DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE **RAPPORT 2022/1**

Geoscientific input to business case for "Lønstrup spa":

Overview of relevant water quality regulations and the chemical composition of Gassum Formation brine

Denitza D. Voutchkova & Lars Henrik Nielsen

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
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G E U S

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GEUS

Contents

1. Preface

This technical report presents a preliminary evaluation of the possibility of using the Gassum Formation geothermal water for establishment of a spa at Lønstrup in Vendsyssel. The assessment is based on GEUS´ comprehensive knowledge regarding the subsurface and utilization of geothermal brines.

The report was prepared by GEUS for Dansk Kyst- og Naturturisme on the request from Alice Bank Danielsen and Charlotte B. Ottesen.

The scope of this report is limited to the following topics:

- an overview of the current national (Danish) and international (EU) regulation regarding water quality for spas with focus on the use of thermal (and mineral) waters (**Section 3**). The overview includes also examples from few European countries with a tradition, existing industry, activity, and/or experience in the use of thermal mineral waters for recreational purposes (**Section 5**).
- a summary of the hazards and risks that need to be considered when establishing and operating natural spas (with thermal water), based on the World Health Organization (WHO) guidelines (**Section 6**).
- characteristics of the Gassum Formation and an overview of existing geochemical analyses of geothermal water produced in the Thisted geothermal plant (**Section 8**). The results are put in the context of the relevant Danish water-quality requirements.

This preliminary assessment ends with recommendations for further work (**Section 9**).

The Danish subsurface comprises several deep sandstone-dominated formations containing warm or hot geothermal, mineral-rich water (i.e. brine). Their location and composition are known at the regional scale, based on investigations and interpretation of data from seismic grids and the deep wells drilled onshore for the exploration of hydrocarbons, salt, and geothermal energy.

The Gassum Formation is regarded as the most promising geothermal formation in Denmark. Its genesis, distribution, depth, and composition are relatively well-understood. The formation brine is used in Thisted and Sønderborg for geothermal energy, and its geochemical composition has thus been investigated previously by GEUS.

Based on the current data and knowledge generated through years of research related to exploration of hydrocarbons and geothermal energy, it is expected that the Gassum Formation brine is the most suitable brine for use at the future spa at Lønstrup. That is why in the last part of this report we focus on the chemical composition of the brine from the wells in Thisted. However, future work should focus on acquiring more data specifically from Lønstrup.

2. Summary

The purpose of this report was two-fold: 1) to overview existing national and international regulation and guidelines with water quality requirements for spas using thermal water; 2) to provide preliminary evaluation on the potential use of Gassum Formation brine for the future spa in Lønstrup. Thermal water from deep wells has not been used yet in Denmark for recreational purposes, so in this report we outline some of the potential issues.

The key findings from this assessment are:

1. The primary Danish water quality requirements relevant to spas are those for public bathing (BEK nr 918 of 27/06/2016), which concern the water clarity, pH, chlorine levels, and microbiological safety of swimming pools. The Danish drinking water quality requirements should also be met (BEK nr 2361 of 26/11/2021), which could be a problem for highly mineralized waters, such as the Gassum Formation brine. Thermal water quality requirements for bathing purposes are not explicitly formulated in the existing Danish laws, so further guidance should be sought by the Danish EPA (Miljøstyrelsen), the Danish Health Authority (Sundhedsstyrelsen), and the local municipality.

2. There is no unified EU legislation on the use of thermal waters for recreational purposes (bathing), and both the EU Drinking Water Directive and the EU Directive on the Exploitation and Marketing of Natural Mineral Waters do not apply for mineral waters used at source for curative purposes in thermal or hydromineral establishments.

3. The common theme in all reviewed scientific papers, national legislation, and the WHO guidelines is that the specific challenges in operating public pools with thermal water, are related to the high temperature and the unique chemical composition (rich in specific ions, high mineralization, and/or organic matter), which may favour microbial growth and the formation of unintended disinfection by-products (esp. brominated or iodinated compounds). Another specific issue to consider is potential radioactivity of the thermal water from deep wells. Risk assessment should be carried out to assess the source-water quality and how the selected spa design, management, and operation of the facilities would affect both the bathing water and indoor air quality in the spa.

4. The characterisation of Gassum Formation, which is the most probable candidate for the Lønstrup spa, is uncertain because of the limited seismic data and deep wells in North Jutland. Based on regional models, it is estimated that the depth to the top of the formation is 1400-1600 m (± 15%) with temperature of the brine ~50°C (± 20%). The dominating lithology is sandstone, and the hydraulic conductivity is expected to be relatively good. There is a need to acquire more seismic data and to drill a deep well in the area to reducing the hydrogeological and the associated economic risks.

3. Sammenfatning

Formålet med denne rapport er primært at præsentere:

- et overblik over danske og internationale regler og retningslinjer vedr. spabade, som bruger termisk vand,
- en foreløbig vurdering af muligheden af at anvende geotermisk vand fra Gassum Formationen i et kommende spabad i Lønstrup,
- samt på denne baggrund at give en række anbefalinger for det videre arbejde frem mod etablering af et spabad.

De væsentligste resultater af studiet er:

- De primære danske krav til vandkvalitet er dem, der gælder for offentlige bade, som regulerer pH og klarhed af vand, klorindhold og mikrobiologi i svømmebassiner (BEK nr. 918 of 27/06/2016).

- Drikkevandsregulativet skal formentlig også anvendes (BEK nr. 2361 of 26/11/2021), hvilket i givet fald vil være et problem for mineralvand med høje ionkoncentrationer såsom Gassum Formationsvandet.

- Da krav til vandkvaliteten for bade, som bruge termisk vand ikke er eksplicit formuleret i den eksisterende lovgivning, anbefales det at søge råd hos Miljøstyrelsen, Sundhedsstyrelsen and de lokale myndigheder.

- Der er ikke en ensartet EU-lovgivning vedr. brugen af termalt vand for rekreative formål (bade). Både EU's drikkevandsdirektiv og EU's direktiv vedr. udnyttelse og markedsføring af naturligt mineralvand sigter ikke på anvendelsen af mineralsk vand til helbredende eller rekreative formål.

- Det er et generelt tema i alle de her gennemgåede videnskabelige afhandlinger, dansk lovgivning og WHO-retningslinjer, at de specifikke udfordringer ved anvendelse af termisk vand i offentlige badebassiner er relateret til den høje temperatur og den unikke kemiske sammensætning (høj koncentration af specifikke ioner og/eller organisk materiale), som kan forårsage vækst af mikrober og dannelse af utilsigtede biprodukter (fx bromid eller jod komplekser).

- Det termiske vand kan være radioaktivt, som det ses i nogle dybe boringer.

- En omfattende risiko analyse bør derfor foretages for at vurdere kvaliteten af det termiske vand og undersøge, hvorledes design, management og drift af spabad faciliteterne kan påvirke kvaliteten af badevandet og luften i spaområdet.

- Vurderingen af Gassum Formations karakteristika i Lønstrup (forekomst, dybde, tykkelse, vandledningsevne, temperatur etc.) er usikker, fordi der kun findes sparsomme data om undergrunden i Nordjylland.

- Formationen forventes at findes under Lønstrup i ca. 1400-1600 meters dybde (± 15%) med en temperatur af formationsvandet på ca. 50°C (± 20%). Den dominerende litologi er sandsten og de hydrauliske egenskaber forventes at være relativt gode og egnede.

- De hydrogeologiske usikkerhedsmomenter, og de heraf afledte investeringsmæssige risici, kan reduceres ved indsamling af nye seismiske data og udførelse af en dyb boring.

4. Relevant Danish and EU regulation

4.1 Public bathing water quality requirements

The relevant Danish regulation to using natural thermal water for public bathing, incl. in spa-centers or swimming poos, is the Ministerial order BEK nr 918 of 27/06/2016 on swimming pool facilities and their water quality [1]. This Ministerial order covers all swimming pool facilities [1]:

"…swimming pools and hot-water pools, including spas, water parks, amusement pool and the like with their associated facilities, when there is public access to the facility, or the facility is established under the auspices of hospitals, sanatoriums, physiotherapy centers, hotels, campsites, schools, holiday camps, and similar, with access for users" §2 [1].

The water used in swimming pool facilities must comply with the requirements listed in Table 1 which concern the clarity, pH, chlorine levels, and bacterial counts (Table 1).

Table 1 *Quality criteria for water used in swimming pool facilities, according to Appendix 1 to § 6, 2. & 3. of BEK nr 918 of 27/06/2016 [1]*

Parameter	**Pool type**	**Unit**	**Quality criteria**		**Notes**
			Minimum	Maximum	
Clarity	all	-	-	-	1
pH	all		6.8–7.0	7.6	2
Free chlorine	Indoor pools ≤ 34 °C	mg/l	0.4	0.8–1.5	3
	Swimming pools > 34 °C, all outdoor basins incl. spa-baths	mg/l	1.0	2.0	4
Bound chlorine	-	mg/l	-	0.5	5
Trihalomethanes (THM)	Indoor pools ≤ 34 °C	µg/l	-	25	
	Swimming pools ≥ 34 °C, all outdoor basins incl. spa-baths	µg/l	-	50	
Total bacterial count at 37°C	all	/100 ml		500	6
Escherichia coli (E. coli)	all	/100 ml		< 1	7
Pseudomonas bacteria	all	/100 ml		< 1	7

1. The water must be clear
2. The operating interval must be determined so that at no time there is a risk that the pH < 6.8 in the pool
3. The measurements must be made continuously
4. For indoor pools with permission for low-chlorination the free chlorine should be 0.4– 0.8 mg/l in opening hours.
5. The content should be as low as possible.
6. In Danish: Kimtal ved 37°C
7. It is checked if the total bacterial count was previously >500/100ml

In addition to these criteria, swimming pool facilities must meet the quality requirements for drinking water (§6 [1]), except for the cases when the facilities are using surface water (§7 [1]). Natural thermal water is not mentioned explicitly, and it does not fall into the "*surface* *water*" exception. The specific drinking water quality criteria are provided in BEK nr 2361 of 26/11/2021 [2], which implements the EU Drinking Water Directive [3].

4.2 Drinking water quality requirements

The requirements listed in Ministerial order BEK nr 2361 of 26/11/2021 (*dk: Drikkevandsbekendtgørelsen*) [2] apply primarily for drinking water quality at the consumers' tap. However, in §1, 1c [2] it is mentioned that the quality criteria are also applicable to any other commercial or public activity not mentioned in the previous texts (i.e. other than waterworks, food-production, other companies producing medicinal or other products for which special requirements are imposed). Under other commercial or public activity is understood institutions, restaurants, hospitals, hotels, amusement establishments etc. (1§, 4 [2]). The criteria would apply also to spas or other similar facilities. However, thermal water or highly mineralized (i.e. mineral) water is not mentioned explicitly [2].

