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INTEGRATED LEGIONELLA RISK ASSESSMENT FRAMEWORK FOR THERMAL SPA HEALTHCARE FACILITIES

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Abstract: As a result of modern anthropogenic activities and urbanized lifestyles, the incidence and prevalence of respiratory diseases have risen significantly in the 20th and 21st centuries, primarily due to the deterioration of air quality. As part of these processes, the spread of the use of spas and rheumatology treatment centers carries new, invisible exposure risks, among which Legionnaires' disease caused by Legionella spp. stands out. The exploitation of thermal and medicinal groundwater resources, which underpins the operation of such facilities, depends directly on hydrogeological conditions: aquifer depth, recharge characteristics and the geochemical composition of the extracted water jointly determine the water temperature ranges, mineral content and flow regimes that are subsequently maintained within the facility's pool and pipework systems. From a water resources and environmental engineering perspective, these same operational parameters – residence time, recirculation rate, water temperature and disinfection regime – are the principal determinants of Legionella colonisation potential, linking the geoscientific basis of thermal water supply directly to the occupational and public health risk profile of the facility. The aim of this research is to identify the risks associated with Legionella exposure in a Hungarian spa, to determine the groups of people at risk, and to formulate technical and operational recommendations to reduce exposure and increase occupational safety. During the study, we mapped the indoor areas associated with aerosol formation, analyzed the operating practices of water and air treatment systems, and reviewed current control protocols.

Keywords*: Legionella, occupational disease, respiratory risks*

1. INTRODUCTION

Hungary has exceptional hydrogeological conditions, one of the most important elements of which is its rich thermal and medicinal water resources. Domestic and European Union regulations precisely define the conditions under which water can be considered natural mineral water: only water originating from a protected aquifer, which is inherently pure and uncontaminated, with a known and stable chemical composition that meets strict microbiological requirements, can be classified as such (Tóth, 1995). Mineral waters are bottled without treatment, directly at the source, and may not contain any foreign substances except carbon dioxide. The official recognition of mineral and medicinal waters is subject to a complex testing system that guarantees their consistent quality (Liebe, 2007).

Medicinal waters, as special mineral waters, have a dissolved mineral or gas content whose medicinal effects have been proven by medical tests. In Hungary, there are currently around 195 recognized mineral waters and 220 recognized medicinal waters, and nearly 1,200 hot springs supply thermal water for various baths and medical treatments. Thanks to its geothermal resources, Hungary has one of the richest thermal water reserves in Europe, ranking among the top five countries on the continent (Szűcs and Székely, 2011).

In recent decades, significant developments have taken place in the infrastructure of thermal and medicinal baths, resulting in around 40 international-standard medical and wellness centers operating in the country. The quality and quantity of minerals dissolved in the water - such as hydrogen carbonates, sulfur, calcium, magnesium, and various gases - determine the therapeutic value of these waters. Traditional water-based treatments and the rise of health tourism are attracting more and more visitors, and the economic and health significance of medicinal waters continues to grow.

However, the operation of thermal water facilities creates a unique microclimate: the constantly high humidity, warm water, vapors, and aerosols not only shape the bathing experience, but also determine the everyday lives of those working in the baths (Márton, 2009). Although the quality of medicinal waters is controlled and their natural origin ensures their safe use, the internal environment of the facilities may also pose certain health risks.

Therefore, in addition to examining the hydrogeological and medicinal water conditions, increasing attention must also be paid to the effects on employees working in spas in a permanently warm, humid environment.

2. Modern challenges of respiratory diseases and the significance of Legionella

Respiratory diseases have always been present throughout human history, but in the 20th and 21st centuries, modern lifestyles and human activities have significantly changed the significance and frequency of such diseases (WHO, 2020).

One of the biggest changes has been the spread of mass transportation and travel, which has enabled people to travel greater distances, but has also increased the chance of disease spreading (Baker and Fidler, 2006). Another change associated with modern lifestyles is air pollution, which contributes to the development and worsening of respiratory diseases (Cohen et al., 2017). Since the Industrial Revolution, industrial emissions and the use of transportation vehicles have caused a deterioration in air quality, which increases the likelihood of respiratory diseases.

