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# Harnessing the distinctive qualities of Lithuanian natural mineral water for SPA services and human health

***Lolita Rapolienė, Justina Raulušonytė, Erika Vasiliauskienė, Diana Šaparnienė, Artūras Razbadauskas, Giedrė Kurienė, Aelita Bredelytė, Inga Dailidienė****

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**Abstract.** Lithuania is rich in natural mineral waters and has a couple of centuries of history of using them for human health. The use of mineral water in medical SPAs has been popular since ancient times and continues to be important as a complement to modern medicine. Medical SPAs aim to achieve various health benefits by employing diverse types of mineral water with unique physicochemical compositions. The composition of mineral water used varies among different countries due to differences in hydrogeologic conditions, temperature, and chemical composition. While many countries have been investigating the properties of mineral water used for therapeutic purposes, scientifically grounded insights about the uniqueness of mineral water in Lithuanian medical SPAs are still limited. This study aims to investigate the physicochemical properties of mineral water used in Lithuanian medical SPAs and to evaluate their potential benefits for human health. To reach the research aim, a quantitative study was conducted in six of the most popular medical SPAs. The research results indicate that the mineral water used in medical SPAs is highly mineralized sodium chloride (salt) mineral water with significant calcium, magnesium, and sulphate levels. The mineral water is safe with regard to the presence of heavy metals. The tested mineral water could be used for the complementary treatment of nervous, rheumatic, skin, respiratory, cardiovascular, and metabolic disorders.

**Keywords**: *natural groundwater resources; balneotherapy; application in medical SPA*

✉ *Lolita Rapolienė (lolita.rapoliene@ku.lt), ORCID 0000-0002-5089-4095;*
*Klaipėda University, Faculty of Health Sciences, Nursing Department, Klaipėda, Lithuania;*
*Justina Raulušonytė (justina.raulusonyte@gmail.com), ORCID 0009-0002-9045-4307;*
*Vilnius University, Faculty of Medicine, Vilnius, Lithuania;*
*Erika Vasiliauskienė (er.vasiliauskiene@gmail.com), ORCID 0000-0002-1536-2595;*
*Klaipėda University, Marine Research Institute, Klaipėda, Lithuania;*
*Diana Šaparnienė (diana.saparniene@ku.lt), ORCID 0000-0002-0597-3309;*
*Klaipėda University, Faculty of Social Sciences and Humanities, Department of Social Geography and Tourism, Lithuania;*
*Artūras Razbadauskas (arturas.razbadauskas@ku.lt), ORCID 0000-0002-6524-5354;*
*Klaipėda University, Klaipėda, Lithuania;*
*Giedrė Kurienė (giedremiliauskaite@gmail.com), Klaipėda University,*
*Marine Research Institute, Klaipėda, Lithuania;*
*Aelita Bredelytė (taelita.bredelyte@ku.lt), ORCID 0000-0002-5782-0937;*
*Klaipėda University Hospital Branch "Seamen's Hospital", MD of Physical Medicine and Rehabilitation, Klaipėda; Lithuania;*
*Inga Dailidienė* (inga.dailidiene@ku.lt), ORCID 0000-0001-7919-6090;*
*Lithuanian Business College, Klaipėda, Lithuania*

**Corresponding author*

## INTRODUCTION

Mineral water, taken from nature, has been used for wellness and treatment since ancient times. The practice of bathing in mineral water has been a part of various cultures throughout history, with claims of potential health improvements such as soothing skin conditions, relieving muscle and joint pain, and promoting overall relaxation. In ancient Greece and the Roman Empire, recreational and salubrious usage of baths became so popular that it launched a term still used today, meaning "health through water", in Latin: "sanitas per aquam", or "SPA". During the Renaissance, using baths for medicinal purposes started to regain popularity after a period out of the spotlight and began to be widely explored and scientifically evaluated during the 18th and 19th centuries.

