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Review

Mitigation of opportunistic pathogens in hot water systems: a review focused on premise plumbing in South Africa

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Water reticulation systems (i.e., premise plumbing) serve as a reservoir for opportunistic premise plumbing pathogens (OPPPs) to survive within these premise systems. OPPPs can be transmitted to individuals mainly via inhalation of aerosols from these water systems. These OPPPs can adapt, thrive and survive under a range of different conditions, which include high temperatures and low oxygen levels during stagnation, conditions often associated with household plumbing systems, including hot water systems (HWS). Hospitals are of specific concern as infections caused by OPPPs predominantly affect individuals who have underlying illnesses or health conditions. The current South African National Standard (SANS) 241 for drinking water does not provide information regarding testing for the presence of OPPPs, while the SANS 893 and 893-1 standards only provide a guideline for *Legionella* in water systems. The presence of OPPPs within HWS and premise plumbing is a concern, and a need exists to establish remediation and mitigation measures to control the presence of OPPPs in buildings. This review addresses risk analysis, evaluation and measures, which include the control of geyser temperatures and training of plumbers, as well as sampling and detection of OPPPs. This should limit the number of infections amongst individuals and will thus lessen the financial burden on health care systems and the economy.

INTRODUCTION

Water from plumbing in buildings (i.e., premise plumbing) serves as a reservoir for opportunistic premise plumbing pathogens (OPPPs) to survive (Falkinham, 2015). When OPPPs are present, these pathogens can be transmitted to humans via aerosols from showers, humidifiers, aerators on taps, hot tubs and spas (Falkinham, 2020), or through skin contact (Wang et al., 2012). Infections caused by these OPPPs may require hospitalization of individuals with existing health conditions (Falkinham et al., 2015). *Legionella pneumophila*, *Pseudomonas aeruginosa*, *Mycobacterium avium* and other OPPPs are regularly detected in water and swab samples from faucets and pipes, as well as in bioaerosols, which form part of household plumbing, including hot water systems (Wang et al., 2017; Masaka et al., 2021; Moodley et al., 2023).

The presence of these bacteria is not necessarily due to contamination, as these bacteria are naturally occurring in aquatic ecosystems and can therefore adapt and thrive under a variety of conditions, particularly the 'built environment'. Water distribution systems linked to the 'built environment' are known as an ideal habitat for the survival, growth and persistence of bacteria (Falkinham, 2020). Temperature, flow velocity and water use patterns, including periods of stagnation, all affect the survival and growth of bacteria in these environments.

Residual disinfectant concentrations which destroy and prevent the growth of faecal coliforms are often not effective in killing these pathogens when they are incorporated and protected in biofilms attached to surfaces or inside amoeba present in these systems. OPPPs have been noted to be resistant to varying residual levels of disinfection. *Mycobacterium* spp. and *Legionella* spp. have been reported to require higher levels of disinfection to be removed (Cullom et al., 2020).

As studies indicate that the current drinking water treatment methods are ineffective against many waterborne pathogens (Hayward et al., 2022), effective monitoring of OPPPs should also include the evaluation of treatment barriers and management activities for control of these opportunistic pathogens (LeChevallier et al., 2024).

The current South African National Standard (SANS 241; SABS, 2015) only includes microbiological (*E. coli*, protozoan parasites, total coliforms, heterotrophic plate count and somatic coliphage) and chemical determinants (physical and aesthetic, macro- and micro-determinants) and does not include analysis and testing for *P. aeruginosa*, *M. avium* or *Acanthamoeba*, which can all be present in drinking water. SANS 893 and 893-1 (SABS, 2018a) only provide a guideline for the management of *Legionella* in hot and cold water systems.

This review addresses two related questions: The first, an important question from both a health and economic perspective, is whether OPPPs pose a serious problem to the health of South Africans. We therefore focus on the current literature regarding OPPP infections and their abundance in drinking water systems within the South African context. If OPPPs pose a serious problem then the next question is how best to manage this. Based on the elements which support OPPPs in these systems we then explore potential mitigation strategies to manage the risk posed by OPPPs.

