5th Asia Pacific Conference on Industrial Engineering and Operations Management
Tokyo, Japan, September 10-12, 2024
Publisher: IEOM Society International, USA DOI:10.46254/AP05.20240242
Published: *September 10*, 2024

Water Quality Improvement for Food and Beverage Industry vs. SANS:241

Lindiwe Ndlangamandla, Nita Sukdeo
and Sambil Charles Mukwakungu
Department of Quality and Operations Management
University of Johannesburg
Johannesburg, Gauteng, South Africa
lindiwe.kwan@gmail.com, nsukdeo@uj.ac.za,
sambilm@uj.ac.za

Abstract

The food and beverage industry relies heavily on water, not only as a key ingredient but also for essential processes such as cleaning and equipment maintenance. Ensuring high water quality is vital for maintaining product safety, taste, and shelf life. This study examines the consistency of municipal water quality in South Africa, with a particular focus on the Gauteng and Northwest provinces, and its alignment with the South African National Standard (SANS) 241. The research focuses on three companies located in Randfontein, Roodepoort, and Potchefstroom, analyzing historical water quality data over three years (2021–2023). The study aims to assess how inconsistent water quality affects the final product and proposes alternative water management systems to ensure consistently high water quality. The findings highlight significant challenges in maintaining water quality standards, with heavy metal contamination and water hardness being persistent issues. To address these challenges, the study recommends implementing an AI-driven water quality monitoring and control system to enhance the efficiency and water treatment process effectiveness. This research contributes to the advancement of water quality management practices, ensuring the safety and quality of food and beverage products, and underscores the importance of consistent monitoring and adherence to water quality standards.

Keywords
Water Quality, Food and Beverage Operations, SANS:241 Standards, Water Treatment, Heavy Metal Contamination

1. Introduction
Water is made up of two hydrogens and one oxygen atom chemically. The term "universal solvent" refers to aqueous water's ability to dissolve anything that comes into touch with it. In rivers that pass over limestone mountains, calcium carbonate is one of the minerals that is dissolved. In terms of biology, the ocean is home to numerous viruses, single-celled organisms, and multicellular species, as well as the largest mammals (Luckmann et al. 2014).Water is a vital component in most food and beverage production, but it is frequently disregarded. The beverages industry makes extensive use of water, from cleaning to using it as a vital component in drinking. However, recent water quality concerns, such as the high lead levels discovered in Flint, Michigan's supply, have raised some serious concerns. Processors might presume that the municipal water utilized in the plant arrives safely (Lee and Lee 2015).

Water quality can be determined by several variables, bacteria levels, dissolved oxygen concentrations, including the quantity of salt (or salinity), and the number of debris suspended in the water (turbidity). In some bodies of water, the quantity number of tiny algae and levels of pesticides, herbicides, heavy metals, and other contaminants may also be evaluated to determine water quality (Poretti 1990). Municipalities and bottled water firms are among the sources of water that frequently post their water quality data online for public use. The evaluated water quality criteria need to adhere to local government requirements, which are frequently affected by international standards established by businesses, including the World Health Organization (WHO) or organizations that monitor water quality (Luckmann. et al. 2014).

1.1 Problem Statement
Water is a crucial resource for the food and beverage industry because it is a component of food products, is required for processing, and is used for drinking. Water conservation and sustainability are given top attention in this sector when stakeholders in the food supply chain (FSC) make decisions. Freshwater demand, supply, and quality must both be met, necessitating the use of an intelligent and adaptable water quality improvement system (Minhas 2022).

A water quality improvement system can only be introduced if all the stakeholders within the FSC communicate, work together, and take collective action. Hence, a real-time water consumption tracking system is required, allowing for the monitoring of specific information on water quality, and usage activities to detect any specification that can pose a risk to the final product, waste, and discover chances to cut back on consumption (Mullen 2012).The problem proposed for this research is to investigate the inconsistency in water quality from the municipality. Where there has been an observation on many water quality issues that tend to affect the food and beverage industry resulting in recalls of products.

1.2 Research Aim, Objectives, and Question
The aim of the research is to understand all the physical, biological, and chemical qualities that can be used to improve the water quality of the food production industries. The research objectives (RO) this study has set to achieve are: (RO1) to assess the consistency of the municipal water in meeting SANS:241 standards, (RO2) to assess the impact of the inconsistency on the quality of the final product and lastly (RO3) to establish alternative water quality management systems that the organization may implement to ensure consistently acceptable water quality.

From the above research objectives, the following research questions (RQ) have been formulated: (RQ1) What is the consistency of municipal water in meeting SANS:241 standard? (RQ2) What impact does the inconsistency of water quality have on the quality of the final product? And (RQ3) what alternative water quality management systems can be implemented by organizations?

1.3 Scope, Limitations and Significance of the Study
The scope of the study involves assessing the compliance of food and beverage companies in Gauteng and Northwest provinces, South Africa, with the established water quality standards. The assessment focuses on three companies located in Randfontein (West Rand, Gauteng), Roodepoort (East Rand, Gauteng), and Potchefstroom (Northwest province). The methodology includes direct observation of records, review of historical (2021, 2022 and 2023) data on water quality parameters, chemical analysis records, and microbial trends. By analyzing these aspects, the study seeks to identify any deviations from the standards and pinpoint areas where water treatment processes can be improved.

This study has several limitations, including potential biases in data collection, reliance on secondary data, and a narrow focus on specific facilities and companies, which may limit generalizability and depth of analysis. Additionally, the study's scope may overlook broader water quality issues, and its findings may be impacted by external factors, seasonal variations, and evolving technologies. Furthermore, the lack of detailed information on sampling methodologies, water treatment processes, and socio-economic implications, as well as the absence of specific recommendations, may constrain the study's conclusions and applicability.

The study offers important information that can help enhance water treatment processes in the food and beverage industry. It can also assist regulatory bodies in making improvements to water quality standards. Additionally, the study highlights contamination risks, which can aid in environmental conservation efforts. Furthermore, it contributes to technological innovation by showcasing the potential of AI-driven monitoring systems. These contributions improve the well-being of the public, promote a healthier environment, and drive technological advancements.

2. Literature Review
The water quality in the food production industry is the most vital component that all the industries want to utilize to ensure the high quality of the products they will produce. The raw water quality can be assessed, monitored and safety ensured by ensuring the microbial analysis, packaging examination, production processes and sensory evaluation is well done as per the schedule developed by the manufacturer based on the previous data collected. All the tests mentioned can help by identifying the potential hazard that can be carried out by the ingredients used and other contaminants evidence. The sensory evaluation of raw water also plays a huge role by showing the sensory attributes that can impact the quality of water. The color, odor, taste, and texture are efficient for the final assessment of the raw water quality (Aadil. et al. 2019).