Quality requirements for various parameters are provided in Annexes to [2]. For example, Annex 1b [2] provides the quality requirements for chemical parameters, which are based on the EU Drinking Water Directive [3] unless otherwise stated. The nationally set quality requirements for the main constituents, and those set due to health-related concerns are provided in Annex 1c and 1d, respectively [1]. Annex 1f [1] provides indicators for radioactivity, which are based on the Euratom Drinking Water Directive [4]. All these are presented in Table 10–Table 13 (see Appendix 11.1). Some of the quality criteria are relevant only when disinfection is used for treating the water.

4.3 Drinking water quality exemptions

Even though in the Danish Ministerial Order on drinking water quality [2] mineral and/or thermal waters are not mentioned specifically, this is not the case with the EU Drinking Water Directive [3]. The EU Drinking Water Directive **does not apply** (Article 3 (1a & b) [3] for:

- natural mineral waters, as referred to in EU Directive 2009/54/EC [5], recognized by the responsible authorities,
- waters which are medicinal products within the meaning of EU Directive 2001/83/EC [6].

The EU Directive on Waters Used as Medicinal Products [5] is not discussed further here, as it is not relevant in the context of this report. However, if the thermal water at Lønstrup would be used also for medicinal purposes, this Directive should also be complied with.

"*Natural mineral water*", defined in the EU Directive 2009/54/EC [5], is a microbiologically wholesome water originating underground and emerging from a spring tapped at one or more natural or bore exits (Annex I, I. [5]). This directive also states that mineral water can be clearly distinguished from ordinary drinking water by its nature (mineral content, trace elements or other constituents, or certain effects) and original purity, which have both been preserved intact because the water has been protected from all risk of pollution due to its source-location [5]. Another part of the definition also includes the requirement that the composition, temperature, and other essential characteristics of the natural mineral water must remain stable within the limits of natural fluctuation. Specifically, they should not be affected by possible variations in the rate of flow. Article 4 [5] also states that natural mineral water should **not** be disinfected or modified by addition of substances or bacteriostatic elements, and lists few exceptions for removing elements like Fe, S, Mn, As, or free CO_2.

Even though the EU Directive 2009/54/EC [5] provides the definition of *"natural mineral water"*, it also states that **it does not apply** to *"natural mineral waters used at source for curative purposes in thermal or hydromineral establishments."* (Article 3b) [5] The Directive does not provide definition of "*curative purpose*", but it is specific to establishments using thermal or mineral water. One interpretation is that spas and other recreational facilities using mineral and/or thermal water for bathing and wellness purposes are exempt. The Directive focuses on the natural mineral waters which are bottled and sold as a commercial product.

There is no EU directive that provides legal requirements for the recognition of thermal waters, and more importantly there is no official unified definition of what is understood by thermal water and what are the quality requirements for bathing in such waters. Definitions from some European countries are presented in Section 5.

EU Member States may exempt waters from complying with the EU Drinking Water Directive [2] when those are intended exclusively for purposes for which the competent authorities are satisfied that the quality of the water has no influence, either directly or indirectly, on the health of the consumers (Article 3, 3a) [3]. With other words, the appropriate national authorities could grant exemptions, if the water quality does not negatively affect the consumers' health.

To summarize, the EU Drinking Water Directive [3] does not apply for natural mineral waters, as these are regulated based on the EU Directive for Natural Mineral Water [5]. However, the latter does not apply to waters used at source in thermal establishments. There is no unified EU regulation covering the use of such waters and the water quality criteria provided in the EU Drinking Water Directive are not applicable to them. Those are, however, implemented in the Danish legislation through the law and the Ministerial Order on drinking water quality [2], where no special exemptions are currently made for natural mineral or thermal waters.

4.4 Swimming pool quality exemptions

The types of exemptions (dispensations) from the requirements on swimming pool facilities and their water quality that can be granted by the local municipality councils are discussed in Chapter 8 of BEK nr 918 af 27/06/2016 [1].

First, the municipality council (*dk: Kommunalbestyrelsen*) can grant exemption from § 9, 1 [1], which is about the requirement to disinfect the water with chlorine gas (Cl_2) or hypochlorite (ClO^-) solution. Other disinfectants could be approved instead, but the municipality council cannot deviate from the requirement for addition of a disinfectant.

Perhaps more relevant to using thermal water for bathing (spa) purposes is another text (§ 13, 3 [1]), according to which the municipality council may allow other provisions to be deviated from when/if it is:

- necessary to carry out experiments for development of new technology for swimming pools, and
- technically and hygienically justifiable.

Such permit can be granted for a period of up to 2 years and it is conditional on agreement from the Styrelsen for Vand- og Naturforvaltning (SVANA). SVANA was closed in 2017 and all its functions were transferred to the Danish EPA (Miljøstyrelsen). Such an agreement may be granted after a discussion with the Danish Health Authority (Sundhedsstyrelsen) and additional conditions ensuring hygiene and documentation may be requested.

Next to these texts in the Ministerial order, specific guidelines for dispensations could be provided by the authorities. For example, the Nature Agency (Naturstyrelsen) provided additional notes on the requirements for dispensations for artificial swimming lakes [7].

In 2020, the Danish EPA also provided a guidance on the control of swimming pools [8], which expands on, and explains the quality requirements from Table 1, as well as other physicochemical analyses (turbidity, redox, NaCl, organic matter) and other microbiological analyses (enterococci, pathogens, viruses, and protozoa). Drinking water criteria for specific parameters were mentioned in connection to the physicochemical analyses and when relevant to the chemicals added to the water for disinfection and pH adjustment. Nevertheless, drinking water quality, as a criterion for swimming pool water was mentioned broadly throughout the guidance document multiple times.

It could be argued that there is a need for a guidance for thermal mineralized water, as this type of waters is a special case of natural mineral waters and not alike the groundwaters currently abstracted for drinking water purposes in Denmark. Due to this difference in the natural chemical composition, they most probably will not comply with some of the drinking water requirements. In section 8.2, to illustrate this, we compare the chemical composition of Gassum Formation water from the Thisted geothermal wells with the existing quality requirements.

5. Thermal water definitions and relevant quality regulation from few selected European countries

As mentioned in section 4.3, EU Directive 2009/54/EC [5] provides definition of "*natural mineral water*" and exempts those "… *used at source for curative purposes in thermal or hydromineral establishments*" from the requirements in this directive. Even though thermal water is not defined explicitly, it could be inferred that thermal waters are a special case of natural mineral waters.

Annex III [5] provides criteria that could be used for classifying them, based on:

- Mineral salt content (calculated as a fixed residue at 180°C [9]):
    - very low mineral content ≤ 50 mg/l,
    - low mineral content ≤ 500 mg/l,
    - rich mineral content > 1500 mg/l.
- Predominant ionic composition:
    - containing bicarbonate (HCO_3^- > 600 mg/L),
    - sulphate (SO_4^{2-} > 200 mg/L),
    - chloride (Cl^- > 200 mg/L),
    - calcium (Ca > 150 mg/L),
    - magnesium (Mg > 50 mg/L),
    - fluoride (F^- > 1 mg/L),
    - iron (Fe^{2+} > 1 mg/L),
    - sodium (Na > 200 mg/L),
    - acidic (free CO_2 > 250 mg/L)

A recent scientific review [10] showed that the definitions of thermal water in selected European countries vary. The following definitions are used based on the temperature at the outlet [10]:

- must be more than 4°C from the average air temperature – Spain
- should be greater than the mean annual air temperature – Bosnia and Herzegovina
- ≥ 20 °C – Austria, Czech Republic, Italy, Poland, Romania, Slovenia, (> 20 °C for Switzerland, and potentially for Bulgaria)
- ≥ 30 °C – Hungary, Lithuania

The review showed also that there is a wide range of temperature and chemical composition of thermal waters in the selected European countries [10]. Most of the overviewed thermal water sources were used for balneological purposes (859 of 2390) or heating (380), but there were also other uses (512) like agriculture, aquaculture, drinking water, but sources used exclusively for production of energy were not included, except for one site in Italy [10].

Another recent scientific review [11] focused specifically on the recreational use of thermal waters. Relevant regulation from several countries were reviewed and the conclusion of the authors was that the European legislative situation seems fragmented and inconsistent, and that a comprehensive community directive is missing [11].

A few examples of national regulation related to the quality of thermal water used for recreational purposes from countries with a tradition in exploiting these resources are presented next. Within the scope of this report, it was not possible to do a systematic review of existing legislation, the presented examples show different ways of defining and assessing the quality of mineral (and thermal) waters for bathing.

5.1 Hungary

The official national definition of **thermal water** ("*termálvíz*") is water with temperature ≥ 30°C originating from an aquifer [12]. Additionally, there are also definitions for mineral water ("*ásványvíz*") and medicinal water ("*gyógyvíz*") [13]. Mineral water is water from a natural aquifer or aquifer whose mineral content is typically different from that of drinking water intended for regular human consumption, and whose composition complies with the relevant biological and physicochemical requirements. Medicinal water is a mineral water which has been proven to have a medicinal effect and whose medicinal use is authorized in accordance with [13].

To be recognized officially as a mineral water, the water should fulfill the following criteria (Annex 2, [13]):

- It comes naturally or from a groundwater aquifer protected by conservation measures,
- It is clean, free from anthropogenic pollution due to its origin,
- It is harmless to human health in its microbiological, physicochemical, and radioactive properties in the form in which it is used,
- Its composition, the dissolved solids content in the water at the extraction site is almost constant within the limits of natural fluctuation, and
- It has a total dissolved mineral content (TDS):
    - ≥1000 mg/L or,
    - in the range 500-1000 mg/L and contains one of the **biologically active substances**:
        - for external use: Li^+ ≥ 5 mg/L, S^{2-} or S ≥ 1 mg/L, Br^- ≥ 5 mg/L, I^- ≥ 1 mg/L, Ra ≥ 37 Bq/L, free CO_2 ≥ 1000 mg/L, $Si(OH)_4$ ≥ 50 mg/L
        - for internal use: omitted, not relevant to this report

The national regulation also specifies that the external use of recognized mineral water (as bathing water) shall be carried out in such a manner that the bathing temperature and the choice of water treatment technologies do not affect negatively the biologically active substances of the water [13]. Annex 6 [13] lists all the requirements for recognizing natural mineral waters in Hungary, see Appendix 11.2 for details.

Most therapeutic pools in Hungary operate without disinfection in a "fill and drain" mode and there is little information on the treatment options of thermal waters [14]. Bufa-Dőrr et al. (2017) [14] concluded that microbial quality of pool water (especially therapeutic baths, operating in a full-drain mode), whirlpools, and spa pools is often inadequate, but also that more detailed monitoring data is needed to assess further the issue [14]. This topic is further discussed in section 7.