The impact of human activity on respiratory diseases has brought about changes in many ways in the 20th and 21st centuries.

Climate change is also altering atmospheric chemistry and weather patterns, which in turn affects the incidence of allergic diseases and respiratory problems. In addition, social and economic changes also influence the incidence of respiratory diseases, as overwork, stress, and unhealthy lifestyles can cause a number of problems, including respiratory diseases. In today's world, respiratory diseases continue to be a significant problem that affects health and quality of life. The most common respiratory diseases include influenza, pneumonia, asthma, allergic rhinitis, and chronic obstructive pulmonary disease (COPD). Such diseases can have serious consequences, including complications, deterioration of overall health, and lack of timely diagnosis (US CDC, 1999).

The first member of the Legionellaceae family of bacteria was discovered as the causative agent of a pneumonia outbreak during the 1976 American Legion convention in Philadelphia, and the family of bacteria was named after the convention itself. The best-known member of the group is Legionella pneumophila (LP), which is responsible for 95% of diseases caused by members of the Legionellaceae family in humans. Currently, the group consists of more than 50 genetically distinct members, 50% of which may be human pathogens. The natural habitat of these bacteria is water, and despite their presence and numbers, they rarely cause human disease. Legionella bacteria are common and are almost always found in low numbers in environmental water sources such as rivers, lakes, and reservoirs. Microorganisms from natural sources also enter places that form artificial reservoirs for them (urban sewer systems, private water systems, etc.). Their reproduction is facilitated by water temperatures between 20 and 45 °C (Fields et al., 2002). They do not reproduce below 20 °C and are destroyed above 60 °C. However, they can remain dormant in cold water and start reproducing again when the water temperature reaches the appropriate level. Legionella bacteria also require nutrients for reproduction, which can be provided by organisms commonly found in water systems (algae, amoebae, and other bacteria). Sediment, sludge, limescale, rust, and other materials in the water system, together with biofilms, play an important role in the colonization of Legionella bacteria and in providing favorable conditions for their reproduction (US CDC, 1999). The main problem is that biofilm is highly resistant to disinfectants and also protects Legionella bacteria, making Legionella extremely resistant to everyday disinfectants (Wingender and Flemming, 2011). Preventive measures against Legionella must start at the root of the problem, i.e., the biofilm. Measures aimed directly at destroying Legionella bacteria do not provide a long-term solution to the problem (Karches et al., 2021).

The serious illness caused by Legionella pneumophila is accompanied by flu-like symptoms and can spread to other organ systems (fever, cough, headache, muscle and joint pain, diarrhea) (Phin et al., 2014). Pontiac fever differs from this clinical picture in that it is flu-like but without pneumonia, and resolves spontaneously after a few days. People with poor health, weak immune systems, and smokers are more likely to become ill (Vance et al., 2015).

Infection occurs when someone inhales aerosolized water contaminated with Legionella. For this reason, the following places are considered risky in terms of infection:

- showers in hotels, hospitals, and nursing homes; swimming pools and other sports facilities;
- water parks and swimming pools with water features,
- air conditioning systems with wet scrubbers,
- cooling towers,
- areas where water is sprayed for cooling or humidification purposes (e.g., coolant/lubricant in metal cutting, humidification of coal dust with running water) (Beauté, 2017; WEB_1, 2025).

Known risk factors for Legionnaires' disease include older age (>50 years), male gender, immunodeficiency, chronic underlying disease, and heavy smoking. Older people are more susceptible to Legionella infection and are more exposed to increased Legionella exposure from air conditioners or water systems contaminated with the pathogen, to which they have less resistance than young adults. The diagnosis and initiation of therapy are sometimes complicated by the fact that patients seek medical attention late.