Today, water therapy is being practiced in many countries that have a variety of mineral springs considerably different in their hydrogeologic origin, temperature, and chemical composition (Cacciapuoti *et al.* 2020). It is known that pure water ($H_2O$) does not exist in nature and all natural waters have some additional components – chemical elements. Mineral water is generally defined as waters with a content of total dissolved solids (TDS) of at least 1,000 mg/l, as well as natural waters with low mineralization if they contain one or several specific components that have a therapeutic effect on the human organism. The term "natural mineral water" is suitable for both natural springs and other underground continental waters with stable specific physical and chemical properties (Gomes 2013). Depending on the origin, the composition and temperature of chemical elements and the proven healing properties, natural mineral waters are recognized and called "healing mineral water" or "natural medicinal water". Mineral water could be taken from springs (groundwater) or deep wells (geothermal water). All natural mineral waters are groundwater from a hydrogeological point of view.

The relaxation or treatment using natural mineral water is often referred to as balneotherapy (BT, Falagas *et al*. 2009), or crenotherapy (Linc *et al*. 2023), or hydrotherapy, or pelotherapy, or could be combined with other factors (talasotherapy, massages, physical therapy, etc.) and named SPA therapy or health resort medicine (e.g., in German:Kurortmedizin). The patients may either drink natural medicinal water (crenotherapy), bathe in natural medicinal water (hydrotherapy), inhale natural gases, or have some peloid packs (Gutenbrunner *et al.* 2010). All these are associated with clinical improvement in diseases of the skin, as well as respiratory, circulatory, digestive, and nervous systems, among others (Stier-Jarmer *et al*. 2015), providing analgesic, anti-inflammatory, antioxidative, sedative, and muscular rejuvenating effects.

Balneology, also called medical hydrology, is a field of science that studies the methods, applications, and effects of balneotherapy with healing mineral water (baths, drinking, and inhalations), mud, and gases to achieve therapeutic goals. It covers various disciplines: hydrology, hydrogeology, hydrochemistry, physics, microbiology, medicine, public health, health tourism, and etc. (Gomes 2013).

Today, mineral water is used to promote health and wellness. It is known to have a combined effect on the human body: thermal, mechanical, chemical, immunological, and psychological (Rapolienė *et al*. 2016; Fioravanti *et al*. 2017; Gálvez *et al*. 2018; Kardes, Karagülle 2020; Ziemska *et al*. 2019). Natural mineral bathing is widely used for various medical conditions, including musculoskeletal, autoimmune, dermatological, digestive, pulmonary, cardiovascular, peripheral vascular pathologies and neurological disorders (Proksch *et al*. 2005; Korczak, Owczarek 2014; Rapoliene *et al*. 2016; Costantino *et al*. 2019; Antonelli *et al*. 2021; Gebretsadik 2023; Ushiko-shi-Nakayama *et al*. 2024).

Natural healing waters can differ in their chemical content or their physical qualities, which matters for prescribing it for the treatment of certain diseases and with the expectation of a certain effect. There are several classifications of mineral water based on their composition. According to mineralization, mineral water can be of the following types: 1) water with elevated mineralization (1 to 5 g/l ), used as drinking water; 2) water with medium mineralization (5 to 15 g/l), used in balneology and consumed as medicine; 3) water with high mineralization (15 to 35 g/l), used for therapeutic bathing; and 4) brines (35 to 150 g/l), used exclusively for bathing purposes (Komatina 2004; Valeriani *et al*. 2018).

The composition of chemical elements and mineral substance enables to classify natural mineral water as (I) bicarbonate mineral water, (II) sulphate mineral water, (III) chloride mineral water, (IV) calcic mineral water, (V) magnesian mineral water, (VI) fluorite mineral water, (VII) ferrous mineral water, and (VIII) sodium-rich mineral water and to have known effects on health (Quattrini *et al*. 2016; Latour 2017). According to the 2009/54/EC Directive (European Legislation 2009), physical and chemical characterization is used to make a classification of different mineral water (Van der Aa 2003; Casado *et al*. 2015).