5.2 Switzerland

The ordinance by The Federal Department of Home Affairs (FDHA) [15] regulates the treatment, provision, and quality of drinking water as food and commodity. It not only specifies the requirements for drinking water, but also the requirements to:

"…*water in publicly accessible swimming pools, including whirlpools, thermal baths, mineral baths, brine baths, wellness baths, therapy pools, children's paddling pools or similar facilities, as well as publicly accessible water pools with biological treatment of the bathing water*" (Art. 1, 2c) [15].

Section 3 of [15] concerns specifically shower and bath water, where according to the definitions provided in Art. 7 [15] the term "*bath*" includes baths with artificial basin, the water of which is filtered, disinfected, renewed, and recycled (as well as all their operational systems), including thermal-, mineral-, steam baths, and baths with biological water treatment; "water" follows the cited definition above.

Art.7 [15] also gives the following specific definitions:

- **Thermal bath** ("*Thermalbad*"): bath with water originating from groundwater, the temperature of which is > 20 °C at the outlet, and which comes from a spring or a deep borehole
- **Mineral bath** ("*Mineralbad*")*:* bath with facilities that use water from naturally highly mineralized groundwater source that comes from a spring or a deep borehole
- **Baths with biological water treatment** ("*Badanlage mit biologischer Wasseraufbereitung*"): baths with natural or artificial basins, the water of which is recycled and renewed by the existing microflora, but it is not disinfected (incl. also all operational systems)

Water intended for contact with the human body must meet the microbiological requirements in Table 2. The maximum and minimum requirements for water in public baths and shower-facilities are provided in Table 3, while the maximum allowed concentrations for pollutants and disinfection by-products are specified in (see ***Table 4***).

Table 2 *Microbiological requirements for water intended for contact with the human body, Switzerland (Art.9 & Annex 5 [15]); n.d. – not detectable*

Water type	Parameter	Unit	Quality criteria
Water in baths	Aerobic, mesophilic bacteria	CFU/mL	1000
	Escherichia coli (E. coli)	CFU /100 mL	n.d.
	Pseudomonas aeruginosa	CFU /100 mL	n.d.
Water in baths with biological water treatment	Enterococci	CFU/100 mL	50
	Escherichia coli (E. coli)	CFU/100 mL	100
	Pseudomonas aeruginosa	CFU/100 mL	10
Water in whirlpool baths or pools with T > 23 °C with a water cycle that promotes aerosol formation	*Legionella spp.*	CFU/100 mL	100
Steam bath (aerosol formation)	*Legionella spp.*	CFU/100 mL	100
Water in shower systems	*Legionella spp.*	CFU/100 mL	1000

Table 3 *Minimum and maximum requirements for water quality in publicly accessible baths and shower-facilities, Switzerland (*Annex 6 *[15])*

	Category	Parameter	Unit	Quality criteria	
				Minimum	**Maximum**
1	**Water in public baths**	Turbidity	NTU	-	0.5
2	**Chlorine-based disinfection**:				
	- All baths	pH	-	6.8	7.6
	- Swimming and non-swimming pools	Free chlorine	mg/L	0.2	0.8
	- Whirlpools	Free chlorine	mg/L	0.7	1.5
3	**Bromine-based disinfection**:				
	- All baths	pH	-	6.8	7.2
	- Swimming and non-swimming pools	Free bromine	mg/L	0.5	1.4
	- Whirlpools	Free bromine	mg/L	1.2	2.2
4	**Water in baths with biological water treatment:**				
		pH	-	6.0	9.0
		Visibility	m	> 2.0	-
5	**Water in shower systems**	(1)		-	(2)

1. disinfectants according to the list with substances in Annex 4, 5 [15]
2. [2] the maximum values are from the drinking water requirements provided in Annex 2 [15]

Table 4 *Maximum concentrations of pollutants and by-products from disinfection for bathing water, Switzerland (Art. 12 & Annex 7 [15])*

	Category	Parameter	Unit	Maximum quality criteria
1	**Water in public baths**			
	All baths	Bromate	mg/L	0.2
		Chlorate	mg/L	10
		Ozone	mg/L	0.02
	Outdoor pools	Urea	mg/L	3
	Indoor swimming pools	Urea	mg/L	1
2	**Chlorine-based disinfection**:			
	All baths	Chlorine, bound	mg/L	0.2
	Outdoor pools	Trihalomethane (THM) (1)	µg/L	50
	Indoor swimming pools	Trihalomethane (THM) (1)	µg/L	20
3	**Bromine-based disinfection**:			
	All baths	Bromine, bound	mg/L	0.5
		Bromide	mg/L	50
4	**Water in baths with biological water treatment**			
		Total phosphorus	µg/L	10

1. In chloroform equivalents

Based on this, it can be concluded that, in Switzerland, the water quality requirements for drinking water are only applicable in the showering systems, while for the thermal and other types of baths, there are different requirements. These requirements concern the microbiological conditions and the potential pollution resulting from the use of disinfectants, not the natural composition of the thermal (or mineral) waters. It is also notable that there are different quality requirements based on the type of bathing facility.

The specific differences from the Danish requirements from Table 1 are:

- that the maximum quality criteria for bound chlorine value is lower in Switzerland.
- Bromine-disinfection by-products are not mentioned in the Danish requirements for bathing waters
- *Legionella spp.* is not mentioned in ***Table 1***, Danish requirements, however according to the guidance from the Danish EPA [8] additional analyses for pathogens (incl. *Legionella*) can be required as part of specific study and consultation from the Danish Health Authority. The Danish EPA guidance [8] provides also additional information on *Legionella* and the risks associated with specific water temperatures and installations producing aerosols. In future, Danish drinking water will also be checked for *Legionella*, as per the new EU Drinking Water Directive [3]. It must also be noted that indirectly the risk of *Legionella* has been regulated through the temperature requirements for installations for warm water supply [1].

5.3 Spain

In Spain, mineral waters are defined and regulated by the Law of Mines 22/1973, 21 of July [16] and Royal Decree 2857/1978, 25 of August, approving the General Regulation for the Mining Regime [17]. Thermal waters intended for therapeutic or industrial purposes are considered as mineral waters for the purposes of the law (Article 30 [16]). They are defined as those that at the outlet have a water temperature of 4ºC greater than the mean annual air temperature in the same location where the outlet is [16]. If the thermal waters are used for industrial purposes, there is additional definition specifying maximum heat production.

Based on their use, mineral waters are also classified as medicinal ("*Minero-medicinales*") or industrial ("*Minero-industriales*") (Article 23, 1) [16].

Medicinal mineral waters are those that are declared public utility because of their characteristics and qualities, while the industrial mineral waters are those that allow the rational use of the substances they contain [16]. An additional sentence was added to this definition in amendment from 2010 [18], classifying further the medicinal mineral waters based on their use (or destination) into:

- Medicinal mineral waters for therapeutic purposes *("aguas minero-medicinales con fines terapéuticos")*
- Natural mineral waters ("*aguas minerales naturales*")
- Spring waters ("*aguas de manantial*")

This distinction is important, because the Royal decree 1798/2010 [18], which regulates the exploitation and commercialization of *natural mineral waters* and *spring waters* for human consumption, provides the water quality requirements for these two types of waters (Annex

[1] See the Danish Building Code (Bygningsreglement), Chapter 21, §411 (https://bygningsreglementet.dk/Tekniske-bestemmelser/21/Krav)

IV, 1 & 2 [18]). However, it is explicitly stated that the provisions of this decree **are not applicable** to the medicinal mineral waters used for therapeutic purposes (Article 1, 5b) [18].

Thermal waters used in spas can be regulated as medicinal mineral waters for therapeutic purposes in Spain [19]. To be declared as medicinal mineral waters, there are no minimum or maximum quality criteria set, although such waters usually have a high concentration of dissolved minerals, giving them their purported medicinal properties [19].

5.4 Bulgaria

The legal grounds on water ownership and management, including that of mineral water, in Bulgaria are provided in the Water Act [20]. The official definition of mineral water ("*минерална вода*") in the context of this law is given in §1. 17 and includes the listed in the Annex 2 mineral water bodies/resources that are exclusive state property (n > 100), or if not in the list, those with issued certificate and/or complex balneological assessment by the Ministry of Health. The Minister of Health controls the quality of mineral waters that are used for drinking or for prophylactic, medicinal, or hygienic purposes (Article 189) [20], which also includes recreational uses in spas and baths.

The Water Act [20] also covers the relevant issues in respect to hydrothermal energy, and even though there is no explicit definition of "*thermal water*" in [20], there are multiple texts where distinctions for waters with temperature > 20°C are made. When it comes to recreational and bathing use, the same regulation applies irrespective of the temperature of the mineral water.

The specifics about groundwater abstraction and the exploitation of mineral water resources are covered by a Ministerial Ordinance n1 [21]. This Ordinance provides detailed requirements for the hydrogeological assessment, use, and protection of mineral water resources, including what documentation is needed and which are the relevant authorities handling specific issues. According to Article 10 [21], the chemical composition and physicochemical properties of groundwaters, incl. mineral waters, must be characterized through assessment of the background[2], baseline[3], and current levels. Specifically for mineral water, all compounds, and parameters characteristic to the specific source of mineral water must be included in the assessment. These characteristic parameters and compounds are provided in the balneological assessment of the mineral water source [21].

The balneological assessment for the mineral water at each source is issued by the Ministry of Health on the legal basis of the national Health Act (article 75, 3), Water Act (article 155a, 1.4) [20], and the Ministerial Ordinance n1 [21]. The balneological assessment is issued to certify the characteristics and properties of mineral water, intended for abstraction, to be used for drinking, hygiene, treatment, prevention, rehabilitation, sports, and recreational purposes.

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[2] *"…the concentration of a substance or the value of an indicator in a body of groundwater corresponding to no, or only very minor, anthropogenic alterations to undisturbed conditions*" EU Groundwater Directive

[3] *"…the average value measured at least during the reference years 2007 and 2008 on the basis of monitoring programmes implemented under Article 8 of Directive 2000/60/EC or, in the case of substances identified after these reference years, during the first period for which a representative period of monitoring data is available.*" EU Groundwater Directive

The register with issued balneological assessments[4] currently includes 203 mineral water sources (deep wells, springs, etc.) some of which with high temperature.

The balneological assessment includes information about (1) the geological and hydrological characteristics, (2) the chemical composition, radiological, microbiological, and physicochemical properties, as well as (3) recommendations on appropriate use (internal and/or external) of the mineral water and list of health conditions in which the water should not be used. Details on the content of the balneological assessment is given in Appendix 11.3. The balneological assessment provides also a conclusion about the composition of the mineral water, which includes how the mineral water is classified based on different criteria (e.g. temperature, ion-content, etc,) and compliance assessment based on the requirements of Ministerial Ordinance n14 [22].