The following regulations, guidelines, and legislation define the scope of Legionella testing:

- 2005. (2008.) European Guidelines for the Surveillance and Prevention of Travel-Associated Legionnaires' Disease, compiled by the European Working Group for Legionella Infections (EWGLI) and the European Surveillance Network for Travel-Associated Legionnaires' Disease (EWGLINET),
- 2007. Methodological letter from the National Epidemiological Center and the National Institute of Environmental Health on Legionnaires' disease and its prevention,
- 2015. EMMI Decree 49/2015. (XI.6.) on public health regulations concerning media and facilities posing a risk of infection caused by Legionella,
- 2016. Methodological letter issued by the National Epidemiological Center on Legionnaires' disease and its prevention, 2nd expanded edition,
- 2023. Methodological guidelines issued by the National Public Health Center on risk assessment and risk reduction measures for media and facilities posing a risk of Legionella infection (7th edition).

Currently valid standards:

- MSZ EN ISO 19458:2007 Water quality – sampling,
- MSZ EN ISO 5667 - Sampling for microbiological testing,
- MSZ EN ISO 6222:2000 – Determination of colony count at 22°C,
- MSZ 15234:2012 - For sizing the rotational filtration capacity of swimming pools.

For the testing of drinking and domestic hot water in accordance with European regulations, the current standard of the MSZ EN ISO 11731 series (currently MSZ EN ISO 11731:2017) may be used. For other matrices (pool water, cooling water), the results of tests performed in accordance with the withdrawn MSZ EN ISO 11731-2:2008 standard and the Legiolert method are also acceptable (Khayer et al. 2023).

3. DESCRIPTION OF THE SPA IN RELATION TO RISK ASSESSMENT

The spa under investigation was established between 2007 and 2009 and has been in continuous operation since then. The spa is available to inpatients and outpatients with its own therapeutic pools and services. The spa area is located on the ground floor, where the pool area is directly connected to the changing rooms. The pool area has three whirlpool pools and two pools with a filling and emptying system. Two types of medicinal water are used for the treatment of patients at the spa.

Spa treatments financed by the National Health Insurance Fund are available, based on the medicinal water available. Specialized outpatient clinics (osteoporosis and arthritis), physical therapy and rheumatology clinics are organically linked to the medical treatment. The department has 45 active beds, which are intended to treat the musculoskeletal complaints of bedridden patients. In addition to patients treated in the department, outpatient patients with a spa ticket, employees working there, and other guests with a visitor's ticket can also use the spa.

Massage rooms, physiotherapy rooms, physical therapy rooms, underwater jet massage (hereinafter referred to as tangentor) rooms, mud baths, and treatment rooms provide space for medical treatments.

The following physiotherapy services are available:

- Hydrotherapy: weight bath - 1 in the pool area
  - underwater jet treatment (tangentor) - 3 treatment rooms on the ground floor,
- Balneotherapy: - pool baths - 2 in the pool area (radon, sulfur)
  - mud treatment - 1 mud treatment room on the ground floor,
- Mechanotherapy: - physiotherapy - 1 on the ground floor
  - massage - basement 6 units.

The spa is open all year round, so the pools must be emptied, cleaned and disinfected daily or as needed. Particular care must be taken when disinfecting overflow channels, handrails and railings. The disinfectant must be allowed to take effect in all cases, so it should only be rinsed off after the exposure time has elapsed (WHO, 2006). A fully filled pool must be overflowed for 5-10 minutes so that any particles floating on the surface can be removed through the overflow. Cleaning must also extend to the side walls. Contamination of the pool can be prevented by proper water treatment, but coarser sediments settle at the bottom of the pool. These can be removed without water loss after daily operation using an underwater suction cleaning device. Daily use is recommended.

The cleaning and disinfection of the sanitary facilities, medical rooms, waiting rooms, and lobbies in the baths is carried out by the baths' cleaning staff. Other rooms and equipment used for service purposes must be cleaned and disinfected daily. This must be done with a disinfectant solution outside of opening hours.

Areas used by bathers (paths, sidewalks, open areas) must be cleaned daily before opening and after closing. The spa's waste bins must be emptied daily and disinfected continuously. Waste collection takes place according to a specific schedule. Daily waste is collected in covered waste bins lined with nylon bags. The waste collected in this way is emptied into a closed container, which is transported by the public service company on a contractual basis. The washing liquid produced during washing is discharged into the municipal sewage system.