ABUNDANCE OF OPPPs IN WATER SAMPLES IN SOUTH AFRICA

A limited number of studies focusing on the presence of OPPPs, i.e., *Acanthamoeba*, *Legionella*, *P. aeruginosa* and *Mycobacteria*, in water sources in South Africa have been performed to date. In the most recent report, Moodley et al. (2023) investigated the relationship between *Acanthamoeba* and other bacteria, where water and biofilm samples were taken from simulated household hot water systems. This study identified that OPPPs such as *Legionella pneumophila, P aeruginosa* and nontuberculous *Mycobacteria* were present in the simulated systems. The simulated hot water systems were controlled at winter (20°C to 30°C) and higher summer (40°C to 55°C) temperatures. This study reported that *Acanthamoeba* and *P. aeruginosa* were common in the simulated hot water systems.

In another study, Muchesa et al. (2015) reported that drinking water supplied to and distributed through hospitals, and which is used for patient treatment, can be a possible source of nosocomial and occupational infections in three South African hospitals. Free-living amoeba were identified in 72% of samples which were collected from different high-care areas in the hospital. *L. pneumophila* was present in 7 of the 71 positive amoeba samples using the qPCR molecular technique. This study further reported that as *Legionella* was present within these areas in the hospital this could pose a risk to patients.

Potgieter et al. (2021) sampled 398 water and 392 biofilm samples from stored water in rural households. Free-living amoeba (FLA) were identified in the majority of both water (92%) and biofilm (89.8%) samples. In addition to this, 18S rRNA sequencing was performed which further confirmed the presence of *Vermamoeba verformis, Entamoeba* spp., *Stenamoeba* spp., *Flamella* spp. and *Acanthamoeba* spp. These results also identified the potential risk posed by these pathogenic organisms in borehole water in South Africa. Dobrowsky et al. (2016) used molecular detection techniques to establish whether other pathogenic organisms were present in unsterilized and solar-pasteurized harvested rainwater between temperatures of 68°C and 93°C.

With the limited data from these studies conducted in South Africa it is not possible to draw firm conclusions on the relationship between these opportunistic pathogens and their preferred niche, although their presence poses a serious health and economic concern to the public.

Economic impact of opportunistic pathogen infections

The World Health Organization **(WHO)** stated that 5.1 million deaths were caused by infectious and parasitic diseases world-wide in 2019 (Gunjikar and Daniel, 2023). The impact of these infectious diseases is a huge burden for the world economy. There are limited occurrence and epidemiological data available to calculate the economic impact of infections from OPPPs in South Africa, and therefore this review was guided by the studies conducted internationally, such as in the United States of America (USA). It was reported that the cost of Legionnaire's disease in patients in the USA in 2012 was 433 million USD (8 192.36 million ZAR). Other financial impacts in terms of *Legionella* infections on the US economy were calculated by Baker-Goering et al. (2021) (Table 1). After compensating for deaths and based on an assumption that around 60% of the patients were part of the labour market, they estimated a loss of 58 800 workdays (based on 10 days of hospitalization). The reported cost for people infected with nontuberculous *Mycobacteria* (NTM) was 425 million USD (8 041 million ZAR), whereas *P. aeruginosa* caused 2 700 deaths in 2017 with an associated cost of 767 million USD (14 511.64 million ZAR) (Falkinham, 2020).

Cos et al. (2018) further estimated the economic burden of water-related diseases on the economy of Canada at 309–900 million USD (5 850–17 000 million ZAR), of the United Kingdom (UK) at 100 million GBP (1 900 million ZAR), and of Sweden at 1 billion EUR (20.7 million ZAR). These disease incidents were related to problems within the water distribution network, such as broken pipes and post-treatment contaminations.

ELEMENTS INFLUENCING THE GROWTH OF OPPORTUNISTIC PATHOGENS IN DRINKING WATER SYSTEMS

In order for OPPPs to thrive and survive in drinking water systems, various elements are required to support the presence of these organisms. Water stagnation, nutrient concentration, disinfection, temperature, oxygen levels and biofilm formation play a critical role in the growth and presence of OPPPs in drinking water and plumbing systems (Fig. 1), and contribute to the final microbial quality of water in household systems.

Water stagnation or water age

Water age in hospitals, schools and buildings which are not occupied for a prolonged period can cause microorganisms to grow and thrive within these systems because of the stagnation of water with low levels of disinfection (Dowdell et al., 2023). OPPPs posed a health risk during the coronavirus (Covid-19) pandemic when offices, recreational and consumer areas were re-opened after being closed (Wolter et al., 2020). A study was conducted in 11 cities in the USA, Canada, and Switzerland to investigate the risk of Legionnaires disease in 26 buildings during the Covid-19 pandemic. As a result of the design problems of 5 buildings, *L. pneumophila* was present in these buildings. The results also showed that buildings with no disinfection had a higher presence of *L. pneumophila* compared to the buildings which used chloramine for disinfection (Dowdell et al., 2023). In a similar study, Vosloo et al. (2023) sampled water over a period of 6 months from 3 business parks. The samples were analysed using flow cytometry and 16S rRNA gene sequencing, and the results demonstrated that OPPPs were present at higher numbers in business parks compared to the residential sector.