Ordinance n14 [22] deals with the resources, areas and resorts used for recreation/tourism. Mineral water is treated as a recreational resource (Article 2, 1) [22] and it is declared and registered as such by the Health Ministry after expert assessment. The main indicators for declaring and registering the resources as mineral water ("*минерална вода*"), according to Article 7 [22] are 1) deep underground origin, 2) stable physicochemical composition, and properties, which are not affected by climatic or other changes in the natural environment, 3) the total mineralization, ion composition, temperature, redox potential, and the content of at least one of the biologically active substances from ***Table 5***. The mineral water used for any of the listed purposes, including sport and recreation, should comply with the microbiological requirements from ***Table 6***.

Table 5 *Minimum criteria for mineral water for the content of biologically active substances in Bulgaria, according to Article 7, 1 [22]*

Biologically active substances	**Unit**	**Minimum criteria**
Fluoride (**F^-**)	mg/L	2
Bromide (**Br^-**)	mg/L	10
Iodide (**I^-**)	mg/L	5
Ferrous ions (2 or 3 valent)	mg/L	10
Meta silicic acid (**H_2SiO_3**)	mg/L	50
Meta arsenic acid (**$HAsO_3$**)	mg/L	1
Oxidizable iodine-sulphur compounds (as **H_2S**)	mg/L	10
Carbon dioxide (**CO_2**) for:		
• internal use	mg/L	300
• external use	mg/L	400
Radon (Rn)	Bq/L	185

[4] Register of the issued balneologic assessments for mineral water in Bulgaria (accessed 18.01.2022, the last update was on 01.12.2021): https://www.mh.government.bg/bg/administrativni-uslugi/registri/registr-na-izdadenite-ot-mz-balneologichni-ocenki-za-mineralni-v/

Table 6 *Microbiological quality requirements for mineral waters for recreational purposes in Bulgaria, according to Annex 5 [22]* (last amendment of Annex 5: State Gazette n12 of 1995)

Indicators	**Unit**	**Maximum criteria**	**Note**
Total number of mesophilic aerobic microorganisms			
• at 20+2°C for 72 hours	CFU/cm^3	20	
• at 37+1°C for 24 hours	CFU/cm^3	5	
Coliforms at 37°C	/50cm^3	0	1
Escherichia coli at 43°C	/50cm^3	0	1
Enterococci	/50cm^3	0	1
Sulphite reducing *Clostridia*	/10cm^3	0	1
Pseudomonas aeruginosa	/50cm^3	0	1

1. number of samples = 5, no sample out of the 5 should exceed the norm

6. World Health Organization (WHO) guidelines for safe recreational water environments, volume 2

The World Health Organization (WHO) has published guidelines for safe recreational water environments in 2003 (volume 1) and in 2006 (volume 2). Of these, volume 2 is relevant here, as it focuses on swimming pools and similar environments, including natural spas with thermal water [23]. The guidelines in this volume are structured in six chapters of which the following are most relevant:

- Chapter 1. "*Introduction*" provides definitions, overviews the type of hazards and their risk assessment, and presents measures for reducing the risks
- Chapter 3. "*Microbial hazards*" presents the different viruses, bacteria, protozoa, and fungi, and related outbreaks, risk assessment and risk management.
- Chapter 4. "*Chemical hazards*" overviews the different ways of exposure to chemicals in the context of swimming pools, and discusses chemicals derived from the source water, bather, management, and specifically on the disinfection by-products.

A summary of the most relevant points from these chapters is provided next.

The primary aim of the WHO guidelines is the protection of public health and ensuring that the pools and similar environments are operated safe. The guidelines are intended to be used as the basis for developing approaches to controlling **hazards** (see Section 6.1), providing a framework for policy-making and local decision-taking, and as a reference material for industries and operators.

Types of swimming pools, covered by the guidelines [23], based on:

- the water type they are supplied with – fresh, marine, **thermal water**.
- ownership – domestic, semi-public, public
- supervision – supervised or unsupervised
- location – indoor, outdoor, both
- heating – heated or unheated
- different use/structure – traditional rectangular, temporary portable, or specialist pools

The most relevant definition provided in the guideline is for "*natural spa*".

*"**Natural spa** is the term used to refer to facilities containing thermal and/or mineral water, some of which may be perceived to have therapeutic value and because of certain water characteristics may receive minimal water quality treatment."* (p.3 [23])

Thus, the WHO guidelines [23] are relevant to the potential future spa-facilities using geothermal waters at Lønstrup. The term "*natural spa*" would apply because natural thermal mineral water would be used. However, in future more detailed assessments, it will be important to also specify how the thermal water will be used (in what type of facilities).

The WHO guidelines are not covering the "*physical therapy pools"*, also called "*hydrotherapy pools*", but many of the same principles would apply to them too.

6.1 Hazard and risk definition

Hazard is the potential for harm, including injury, illness, or even loss of life, while the risk is the chance that harm will occur. Risk has something to do with the probability of exposure to specific hazard (type and frequency). The most frequent hazards associated with pools (incl. natural spas) are: 1) physical hazards, 2) heat, cold, sunlight, 3) water quality, 4) air quality. Some examples are listed in ***Table 7***.

Table 7 *Examples of health outcomes associated with specific hazards relevant to pools and similar recreational water environments (source: p. 6 [23])*

Health Outcome	**Examples of associated hazards**	**Read more in:**
Drowning	Swimmers under the influence of alcohol, poor swimming ability, no supervision, poor pool design and maintenance	[23]
Impact injuries	Impact against hard surfaces, which may be driven by the participant (diving, accidents on water slides, broken glass, jagged metal)	[23]
Physiological	Acute exposure to heat and UV in sunlight; cumulative exposure to sun in outdoor pools.	[24]
	Heat exposure in hot tubs and natural spas, using thermal water, or cold exposure in plunge pools	Section 6.2
Infection	Ingestion of, inhalation of or contact with pathogenic bacteria, viruses, fungi and protozoa, which may be present in water and pool surroundings as a result of faecal contamination, carried by participants or animals using the water or naturally present.	Sections 6.3, 6.4, 6.5
Poisoning, toxicoses and other conditions that may arise from long-term chemical exposures	Contact with, inhalation of or ingestion of chemically contaminated water, ingestion of algal toxins and inhalation of chemically contaminated air.	

The specific risks to natural spas discussed further in this report are the last 3 categories of ***Table 7***: heat, microbial and chemical contamination.

The assessment of hazard and risk should inform the policies for controlling and managing risks to the health and well-being in water recreation. ***Figure 1*** illustrates how to assess health hazards, their severity, and the required management priority. A similar approach is also discussed in section 7 in relation to the treatment dilemma and the related risks.

A detailed hazard and risk-assessment is beyond the scope of this report but could be beneficial in the future development of the spa. Further investigation is needed to determine what are the specific requirements by the relevant Danish national or local authorities.

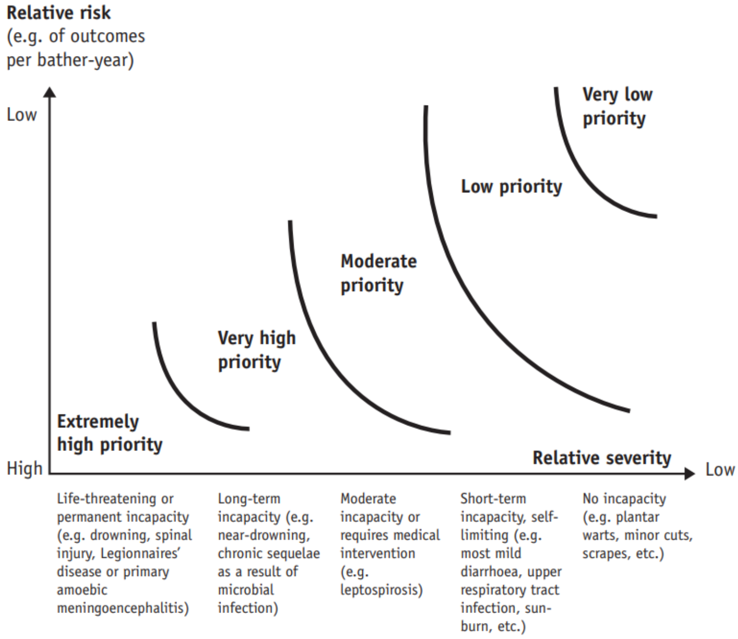

Figure 1 *Example of schematic approach to comparing health hazards encountered during recreational water use (source: p.7 [23])*

6.2 Water temperature

Body overheating can occur in natural spas, where water temperatures are above 40°C [23]. High temperatures could cause drowsiness, which may lead to unconsciousness, which in extreme cases may lead to drowning. High temperature has also been linked to heat strokes and death from extremely hot water (~43°C) [23].

Therefore, WHO recommends that the water temperatures be kept below 40°C [23]. The Danish EPA guideline on swimming pools [8] agrees with this recommendation.

The Danish EPA guideline [8] states that the usual temperature range in pools is 24–28°C, but higher temperatures can be used in special cases, e.g. children pools, therapy pools, spa-baths etc. When the temperature is higher, the rate of bacterial growth and of chemical reactions increases (e.g. chlorine evaporation increases). For pools with high temperatures, the requirements for the circulating water flow through the basin must be complied with [8].

Further information on preventive and management actions can be found in the WHO guideline, p.21 [23].

6.3 Microbial hazards related to thermal water

Chapter 3 of [23] covers in detail the illness and infection associated with microbial contamination, based on the origin of the microbial contaminant (***Figure* 2**). It must be noted that the Danish regulation on public bathing [1, 8] also covers some of these microbial hazards (see for example ***Table 1***). Our summary here is limited to only few microbial hazards specific to natural spas ***Table* 8**.

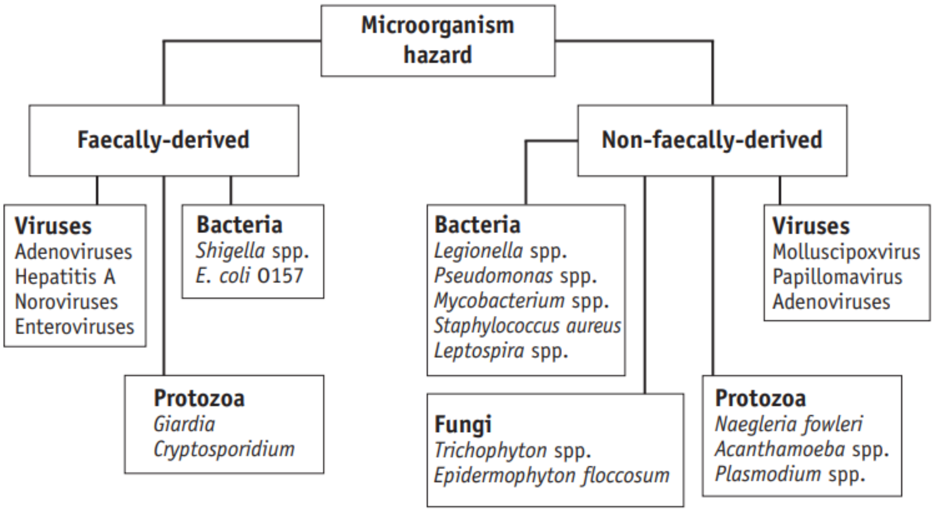

Figure 2 *Potential microbial hazards in pools and similar environments (source: [23]).*

Table 8 *Non-faecally-derived microorganisms related to natural spas (source: [23])*

Organism	**Infection/Disease**	**Source**
Legionella spp.	Legionellosis (Pontiac fever and Legionnaires' disease)	Aerosols from natural spas, hot tubs and their systems. Poorly maintained showers or heated water systems
Naegleria fowleri	Primary amoebic meningoencephalitis (PAM)	Pools, hot tubs, and natural spas, including their systems.

