faced practical hurdles in the department. His mentor, then the department head, couldn't teach one-on-one courses to a single student. "We had to figure out a way for me to gain knowledge and use it to carry out the necessary research," Ikumi says. "Prof Ekama defined my research project to be very comprehensive. My work was very experimental at the time. My first experiment involved the operation and testing of lab-scale systems that replicated three full-scale wastewater treatment plants."

As his research expanded, Ikumi's Master's degree was upgraded to a PhD in civil (wastewater treatment) engineering. The work

demanding a whole host of experiments and further data. This deep immersion in the field only strengthened his fascination, turning his focus on wastewater into what is becoming his life's work.

Ikumi completed his PhD degree and began his postdoctoral fellowship as a research visitor at the Université Laval in Quebec (Canada). He later completed this fellowship at UCT under the Carnegie fellowship that was working to develop a new generation of African academics. Afterwards, he was employed as a senior lecturer in UCT's Department of Civil Engineering.

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Modelling the (un)known

Today, Ikumi specialises in bioprocess modelling and creates computer models of treatment plants. These virtual replicas simulate plant responses to changes, such as load spikes from urban growth or industrial wastewater, without real-world risks.

Ikumi's dynamic 'glass-box' models track carbon, nitrogen, and phosphorus across the plant, revealing treatment progress and outcomes. "Virtually replicating conditions in treatment plants is like assembling a puzzle, challenging yet rewarding. We analyse wastewater for key elements, then track them to compare phosphorus removal methods.

"By entering all this information into virtual systems, we can model outcomes," he explains. "We use equations to translate

biological, physical, and chemical processes into models. These are based on recurring behaviour by microorganisms that treat wastewater. The models then help us design ideal systems and optimise their operation.”

Modelling also helps find bottlenecks, test scenarios, and optimise sludge retention or aeration. This can reduce capital costs by avoiding oversized facilities and cutting significant electricity costs, he adds.

“The models let us then evaluate treatment strategies and find the best approach. For example, we compare biological and chemical phosphorus removal, or explore options such as energy or nutrient recovery and water reuse. Calibration adjusts predictions to real measurements; validation checks accuracy with past data.”

This approach is useful, as each treatment plant has its own challenges. “Input to these model equations includes wastewater characteristics,” Ikumi explains. “We match the flow of components through the treatment system to predict treated water quality under different scenarios. The origin of the wastewater can differ, for instance. It might be runoff from vineyards, food scraps, city garbage, household refuse, slaughterhouse waste, factory byproducts, among countless other sources.

By simulating complex biological processes (such as how bacteria remove contaminants in wastewater), these models enable better decisions for design, operation, and upgrades, helping treatment plants avoid costly inefficiencies.

“These scenarios illustrate how using mathematics can help you choose the cheapest option, remove pollutants, and ensure the water meets environmental standards. So, you’re using mathematical equations to help guide design choices in water quality work, training, or use.

“This work delivers practical engineering tools for informed decisions – whether designing new systems or optimising

current processes – streamlining expert oversight of wastewater treatment.”

For new plants, these models help select cost-effective, compliant designs. For upgrades, the models minimise energy, chemicals, and waste by guiding resource recovery. They also future-proof plants for climate change and urban growth by ensuring compliance and enabling recovery, he points out.

South Africa’s ongoing water crisis makes these advances increasingly urgent. Recent ‘Green Drop’ reports reveal stark failures: only 2% of the country’s 995 wastewater plants earned certificates in 2022, with 34% critical. These and other audit reports highlight pollution and water resource waste, underscoring the need for reforms in municipal water and sanitation services.

About 88% of South Africa’s wastewater treatment plants are also high risk. They often exceed design capacity, deal with dysfunctional processes and equipment, and experience non-compliance issues.

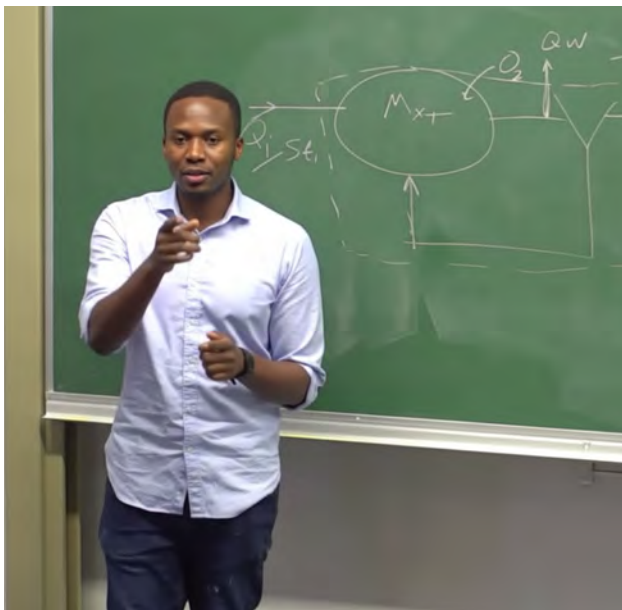
Defining the future of wastewater

Ikumi has worked on many projects that identified real problems in treatment systems that are overwhelmed.

“Our research group focuses on envisioning the ideal future of wastewater treatment systems. We use the glass-box model as a tool to help us adjust our designs to address the specific problems of a wastewater treatment plant. We use bioprocess modelling to define and pursue that vision. This modelling approach informs our exploration of future systems. It makes it very clear how the system’s inputs are changed and why they produce different outputs.”