Nutrient requirements

Falkinham (2020) reported that in order for OPPPs to survive in water bodies and on soil surfaces they require low nutrient

Table 1. Financial costs of *Legionella* infections for the USA economy (Baker-Goering et al., 2021)

Legionella impact	Estimate (range)
Medical costs (1) for estimate and range	7 662 120 000 ZAR (402 000 000 USD)
Productivity losses from workdays lost	412 352 693 ZAR (21 634 454 USD)
Productivity losses from premature deaths	7 846 216 46 ZAR (411 658 786 USD)
Total economic burden	15 915 771 960 ZAR (835 035 255 USD)

Note: 1 USD = 19.06 ZAR

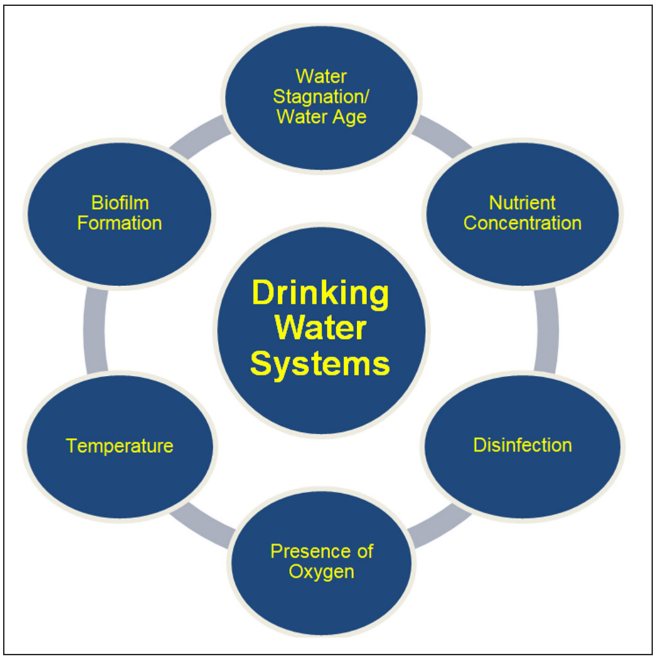

Figure 1. Factors influencing OPPPs in drinking water systems

concentrations. This is often the case in treated drinking water systems. Various OPPPs are known to resist amoebae digestion and once in the intercellular environment they obtain the necessary nutrients to grow and multiply (Buse et al., 2012). These OPPPs form biofilms and grow at low organic concentrations, especially under stagnant conditions (Falkinham, 2020).

Disinfection

Water treatment plants in South Africa typically use chlorine and chloramines (ammonia is added to chlorine) for disinfection of drinking water (McDowell, 2004). Chlorine is also used for the disinfection of effluent from wastewater in order to eliminate harmful bacteria and viruses (McDowell, 2004).

Muchesa et al. (2014) reported that 87.2% of samples from wastewater treatment plants contained amoeba which indicates that the chlorine level was not effective in destroying amoeba. The bacteria inside these protists are well protected from the effects of disinfectants (Cullom et al., 2020). *P. aeruginosa* isolated from hospital water and wastewater was found to be resistant to both antibiotics and disinfectants, while *M. avium* also showed resistance to antibiotics and disinfectants, as a result of the presence of a lipid-rich outer membrane which provides an impermeable layer for these agents (Falkinham, 2020).

Temperature

Temperature is an important element which influences the persistence of amoebae that could serve as a reservoir for the bacteria of interest. *Acanthamoeba* spp. were more regularly detected during summer and autumn sampling, indicating that their growth was temperature dependent as these months are typically characterised by higher temperatures (Muchesa et al., 2014). Moodley et al. (2023) also reported that *Acanthamoeba* was detected in a geyser (55°C) during their experiments. The heating of water over 60°C for 5 min may not be sufficient to destroy *Legionella* present in hot water systems (Buse et al., 2012). In a study conducted in Quebec, Canada, it was reported that although the thermostat of the hot water systems was set at 60°C, 40% of the water heaters were colonized by *Legionella*, as the water temperature at the bottom of the tank only reached 30°C to 40°C (Lévesque et al., 2004). *Legionella* can persist at temperatures of 20°C to 50°C when iron and L-cysteine are present (Leslie et al., 2021). Moodley et al. (2023) further reported that *Legionella pneumophila* was present in the hot water systems tested, even though the system was run at high temperatures.