It should be noted that not all waters are therapeutic, and their therapeutic properties are determined by the type and concentration of active biochemical components. There are certain requirements for the use of mineral water for humans in each country. For example in Lithuania, the following regulations are related to natural mineral water: the hygiene norms "Public health safety requirements for swimming

pools" (HN 109:2016), "Mineral and sea water for external use health safety requirements" (HN127:2010), and "Drinking water safety and quality requirements" (HN 24:2023 ).

Lately, many countries have been investigating the properties of water used for treatment in their local SPA centres. The need is growing due to the increasing attention to health and disease prevention using balneological procedures and natural resources for various therapies.

This study systematically examines and compares the natural mineral water of resort areas, offering informed recommendations for their optimal utilization. Focusing on Lithuania, the research delves into the distinctive qualities of its natural mineral waters, exploring their application for the advancement of SPA services and human well-being.

Nowadays, information about natural mineral water properties in such Lithuanian institutions is still limited. Our study aimed to assess and characterize the physico-chemical properties of mineral water used in Lithuanian medical SPAs and to evaluate potential benefits for human health. This study is related to a wider application of natural mineral water in the fields of healing and wellness.

## RESEARCH AREA, MATERIALS AND METHODS

Groundwater is an integral part of the hydrosphere and is considered a valuable subsurface resource accumulated in the pores and fractures of rocks (Grigelis, Kadūnas 1994). Compared to surface water, groundwater has several advantages. It is naturally better protected from contamination, and it contains a higher concentration of dissolved minerals that are essential for human health (Kadūnas *et al*. 2018).

Lithuania is part of the Baltic Artesian Basin, the total area of which is 460 thousand km². About 200 thousand km² of the basin are under the Baltic Sea (Grigelis, Kadūnas 1994). Three structural parts are distinguished in the Baltic Artesian Basin: the central one, where the crystalline foundation sank at a depth of 500–5000 m, as well as the northern and southeastern slopes of the artesian basin, where the crystalline foundation sank no deeper than 500 m. The crystalline foundation, which is also the foundation of the artesian basin, is covered by layered sedimentary rocks with different filtration properties. They are separated from each other by Triassic and Silurian-Ordovician regional aquicludes. Like other artesian basins, ot is characterized by the vertical zonation of groundwater. Physical geographical conditions and the arrangement of geological layers determine the distribution of groundwater. In the lower part of the artesian basin, the aquifers are more compact, and there is almost no vertical water circulation. Consequently, the conditions that existed in the geological past are more likely to be preserved here, leading to higher salt concentrations, greater chemical diversity, and elevated temperatures (Grigelis, Kadūnas 1994).

Geologists extensively study groundwater resources as one of the primary mineral resources of Lithuania. Researchers have summarized previous studies and present data on the mineralization of mineral waters, thermal water energy resources, and their main usage locations (Juodkazis 1992; Grigelis, Kadūnas 1994; Kadūnas *et al*. 2018).

In Lithuanian resorts (Druskininkai, Birštonas, Likėnai), mineral water has been used for therapeutic purposes in sanatoriums for over a hundred years (Grigelis, Kadūnas 1994). According to the same source, the mineral water from the Druskininkai and Birštonas deposits is associated with Triassic, Cretaceous, and Quaternary sediments, while the mineral water in Palanga is extracted from Paleozoic Devonian system rocks.