2.1 Importance of Water Quality in the Food and Beverage Industry

The food and beverage industry relies heavily on water quality, which is a crucial factor for the safety of both humans and animals. Contaminated water not only poses health risks but also affects product taste and longevity (Sharma and Bhattacharya 2016; Luvhimbi et al. 2022). To produce high-quality products, manufacturers require clean, disinfected water that meets strict purity standards throughout every step in the production process - from ingredients to packaging materials along with pipes or any equipment used. Any impurities present can significantly impact efficiency even if they don't come into contact directly with end-products. Furthermore, it's essential to maintain good quality when using boilers or cooling towers by minimizing concentrated solids going through such systems as corroded components cause faster wear-and-tear leading to scale build-up while reducing overall performance.

2.2 Advanced Purification Technologies

Advanced industrial reverse osmosis purification technology plays a crucial role in the food and beverage industry. As highlighted by Hutton and Chase (2017), and later by Bhagwat (2019), the quality of water used in this sector directly affects consumer health, making it essential to maintain stringent water treatment standards. Water employed in food preparation, processing, or cleaning must adhere to high drinking-water standards, achievable through industrial-grade reverse osmosis systems (World Health Organization 2017). Furthermore, cleanliness is vital for plants producing consumables, encompassing the washing of equipment, storage facilities, and transport vehicles in specific zones (Lelieveld et al. 2014). Utilizing an industrial reverse osmosis system not only improves utility efficiency but also reduces downtime and lowers costs related to repairs and maintenance (Yang et al. 2019).

2.3 Water Reuse and Recycling

Implementing water reuse and recycling is a crucial strategy for food and beverage manufacturers, especially given the challenges of uncertain water supply reliability (Bailone et al. 2022). Advanced industrial water purification systems, like Closed-Circuit Reverse Osmosis (CCRO), offer innovative ways to convert feed and waste into clean, reusable water (Gu et al. 2021). This technology provides intelligent, autonomous solutions that allow companies to reclaim valuable fluids and significantly cut down on waste, thus lowering costs associated with supplies and production (Gu et al. 2021; Hong et al. 2023). By embracing these water management technologies, manufacturers can enhance their operational efficiency and reduce their environmental impact (UN Environment Programme 2004).

2.4 Heavy Metals and Water Quality – A Growing Concern

Heavy metals in natural water sources are a serious concern for both environmental and human health (WHO 2017; Mitra et al. 2022). Contaminants like lead, mercury, and arsenic can infiltrate water systems, leading to severe health conditions, such as cancer, neurological damage, and organ failure (Atef et al. 2022). To address this, the food industry, especially beverage manufacturers, is increasingly implementing water tracking systems to remove heavy metals from raw water used in production (Bhagwat 2019; Birniwa et al. 2024). This is essential to prevent the accumulation of these harmful substances in food products, which could endanger consumer health.

Effective detection and monitoring of heavy metals in water are crucial. Electrochemical sensors have become a promising tool for this purpose, providing several benefits over traditional methods (Waheed et al. 2018). These sensors can detect metal ions in water systems, improving detection capabilities through enhanced conductivity and catalytic activity (Hui et al. 2022; Mohanadas et al. 2023). Furthermore, advances in nanotechnology have led to the creation of nanostructured electrochemical sensors, which offer superior sensitivity and selectivity for detecting heavy metals (Maghsoudi et al. 2021; Raju et al. 2023; Xu et al. 2022).

2.5 Conductivity and pH Measurements

In water tracking systems, especially within chromatography systems, measuring conductivity and pH is crucial (Zulkifli et al. 2018). Conductivity serves as a key control parameter that helps automate these systems by detecting salt gradients through electrochemical sensors. This measurement allows for the precise management of buffer dilution, which is essential for maintaining the system's optimal performance. Additionally, conductivity monitors are critical in identifying harmful salt ions, protecting both the system's integrity and human health (World Health Organization 2022).

However, it is important to understand that both conductivity and pH measurements can be affected by temperature changes (LeClair et al. 2010). Fluctuations in temperature can alter the accuracy of these readings, making temperature control and compensation essential in water tracking systems (Xu et al. 2021). Utilizing advanced sensors and monitoring systems can help mitigate these temperature-related effects, ensuring that conductivity and pH measurements remain accurate and reliable (Waheed et al. 2018).

2.6 Water Quality Improvement for the Food and Beverage Industry

In the food and beverage industry, maintaining high water quality is essential as it directly influences the shelf life and quality of products. The pH levels of raw water must be carefully regulated to avoid the denaturation of ingredients, which is critical for ensuring product stability (LaClair and Etzel 2010). Additionally, it's vital to remove total dissolved solids and heavy metals, such as lead, mercury, and arsenic, to maintain water quality (Abdullah et al. 2019). Improving water quality is critical to ensure the safety and integrity of food products and operations. Poor water quality can lead to contamination, foodborne illnesses, and other health concerns (Ashbolt 2004; Cissé 2019; World Health Organization 2023). Ensuring high water quality is essential for maintaining consumer trust and protecting the industry's reputation.

Several techniques are used to remove heavy metals, including ionic exchange, precipitation, coagulation, and membrane separation. Among these, membrane technologies like microfiltration and nanofiltration are particularly effective at removing impurities and enhancing water quality (Gomes et al. 2020). Furthermore, innovative water treatment methods, such as High-Pressure Processing (HPP) and Boron Nitride Membranes (BN), are promising for improving water quality (Roobab et al. 2021).

2.7 Water Quality Standards and Minimum Requirements for Drinkable Water

In South Africa, the National Standard SANS 241 sets minimum standards for potable water, covering microbiological, physical, aesthetic, and chemical aspects (John and Trollip 2009). This standard ensures that drinking water is safe for human consumption. The South African National Standard, SANS 24 outlines the physical, chemical, and microbiological criteria that water must meet to ensure it is safe for drinking and other domestic uses, thereby protecting public health (John and Trollip 2009; Rimmell 2023). This standard covers the physical, chemical, and microbial aspects of water quality and aligns with international guidelines set by the World Health Organization (World Health Organization 2022). For the food processing sector, compliance with SANS 241 is essential as it ensures the safety and quality of water used in processing, reducing the risk of waterborne contaminants and maintaining consumer confidence. Meeting these standards not only helps in producing high-quality food products but also supports the industry's reputation and contributes to economic growth (Cao and Shao 2024). To ensure comprehensive coverage of all relevant aspects, SANS 241 establishes specific criteria for various water quality determinants. These criteria are organized into a series of tables, each detailing the permissible limits for different contaminants and attributes of water. Below is an overview of these key determinants as compiled by Integral Laboratories in South Africa:

Table 1. Microbiological Determinants (Integral Laboratories 2021)

Determinants	**Unit**	**Risk**	**Standard Limit**
E. coli/Faecal Coliforms	Count per 100 mL	Acute health	Not Detected
Cryptosporidium spp	Count per 10 L	Acute health	Not Detected
Giardia spp	Count per 10 L	Acute health	Not Detected
Total Coliforms	Count per 100 mL	Operational	≤ 10
Heterotrophic Plate Count	Count per 1 mL	Operational	≤ 1000
Somatic Coliphages	Count per 10 mL	Operational	Not Detected

Table 2. Physical and Aesthetic Determinants (Integral Laboratories 2021)

Determinants	**Unit**	**Risk**	**Standard Limit**
Colour	mg / L as Pt-Co	Aesthetic	≤ 15
Conductivity @ 25°C	mS / m	Aesthetic	≤ 170
Total Dissolved Solids	mg / L	Aesthetic	≤ 1200
Turbidity	NTU	Operational	≤ 1
Turbidity	NTU	Aesthetic	≤ 5
pH @ 25°C	pH Units	Operational	≥ 5 to ≤ 9.7

.Table 1 presents the standard limits for microbiological indicators, which include acute health risk indicators such as E. coli and Cryptosporidium spp. The presence of these contaminants must be absent to ensure the immediate safety of drinking water. Table 2 outlines the permissible limits for physical and aesthetic qualities of water, such as color, conductivity, total dissolved solids, and turbidity. While these factors may not always pose direct health risks, they significantly affect the water's overall acceptability and palatability

Table 3. Chemical-Macro Determinants (Integral Laboratories 2021)

Determinants	**Unit**	**Risk**	**Standard Limit**
Free chlorine	mg / L as C12	Chronic health	≤ 5
Monochloramine	mg / L	Chronic health	≤ 3
Nitrate	mg / L as N	Acute health	≤ 11
Nitrite	mg / L as N	Acute health	≤ 0.9
Combined nitrate plus nitrite (2)	mg / L as N	Acute health	≤ 1
Determinants	**Unit**	**Risk**	**Standard Limit**
Sulphate	mg / L as SO4	Acute health	≤ 500
Sulphate	mg / L as SO4	Aesthetic	≤ 250
Fluoride	mg / L as F	Chronic health	≤ 1.5
Ammonia	mg / L as N	Aesthetic	≤ 1.5
Chloride	mg / L as CI	Aesthetic	≤ 300
Sodium	mg / L as Na	Aesthetic	≤ 200
Zinc	mg / L as Zn	Aesthetic	≤ 5

This section, as shown in Table 3, specifies the limits for macro-chemical substances, which include chemicals like chlorine, nitrate, and fluoride. These are monitored for both acute and chronic health risks, often resulting from treatment processes or environmental contamination.

Table 4. Chemical-Micro Determinants (Integral Laboratories 2021)

Determinant	**Unit**	**Risk**	**Standard Limit (µg/L)**
Aluminium	(µg/L as Al)	Operational	≤ 300
Antimony	(µg/L as Sb)	Chronic health	≤ 20
Arsenic	(µg/L as As)	Chronic health	≤ 10
Barium	(µg/L as Ba)	Chronic health	≤ 700
Boron	(µg/L as B)	Chronic health	≤ 2400
Cadmium	(µg/L as Cd)	Chronic health	≤ 3
Chromium (Total)	(µg/L as Cr)	Chronic health	≤ 50
Copper	(µg/L as Cu)	Chronic health	≤ 2000
Cyanide (Recoverable)	(µg/L as CN)	Acute health	≤ 200
Iron	(µg/L as Fe)	Chronic health	≤ 2000
Iron	(µg/L as Fe)	Aesthetic	≤ 300
Lead	(µg/L as Pb)	Chronic health	≤ 10
Manganese	(µg/L as Mn)	Chronic health	≤ 400
Manganese	(µg/L as Mn)	Aesthetic	≤ 100
Mercury	(µg/L as Hg)	Chronic health	≤ 6
Nickel	(µg/L as Ni)	Chronic health	≤ 70
Selenium	(µg/L as Se)	Chronic health	≤ 40
Uranium	(µg/L as U)	Chronic health	≤ 30

Table 4 details the allowable concentrations of trace elements and metals, including arsenic, cadmium, and lead. Monitoring these contaminants is critical due to their potential long-term health effects.

Table 5. Organic Determinants (Integral Laboratories 2021)

Determinant	**Unit**	**Risk**	**Standard Limit (µg/L)**
Total Organic Carbon	(mg/L)	Chronic health	≤ 10

Trihalomethanes: - Chloroform - $CHCl_3$ - Bromoform - $CHBr_3$ - Dibromochloromethane - $CHBr_2Cl$ - Bromodichloromethane - $CHBrCl_2$	 (μg/L) (μg/L) (μg/L) (μg/L)	 Chronic health Chronic health Chronic health Chronic health	 ≤ 300 ≤ 100 ≤ 100 ≤ 60
Combined trihalomethanes (3)	(μg/L)	Chronic health	≤ 1
Determinant	**Unit**	**Risk**	**Standard Limit (μg/L)**
Total Microcystin	(μg/L)	Chronic health	≤ 1
Phenols as C_6H_5OH	(μg/L)	Aesthetic	≤ 10

Table 6 summarizes the required compliance percentages for different risk categories under SANS 241:2015, ensuring a high standard of water quality across all parameters.

Table 6. Compliance Percentages (Integral Laboratories 2021)

Risk	**Required Compliance to SANS 241:2015**
Acute health microbiological	99.00%
Acute health chemical	99.00%
Chronic health	97.00%
Aesthetic	95.00%
Operational	95.00%

These tables collectively outline the rigorous standards set forth to protect public health and guarantee the safety and quality of drinking water in South Africa. Adherence to these standards is not only a legal obligation but also a crucial aspect of maintaining public trust and safeguarding consumer well-being.

2.8 Challenges in Water Treatment Systems

Despite the importance of water quality, there are challenges in implementing and maintaining effective water treatment systems within the food and beverage industry. High costs and reliance on outdated treatment methods often prevent the adoption of newer, more efficient technologies (Mullen 2020).