Presence of oxygen

P. aeruginosa can survive at low oxygen levels as well as in the absence of oxygen (Bedard et al., 2016). *L. pneumophila* and other OPPPs have also been reported to be capable of growing at low oxygen levels (Falkinham, 2020).

Biofilm formation

Biofilms have the ability to protect living and dead bacteria, protozoa and other microorganisms. Cells attach to form a biofilm and are therefore difficult to wash away; the microbial cells are also protected from disinfectants in the water system (Falkinham, 2020). Biofilms develop through different stages (attachment, maturation and the formation of the extracellular matrix), and thereafter parts of the biofilm can detach. During the different stages, biofilms create three-dimensional structures that allow nutrients to enter the network and also for the removal of waste products (Khweek and Amer, 2018). OPPPs such as *L. pneumophila*, *P. aeruginosa*, *B. cepacian*, *S. maltophilia* and *A. baumanni* have been associated with biofilms in premise plumbing.

MEASURES TO MITIGATE OPPORTUNISTIC PATHOGENS IN WATER SUPPLY SYSTEMS

Current South African guidelines for the control of OPPPs

The only South African guidelines currently available for the control of OPPPs are solely for *Legionella*. The South African National Institute for Communicable Diseases (NICD) provides guidelines relating to the risk of Legionnaires' disease in water systems (NICD, 2020), whereas the South African Bureau of Standards (SABS) publishes South African National Standards (SANS) giving detailed information on the risk, evaluation, assessment and treatment for *Legionella* as part of SANS 893-1 and 893-2 (SABS, 2018a, b). The SANS 893-2: 2018 standard provides guidelines, measures, control and monitoring programmes for hot and cold water systems, and states the importance of controlling temperatures at or above 60°C for hot water systems.

The SANS 241 document does not include requirements for sampling and analysis for opportunistic pathogens in drinking water in South Africa (SANS 241-1: 2015; SABS, 2015). Currently there are also no guidelines for the management of OPPPs such as *Acanthamoeba*, *P. aeruginosa* and *M. avium* in drinking water and hot water systems.

International standards and regulations for opportunistic pathogen management

In Canada and Australia, the national regulations state that hot water distribution temperatures should be above 60°C and this strategy has been accepted by the World Health Organisation (WHO, 2022) in order to reduce pathogen growth. These temperature ranges are further supported by the Australian Environmental Health Standing Committee (enHealth) Guidelines for managing *Legionella* in old-age facilities. It was recommended that premise plumbing systems should circulate hot water at temperatures higher than 60°C, but cold water should be circulated at levels below 20°C to minimise the risk of infections (Leslie et al., 2021).

The ANSI/ASHRAE Standard 188-2018, 'Legionellosis: Risk Management for Building Water Systems', established the minimum risk management criteria for Legionnaires' disease. This was developed specifically for *Legionella* control in high-risk buildings, and also states that the temperatures of heater outlets should be above 60°C and the temperature throughout the distribution system should be maintained above 51°C (Leslie et al., 2021). No specific information was obtained in terms of the control and management of other OPPPs such as *P. aeruginosa* and *M. avium* in water distribution systems.

Risk assessment to inform the development of measures to manage opportunistic pathogens in drinking water systems in South Africa

A comprehensive approach should be followed to estimate the nature of the current situation and to develop the required measures to control or prevent the risk that OPPPs might pose to the community. For this the 'generic framework for integrated risk management' (Rosen et al., 2008) could be employed. This approach consists of three main components: risk analysis, risk evaluation and risk reduction/control, and can be used to develop safety plans and mitigation measures for water systems (Fig. 2) (Rosen et al., 2008).

One of the key requirements for any risk assessment is data on the occurrence of the OPPPs in the water system that is being assessed. The data are used for estimating the risk (risk analysis) as well as monitoring the success of any management options which need to be implemented (risk reduction/control). Detection is typically based on a range of culture and molecular techniques. Polymerase chain reaction (PCR), quantitative polymerase chain reaction (qPCR), fluorescence in situ hybridization (FISH), and gene sequencing including 16S RNA sequencing have been used to establish the presence of OPPPs in water samples. Based on a meta-analysis of published studies, Hayward et al. (2022) reported that there was a disparity in the methods used to detect OPPPs in water samples. Most of the studies made use of culturing methods, including membrane filtration and selective broth or agar inoculation. Molecular techniques, such as PCR, FISH and 16S RNA sequencing were used in approximately 16% of the studies.