Therapeutic treatment tubs (tangentors) must be cleaned and disinfected after each treatment. The tubs are cleaned and disinfected with a 10% solution of Laudamonium for 5 minutes. After rinsing, they are filled with hot water at a temperature of 35-36 °C. The tangentor treatment units are usually descaled every 2 weeks.

At the end of the day's treatments, the tangentor is washed with a 2% solution of Sekusept Active for 30 minutes. The surrounding floor and wall surfaces are cleaned and disinfected. Limescale removal is carried out at regular intervals. The instructions for preparing and using disinfectants are posted on the wall of the treatment room.

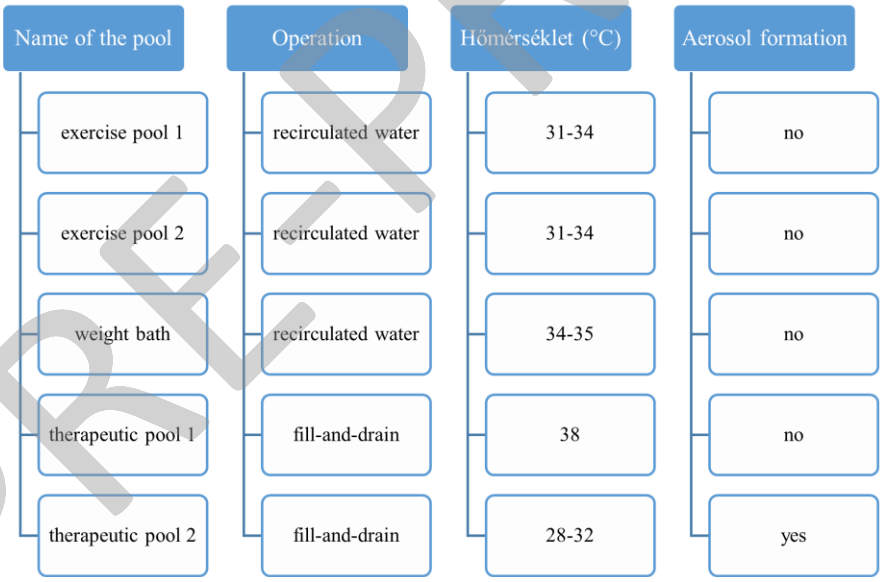

Figure 1

Characteristics of pools in terms of aerosol formation (Note to authors: temperature labels within Figure 1 appear in Hungarian and should be translated to English prior to final submission)

Major maintenance (shutdown) is carried out twice a year, in spring and autumn. The water in the pools is completely replaced at this time. The pools are cleaned when drained using a sodium hypochlorite solution (150 g/l sodium hypochlorite). The end fittings are also descaled and disinfected.

The pools are filled with treated well water of drinking water quality. The water supply facilities include wells available to the spa.

The facility has no other aerosol-forming elements (e.g., high-pressure washers, humidifiers, mist gates, fountains, solar collectors, garden sprayers, indoor or outdoor decorative water systems, etc.).

3.1. Characteristics of media in the facility that pose a risk of Legionella exposure

The characteristics of the pools are listed in Figure 1. The temperature of the domestic hot water system can be raised above 60 °C as required, and circulation is ensured. In order to avoid the risk of scalding, high-temperature flow-through only takes place outside opening hours.

There are a total of 8 public showers in the spa area, 23 in the hospital area, as well as 37 toilets, 8 urinals and 60 washbasins, i.e. other water facilities. People over the age of 65 are a risk group among users. Approximately 50% of patients are over the age of 65, of whom 15-20% have weakened immune systems. The proportion of smokers is 30% among patients and 5% among employees.

4. WATER TREATMENT METHODS AND TECHNICAL SOLUTIONS

No flocculants are used in the water treatment technology. A 30% sulfuric acid solution and a sodium hypochlorite (150 g/l) solution are added as pH adjusters. The disinfectant and pH adjuster are added automatically, controlled by the pool water chlorine content and pH measuring device.