3. Methods

3.1. Research Approach

This study utilizes a mixed-methods approach, incorporating both quantitative and qualitative methods, which are often applied in behavioral, social, and health sciences, particularly in multidisciplinary settings and complex systems (Creswell and Clark 2017). The study is structured in two phases:

Phase 1: Analytical Approach

1. Statistical Analysis: The study performed rigorous quantitative analysis on historical water quality data, utilizing statistical methods to identify trends and patterns over a three-year period from 2021 to 2023. The data were compared against the SANS:241 standards to assess compliance levels.
2. Trend Analysis: Historical data were analyzed to evaluate the companies' compliance with SANS:241 standards over the past three years in Randfontein, Potchefstroom, and Roodekop.

Phase 2: Observational Approach

1. Direct Observation of Records: Researchers examined historical records from three companies located in Randfontein (West Rand, Gauteng), Roodepoort (East Rand, Gauteng), and Potchefstroom (Northwest province), South Africa. The reviewed records included water quality parameters, chemical analysis results, and microbial trends.
2. Focus Groups and Observations: Separate focus groups were held with quality control managers, production supervisors, and technical staff from each company. These discussions centered around water treatment processes, compliance with standards, and potential areas for improvement. Additionally, direct observations

were conducted to gather data on behaviors, processes, and conditions within the companies' operational settings.

By integrating these methodologies, the study seeks to offer a comprehensive overview of water quality management practices within the food and beverage industry. It aims to pinpoint areas for improvement and guide the development of more effective water quality management systems.

3.2. Data Collection and Analysis

This study utilized a secondary data collection approach to evaluate the effectiveness of existing water tracking systems in enhancing water quality. Historical records from three companies located in Randfontein, Roodepoort, and Potchefstroom, South Africa, were gathered and analyzed. The specific data collected included:

- **Chemical Analysis Records:** Details on the chemical composition of water, including the presence of any contaminants or chemical imbalances.
- **Microbial Test Results:** Information on the microbial content in water samples, highlighting potential biological contaminants.
- **Water Quality Parameter Records:** Measurements of various water quality indicators, such as pH levels, conductivity, and total dissolved solids.

These records were scrutinized to evaluate the performance of the current tracking systems over a three-year period. The data were compared against the SANS:241 standards to determine compliance and pinpoint areas needing improvement. Through this examination of existing data, the study aimed to identify efficient tracking systems and provide insights into developing effective water quality management practices within the food and beverage industry.

3.3. Validity of Results

This study establishes validity through a thorough mixed-methods approach, integrating both quantitative and qualitative data collection and analysis, as recommended by Creswell and Clark (2017). By using secondary data from three companies in different locations (Randfontein, Roodepoort, and Potchefstroom), the study ensures a diverse and representative sample, adhering to the principles of external validity (Merriam and Tisdell 2015).

The analysis of historical records, including chemical analysis, microbial test results, and water quality parameter records, offers a comprehensive view of water quality management practices. This aligns with the concept of data triangulation, which strengthens the study's conclusions by cross-verifying information from multiple sources (Denzin 1978). The comparison of these data against SANS:241 standards provide criterion validity, as these standards are a recognized benchmark for water quality in South Africa (John and Trollip 2009).

The inclusion of focus groups and observations with quality control managers, production supervisors, and technical staff adds face validity by gathering rich, contextual data (Krueger and Casey 2014). This triangulation of data sources and methods enhances the study's internal validity. Moreover, the application of statistical analysis and trend analysis ensures reliability by providing consistent and reproducible results (Silverman 2004).

By evaluating the effectiveness of current tracking systems and identifying areas for improvement, the study establishes construct validity. It effectively investigates the underlying constructs of water quality management practices (Bryman 2016). Ultimately, the findings contribute to the development of effective water quality management practices in the food and beverage industry, ensuring the production of safe and high-quality products. This approach is consistent with the principles of validity and reliability in research (Creswell and Clark 2017).

4. Results and Discussion

To ascertain if the municipality complies with SANS: 214, samples were taken from three different companies. The findings of the tests were acquired and validated by a certified lab that compares the chemical analyses of the water with SANS 214 to ascertain whether the company is following the rules or not. Three companies which were Randfontein, Potchefstroom, and Roodekop—where the information below was randomly selected—were named after their respective locations.

4.1. Quantitative Results from the Three Companies

4.1.1 Randfontein Company

The water quality parameters at the Randfontein company exhibited consistent trends and patterns over the three-year period from 2021 to 2023. The pH levels (1) ranged from 5.713 in 2021 to 6.304 in 2023, consistently remaining within the acceptable range of 5 to 9, indicating appropriate acidity and alkalinity levels. The temperature of the water (2) stayed stable at 25°C across all three years, adhering to the maximum limit of 27°C, thereby ensuring no significant thermal impact on water quality. Turbidity values (3) were recorded at 3.22 NTU in 2021, 3.45 NTU in 2022, and 3 NTU in 2023, all below the limit of 5 NTU, reflecting a low level of particulate matter in the water. Conductivity (4) decreased slightly from 11.8 µS/cm in 2021 to 10 µS/cm in 2023, significantly below the allowable limit of 170 µS/cm, indicating a low concentration of dissolved salts.

Total Dissolved Solids (TDS) levels (5) also showed a decrease, from 8 µS/cm in 2021 to 6.9 µS/cm in 2023, well below the permissible level of 1,200 µS/cm. Alkalinity (6), measured as CaCO3, declined from 24 mg/l in 2021 to 0 mg/l in subsequent years, within the limit of 200 mg/l, indicating low buffering capacity. Water hardness (7), also measured as CaCO3, increased slightly from 90 mg/l in 2022 to 120 mg/l in 2023, remaining within the acceptable range of 180 mg/l, suggesting moderate levels of calcium and magnesium. The concentration of copper (8) stayed minimal, ranging from 0.15 mg/l in 2021 to 0.2 mg/l in 2023, at or below the limit of 0.2 mg/l, thus minimizing the risk of copper toxicity. Sulphate levels (9) increased from 12 mg/l in 2021 to 44 mg/l in 2023, within the permissible limit of 250 mg/l, indicating a low presence of sulphate ions. Chloride concentrations (10) ranged from 4.1 mg/l in 2022 to 10.2 mg/l in 2023, significantly below the allowable limit of 300 mg/l. Sodium levels (11) varied slightly, with 100 mg/l in both 2021 and 2023, and 150 mg/l in 2022, all within the permissible limit of 200 mg/l.