Next-generation sequencing has the ability to increase the potential pathogen species library by increasing the number of genera and species. 16S profiling can be used together with qPCR, as these molecular techniques can be used to identify other members of the microbial communities within the water systems (Huang et al., 2022).

The following risk-reduction options have been suggested (risk evaluation). It is important that the cost efficiency and cost–benefit ratio of these options be calculated when developing the management guidelines. The guidelines include:

- Water sampling, maintaining correct geyser temperature, and regular flushing of showers and taps for hot water systems and premise plumbing in buildings and households.
- Water sampling from the outlet of the tank (tap), the recirculating systems and the drain valves (Wang et al., 2017).

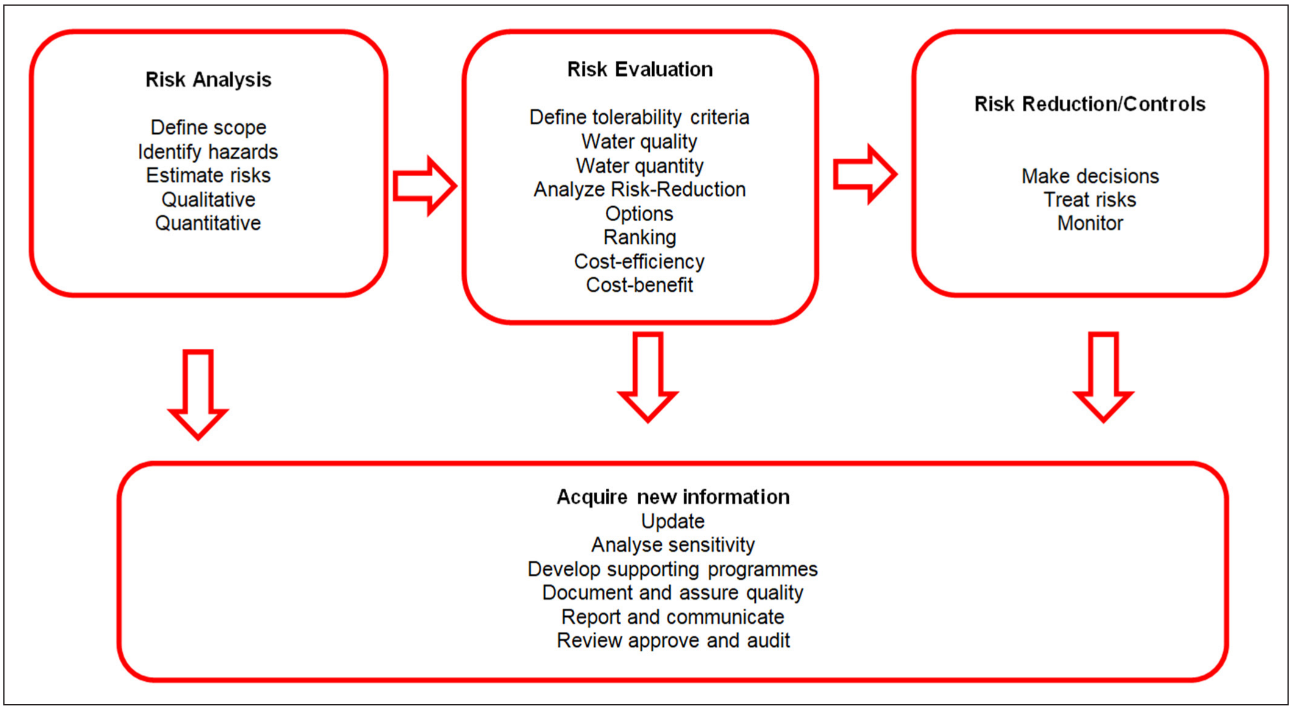

Figure 2. Main components of TECHNEAU Generic Framework for Integrated Risk Management as implemented as part of water safety plans (adapted from Rosen et al., 2008)