In Lithuania, as in many European countries, balneotherapy is widely used and included in national health systems due to the country's abundance of natural mineral water resources. Balneotherapy (from Latin: *balneum* "bath" and Greek: *therapeia* "treatment, care") refers to medical treatments using mineral water and is also utilized for preventive purposes. Compared to neighbouring countries, Lithuania is rich in natural mineral water and favourable geothermal conditions. The natural geothermal (from Greek: *geo* "earth" and *therme* "heat") water resources are particularly suitable for exploitation in western Lithuania due to their specific physical thermal properties and high mineralization (Fig. 1). Water temperature is crucial in balneology (Grigelis, Kadūnas 1994). Mineral water with a temperature of 37–40 °C is highly valued, as it does not require heating and can be directly used in therapeutic treatments. As is well known, groundwater at such temperatures is found at depths of 900–1200 meters and is only present in the western part of Lithuania, west of the Central Lowland (Grigelis, Kadūnas 1994). However, the practical applications of this resource have been understudied, and its broader utilization in balneology remains limited.

Balneotherapy and wellness services offered in SPAs are considered one of the most promising sectors of health tourism in Lithuania. The studied mineral water is groundwater with a unique chemical composition, naturally formed in nature. The purpose of this study was to compare the physical and chemical properties of mineral water from different Lithuanian resort areas and to assess their potential impact on human health and their applicability in balneotherapy. The healing properties of mineral water depend on its