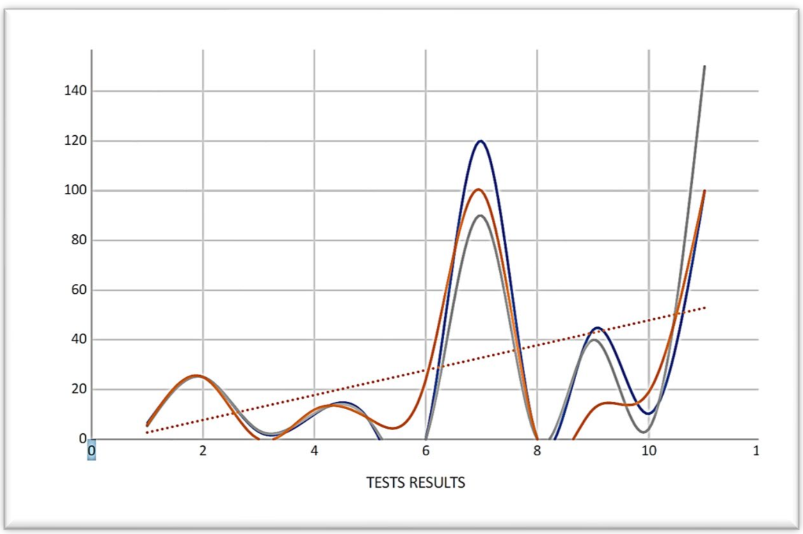

Figure 1. Trend Analysis of Results from the Randfontein Company

Figure 1 highlights variations in water quality over the three years, with some years showing higher concentrations for specific tests. The increasing trend observed in 2022 could indicate deteriorating water quality or changes in testing sensitivity. Notable peaks in 2021 and 2023 suggest potential areas where water quality may exceed acceptable levels, necessitating closer monitoring and possibly corrective actions to ensure compliance with SANS:241 standards.

4.1.2 Potchefstroom Company

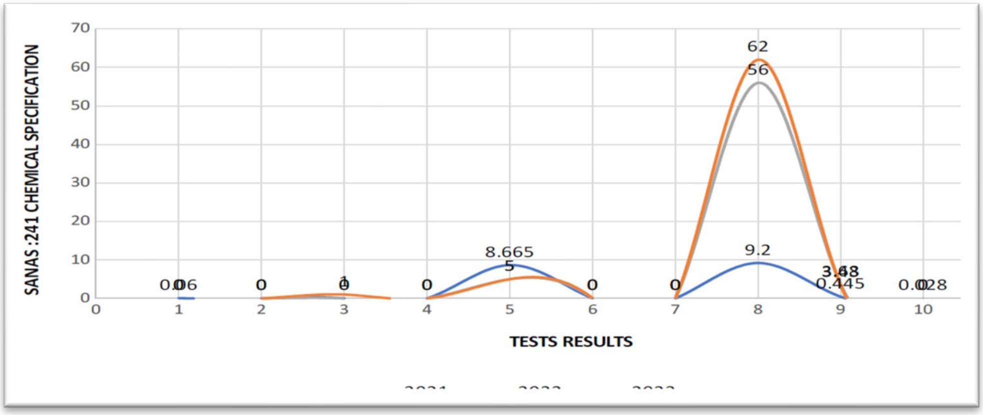

Figure 2. 3 Years Results Analysis from the Randfontein Company

The chlorine levels (1) remained consistently below 0.05 mg/l across all three years, well within the specified limit of ≤5 mg/l, indicating effective chlorine control without exceeding safety limits. Monochloramine concentrations (2) were consistently below 0.18 mg/l each year, complying with the specified limit of <0.18 mg/l, ensuring no harmful levels of this disinfectant byproduct. Nitrate levels (3) were very low, with readings below 1 mg/l in 2021 and 2022 and dropping further to below 0.02 mg/l in 2023. These values are significantly lower than the specified limit of <6.0 mg/l, indicating minimal nitrate contamination. Nitrite levels (4) were consistently low, staying below 0.02 mg/l in 2021, below 0.05 mg/l in 2022, and less than 1 mg/l in 2023, well within the specified limit of ≤0.9 mg/l, indicating effective control of nitrite levels. Sulfate concentrations (5) were 5 mg/l in 2021, below 5 mg/l in 2022, and increased to 11 mg/l in 2023, all within the specified limit of <200 mg/l, indicating low sulfate presence. Fluoride levels (6) were consistently below 0.1 mg/l each year, well within the specified limit of <0.7 mg/l, indicating safe levels of fluoride. Ammonia levels (7) remained consistently low, below 0.05 mg/l each year, within the specified limit of <0.2 mg/l, ensuring minimal ammonia presence. Chloride concentrations (8) decreased from 62 mg/l in 2021 to 56 mg/l in 2022, and further dropped to less than 0.05 mg/l in 2023, all within the specified limit of <100 mg/l, indicating effective chloride control. Sodium levels (9) were 3.43 mg/l in 2021, increased to 3.68 mg/l in 2022, and significantly dropped to 0.786 mg/l in 2023, well within the specified limit of <100 mg/l, indicating safe sodium levels. Zinc concentrations (10) were 0.028 mg/l in 2021, 0.008 mg/l in 2022, and 0.008 mg/l in 2023, all within the specified limit of <3.0 mg/l, indicating very low zinc presence.

4.1.3 Roodekop Company

The water quality parameters at the Roodekop company, measured over three years (2021, 2022, and 2023), mostly complied with the specified standards according to SANS:241. The pH levels (1) were stable, ranging between 7.01 and 7.256, within the acceptable range of ≥5 to ≤9. The water temperature (2) remained constant at 25°C each year, adhering to the limit of ≤27°C. Turbidity (3) slightly increased from 3 NTU in 2021 to 4 NTU in 2023 but remained below the specified limit of ≥5 NTU, indicating clear water. However, conductivity levels (4) consistently exceeded the limit of ≤170 µS/cm, with values of 222 µS/cm in 2021, 225 µS/cm in 2022, and 210 µS/cm in 2023, indicating higher levels of dissolved salts.

Total Dissolved Solids (TDS) (5) remained stable and well within the limit of ≤1,200 µS/cm. Chlorine levels (6) were very low across the years, indicating effective chlorine control, with values ranging from 0.03 mg/l to 0.11 mg/l, within the acceptable limit of ≤5 mg/l. Alkalinity (7) decreased from 82 mg/l in 2021 to 46 mg/l in 2023, remaining within the limit of ≤200 mg/l. Water hardness (8) increased slightly but stayed within the acceptable range, moving from 100 mg/l in 2021 to 135 mg/l in 2023. Copper (9) concentrations significantly decreased from 17 mg/l in 2021 to as low as 0.04 mg/l in 2022, well within the limit of ≤0.2 mg/l. Sulphate levels (10) increased over the years but stayed within the acceptable range, with a peak of 68 mg/l in 2023. Chloride levels (11) were consistent and within the limit, ranging from 23.5 mg/l to 24.2 mg/l. Lastly, sodium levels (12) showed a slight increase from 100 mg/l in 2021 to 109 mg/l in 2023, remaining within the specified limit of ≤200 mg/l. Despite the consistent issue with conductivity, the overall water quality was stable and suitable for use in the food and beverage industry.