- Premise plumbing must be installed, maintained and repaired correctly to ensure that there is no risk to humans, the environment, property and municipal infrastructure. Plumbing services must be carried out correctly to avoid further risks and contamination of water and the leaching of chemicals from corroded pipes and fittings, which poses a serious threat to individuals residing on the premises. The plumbers therefore require correct training to assess and evaluate premise plumbing related issues to avoid further contamination of water systems. In addition to this, a correctly designed plumbing system can reduce the risk of contamination of the drinking water supply and waste removal systems.
- Aerosol-producing equipment should have proper treatment and disinfection plans for regular flushing.
- Raising the temperature of hot water systems to approximately 70°C for 24 hours will assist with the decontamination of the hot water systems. This is followed by flushing the system for 5 min to remove OPPPs and biofilms. For the decontamination to be effective, the outlet temperature should be maintained at 60°C (Leslie et al., 2021).
- Maintaining the water temperature of hot water systems such as solar water heaters and electric geysers at 60°C to eliminate OPPPs from the systems. It is therefore necessary for regular flushing of showers (2 min) and bathtubs since the biofilms can survive within the pipes of the premise plumbing. In addition to this, monthly, quarterly, 6-monthly and annual sampling should be conducted on buildings such as hospitals, water treatment plants, and homes and offices which are not in use for a long period of time.

Apart from the abovementioned practical steps that can be implemented to reduce the risks posed by OPPPs, attention should also be given to the regulatory environment. The guidelines published by the NICD only address measures for the prevention of *Legionella* but should be updated to include measures for all OPPPs present in both hot water systems and premise plumbing. The level of disinfection which is required for resistant microbial pathogens is dependent on the disinfectant method or technology, the concentration of disinfectant, contact time, pH and temperature (WHO, 2022). The SANS drinking water standard should also be revised to include the sampling, testing and analysis (limits and ranges) of OPPPs in drinking water, hot water systems and premise plumbing.

CONCLUSIONS

Several studies conducted in South Africa have shown that the presence of OPPPs in drinking water, hot water and premise plumbing can pose a health risk to humans if proper risk measures are not put in place to mitigate these health concerns. Infections from opportunistic pathogens represent an economic burden. Data from the USA, UK, Canada and Sweden have been reported, but this review does not address any calculations of the economic burden of opportunistic pathogens in South Africa as no epidemiological data could be obtained.

This review has identified that the current measures for the prevention and control of OPPPs in South Africa are inadequate and there is a need for a comprehensive risk assessment which addresses: risk analysis, risk evaluation and risk reduction/control. This should be conducted on drinking water distribution systems with a special emphasis on premise plumbing and hot water systems in buildings and households.

As part of this process, regular sampling, testing and analysis for the presence of OPPPs should be conducted to evaluate any risk reduction or control measures that have been implemented. These data will also be critical when updating national guidelines and standards for OPPPs in water systems. Implementation of the proposed comprehensive risk assessment approach will ultimately limit the number of infections in the community, thus increasing quality of life while also reducing the overall loss to the economy. The quantitative microbial risk assessment (QMRA) model (Viñas et al., 2018) can be used to prevent and control infections in water systems.

It is recommended that quarterly sampling be conducted on buildings such as hospitals, water treatment plants, and homes and offices which are not in use for a long period of time. Regular sampling, and analysis of water using the molecular and culture techniques available is required. Standards and guidelines should be revised to include sampling, testing and analysis for OPPPs, as this data are required to develop risk reduction options and to monitor the effectiveness of such measures when implemented.

CONFLICT OF INTEREST

There was no conflict of interest for any party involved in this research work.

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AUTHOR CONTRIBUTIONS

SJM – conceptualisation of study, data collection and analysis, writing of manuscript; PM – data collection, writing of manuscript; SNV – data analysis, writing of manuscript; TGB – review and writing of manuscript and AS – review and writing of manuscript.

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REFERENCES

BAKER-GOERING M, ROY K, EDENS C and COLLIER S (2021) Economic burden of Legionnaires' disease, United States, 2014. *Emerg Infect. Dis.* **27** (1) 255–257. https://doi.org/10.3201/eid2701.191198

BEDARD E, PREVOST M and DEZIE E (2016) *Pseudomonas aeruginosa* in premise plumbing of large buildings. *Microbiol. Open* **5** (6) 937–956. https://doi.org/10.1002/mbo3.391

BUSE HY, SCHOEN ME and ASHBOLT NJ (2012) *Legionella* in engineered systems and use of quantitative microbial risk assessment to predict exposure. *Water Res.* **46** (4) 921–933. https://doi.org/10.1016/j.watres.2011.12.022