No longer mere treatment plants, these facilities can embody ‘circularity’: a design principle focused on using resources efficiently and minimising waste, such as reclaiming water for reuse, capturing biogas for energy, and recovering nutrients for

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Ikumi’s research creates advanced frameworks for designing and optimising water and resource recovery facilities, with the main goal of supporting risk-informed decisions under uncertainty.

agriculture. "For example, sometimes the challenge is building a new plant from scratch to handle a specific type of waste," Ikumi explains. "Some coal-to-fuel processes, for instance, produce waste that is very strong and rich in organic material, requiring specialised handling. There are also many design options to consider."

Expanding knowledge horizons

The Water Research Commission (WRC) has been central to his career. "This support gave me a platform for in-depth, long-term research I couldn't do otherwise," he says. "WRC funding lets us move from understanding processes to shaping infrastructure decisions."

The WRC has funded over ten projects in which he participated – many under his leadership. Ikumi's research includes developing a full-cost recovery model for wastewater infrastructure, digital twins for reclamation and reuse, and models to track micropollutants and pathogens in local treatment plants.

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Prof David Ikumi (second from left) as a panellist during a Water Engagement Day event.

Some of his work combines AI-powered models, real-time sensors, and digital twins – virtual plant replicas that recalibrate and predict in real time. "With mathematical models, recent projects let me integrate artificial intelligence (AI) into my work. I'm interested in models that teach themselves, using AI for solutions to different waste types, and new ways to study and monitor microbes."

He envisions, for example, a Cape Flats or Zandvliet digital twin in Cape Town projecting optimisations as treatment plant conditions shift. "I want to explore how digital technology can help these plants learn and improve, and create a flexible, model-based framework. The next generation of wastewater plants will be digitally enabled learning systems."

"My research is shifting to integrating water and sanitation systems into future smart cities, especially through wastewater treatment plants."

Expanding on this vision, he says, "Real-time sensors and digital models give me a system that knows exactly what is happening in that plant and shows what actions are needed as things change."

Ikumi's research creates advanced frameworks for designing and optimising water and resource recovery facilities, with the main goal of supporting risk-informed decisions under uncertainty.

This work integrates fundamental process understanding with data-driven intelligence to develop adaptive, AI-enabled

platforms that combine mechanistic modelling and probabilistic evaluation.

Transitioning beyond the technical realm, collaborations with social anthropologists and governance experts help him to challenge public perceptions and policy bottlenecks related to wastewater treatment facilities. "Technical solutions fail without buy-in from key roleplayers," he notes. "We need to learn to communicate our results in a clear and accessible manner to decision-makers."

As a lecturer, Ikumi extends this integrated approach by equipping graduates in water quality engineering for bioprocess design and operation. Drawing on chemistry, microbiology, and mathematics, he champions modelling for plant-wide integration: from activated sludge (a process using microbes to break down waste) to sludge digestion (breaking down organic matter into biogas).

Beyond technical outputs, the influence of WRC-funded research is evident through skills development and industry collaboration. Numerous postgraduate students educated through these projects now work in municipalities, consulting firms, and research institutions, driving improved operational methods and accelerating the adoption of innovation. Engagement with water utilities, regulators, and professional associations has also ensured research findings are converted into practical guidance, advancing data-driven policy design and infrastructure strategy.

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Future plans

Looking ahead, Ikumi emphasises the need for sustained investment in long-term, system-oriented research programmes. "The water sector faces many challenges: climate change, urbanisation, energy constraints, and emerging contaminants. Integrated solutions must span disciplines and institutional boundaries."

He believes that the next generation of wastewater infrastructure should be adaptive systems. "These systems must learn from data, optimise resource recovery, and support societal goals such as climate mitigation and the development of the circular economy."

Current projects focus on system-wide approaches to alternative water reuse, such as combining acid mine drainage with municipal wastewater for fit-for-purpose reuse and potable water savings.

He also hopes to better understand the microbial interactions that affect treatment performance. Inspired by biological systems, Ikumi examines polyphosphate-driven energy regulation to enhance the resilience of engineered systems.

Ikumi and his team build integrated plant-wide models that connect activated sludge, settling processes, and biofilm-based technologies, accounting for microbial competition, solids separation, and contaminant tracking. Experimental platforms

and virtual laboratory networks are developed to improve data quality, standardisation, and collaboration.

His future focus includes more work on AI-digital twin frameworks, African collaboration on urbanisation and climate resilience, and advancing resource circularity locally.

Ikumi aims to make a tangible difference: connecting universities and businesses, applying data tools in cities, advancing digital systems, and supporting African research. "I want research to be implemented in action on the ground," he says.

"Wastewater holds untapped power," he asserts. "We need to unlock it and translate that potential into real systems that improve water security and sustainability."

"More and more, we are starting to see wastewater and what it contains in a new way, where nothing is wasted. This could make a huge difference for the communities we work with.

"Hopefully, we inspire our students and future researchers and engineers along the way. My ultimate hope is that through innovation, collaboration, and putting our research to work in real communities, we not only envision but deliver a future where everyone has secure, sustainable water. This is the legacy I aim to build."



To read more on David Ikumi's research, visit: <https://orcid.org/0000-0001-9158-2525>

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Part of the team for the ERASE (Evaluation of Resource Recovery Alternatives in South African water Treatment systems) project, funded by a DANIDA grant and coordinated by the Technical University of Denmark alongside the University of Cape Town.