Legionella species (spp.)

Natural spas with thermal water and the associated equipment create an ideal habitat (warm, nutrient-containing aerobic water) for the *Leigionella* species. *Legionella* are Gram-negative, non-spore-forming, aerobic bacilli, which may be free-living or living within amoebae and other protozoa or within biofilms.

Legionella spp. can cause legionellosis—range of pneumonic and non-pneumonic diseases. Legionnaires' disease is a form of pneumonia. Specific risk factors to pools and hot tubs include the frequency of use and the length of time spent in or around the tub/pool. Pontiac fever is another related, non-pneumonic, non-transmissible, non-fatal, influenza-like illness.

The WHO guidelines refer to couple of studies showing that thermal spring water may be a source of high numbers of *Legionella* spp. and have been implicated in cases of legionnaires' disease (see [23] for references).

Number of management strategies are listed in [23]. The critical control to the growth of *Legionella* in both hot tubs and natural spas is the physical cleaning of surfaces in and around the pool. Where chlorine is used for disinfection, the free chlorine concentration should be ≥ 1 mg/L.

The Danish EPA guideline [8] also has a section on *Legionella* (under additional microbiological analyses that may be requested by the health authorities but are not part of ***Table 1***) and provides guideline on operation of showers. It also agrees with the WHO guidelines on the free chlorine concentration (≥ 1 mg/L) and adds that aerosol-forming devices should be disinfected regularly with chlorine (5-10 mg/L).

Naegleria fowleri

Naegleria fowleri (*N. fowleri*) is a free-living amoeba, present in fresh water and soil. As part of its life cycle, it does not require the infection of a host organism to complete it, and it also includes environmentally resistant encysted form. *N. fowleri* is thermophilic, prefers warm water and reproduces successfully at temperatures up to 46°C. It can cause primary amoebic meningoencephalitis. The infection is usually acquired by exposure to water in ponds, natural spas, and artificial lakes, but it is an extremely rare disease [23]. The risk of infection can be reduced by choosing an appropriate source of water, proper cleaning, maintenance, coagulation-filtration, and disinfection [23]. The Danish EPA guideline [8] does not mention this specific amoeba.

6.4 Chemical hazards

The chemicals in pool water can be derived from the source water, deliberate additions (e.g. disinfectants), and the pool users themselves (***Figure* 3**).

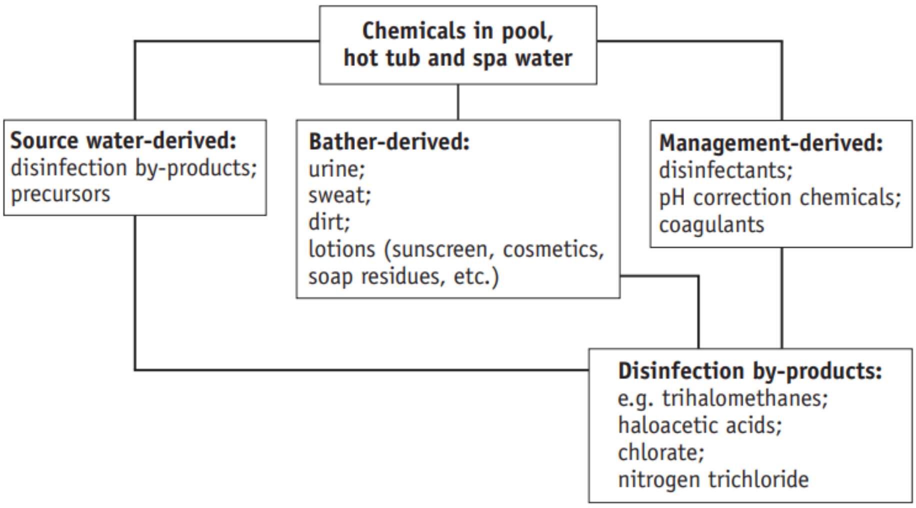

Figure 3 *Possible pool water contaminants in pools and natural spas (source: [23])*

Most of these hazards are relevant to the design, operation, and management of the pools and spas.

The WHO guidelines [23] give relatively very little attention to the source water-derived chemicals in comparison to the other groups of contaminants. The issues mentioned specifically with this respect are:

- **Organic matter** – precursor of disinfection by-products. The context in which this was mentioned was municipal drinking water supply, but it could be relevant to any other water type with high content of organic matter.
- **Bromide** – mentioned in the context of seawater, however it may be relevant to thermal highly-mineralised water as well, if it contains bromide. Of the other halogen elements, iodide was also mentioned, as it may produce iodinated by-products.
- **Radon** – mentioned in the context of groundwater, but could be relevant to thermal water, if it contains radon. In this case, good ventilation of indoor pools and hot tubs is important. The drinking water quality guideline for radon is to be considered [23].

The management-derived chemicals are those added to pool water to achieve the required (microbiological) water quality. WHO lists number of disinfectants and their use, e.g. chlorine-based disinfectants, chloring dioxide, bromine-based disinfectants, ozone, and ultraviolet radiation. Other management-derived chemicals are related to pH adjustment or coagulation process used for removal of dissolved, colloidal, or suspended matter.

By far the most important chemical hazards in the WHO guideline are related to disinfection by-products. Trihalomethanes (THM), chloramines, chlorite, and chlorate, as well as other disinfection by-products are discussed in detail throughout Chapter 4 of [23].

It must be noted that the Danish regulation on swimming pool facilities [1] and their water quality also provides criteria for free and bound chlorine, and THM (***Table 1***), and number of other disinfection by-products are also listed in the existing Danish drinking water requirements [2]. Detailed information about the disinfection chemicals used in Denmark can also be found in [8].

When choosing the disinfection method in the design phase of the future spa (fed with thermal mineralized water), it will be important to consider the natural composition of the source-water and to assess the risk of disinfection by-products with harmful health effects.

6.5 Air quality

For indoor swimming pools, air quality considerations should also be made when designing the spa-facilities. Good ventilation should be assured for the indoor areas housing natural spas [23].

The two main health concerns related to air quality are *Legionella* and the disinfection by-products (esp. chloramines). *Legionella* was already discussed in section 6.3. To minimize the exposure to disinfection by-products, inhalation should also be minimized, as it is the dominant route of exposure during recreational water use. Concentrations of disinfection by-products decrease rapidly with distance from the water, which has implications for ventilation design. Radon is another potential concern, discussed briefly in section 6.4.

Ventilation rates for indoor swimming pools and thermal baths may be specified in building codes, but this topic is beyond the scope of this report.

7. The treatment dilemma

The use of natural mineral and thermal water for spa purposes has a long history, and with that there are different cultural and social contexts of their uses [11]. Some consider these waters to be "untouchable", meaning that their specific composition should be preserved to maintain claimed health benefits [25], which are supposed to derive from their unique physicochemical or microbiological properties [11].

The management of spa facilities with thermal water is a compromise between reducing contamination (assuring bathing safety) and maintaining the original characteristics of the thermal water [25]. The WHO guidelines [23] also notes that in certain circumstances, in some natural spas with thermal and mineral water, it may not be possible to treat the water in the usual way (i.e. by recycling or disinfection) because "*the agents believed to be of benefit, such as sulfides, would be eliminated or impaired*" [23]. Moreover, some naturally occurring substances in thermal waters, e.g. humic substances and ammonium, may reduce the effect of disinfection [23]. Non-oxidative methods of water treatment could be used and the rate of water exchange should be very high (or drain-down should be used) in such cases [23].

A study from Hungary, published in the Journal of Water & Health (2021) focused on the need to balance the disinfection risks and benefits in therapeutic waters (incl. thermal pools) [27]. The context of the study was that traditionally in Hungary (among other countries like Italy and Turkey) these thermal therapeutic pools are operated in a fill-and-drain mode (without recirculation) and without disinfection to preserve the so called biologically active substances [27]. The authors posit that introduction of disinfection in therapeutic pools is inevitable to assure microbiological water safety, however the challenge is how to design appropriate treatment of waters with high temperature, high organic matter content, and complex chemical composition, while preserving their therapeutic effects [27]. The study included seven spas from Hungary which use disinfection by hydrogen peroxide or hypochlorite (and UV as secondary treatment) and assessed the effect of these disinfectants on the water composition.

The results of the study showed that microbial quality was improved by both disinfectants, but: hypochlorite reduced the concentrations of sulphide, bromide, and iodide by 40-99% and resulted in high levels of disinfection by-products. Hydrogen peroxide only affected sulphide (91% reduction) [27]. The conclusions were that:

- Hypochlorite disinfection can be recommended only for thermal waters with low quantity of organic compounds, ammonium ion, and non-oxidizable therapeutic components, e.g. meta silicic acid, lithium ion, or high total mineral content [27].
- Hydrogen peroxide is a more flexible option, but the operational cost may be higher, and the dosing must be maintained at optimal levels [27].
- UV treatment can only be applied as a secondary method, its efficiency may be lowered by the turbidity of the water or the deposition of minerals on the surface of the UV lamp [27].

- Other technological steps also alter the composition, and this should be considered too, e.g. deposition of minerals in the supply network, evaporation of volatile compounds like radon, dilution with cold water [27].

Review and critical assessment of different disinfection solutions for the use in spa pools (chlorine-based disinfectants, ozone, UV irradiation, bromine-based disinfectants, stabilized silver/copper, hydrogen peroxide) and the current and potential applications of antimicrobial nanomaterials (e.g. silver nanoparticles, chitosan, graphene oxide, H_2S, nano TiO_2, ultrafiltration, and ZnO) can be found in [11]. The antimicrobial activity at four Italian thermal waters the additional effect of using photocatalytic nanotechnologies based on TiO_2 photocatalysis were tested, but further research is needed to validate the results [26]. The authors, therefore advocated for the use of Water Safety Plan for spa facilities [26].

The proposed Water Safety Plan approach (***Figure* 4**a) should consider: 1) The specific water composition and availability, 2) The distribution system (e.g. engineering and materials), 3) The intended use (e.g. recreational, rehabilitative, medicinal, wellness, etc.), 4) The potential sources of contamination, 5) The exposed population (age, disability, health status, etc.), 6) The allowable crowding thresholds [26].