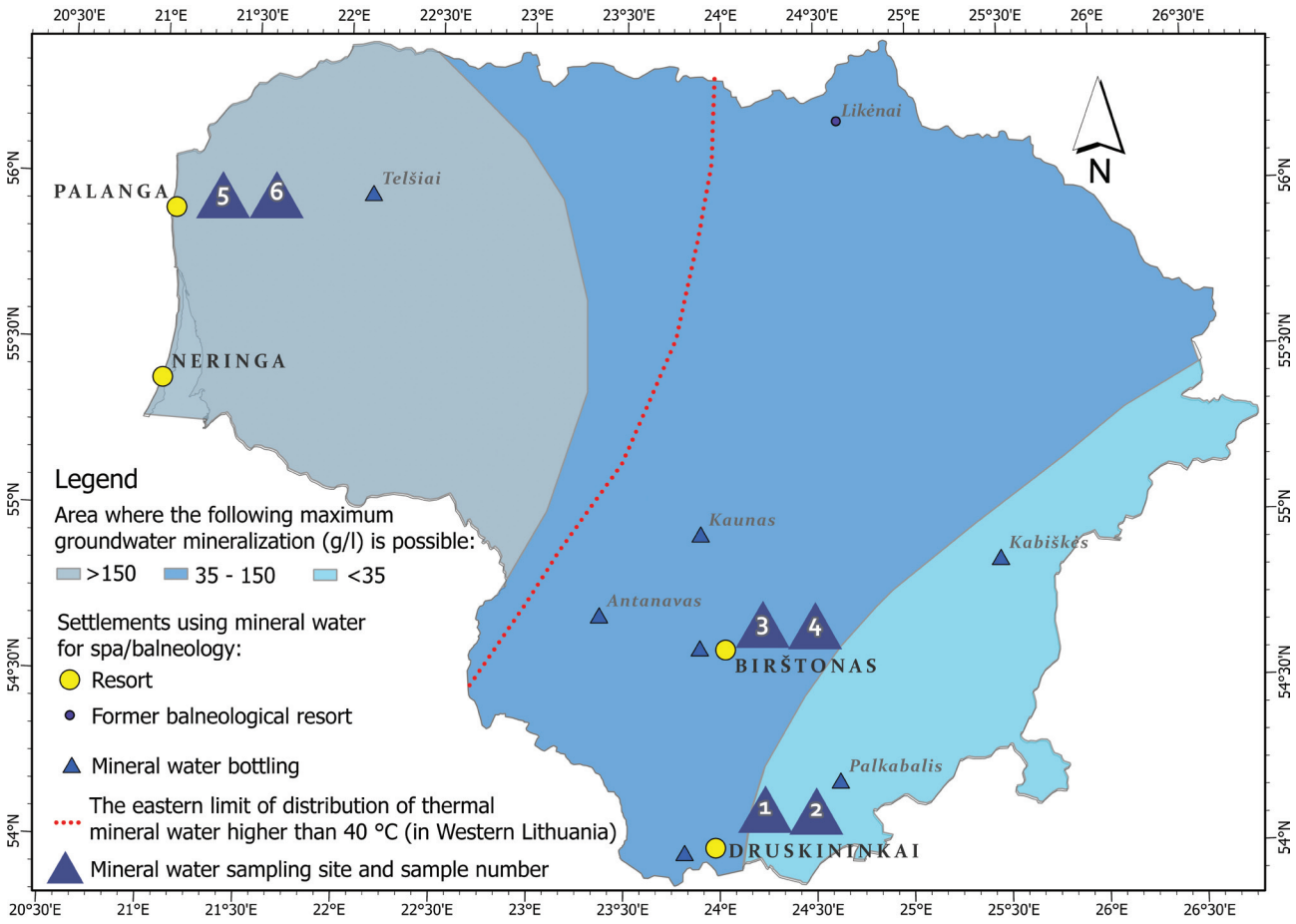


**Fig. 1** The mineral water resources, mineralization, and their use in Lithuania. Number in triangle indicates the mineral water sampling site (modified from Rapoliene *et al*. 2024)

chemical composition, which determines the methods and indications for its therapeutic use.

In Lithuania, the mineral water utilized for balneology is recognized for its unique chemical composition and therapeutic properties. Several notable resorts in Lithuania employ mineral water for balneological purposes. The primary resorts include Druskininkai, Birštonas, and Palanga. The Druskininkai resort, operating since 1837, and the Birštonas resort, operating since 1846, have long-standing traditions in balneology. It should be noted that although the former Likėnai resort currently lacks official resort status, it is particularly noteworthy. The natural sulfide mineral water was exclusively used only in the former Likėnai resort. The Likėnai balneology resort was founded in 1890, and until 1960, "Smardonė" spring water, which contained about 3–6 mg/l of hydrogen sulfide, was used for treatment there (Grigelis, Kadūnas 1994). According to the same resource, Palanga is the youngest balneological resort in Lithuania, where the first well named "Palanga" was drilled in 1959. Historically, for several centuries, this resort has been known as a climatic resort located by the Baltic Sea, characterized by a maritime climate typical of the Baltic region.

This study analyzed three Lithuanian resort areas (Palanga, Birštonas, Druskininkai) that use deep well mineral water for SPA services. All six samples were taken from medical SPA centres exploiting geological wells (Fig. 1, Table 1). The geological wells vary in depth and have a differing number of aquifer layers. Information about the wells was obtained from the Lithuanian Geological Survey under the Ministry of the Environment of Lithuania. Research on the quality and health safety of natural mineral water resources was conducted as part of the Lithuanian Science Council (LMT) project LUGISES, "Efficiency and safety of using unique natural resources of Lithuania to improve the mental and physical health of the body related to stress" / S-REP-22-6. Quantitative research of 6 mineral water used in 6 Lithuanian medical SPAs was conducted in the certified laboratory in February–March 2023 (probes 1, 2, 3, 5, and 6) and September 2019 (probe 4). Data on the physical and chemical qualities of mineral water were obtained. All medical SPAs use mineral water from their wells. In Lithuania, the quality of therapeutic waters is controlled by the Lithuanian National Public Health Centre under the Ministry of Health of Lithuania.