Chlorine gas flows through a vacuum pipe in a quantity set by a rotameter to an injector installed at the dosing point, where it is mixed with the water operating the injector and chlorinated water is added to the water to be treated (Li and Mitch, 2018). Each pool has a separate rotameter to ensure that the water in each pool continuously meets the specified bacteriological requirements.

The pH adjuster and chlorine dioxide must also be dosed separately for each pool using separate dosing pumps. The chemical must be refilled weekly in the water machine room. The disinfectant, chlorine, and pH adjuster must be added to the water to be purified before filtration. After opening hours, in the evening and at night, they must be replenished weekly, as described in the chemical product information sheet. The Redox (Hypo) is set to a pH value between 7.3 and 7.6 in accordance with the regulations of the State Public Health and Medical Officer Service.

The circulating pools receive 5% fresh water daily, which means that the entire water volume is replaced every 20 days.

Other equipment that poses a risk in terms of aerosol formation includes therapeutic treatment tubs and showers in the facility.

Treatment tub: tangentor

The tub must be cleaned and disinfected after each treatment with a 10% solution of Laudamonium (100 g active ingredient content: 9.99 g benzalkonium chloride).

No air conditioning equipment was found in the examined areas where the therapeutic pools are located. The therapeutic pool area is covered by a central dry air treatment system. Its purpose is to extract moisture.

5. Risk management measures currently in place at the facility

Frequency and performers of technical inspections

Technological machinery and equipment:

- Pumps, filters, and dispensers are checked periodically on a daily basis, provided that no malfunction occurs.
- All technological equipment is also inspected periodically on a daily basis.
- Operating technological equipment is continuously monitored by operating personnel and controlled by measuring instruments that monitor operating conditions.
- Operating technological equipment is checked on site by operators every two hours, and the measurement results are recorded in an operating log.
- The condition of the pumps is monitored by water meters and pressure gauges.
- The filters are monitored by vacuum gauges and pressure difference gauges.
- The operating status of the dosing devices and the technology (pool water) is continuously monitored and controlled by free chlorine and pH meters. In addition, manual measurements are taken six times a day (three times per shift).
- The measurement results are recorded in an operating log.

Measuring the temperature of the bathing water

The water temperature measurement results are recorded 3 times per shift (i.e. 6 times per day). The measurement results are recorded in the operating log. Test points: at each pool. The person responsible for measuring the water temperature and detecting the results is the maintenance engineer/water technician.

Measuring the water temperature of the domestic hot water system

The temperature of the domestic hot water system is checked once a month. The measurement results are recorded on a control sheet. The measurement is performed with a certified (calibrated) water meter. The water temperature is detected after 2 minutes of cold water flow and 1 minute of hot water flow.

Sampling points in cold water systems: the furthest tap; in hot water systems: the taps with the least favorable circulation, at the point closest to the return of the circulation to the domestic hot water generator. The number of samples must be determined taking into account the complexity of the system.

Technical background

The water in the REDO water purifier is treated by adding REDOlyt disinfectant. REDOlyt is produced in the device itself using an electrolytic process, after which it is added to the water to be disinfected. The system does not use any additional chemicals (Chen and Wang, 2022). The technology is based solely on special salt and electricity in the water to be disinfected. The process destroys all bacteria, microbes, viruses, and fungi and regulates the pH value of the water.

6. POSSIBLE RISK REDUCTION MEASURES FOR THE FACILITY

For pools:

- inspection of the water treatment and circulation system,
- disinfection of sand filters, shock disinfection in case of colonization,
- disinfection of recreational elements by overchlorination (during this time, the recreational elements cannot be used),
- disinfection of the entire pool (Nguyen et al., 2012).