The Water Safety Plan also adopts a hazard-exposure-risk framework (***Figure* 4**b). This is like the approach of assessing health hazards, their severity, and the required management priority discussed in the WHO guidelines (Section 6.1 and ***Figure 1***).

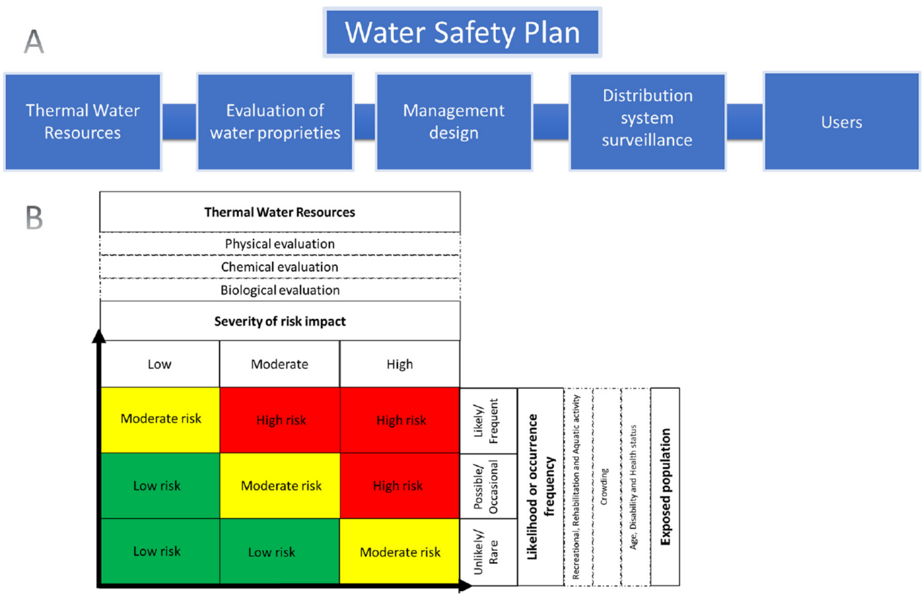

Figure 4 *Margarucci's (2019) proposal for a proactive risk-management strategy for facilities using thermal water resources for recreational purposes; (A) Water Safety Plan; (B) Risk assessment matrix (figure source:[26])*

8. Gassum Formation

The most likely geothermal formation water (brine) to be utilized for the potential future spa in Lønstrup is from the Gassum Formation. The Gassum Formation (Upper Triassic–Lower Jurassic period) (***Figure* 5**) is regarded as the most promising geothermal formation in Denmark [28].

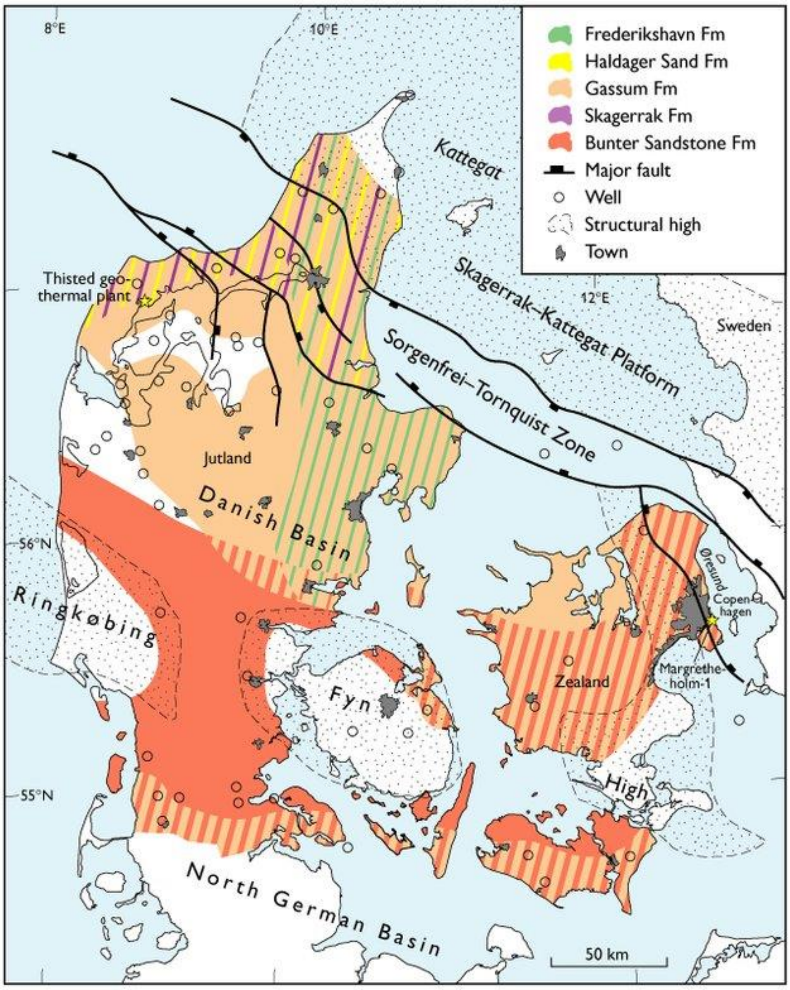

Figure 5 *Map of Denmark showing the regional geothermal potential of different aquifer formations (depth 1000-2500 m); Gassum formation (Fm) is shown in light orange (source: [28]). See **Figure 6** for more details and focus on North Jutland.*

The genesis, distribution, depth, and composition of Gassum Formation are relatively well-understood [28, 29] and are discussed in section 8.1. The brine from this formation is used in Thisted and Sønderborg for geothermal energy; therefore, we overview in section 8.2. the chemical composition of the brine from Thisted based on the available data.

8.1 Gassum Formation characteristics in North Jutland

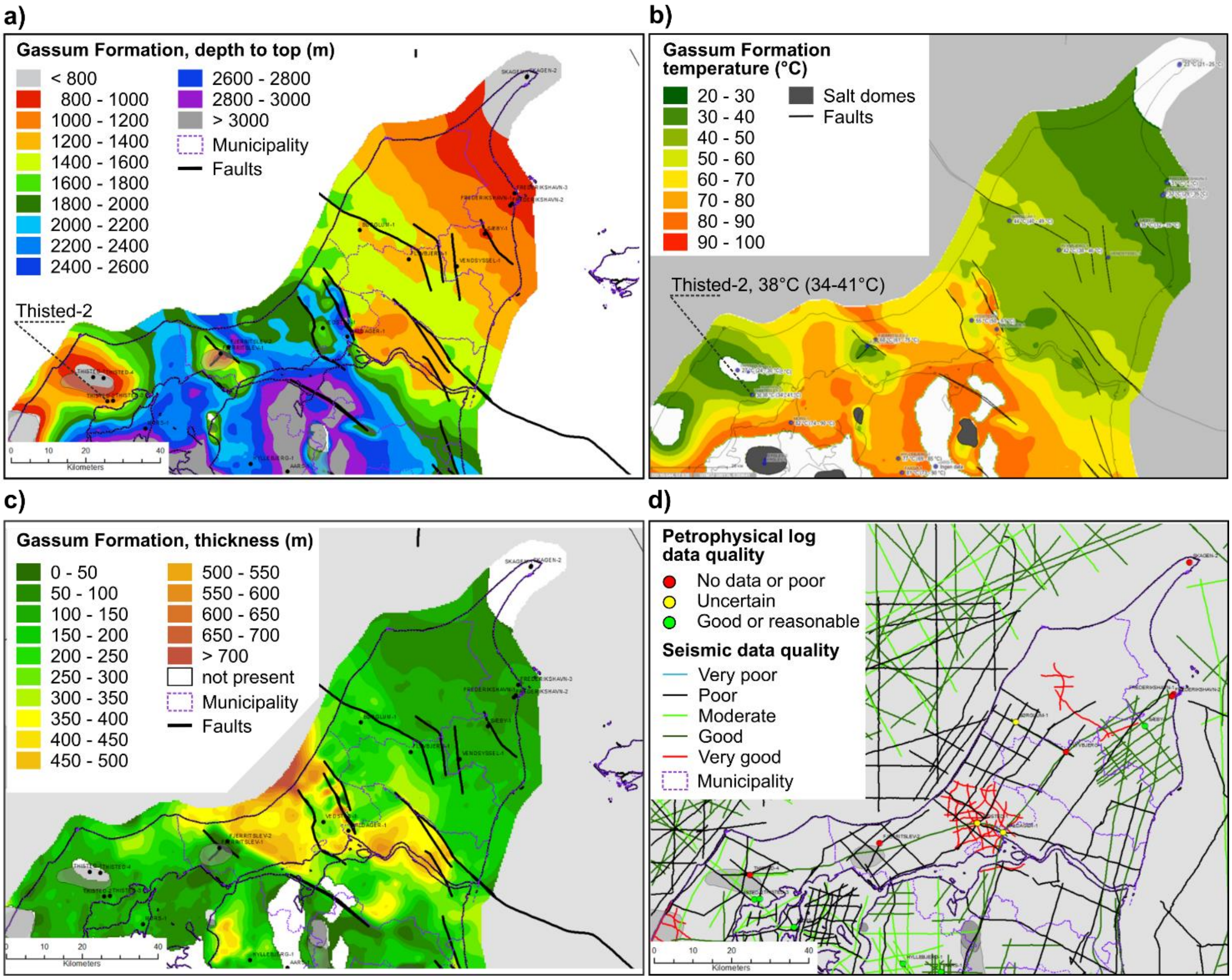

Figure 6 Gassum Formation characteristics and the location of Thisted-2 deep borehole; a) depth to the top of the formation (ref. level subsea); b) estimated temperature at the formation top with corrected measured data from the wells; c) estimated thickness of the formation; d) distribution and quality of seismic data and the petrophysical log-data at the deep wells. (source: https://data.geus.dk/geoterm/)

Depth

Based on the current mapping of the subsurface in Vendsyssel, the expected depth to the top of the Gassum Formation is approx. 1400–1600 m in the Lønstrup area (***Figure* 6**a). The depth probably increases toward Southwest and decreases toward Northeast. The uncertainty on this depth estimate may be up to ±15% because it is based on interpretation of few seismic lines with poor quality, a poorly defined velocity to depth relation, and poor tie to the deep wells, Børglum-1, Flyvbjerg-1, and Vendsyssel-1, that penetrated the top of the Gassum Formation at approx. 1225–1350 m below sea level. The data-availability in the area and their quality are shown on ***Figure* 6**d.

Lithology

The lithological composition of the formation is expected to be dominated by sandstones with interbedded mudstones and siltstones as shown by the Børglum-1 and Flyvbjerg-1 wells. The reservoir properties and thus the hydraulic conductivity is expected to be relatively good. The estimated thickness of the formation in the area is shown on ***Figure* 6**c.