**Table 1** Information about sampled mineral water wells

| No. of sample / SPA centre | Well No. (in LGS GF) | Coordinates (1942, ellipsoidal) | Well depth, m | Aquifer explored, depth, m (top/bottom) | Lithology of aquifer/ geological age (period, epoch) | Name of location | Resort (city) | Year of drilling |
|---|---|---|---|---|---|---|---|---|
| 1 | 54342 | 54°01'04,57" 23°58'59,61" | 318.0 | 269.0/317.0 | Sandstone/$T_1$ | "Draugystė" Sanatorium | Druskininkai | 2013 |
| 2 | 38047 | 54°01'32,2" 24°01'15,19" | 321.0 | 290.0/321.0 | Clay, sandstone, granite/ PR-$T_1$ | "Eglė" Sanatorium | Druskininkai | 2005 |
| 3 | 17230 | 54°36'06,63" 24°02'05,78" | 306,0 | 248.0/304.0 | Sand, clay, sandstone, marl/$P_2$-$T_1$ | "Tulpė" Sanatorium | Birštonas | 1966 |
| 4 | 18778 | 54°36'06,8" 24°01'40,98" | 315.0 | 245.0/257.0 | Sandstone, clay/$T_1$ | "Versmė" Sanatorium | Birštonas | 1976 |
| 5 | 70580 | 55°56'31,19" 21°04'26,97" | 570.0 | 522.0/567.0 | Clay, sandstone/ $D_2$–$D_3$ | "Gradiali" Sanatorium | Palanga | 2019 |
| 6 | 10880 | 55°30'32,78" 21°19'11,28" | 2154.0 | 1989.3/2134.2 | Sandstone aleurolite, clay/Cm | "Atostogų parkas" SPA Centre | Klaipėda district | 1970 |

Geological age (period, epoch) of aquifer: PR – Proterozoic, Cm – Cambrian, $D_2$–$D_3$ – Middle and Late Devonian, $P_2$ – Late Permian, $T_1$ – Early Triassic. LGS GF – Geological Fonds (Archive) in the Lithuanian Geological Survey.

The samples of mineral water were taken, preserved, transported, and analyzed according to the requirements of Lithuanian Standards Board (LST) and ISO standards. Separate samples were taken for pH, hardness, anions, cations, SiO2, PO4, CN, Fe, heavy metals, and Hg. Membrane filters, verified according to the requirements of LST ISO 7704, were used for filtration. The assessment of heavy metals (As, Ba, Cd, Cr, Cu, Mn, Ni, Pb, Sb, Se, Hg) in mineral water from five medical SPAs (samples 1, 2, 3, 5, 6) was conducted using atomic absorption spectrometry with a graphite furnace.

The mineralization of the samples was compared with the established legal standards of Lithuania and Europe. The main biological functions of the mineral found in the studied waters and its possible application are directly associated with specific mineral compositions of water. In this paper, based on the mineralization studies and other scientists' research results, we determined and recommended the possible applicability of different mineral water sources in the main human biological functions in the body. The article discusses natural medicinal resources, there chemical composition of mineral water, and their therapeutic applications. Classifications of medicinal mineral water were searched and reviewed in the National Library of Medicine (PubMed, more information: https://pubmed.ncbi.nlm.nih.gov). It was mainly based on the type of mineral water and its therapeutic dose (Table 2) according to the 2009/54/EC Directive (European legislation 2009) and the classification of medicinal mineral water (modified Papp's system) (Varga 2010). These studies are important to ensure that mineral water meets all health and safety standards and can be widely used in both balneology and other wellness fields.

**Table 2** Type of mineral water and its therapeutic dose according to the 2009/54/EC Directive (European legislation 2009)

| Type of mineral water | Main chemical composition formula | Therapeutic dose |
|---|---|---|
| Bicarbonate mineral water | $HCO_3^-$ | > 600 mg/l |
| Sulphate mineral water | $SO_4^{2}$ | > 200 mg/l |
| Sulphourous mineral water | $S^2$ | > 1.0 mg/l |
| Calcic mineral water | $Ca^{2+}$ | > 150 mg/l |
| Magnesiac mineral water | $Mg^{2+}$ | > 50 mg/l |
| Fluorurate mineral water | $CaF_2$ | > 1 mg/l |
| Ferrous mineral water | Fe+ | > 1 mg/l |
| Sodium-rich mineral water | $Na^+$ | > 200 mg/l |
| Low-sodium mineral water | $Na^+$ | < 20 mg/l |

## RESULTS

The samples from Druskininkai, Birštonas, and Palanga resorts exhibited a diverse range of content and composition of mineral substances and chamical elements, making them suitable for various therapeutic applications. Their high mineralization levels, particularly in terms of sodium, calcium, and chloride, suggest a significant therapeutic potential, especially for conditions requiring these minerals.