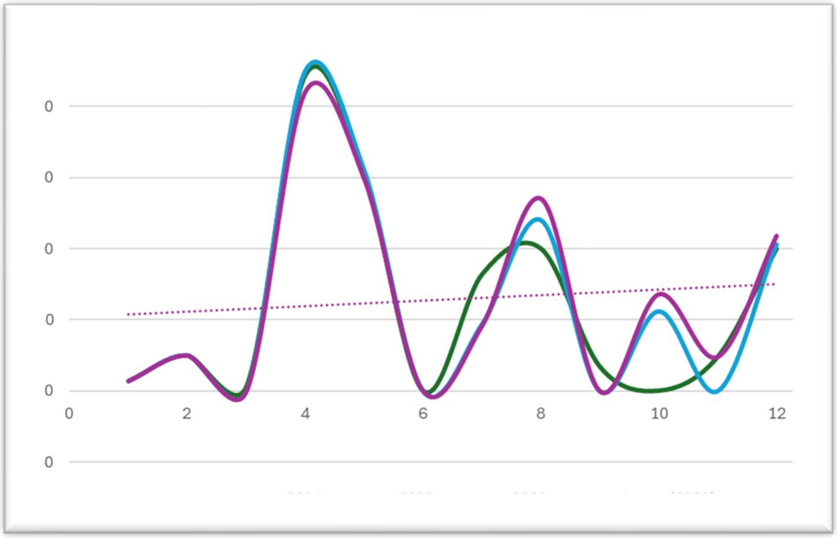

Figure 3. Trend Analysis of Results from the Roodekop Company

4.1.2 Qualitative Results

Focus group discussions and observations conducted at the Randfontein company revealed several insights into water treatment processes and their associated challenges. Dissolved minerals, particularly calcium and magnesium, significantly impact water hardness, and water treatment processes, while purifying the water, can sometimes unintentionally increase hardness. Agricultural practices and geological factors also contribute to the mineral composition and hardness of water, with fertilizers containing calcium and magnesium, along with natural mineral deposits, being significant contributors. Compliance with standards highlighted areas for improvement, as a gradual increase in water hardness was observed. Although water softening processes were effective, they resulted in higher sodium levels. Human activities, such as improper waste disposal and agricultural runoff, significantly impacted sodium levels. Proximity to agricultural areas led to chemical runoff into municipal dams, increasing water hardness, while water softeners and chemical cleaning processes further contributed to sodium levels. Observations of day-to-day water management practices underscored the need for enhanced water treatment and management practices to address mineral and sodium levels in the water.

The focus group discussions from the Potchefstroom company found that employees are concerned about the levels of chlorine in the water supply. Participants agreed that chlorine is necessary for disinfecting water, but they also mentioned that there can be excessive amounts if the dosage control is not adequate. Based on the collected data, it seems that the chlorine levels have been slowly getting closer to the recommended specification over the years. This could mean that the municipality has not been consistently regulating the amount of chlorine added. During the warmer months, the water quality needs to be maintained by increasing the chlorine levels due to seasonal fluctuations. However, the participants made it clear that these adjustments should be reversed when the seasons change to prevent chlorine levels from remaining consistently high. It is important to have precise control over the dosage of chlorine and to be adaptable to different seasons in order to ensure the best water treatment.

The focus group discussions at the Roodekop company identified several key factors contributing to fluctuations in water turbidity, which is the cloudiness or haziness of water caused by tiny particles. Participants pointed out that soil erosion and sediment runoff, particularly in areas undergoing significant land use changes, construction, or agricultural activity, lead to elevated turbidity levels. Additionally, algal blooms, driven by nutrient pollution from agricultural runoff, industrial discharges, or inadequate sewage treatment, contribute to increased turbidity due to the decomposition of algae. Inadequate water treatment processes, such as improper chemical dosage and water softening techniques, were also noted as contributors, potentially leading to variable chlorine levels and increased sodium in the water supply. Aging infrastructure, including issues like leaks, pipe corrosion, and cross-contamination, was identified as another factor affecting water quality, causing fluctuations in chlorine, hardness, and salt levels. These findings indicate that a combination of environmental, treatment-related, and infrastructure factors contributes to periodic increases in water turbidity, underscoring the need for comprehensive monitoring and adaptive management strategies.

5. Conclusion and Recommendations

The analysis of water quality data reveals that the food industry continues to face significant challenges in accessing high-quality water. The persistence of heavy elements and imbalances in water chemistry indicates that the municipality has not yet fully complied with the South African National Standard (SANS) 241 requirements for potable water. This non-compliance may stem from inadequate treatment processes, poor infrastructure maintenance, or financial constraints.

The provision of substandard water by the municipality necessitates notifying local communities and food industries so they can implement additional treatment measures. Water that does not meet SANS 241 standards poses health risks to humans and animals, compromises product quality, and can negatively affect taste and shelf life. Regulatory frameworks, such as the Safe Drinking Water Act (SDWA), stress the importance of monitoring and compliance to ensure consumer safety. Our findings highlight the need for improved water treatment and quality control measures to achieve the required 95% average quality score. Daily water quality tests conducted by regulatory agencies are essential in ensuring the safety and security of water supplies. Ultimately, this study emphasizes the critical importance of consistent monitoring and adherence to water quality standards to protect public health and environmental sustainability.

Based on the study's findings, the implementation of an AI-driven Water Quality Monitoring and Control System is recommended to enhance the efficiency and effectiveness of water treatment processes. This system should integrate advanced sensors, data analytics, and machine learning algorithms to provide real-time monitoring, predictive insights, and automated control. Specifically, the system should include the following features:

1. **Real-time Monitoring**: Continuous monitoring of key water quality parameters, such as pH levels, dissolved oxygen, turbidity, and chemical concentrations, to enable the prompt detection of any deviations or anomalies.
2. **Advanced Data Analysis and Predictive Capabilities**: The system should leverage data analysis and predictive modeling to identify patterns and forecast potential water quality issues, allowing for proactive interventions.
3. **Automated Control and Adjustment**: Automated regulation of water treatment processes, including chemical dosage, filtration system control, and water flow rate adjustments, to ensure that water quality parameters remain within optimal ranges.
4. **Automated Alerts and Notifications**: The system should generate automated alerts for operators or water management personnel in response to abnormal water quality conditions, enabling swift corrective actions.