In drinking water and domestic hot water systems:

- heat disinfection at 70 °C, at least 3 minutes of flow: for heat disinfection of the domestic hot water system, the temperature of the hot water entering the network must be raised to at least 70 °C, then, proceeding in stages from the furthest point, all outlets must be flushed with hot water for 3 minutes. In addition, the water temperature must be checked at the same time.
- Chemical disinfection: in this case, a high-dose, shock-like chemical treatment that can be used to reduce risk immediately. With appropriately selected additional disinfection, it is also suitable for reducing the number of Legionella bacteria. The latter may be a good solution if the flow in the water network is adequate, but a water temperature of >50 °C cannot be achieved for some reason. Only substances registered by the National Public Health Service may be used to disinfect drinking and domestic hot water. After shock disinfection, the chemically treated water must be completely drained and then flushed with clean water until the residual disinfectant concentration drops to the background level. Recommended concentration for disinfection:
  - Hypochlorite: for shock disinfection, 20-50 mg/l of free active chlorine content must be ensured. The exposure time is at least 2 hours at a concentration of 20 mg/l and at least one hour at 50 mg/l, but it is more practical to leave the chemically treated water in the system for 12 hours. In the case of continuous disinfection, there is no limit for free active chlorine content, but the bound chlorine content must not exceed 3 mg/l. Legionella is less sensitive to chlorine-based disinfectants than other bacteria. The use of hypochlorite-based agents is not recommended for continuous supplementary disinfection.

- Chlorine dioxide: Chlorine dioxide is a more effective disinfectant than chlorine and may also be suitable for removing existing biofilm. For shock disinfection, the recommended final concentration is 10-50 mg/l, with an exposure time of 12 hours. For continuous disinfection, the maximum chlorine dioxide concentration at the outlet may be 0.4 mg/l. The amount to be dosed must be determined on site depending on this. It is advisable to dose chlorine dioxide into cold water before heating, as it decomposes very quickly in hot water. If chlorine dioxide cannot be detected at the outlet, the disinfection is probably not effective.

– Use of point-of-use bacterial filters.

Preventive cleaning and disinfection of the hot and cold water systems is necessary:

– if deemed necessary during routine inspections,
– if the system has not been used for more than a month,
– if fundamental changes have been made to the entire system or part of it, maintenance work has been carried out and the system remains contaminated,
– if Legionnaires' disease is suspected.

7. Preventive action plan and presentation for possible Legionella exposure. Proposed solutions

The following table presents the Legionella prevention plan for the various media found in the facility.

Table 1

Preventive action plan for Legionella in the media found in the facility

Description	Legionella prevention measures	Frequency	Responsible person
Therapeutic pool 1 Gymnastics pool 1. Gym pool 2. Weight bath Therapeutic pool 2	– Pool cleaning, disinfection – Regular maintenance and disinfection of the entire water circulation system – Cleaning, disinfecting, and replacing air filters in air blowers – water treatment – Regular microbiological control	According to the cleaning and disinfection frequency specified in the Spa Operating Regulations	Spa department manager, water engineer
Treatment tub – tangentor	– cleaning, disinfection – disinfection of the pump system	After each use and monthly	Bath section manager, water engineer
Hot water for use	– cleaning, disinfection, descaling – temperature monitoring	Regularly as needed	Technical and operations manager, water engineer

Description	Legionella prevention measures	Frequency	Responsible person
	– thermal disinfection if necessary		
Cold water	– to prevent contamination from settling – temperature monitoring – thermal disinfection if necessary	Regularly as needed	Technical and operations manager, water engineer
Showers	– Disassembly, cleaning, disinfection, and descaling of shower heads and hoses	As needed, but at least once a month	Bathroom manager, water engineer, and cleaner
Air conditioning systems (central, split)	– regular cleaning, disinfection, maintenance – check condensate drainage, fins, drip tray, tank – avoid standing water	Every six months	Technical and operations manager, water engineer