CULLOM AC, MARTIN RL, SONG Y, WILLIAMS K, WILLIAMS A, PRUDEN A and EDWARDS MA (2020) Critical review: Propensity of premise plumbing pipe materials to enhance or diminish growth of *legionella* and other opportunistic pathogens. *Pathogens* **9** (11) 957. https://doi.org/10.3390/pathogens9110957

DOBROWSKY PH, KHAN S, CLOETE TE and KHAN W (2016) Molecular detection of *Acanthamoeba* spp., *Naegleria fowleri* and *Vermamoeba* (*Hartmannella*) *vermiformis* as vectors for *Legionella* spp. in untreated and solar pasteurized harvested rainwater. *Parasites Vectors* **9** Article No. 539. http://doi.org/10.1186/s13071-016-1829-2

DOWDELL KS, GREENWALD HD, JOSHI S, GRIMARD-CONEA M, PITELL S, SONG Y, LEY C, KENNEDY LC, VOSLOO S, HUO L and co-authors (2023) *Legionella pneumophila* occurrence in reduced-occupancy buildings in 11 cities during the COVID-19 pandemic. *Environ. Sci. Water Res. Technol.* **9** 2847–2865. https://doi.org/10.1039/D3EW00278K

FALKINHAM JO, PRUDEN A and EDWARDS M (2015) Opportunistic premise plumbing pathogens: increasingly important pathogens in drinking water. *Pathogens* **4** (2) 373–386. https://doi.org/10.3390/pathogens4020373

FALKINHAM JO (2015) Common features of opportunistic premise plumbing pathogens. *Int. J. Environ. Res. Public Health* **12** (5) 4533–4545. https://doi.org/10.3390/ijerph120504533

FALKINHAM JO (2020) Living with *Legionella* and other waterborne pathogens. *Microorganisms* **8** (12) 2026. https://doi.org/10.3390/microorganisms8122026

GUNJIKAR T and DANIELS A (2023) Treating infectious diseases: an opportunity to drive global health and wealth. URL: https://insights.issgovernance.com/posts/treating-infectious-diseases-an-opportunity-to-drive-global-health-and-wealth/

HAYWARD C, ROSS KE, BROWN MH, BETHAM R and WHILEY H (2022) The presence of opportunistic premise plumbing pathogens in residential buildings: a literature review. *Water* **14** (7) 1129. https://doi.org/10.3390/w14071129

HUANG H, ZAN S, MING H, LI M, XU J, XIE Y, WANG W and FAN J (2022) 16S Next-generation sequencing and quantitative PCR reveal the distribution of potential pathogens in the Liaohe estuary. *Front. Mar. Sci. Sec. Mar. Fish. Aquacult. Living Resour.* **9**. https://doi.org/10.3389/fmars.2022.1044260

KHWEEK AA and AMER AO (2018) Factors mediating environmental biofilm formation by *Legionella pneumophila*. *Front. Cell. Infect. Microbiol.* **8** 38. https://doi.org/10.3389/fcimb.2018.00038

LECHEVALLIER MW, PROSSER T and STEVENS M (2024) Opportunistic pathogens in drinking water distribution systems – a review. *Microorganisms* **12** (5) 916. https://doi.org/10.3390/microorganisms12050916

LESLIE E, HINDS J and FAISAL HI (2021) Causes, factors, and control measures of opportunistic premise plumbing pathogens – a critical review 1. *Appl. Sci.* **11** (10) 4474. https://doi.org/10.3390/app11104474

LÉVESQUE B, LAVOIE M and JOLY J (2004) Residential water heater temperature: 49 or 60 degrees Celcius. *Can. J. Infect. Dis. Med. Microbiol.* **15** 109051. 2 pp. https://doi.org/10.1155/2004/109051

MASAKA E, REED S and DAVIDSON M (2021) Opportunistic premise plumbing pathogens. A potential health risk in water mist systems used as a cooling intervention. *Pathogens* **10** (4) 462. https://doi.org/10.3390/pathogens10040462

MCDOWELL M (2004) Water purification methods – and the South African position. April 2004. *South African Instrumentation and Control*. April 2004. URL: https://www.instrumentation.co.za/article.aspx?pklarticleid=2906 (Accessed 4 May 2021).