Implementing this AI-driven system will allow water treatment facilities to optimize their operations, reduce operational costs, and enhance overall system performance, ultimately improving water quality and safeguarding public health.

Future research in water quality management for the food and beverage industry should prioritize the development of AI-driven monitoring systems that incorporate advanced analytics and machine learning to enable proactive water quality control. This research could explore the impact of seasonal variations on water quality, leading to the creation of adaptive treatment protocols that ensure consistent standards throughout the year. Longitudinal studies on compliance with SANS:241 standards, along with an examination of the socio-economic factors that influence compliance, could offer valuable insights for enhancing policy. Additionally, investigating advanced water reuse technologies, evaluating heavy metal removal techniques, and assessing the economic and environmental impacts of water quality standards will be critical areas of focus. Further research might also explore innovations in sensor technology for more accurate monitoring and examine the role of community and industry engagement in improving water quality management practices.

References

Aadil, RM, Madni, GM, Roobab, U, Rahman, UU & Zeng, X-A., Quality Control in Beverage Production: An Overview. In: Elsevier eBooks. 1–38. doi.org/10.1016/b978-0-12-816681-9.00001-1. 2019.

Abdullah, N, Yusof, N, Lau, WJ, Jaafar, J & Ismail, AF. Recent trends of heavy metal removal from water/wastewater by membrane technologies. Journal of Industrial and Engineering Chemistry. 76:17–38,2019. doi.org/10.1016/j.jiec.2019.03.029. 2019.

Ashbolt, NJ., Microbial contamination of drinking water and disease outcomes in developing regions. Toxicology. 198(1–3):229–238,2004. doi.org/10.1016/j.tox.2004.01.030. 2004.

Atef, M, Saud, N, Al-Attar, A, Zeid, I & Felemban, L., An Update to Toxicological Profiles of Heavy Metals, Especially Lead as Hazardous Environmental Pollutant: A Review. Current Science International. (January, 1). doi.org/10.36632/csi/2022.11.1.4. 2022.

Bailone, RL, Borra, RC, Fukushima, HCS & Aguiar, LK., Water reuse in the food industry. Discover Food. 2(1). doi.org/10.1007/s44187-021-00002-4. 2022.

Bhagwat, VR., Safety of Water Used in Food Production. In: Elsevier eBooks. 219–247. doi.org/10.1016/b978-0-12-816333-7.00009-6. 2019.

Birniwa, AH, Habibu, S, Abdullahi, SS, Mohammad, REA, Hussaini, A, Magaji, H, Al-Dhawi, BNS, Noor, A, et al., Membrane technologies for heavy metals removal from water and wastewater: A mini review. Case Studies in Chemical and Environmental Engineering. 9:100538. doi.org/10.1016/j.cscee.2023.100538. 2024.

Bryman, A., Social Research Methods. Oxford University Press. 2016.

Cao, C & Shao, K., Improving quality standards of purchase policy and sustainable staple food safety. Frontiers in Sustainable Food Systems. 8. doi.org/10.3389/fsufs.2024.1329239. 2024.

Cissé, G., Food-borne and water-borne diseases under climate change in low- and middle-income countries: Further efforts needed for reducing environmental health exposure risks. Acta Tropica. 194:181–188. doi.org/10.1016/j.actatropica.2019.03.012. 2019.

Creswell, JW & Clark, VLP., Designing and Conducting Mixed Methods Research. SAGE Publications, Incorporated. 2017.

Gomes, IB, Maillard, J-Y, Simões, LC & Simões, M., Emerging contaminants affect the microbiome of water systems—strategies for their mitigation. Npj Clean Water. 3(1). doi.org/10.1038/s41545-020-00086-y. 2020.

Gu, H, Plumlee, MH, Boyd, M, Hwang, M & Lozier, JC., Operational optimization of closed-circuit reverse osmosis (CCRO) pilot to recover concentrate at an advanced water purification facility for potable reuse. Desalination. 518:115300. doi.org/10.1016/j.desal.2021.115300. 2021.

Hong, S, Park, K, Alayande, AB & Kim, Y Eds., Seawater Reverse Osmosis (SWRO) Desalination: Energy Consumption in Plants, Advanced Low-Energy Technologies, and Future Developments for Improving Energy Efficiency. IWA Publishing. doi.org/10.2166/9781789061215. 2023.

Hui, Y, Huang, Z, Alahi, MEE, Nag, A, Feng, S & Mukhopadhyay, SC., Recent Advancements in Electrochemical Biosensors for Monitoring the Water Quality. Biosensors. 12(7):551. doi.org/10.3390/bios12070551. 2022.

Hutton, G & Chase, C., Water Supply, Sanitation, and Hygiene. In: The World Bank eBooks. 171–198. doi.org/10.1596/978-1-4648-0522-6_ch9. 2017.

Integral Laboratories. SANS 241-1:2015 Drinking Water Specification. 2021.

Krueger, RA & Casey, MA., Focus Groups. SAGE Publications, Incorporated. 2014.

LaClair, CE & Etzel, MR. Ingredients and pH are Key to Clear Beverages that Contain Whey Protein. Journal of Food Science. 75(1). doi.org/10.1111/j.1750-3841.2009.01400.x. 2010.

Lee, I & Lee, K. The Internet of Things (IoT): Applications, investments, and challenges for enterprises. Business Horizons. 58(4):431–440. doi.org/10.1016/j.bushor.2015.03.008. 2015.

Lelieveld, HLM, Holah, J & Napper, D., Hygiene in Food Processing. Elsevier. Available from: http://books.google.ie/books?id=Qf-iAgAAQBAJ&printsec=frontcover&dq=Hygiene+in+food+processing:+Principles+and+practice:+Second+edition&hl=&cd=1&source=gbs_api. 2014.

Luckmann, J, Grethe, H, McDonald, S, Orlov, A & Siddig, K., An integrated economic model of multiple types and uses of water. Water Resources Research. 50(5):3875–3892,2014. doi.org/10.1002/2013wr014750. 2014.

Luvhimbi, N, Tshitangano, TG, Mabunda, JT, Olaniyi, FC & Edokpayi, JN., Water quality assessment and evaluation of human health risk of drinking water from source to point of use at Thulamela municipality, Limpopo Province. Scientific Reports. 12(1),2022. doi.org/10.1038/s41598-022-10092-4. 2022.

Maghsoudi, AS, Hassani, S, Mirnia, K & Abdollahi, M., Recent Advances in Nanotechnology-Based Biosensors Development for Detection of Arsenic, Lead, Mercury, and Cadmium. International Journal of Nanomedicine. Volume 16:803–832,2021. doi.org/10.2147/ijn.s294417. 2021.