8. Risk Assessment Methodology

The risk assessment was carried out in accordance with the framework established by the 2023 Methodological Guidelines of the National Public Health Center (NNK, 7th edition) and the applicable provisions of EMMI Decree 49/2015. (XI.6.). The assessment followed a structured, site-specific approach comprising four sequential steps, illustrated in Figure 2: (1) identification and mapping of all aerosol-generating media and water systems present in the facility; (2) characterisation of each medium with respect to parameters known to influence Legionella growth and dispersal, including water temperature, residence time, flow dynamics, and disinfection practice; (3) evaluation of exposure likelihood based on proximity, duration of contact, and the vulnerability profile of the user population; and (4) classification of risk level as high, medium, or low using a qualitative matrix in which the axes represent the probability of Legionella colonisation reaching infectious concentrations and the severity of potential health consequences. Media receiving a high-risk classification were those where temperature conditions, stagnation potential, and aerosol-generating capacity combined with the presence of an immunocompromised user population to create a plausible pathway for disease. Recommendations were formulated for each high-risk medium to reduce either the likelihood of colonisation or the probability of exposure, or both.

9. Discussion

The contribution of this study should not be understood as residing in any single preventive measure proposed for the examined facility – recommendations such as separating shower stalls, increasing the frequency of split air-conditioner disinfection, or applying heat or chemical disinfection to specific water systems are, individually, well established practices already described in the regulatory and technical literature on Legionella control. Rather, the principal value of the work lies in the integrated risk assessment approach applied across the full set of aerosol-generating media within a single thermal spa healthcare facility. By systematically mapping pools, treatment tubs, shower systems, domestic hot and cold water networks, and air-handling equipment within one coherent framework, and by linking each medium's physical operating parameters – temperature, retention time, disinfection regime, and user proximity – to a uniform risk classification, the study demonstrates how site-specific hydrogeological and water engineering characteristics translate into an occupational and public health exposure profile. This integration is particularly relevant for facilities combining medicinal water use with a vulnerable patient population, where no single technical intervention is sufficient and where the relative priority of preventive measures can only be established by assessing all exposure pathways jointly rather than in isolation.

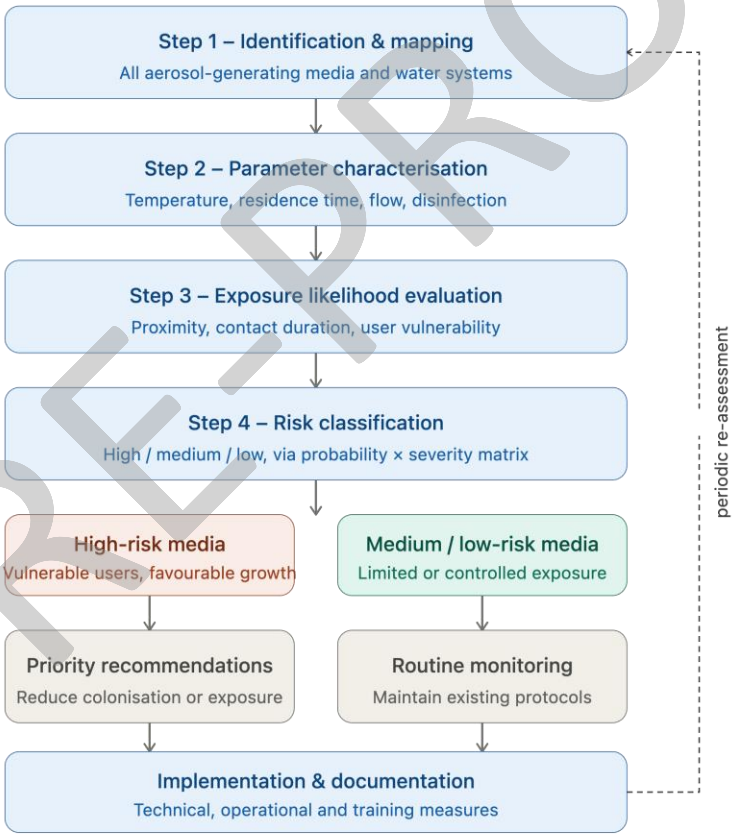

Figure 2

Four-step risk assessment methodology applied in this study (diagram to be inserted by authors – see accompanying figure file)

From a methodological standpoint, the integrated framework presented here is transferable: the four-step sequence of medium identification, parameter characterisation, exposure likelihood evaluation, and risk classification (Figure 2) does not depend on the specific configuration of the examined facility and can in principle be applied to other thermal or medicinal water facilities with differing pool layouts, water sources, or treatment technologies. This transferability, rather than the specific numerical risk ratings obtained for this one facility, constitutes the generalisable contribution of the study to the field of occupational risk assessment in balneological and healthcare-adjacent settings.