MOODLEY SJ, MUCHESA P, BARTIE C, BARNARD TG, CLARKE R and VENTER SN (2023) Prevalence of free-living acanthamoeba and its associated bacteria in energy-efficient hot water systems in South Africa. *Water SA* **49** (1) 1–7. https://doi.org/10.17159/wsa/2023.v49.i1.3947

MUCHESA P, LEIFELS M, JURZIK L, BARNARD TG and BARTIE C (2015) Free-living amoebae isolated from a hospital water system in South Africa: a potential source of nonsocomial and occupational infection. *Water Suppl.* **16** (1) 70–78. https://doi.org/10.2166/ws.2015.106

MUCHESA P, MWAMBA O, BARNARD TG and BARTIE C (2014) Detection of free-living amoebae using amoebal enrichment in a wastewater treatment plant of Gauteng Province, South Africa. *BioMed Res. Int.* **2014** 575297 10 pp. https://doi.org/10.1155/2014/575297

NICD (National Institute for Communicable Diseases, South Africa) (2020) Control of *Legionella* in water systems during the COVID-19 pandemic. URL: https://www.nicd.ac.za/control-of-legionella-in-water-systems-during-the-covid-19-pandemic/ (Accessed 6 June 2022).

POTGIETER N, VAN DER LOO C and BARNARD TG (2021) Co-existence of free-living amoebae and potential human pathogenic bacteria isolated from rural household water storage container. *Biology* **10** (12) 1228. https://doi.org/10.3390/biology10121228

ROSEN L, LINDHE A, HOKSTAD P, SKLET A, RØSTUM J and PETTERSSON TJR (2008) Generic framework for integrated risk management in water safety plans. In: *Proceedings of the 6th Nordic Drinking Water Conference*, Oslo, 9–11 June 2008. 193–203. URL: https://research.chalmers.se/en/publication/72032 (Accessed 29 February 2024).

SABS (South African Bureau of Standards) (2015) The South African National Standard 241-1: Drinking Water Part 1: Microbiological, physical, aesthetic and chemical determinands. South African Bureau of Standards, Pretoria.

SABS (South African Bureau of Standards) (2018) South African National Standard 893-1. Legionella Part 1: Risk management. South African Bureau of Standards, Pretoria.

SABS (South African Bureau of Standards) (2018) South African National Standard 893-2 Legionella Part 2: The control of *Legionella* in water systems. South African Bureau of Standards, Pretoria.

VIÑAS V, MALM A and PETTERSON T (2018) Overview of microbial risks in water distribution networks and their health consequences: quantification, modelling, trends and future implications. *Can. J. Civ. Eng.* **46** (3) 149–159. https://doi.org/10.1139/cjce-2018-0216

VOSLOO S, HUO L, CHAUHAN U, COTTO I, GINCLEY B, VILARDI KJ, YOON B, GABRIELLI M, PIEPER KJ, STUBBINS A and PINTO AJ (2023) Gradual recovery of building plumbing-associated microbial communities after extended periods of altered water demand during the COVID-19 pandemic. *Environ Sci Technol.* **57** (8) 3248–3259. https://doi.org/10.1021/acs.est.2c07333

WANG H, EDWARDS M, FALKINHAM JO and PRUDEN A (2012) Molecular survey of the occurrence of *Legionella* spp., Mycobacterium spp., *Pseudomonas aeruginos*a, and amoeba hosts in two chlorinated drinking water distribution systems. *Appl. Environ. Microbiol.* **78** (17) 6285–6294. https://doi.org/10.1128/AEM.01492-12

WANG H, BEDARD E, PREVOST M, CAMPER AK, HILL VR and PRUDEN A (2017) Methodological approaches for monitoring opportunistic pathogens in premise plumbing: A review. *Water Res.* **117** 68–86. https://doi.org/10.1016/j.watres.2017.03.046

WOLTER N, CARRIM M, WALAZA S, CHANDU L, MORIFI M, LAWRENCE C, COHEN C and VON GOTTBERG A (2020) Notified Legionnaires' disease in South Africa, 2018–2020. URL: https://www.nicd.ac.za/wp-content/uploads/2021/01/NICD-Bulletin-Vol18-Iss3-December2020-NOTIFIED-LEGIONNAIRES-DISEASE.pdf (Accessed 30 March 2023).

WHO (World Health Organisation) (2022) Guidelines for drinking-water quality: fourth edition incorporating the first and second addenda. World Health Organization, Geneva. URL: https://iris.who.int/bitstream/handle/10665/352532/9789240045064-eng.pdf?sequence=1&isAllowed=y#page=73 (Accessed 12 December 2024).