Merriam, SB & Tisdell, EJ., Qualitative Research. John Wiley & Sons. 2015.

Minhas. Production volume of aerated and soft drinks in India FY 2015-2018. United States: Statista. Available from: https://www.statista.com/statistics/762413/india-aerated-and-soft-drinks-production-volume/ [Accessed 12 August 2024]. 2022.
Mitra, S, Chakraborty, AJ, Tareq, AM, Emran, TB, Nainu, F, Khusro, A, Idris, AM, Khandaker, MU, et al., Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. Journal of King Saud University - Science. 34(3):101865. doi.org/10.1016/j.jksus.2022.101865. 2022.
Mohanadas, D, Rohani, R, Sulaiman, Y, Bakar, SA, Mahmoudi, E & Zhang, L-C., Heavy metal detection in water using MXene and its composites: A review. Materials Today Sustainability. 22:100411. doi.org/10.1016/j.mtsust.2023.100411. 2023.
Mullen, K. , Information on Earth's Water. Available from: https://www.ngwa.org/what-is-groundwater/About-groundwater/information-on-earths-water [Accessed 12 August 2024]. 2020.
Poretti, M., Quality control of water as raw material in the food industry. Food Control. 1(2):79–83,1990. doi.org/10.1016/0956-7135(90)90089-u. 1990.
Raju, CV, Cho, CH, Rani, GM, Manju, V, Umapathi, R, Huh, YS & Park, JP. Emerging insights into the use of carbon-based nanomaterials for the electrochemical detection of heavy metal ions. Coordination Chemistry Reviews. 476:214920. doi.org/10.1016/j.ccr.2022.214920. 2023.
Rimmell, S., The Importance of SANS 241 Testing. Available from: https://foodconsulting.co.za/the-importance-of-sans-241-testing/#:~:text=The%20South%20African%20National%20Standard%20(SANS)%20241%20Drinking%20Water%20Specification,physical%20properties%20of%20the%20water. [Accessed 12 August 2024]. 2023.
Roobab, U, Shabbir, MA, Khan, AW, Arshad, RN, Bekhit, AE-D, Zeng, X-A, Inam-Ur-Raheem, M & Aadil, RM., High-pressure treatments for better quality clean-label juices and beverages: Overview and advances. LWT. 149:111828. doi.org/10.1016/j.lwt.2021.111828. 2021.
Sharma, S & Bhattacharya, A. Drinking water contamination and treatment techniques. Applied Water Science. 7(3):1043–1067. doi.org/10.1007/s13201-016-0455-7. 2016.
Silverman, D. Qualitative Research. SAGE. 2004.
UN environment Programme. Water and wastewater reuse: an environmentally sound approach for sustainable urban water management. Available from: https://www.unep.org/resources/report/water-and-wastewater-reuse-environmentally-sound-approach-sustainable-urban-water [Accessed 12 August 2024]. 2004.
Waheed, A, Mansha, M & Ullah, N., Nanomaterials-based electrochemical detection of heavy metals in water: Current status, challenges and future direction. TrAC Trends in Analytical Chemistry. 105:37–51,2018. doi.org/10.1016/j.trac.2018.04.012. 2018.
World Health Organization. Guidelines for drinking-water quality - 4th ed. World Health Organization. Available from: https://www.who.int/publications/i/item/9789241549950 [Accessed 12 August 2024]. 2022.
World Health Organization. Drinking-water. Available from: https://www.who.int/news-room/fact-sheets/detail/drinking-water#:~:text=Contaminated%20water%20and%20poor%20sanitation,hepatitis%20A%2C%20typhoid%20and%20polio. [Accessed 12 August 2024]. 2023.
Xu, X, Yang, S, Wang, Y & Qian, K. , Nanomaterial-based sensors and strategies for heavy metal ion detection. Green Analytical Chemistry. 2:100020. doi.org/10.1016/j.greeac.2022.100020. 2022.
Yang, N, Zhou, N, Feng, N, Rui, N, Zhang, N & Zhang, N. A Review on Reverse Osmosis and Nanofiltration Membranes for Water Purification. Polymers. 11(8):1252. doi.org/10.3390/polym11081252. 2019.
Zulkifli, SN, Rahim, HA & Lau, W-J., Detection of contaminants in water supply: A review on state-of-the-art monitoring technologies and their applications. Sensors and Actuators B Chemical. 255:2657–2689. doi.org/10.1016/j.snb.2017.09.078. 2018.

Biographies

Lindiwe Kwanele Ndlangamandla is a Quality Operations Analyst at Tiger Brands, bringing a wealth of knowledge and experience in food technology and quality management. She holds a National Diploma and an Advanced Diploma in Food Technology from the University of Johannesburg. Recently, she obtained a Postgraduate Diploma in Quality from the University of Johannesburg, where she focused her research on Water Quality improvement for Food and Beverage Industry vs. SANS: 241. Her research interests revolve around continuous improvement and innovative solutions for water quality challenges, aiming to ensure compliance with rigorous standards. Lindiwe is committed to leveraging her expertise to drive quality improvements within the food and beverage sector. Her academic and professional goals are cantered on advancing the field of quality management, developing effective strategies for water quality improvement, and supporting high-quality practices in the industry.

Prof Nita Inderlal Sukdeo is currently an Associate Professor in the Department of Quality and Operations Management within the School of Mechanical and Industrial Engineering at the University of Johannesburg, South Africa. She obtained a master's in quality from the Durban University of Technology and a PhD in Engineering Management from the University of Johannesburg. She is an active researcher in the field of total quality management and operations management. Her field of expertise also include advanced manufacturing technologies, smart factory, Quality 4.0, quantitative analysis, quality management systems, quality auditing and risk assessment. She is a qualified Lead Auditor, proficient in ISO standards and certification. She is chairperson and director of the Society for Operations Management in Africa (SOMA), a professional member of the South African Society for Quality (SASQ). She is an active participant and session chair of the IEOM Women in Industry and Academia panel session Africa edition.

Sambil C. Mukwakungu, an award-winning academic, has taught first-year Operations Management, Food Production, and Quality Management at the University of Johannesburg. His love of teaching and learning has changed at least one student's life each year. Service Operations Management, Lean Operations, Continuous Improvement, business innovation, and higher education innovation are his research interests as a young researcher. He and his team from the IEOM UJ Student Chapter received the 2018 IEOM Outstanding Student Chapter Gold Award for their exceptional chapter activities and contributions to industrial engineering and operations management. He also won Best Track Paper Awards at the 2016 and 2018 IEOM Conferences in Rabat, Morocco, and Paris, France. While pursuing his PhD at the University of Johannesburg, he supervises Operations Management master's students.