Several limitations of the present work should be acknowledged. First and most importantly, the risk classifications presented in this study are derived from a qualitative assessment based on documented operating parameters, regulatory thresholds, and the authors' professional judgement; the assessment was not supplemented by site-specific microbiological sampling or water quality measurements for Legionella spp. or related indicator organisms. Consequently, the high, medium, and low risk designations reflect the structural and operational potential for Legionella colonisation and exposure rather than confirmed, measured contamination levels at the time of inspection. Second, the vulnerability parameters used to characterise the user population (the proportion of patients over 65 years of age, the proportion who are immunocompromised, and smoking prevalence) were based on facility-reported figures rather than an independent epidemiological survey, and may therefore be subject to reporting imprecision. Third, the assessment reflects a single point-in-time inspection of one facility; seasonal variation in water temperature, occupancy, and maintenance scheduling could alter specific risk ratings, and the findings should not be extrapolated to other facilities without a comparable site-specific assessment. Future work should prioritise the integration of quantitative microbiological monitoring (culture-based or PCR-based Legionella quantification) with the qualitative framework presented here, in order to validate the risk classifications against measured colonisation levels and to refine the threshold parameters used in the assessment matrix.

10. SUMMARY

After inspecting the facility and assessing the risks, we have drawn the following technical and occupational safety conclusions:

The quantitative risk profile of the examined facility is characterised by the following key parameters. Approximately 50% of patients are over 65 years of age, a group with a documented relative risk of Legionnaires' disease approximately 2–3 times higher than that of younger adults; 15–20% are immunocompromised, for whom the case fatality rate of Legionnaires' disease may reach 40–80% compared to approximately 5–10% in the general population. Thirty percent of patients are smokers, a factor associated with a 3–4-fold increase in susceptibility. Pool water temperatures range from 32 to 38 °C – fully within the optimal growth range of 20–45 °C for Legionella – while the circulating pool system replaces only 5% of its volume with fresh water per day, creating a 20-day hydraulic retention time that is conducive to biofilm accumulation. Taken together, these parameters indicate that the facility's user population is substantially more vulnerable than the general public, and that the physical characteristics of several water systems create conditions under which Legionella growth cannot be excluded without active and sustained preventive management.

Legionella aerosol formation within the facility poses the greatest risk to employees during work in rooms equipped with tangent showers and split air conditioning systems. Provided that the built drainage system is functioning properly, the only real danger in terms of Legionella colonisation is posed by wet air conditioning systems. In the case of pools, aerosol inhalation could be a concern for those who remain in the small space above the water surface for long periods of time. In contrast, this may be a potential source of danger for people in tangentor bathtubs, which is why the risk assessment includes the danger of increased aerosol formation. For those who are in the area of the pools and bathtubs under investigation, dry air handling systems do not pose a danger as long as the filter cartridges are replaced in accordance with the operator's and legal requirements.

In the case of pipe systems, hard water increases the risk of limescale deposits and, with it, the risk of Legionella colonies forming. Therefore, water softening is important as an extra line of defense. In the case of wet air conditioning systems, it is important to disinfect the system regularly, even more frequently than required, by a spa facility.

Due to the lack of continuous exposure, the issuance of personal protective equipment and the establishment of a distribution system is not justified in the institution. Compliance with current regulations and standards is sufficient for the level of protection.

Our technical recommendation for improving the protection of the affected area: It would be advisable to place the shower stalls in a separate room. They are currently located in an open room, with no separation. Separation would also be applicable to the showers in the pool area. An operational plan should be prepared for the more frequent disinfection of split air conditioners and carried out in a documented manner.

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