Temperature

The temperature of the brine is mainly dependent on the depth of the formation, and it is estimated to be approx. 50°C (***Figure* 6**b). The uncertainty may be ±20% or more, as the temperature estimate is dependent on both the actual depth of the formation, and the temperature gradient at Lønstrup, which is most likely between 25–30 °C/km.

Need for reducing the uncertainty

It is emphasized that the currently available data about the deep subsurface around Lønstrup is sparse and scattered, and therefore the depth and temperature estimates may differ significantly from the real figures.

These uncertainties can be reduced by acquiring new seismic data and/or drilling a new deep well. New seismic data will allow a better constrained mapping of the top of the formation and its thickness and may indicate presence of fault systems that need to be accounted for. Better-constrained temperature and more detailed lithology information of the Gassum Formation requires the drilling of a new deep well in the area.

8.2 Chemical composition of the Thisted formation water

The Gassum Formation brine has been utilized in the Thisted geothermal plant since 1984. Studies of the geochemical composition of Gassum brines in the Danish subsurface have shown that the composition, is dependent on the burial depth, among other factors [30]. In Thisted, the Gassum brine is produced from approx. 1250 m of depth. It is thus expected that the geochemical composition of the Gassum brine below Lønstrup may be relatively similar to the composition of the brine in Thisted. The geochemical composition of the Thisted brine has been analyzed to evaluate the risks of corrosion, scaling and precipitation in the geothermal facilities at Thisted [30].

Based on the existing data for the formation water at Thisted geothermal wells (Table 9), the pH is lower than the range provided ***Table 1*** [1].

Based on the temperature of the formation water (assuming that the temperature in the spa facilities will be similar), the quality criteria for free chlorine and THM (Table 1) specific to swimming pools > 34 °C and all outdoor basins incl. spa-baths would be applicable.

Based on a comparison with the Danish drinking water requirements (see Table 10 – Table 14) [2], all three samples exceed the quality criteria for Cl^-, Na, Fe, Mn, and Pb, but comply with the criteria for SO_4^{2-} and Zn. At this point it is not possible to assess fully the compliance with the Danish drinking water standards, as many of the parameters are not measured.

If the definition for natural mineral water from the EU Directive on the Exploitation and Marketing of Natural Mineral Waters [5] (see section 5) is used, the Thisted brine would be classified as having a rich mineral content with high content of Cl, Ca, Mg, Fe, Na.

By its temperature, it would be classified as thermal mineral water according to the definitions used in many countries.

Table 9 *Chemical analyses of formation water from Thisted geothermal wells and compliance with the relevant Danish quality criteria from [1, 2]; PB – production boring*

Parameter / Well (Year)	Unit	Thi-2 (1983)	Thi-2 (2015)	PB (2017)	Criterion [ref.]	Compl.
Temperature	°C	-	-	43.2	-	-
pH	-	6.4	6.2	5.9	6.8-7.6 [1]	No
Total dissolved solids (**TDS**)	g/l	167	167	160	-	-
Hydrogen Carbonate (**HCO_3^-**)	mg/L	40	45	31	-	-
Chloride (**Cl^-**)	mg/L	102000	102000	98642	250 [2]	No
Bromide (**Br^-**)	mg/L	290	430	314	-	-
Iodide (**I^-**)	mg/L	1.6	7	-	-	-
Sulphate (**SO_4^{2-}**)	mg/L	25	69	-	250 [2]	Yes
Sodium (**Na**)	mg/L	55000	55000	51882	175 [2]	No
Calcium (**Ca**)	mg/L	7500	7400	6909	-	-
Magnesium (**Mg**)	mg/L	1700	1500	1564	-	-
Strontium (**Sr**)	mg/L	360	350	370.04	-	-
Potassium (**K**)	mg/L	250	265	248	-	-
Iron (**Fe**)	mg/L	36	30	8	0.2 [2]	No
Manganese (**Mn**)	mg/L	16	13	15	0.05 [2]	No
Ammonium (**NH_4^+**)	mg/L	<	20.5	-	-	-
Zinc (**Zn**)	mg/L	0.6	0.09	1.0	3 [2]	Yes
Barium (**Ba**)	mg/L	12	13	18	-	-
Lithium (**Li**)	mg/L	13	7.5	-	-	-
Lead (**Pb**)	mg/L	0.04	0.02	0.01	0.005 [2]	No
Silicon (**Si**)	mg/L	-	-	4.65	-	-

It must be noted that the criteria for bathing water [1] relate to the water quality in the swimming pool (or the other spa facilities) not at the well. Some of the water quality parameters are redox sensitive, so the water contact with the atmosphere either during the treatment process, or in the swimming pool, may alter the water composition.

Further guidance from the Danish EPA is potentially needed to clarify which specific drinking water criteria should be complied with in the special case of thermal water used for bathing. It would be important also to assess what would be the effect of disinfection for the specific composition of the thermal water at Lønstrup.

9. Recommendations for future work

In the previous chapters we presented an overview of both the national and international regulation relevant to using thermal water for bathing (e.g. in a spa) and a preliminary assessment and a basic characterization of the Gassum Formation brine. On that basis, in this section we provide recommendations for further investigations aiming at reducing the hydrogeological and geochemical risks – and thus the associated economic risks – linked to the sparse data that is currently available in North Jylland.

We recommend to:

1. **Acquire new seismic data and drill a new deep well at Lønstrup**

The seismic grid in North Jutland, at Lønstrup, is sparse, which results in higher relative uncertainties in the characterization of the Gassum Formation thermal potential. Acquiring new seismic data will allow for a better constrained mapping of the top of the formation, its thickness, and may indicate the presence of unmapped fault systems, which should be accounted. To constrain better the temperature and to gather more detailed lithological information of the Gassum Formation at this area requires drilling of a new deep well.

2. **Sampling and extended chemical and microbiological analyses of the brine at Lønstrup**

The preliminary assessment of the chemical composition presented here was based on the brine at Thisted, since there is no available information from the Lønstrup area. The chemical composition may differ depending on the location, depth, and temperature of the brine. Sampling from the new deep well would help with constraining the uncertainty in the chemical composition and to better characterize this fluid which is intended for bathing purposes. Without such data it is impossible to assess the associated potential health and operational risks of using the thermal water for bathing purposes in a spa.

3. **Seek guidance from the national authorities on the special case of using natural thermal, highly mineralised water for public bathing**

The presented regulation and guidance overview showed that there is a gap in the regulation of thermal waters used for bathing purposes (e.g. in spa) in Denmark. There is no unified and broadly accepted international framework, as different countries regulate in different ways. The composition, mineralization, and temperature of these waters is very different from the usual water used for bathing or drinking water purposes in Denmark, which poses unique challenges in the design and operation of the potential future spa in Lønstrup. The municipality council (Kommunalbestyrelsen) can grant dispensations from the regulations for swimming pools, but it is perhaps necessary to obtain specific guidance from the Danish EPA (Miljøstyrelsen) and/or the Danish Health Authority (Sundhedsstyrelsen).

4. **Develop a water safety plan (hazard-exposure-risk assessment)**

It is necessary to consider the entire cycle of utilizing Gassum formation brine for bathing in a spa—from abstraction, through transport, treatment, use different spa-facilities, re-injection or discharge of the “used water”. Some aspects of this were briefly discussed in this report, but further work is needed for assuring safe water and air quality.

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11. Appendix

11.1 Danish drinking water quality criteria

Table 10 *Drinking water quality requirements for chemical parameters according to Annex 1b of BEK nr 2361 af 26/11/2021 (dk: Drikkevandsbekendtgørelsen) [2]*

Parameter	Unit	Quality criteria	Notes	EU DWD
Acrylamide	µg/L	0.10	1	Same
Antimony (**Sb**)	µg/L	5.0		10.0
Benzene	µg/L	1.0	2	Same
Benzo(a)pyrene	µg/L	0.010	3	Same
Boron (**B**)	mg/L	1.0	4	1.5 (2.4)
Bromate (**BrO_3^-**)	µg/L	10	5	Same
Chromium (**Cr**)	µg/L	50		(25)
Copper (**Cu**)	mg/L	2.0		Same
Cyanide (**CN^-**)	µg/L	50		Same
1,2-dichlorethane	µg/L	3.0		Same
Epichlorohydrin	µg/L	0.10	1	Same
Fluoride (**F^-**)	mg/L	1.5		Same
Mercury (**Hg**)	µg/L	1.0	6	Same
Nickel (**Ni**)	µg/L	20		Same
Nitrate (**NO_3^-**)	mg/L	50	7	Same
Aldrin, dieldrin, heptachlor, heptachlor epoxide	µg/L	0.030	8	Same
Other pesticides	µg/L	0.10	8, 9	Same
Pesticides Total	µg/L	0.50	10	Same
Polycyclic aromatic hydrocarbons	µg/L	0.10	3, 11	Same
Selenium (**Se**)	µg/L	10		20
Vinyl chloride	µg/L	0.50	1	Same

Notes to *Table 10*:

1. The parametric value of 0,10 µg/l refers to the residual monomer concentration in the water as calculated according to specifications of the maximum release from the corresponding polymer in contact with the water.
2. Indicator for oil and petrol products
3. Indicator for tar products
4. Efforts should be made to supply water with as low concentration as possible and below 300 µg/l
5. It applies within supply areas where water is produced or distributed from plants that disinfect the water with chlorine, ozone, or similar highly oxidizing substances. Whenever possible, without affecting disinfection, a lower value is sought.
6. Efforts should be made to supply water with as low concentration as possible and < 0.1 µg/L
7. It should be ensured that $[NO_3^-]/_{50} + [NO_2^-]/_3 \leq 1$
8. Applies to each individual pesticide
9. Definition of pesticides and relevant pesticides is also provided in the Annex 1b of BEK nr 2361 af 26/11/2021
10. Sum of detected and quantified pesticides, according to the provided definition
11. Sum of concentrations of the following specified compounds: benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(ghi)perylene, and indeno(1,2,3-cd)pyrene

Table 11 *National drinking water quality requirements for the main constituents, according to Annex 1c of BEK nr 2361 af 26/11/2021 (dk: Drikkevandsbekendtgørelsen) [2]; * Table 1 applies instead*

Parameter	Unit	Quality criteria	Note	EU DWD 2020
Aluminium (**Al**)	µg/L	200		Same
Ammonium (**NH_4^+**)	mg/L	0.05	1	0.50
Chloride (**Cl^-**)	mg/L	250	2	Same
Colour	mg Pt/L	15		Same
Conductivity	µS/cm	2500 at 20˚C	2, 3	Same
pH *	pH-unit	7.0 – 8.5	4	≥ 6.5 & ≤ 9.5
Iron (**Fe**), total	µg/L	200		Same
Manganese (**Mn**), total	µg/L	50		Same
Odour, Taste *	-	Subjective assessment	5	-
Oxygen demand (COD)	mg/l O2	5.0	6	Same
Sulphate (**SO_4^{2-}**)	mg/L	250		Same
Sodium (**Na**), total	mg/L	175		200
NVOC (C)	mg/L	4		-
Turbidity *	FNU	1		-

Notes to *Table 11*:

1. For disinfection with chloramine, a higher value, but below 0.2 mg/L can be accepted. Ammonium content up to 0.50 mg/L can be accepted when the drinking water is not filtered at the waterworks, if it can be documented that the quality requirement for nitrite at the consumer tap has been complied with. Exceedances of the quality requirement applicable to the tap because of renewal of filter materials may occur, but should be reduced as much as possible and must not exceed 0.50 mg/l.
2. The water must not be aggressive
3. The conductivity should be at least 300 µS/cm at 25˚C
4. The water must not be lime aggressive.
5. The water must not have a different taste and smell, except for disinfectants.
6. This parameter should not be measured if the NVOC parameter is analyzed.

Table 12 *National quality requirements with health consideration according to Annex 1d of BEK nr 2361 af 26/11/2021 (dk: Drikkevandsbekendtgørelsen) [2]*

Parameter	Unit	Quality criteria	Note	EU DWD 2020
Arsenic (**As**)	µg/L	5		10
Lead (**Pb**)	µg/L	5		5 (10)
Cadmium (**Cd**)	µg/L	3		5
Cobalt (**Co**)	µg/L	5		-
Nitrite (**NO_2^-**)	mg/L	0.10	1	0.50
Silver (**Ag**)	µg/L	10	2	-
Zink (**Zn**)	mg/L	3		-
Pentachlorophenol (PCP)	µg/L	0.01	3	-
Chlorite (**ClO_2^-**)	µg/L	50	4, 5	250 (700)
Chlorate (**ClO_3^-**)	µg/L	50	4, 5	250 (700)
Sum of ClO_2^- and ClO_3^-	µg/L	50	5	-
Trifluoroacetic acid	µg/L	9		-
Fluoranthene	µg/L	0.1	6	-
Sum of PFAS	µg/L	0.1	7	Definition differs
Sum of PFOA, PFOS, PFNA & PFHxS	µg/L	0.002		-
Chlorinated volatile organic compounds	µg/L	1	8, 9	-
Sum of chlorinated volatile organic compounds	µg/L	3	9	-
Sum of trihalomethanes	µg/L	25	5, 10	100

Notes to *Table 12*

1. It should be ensured that $[NO_3^-]/_{50} + [NO_2^-]/_{3} \leq 1$; For disinfection with chloramine, a higher value, but < 0.5 mg/l can be accepted. Exceedances of the quality requirement applicable to the tap as a result of filter-renewal may occur, but should be reduced as much as possible and must not exceed 0.5 mg/l. The value 0.1 mg/l is complied with when leaving the waterworks, however higher values can be accepted when it can be documented that the quality requirement for nitrite at the consumer tap has been complied with.
2. Applies within the supply areas where water is produced or distributed from waterworks where silver is used for disinfection.
3. The specified quality requirement cannot be determined sufficiently well with the method commonly used in the laboratories. Until better techniques have been developed, a method having a detection limit not exceeding 0.01 µg/L may be used.
4. The substance is present as a decomposition product in chlorine solutions and the content may be further increased with time if left standing.
5. The quality parameter applies for water supply areas where water is produced or distributed from waterworks that disinfect the water with chlorine compounds.
6. Indicator for tar products.
7. By PFAS is meant: PFBS, PFHxS, PFOS, PFOSA, 6:2 FTS, PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA
8. Value applies to each individual substance.
9. Chlorinated volatile organic compounds are understood to mean: di- and trichloromethane, dichloroethanes, 1,2-dichloroethane, trichloroethene and trichloroethanes, tetrachloroethene and tetrachloroethanes. If the content of trichloromethane (chloroform) in the raw water is greater than 1 µg/L, it must be determined whether the source is natural or contaminated. If the content is natural, a higher value can be allowed, but ≤ 10 µg/L.
10. By trihalomethanes is meant the sum of the content of chloroform, bromodichloromethane, dibromochloromethane and bromoform, which is formed by chlorination of the natural content of organic matter in the water. Chlorination should be carried out so that the content is as low as possible.

Table 13 *Quality criteria for radioactivity according to Annex 1f of BEK nr 2361 af 26/11/2021 (dk: Drikkevandsbekendtgørelsen) [2]*

Radioactivity indicators	Unit	Quality criteria	Note
Radon	Bq/L	100	1, 2, 4
Tritium	Bq/L	100	1, 3
Total indicative dose	mSv/y	0.10	1, 2, 3

Notes to *Table 13*

1. The measurement is performed at selected stations at national level
2. Measurements should only be taken if there is a risk of radioactivity
3. By indicative dose is meant: the aqqumulated effective dose for one year of ingestion resulting from all the radionuclides whose presence has been detected in a drinking water supply, of natural and artificial origin, whith the exception of tritium, 40K, radon, and short-lived decay products from radon
4. In special cases, a higher value can be accepted, but < 1000 Bq/L

The EU drinking water directive [3] has also quality criteria for elements that are not included in the Ministerial order on drinking water quality [2] (Table 14).

Table 14 *Quality criteria from EU Drinking Water Directive [3], not included in BEK nr 2361 af 26/11/2021 (dk: Drikkevandsbekendtgørelsen) [2]*

Parameter	Unit	Quality criteria	Note
Bisphenol A	µg/L	2.5	
Haloacetic acids (HAAs)	µg/L	60	1
Tetrachloroethene and Trichloroethene	µg/L	10	2
Uranium (**U**)	µg/L	30	

Notes to *Table 14*

1. This parameter shall be measured only when disinfection methods that can generate HAAs are used for the disinfection of water intended for human consumption. It is the sum of the following five representative substances: monochloro-, dichloro-, and trichloro-acetic acid, and mono- and dibromo-acetic acid.
2. The sum of concentrations of these two parameters.

11.2 Hungary

Test requirements for recognizing natural mineral waters (Annex 6, [2])

- Field measurements:
    - temperature, pH, specific conductivity (at 20°C degrees), dissolved oxygen, free carbonic acid
- Laboratory measurements:
    - **main constituents** (mg equivalents and % of the anion/cation): cations: Na^+, K^+, Li^+, NH_4^+, Ca^{2+}, Mg^{2+}, Fe, Mn; anions: NO_3^-, NO_2^-, Cl^-, Br^-, I^-, F^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}, PO_4^{3-}, S^{2-}
    - **other parameters**: alkalinity, total solids (evaporation residue 180°C-260°C), total dissolved minerals, chemical oxygen demand (COD), total organic carbon (TOC), total hardness, metasilicic acid (H_2O_3Si), metaboric acid ($B_3H_3O_6$), color, smell
    - **inorganic micropollutants (indicators)**: Sb, As, Ba, Cd, Cr, Cu, Zn, Pb, Hg, Ni, Se, Al, cianides (CN^-)
    - **organic micropollutants (indicators):** total aliphatic hydrocarbon test (TPH) or UV oil index, phenol index, volatile aromatic hydrocarbons (VAHs: benzene, toluene, ethylbenzene, mp-xylene, o-xylene, styrene, naphthalene), polycyclic aromatic hydrocarbon (PAHs, benz(a)pyrene, benz(b)fuoranthene, benz(k)fluoranthene, benz(ghi)perylene, indeno(1,2,3-cd)pyrene); adsorbable organic halides (AOX), where if AOX > 10µg/l, the following volatile chlorinated hydrocarbon components must be tested: 1,2-dichloroethane, cis-1,2-dichloroethylene, tetrachlorethylene, trichlorethylene, chloroform, bromoform, dibromochloromethane, bromodichloromethane, vinyl chloride, epichlorohydrin.
    - **pesticides:** the substances tested for drinking water according to the Government Office of the Capital City of Budapest
- Isotope studies:
    - Tritium
    - Rn activity – only if the classification of water as mineral water is possible on the basis of Rn content, or it is justified from a public health perspective
- Bacteriological tests

- Colony count at 22°C and 37°C CFU/ml
- Coliform bacteria (CFU/100 ml), Escherichia coli (CFU/100 ml)
- Enterococcus (CFU/100 ml),
- Pseudomonas aeruginosa (CFU/100 ml)
- Sulphite-reducing anaerobes (Clostaridia) (CFU/50 ml)

11.3 Bulgaria

Content of the balneological assessment issued by the Minister of Health for individual sources of mineral water (deep well, spring, etc.):

- The geological and hydrological characteristics
  - location of the source at the surface – address, geographical coordinates, elevation
  - geological formation where the mineral water comes from
  - recharge zone of the mineral water resource
  - information about the borehole itself (or the other water-capturing installations), the piezometric level in the borehole, the depth, the water debit, as well as the construction of the borehole (materials, diameter, etc.)
  - exploitation permits granted by the Minister of Environment and Water
  - protection zone of the mineral source
- Composition
  - anions (mg/l & eq%): F^-, Cl^-, SO_4^{2-}, CO_3^{2-}, HCO_3^-, $HSiO_3^-$, NO_3^-, NO_2^-, sum of anions
  - cations (mg/l & eq%): NH_4^+, Li^+, Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe-total, Mn^{2+}, sum of cations
  - characteristics (mg/l, unless stated differently): dry residue at 180°C and 260°C, electrical conductivity (μS/cm), pH, temperature, H_2SiO_3, total mineralisation, CO_2, H_2S, debit (l/s), description of color, smell, residue
  - microelements (mg/l): Al, As, Sb, Cd, Cr, Cu, Ni, Pb, Se, Hg, Ag, Zn, Ba, B, CN^-
  - radiological indicators (Bq/L unless stated differently): total α- and β-activity, ^{226}Ra, ^{222}Rn, natural U, total indicative dose (mSv/y)
  - microbiological indicators: total colony count at 20+2°C for 72h and 37+1°C for 24h, coliforms at 37°C, *Escherichia coli* at 43°C, fecal streptococci (*Enterococci*), sulphite reducing Clostridia, *Pseudomonas aeruginosa*
  - Conclusion about the mineral water composition: it includes classification based on temperature, ions, and if there is evidence for microbial pollution, as well as assessment based on the requirements form Ordinance n14 of 1987 (last amendment in 2004), see main text for the requirements.
- Characteristics: account on the therapeutic and prophylactic characteristics of the water based on its mineral content. The characterisation also includes guideline and warning for specific uses, for example if the water is used for balneotherapy (with temperatures between 35-37°C) through external use (bathing), internal use (drinking), or inhalation. There is also list of health conditions in which the mineral water should not be used for balneological therapy. For sport and restorative uses there is also recommendation on temperature adjustments (up to 28°C)