A country's natural mineral water is one of the main natural medicinal and human health resources. Our study revealed the mineral waters used in 6 medical SPAs were of high mineralization – brine, low acidic-alcaline, natrium, calcium, magnesium, sulphate-rich chloride mineral water in significant quantities of potasium, and bromium. The composition of mineral water used in SPA treatment is provided in Table 3, which is compiled based on the mineral composition determined by the laboratory analysis of water samples from six places where Lithuanian mineral water is found (Fig. 1).

Mineral waters used in medical SPAs were 16.8–82.5 g/l TDS, which corresponds to high-very high mineralization and brine mineral water, and according to HN 127:2010 (HN, 2010) can be used undiluted or diluted with tap or lower mineralization water for high (15–35 g/l) and very high (> 35 g/l) mineralization baths. Most abundant cation in tested waters was sodium followed by calcium and magnesium, most abundant anion was chloride followed by sulphate, the richest in sodium as well as calcium and chlorine were waters from the 1st and 6th centres; big amounts of magnesium were in the 1st–4th and 6th centres; potassium, boron and bromide were a few times richer in the 6th centre than in others; the 1st and 4th centres were the richest in sulphur; and the 2nd and 3rd in silica; and the most carbonated waters were from the 3rd and 5th centres.

When assessing with the modified Papp's system, all of the centres' water could be classified as chlorinated (saline), as $Na^+$ was the dominant cation and t $Cl^-$ was the dominant anion. The waters of the 1st centre can also be classified as ironic (ferrous) because the amount of $Fe^{2+}$ was higher than 10 mg/l. The water of the 6th centre could also be classified as ironic; however, as the value of $Fe^{2+}$ for this centre is missing the conclusion cannot be made. None of the centres' waters were sulphuric nor sulphated or carbonated, but had a high bromide concentration, especially the 6th centre.

The analyzed samples differ in mineralization and are classified differently, as it is known (Juodkazis 1992) that mineral water from all balneological groups forms under various and complex hydrogeodynamic and hydrogeochemical conditions, complicated by tectonic faults, erosional incisions, and lithological rock changes. The mineral water from Druskininkai (samples 1 and 2) and Birštonas (samples 3 and 4) is associated with Triassic, Cretaceous, and Quaternary deposits, whereas in Palanga (samples 5 and 6), the mineral water is extracted from Paleozoic Devonian system rocks (Grigelis, Kadūnas 1994). The geological wells vary in depth and have differing numbers and depths of aquifer layers (Table 2). Mineral water is classified into balneological groups. Based on the results of this study, the mineral water from the studied resorts can be assigned to the following classifications (Table 4 and Fig. 2).

Table 4 summarizes the classification of mineral water samples from Druskininkai, Birštonas, and Palanga based on their mineralization levels and chemical composition. The samples from Druskininkai (samples 1 and 2) are classified as very highly mineralized waters (> 35 g/l) and are characterized as chloride sodium waters with high calcium, magnesium, and sulfate content. Similarly, Palanga's sample 6 is also classified as very highly mineralized (brine) water with the same chemical characteristics. In con-

**Table 3** Classification of sampled mineral waters according to the Nauheim Congress (1911) and changes in Salzuflen (1934) and the Polish Ministry of Health Regulation (2006) (Ziemska *et al*. 2019). Samples: 1, 2 – Druskininkai; 2, 3 – Birštonas; 5, 6 – Palanga (for location see Fig. 1)

| Parameters (mg/l) | 1 | 2 | 3 | 4 | 5 | 6 | Element values (HN 2003; European Legislation 2009) | European SPAs Association minimum standards (ESPA 2022) |
|---|---|---|---|---|---|---|---|---|
| Cations | | | | | | | | |
| $Na^+$ | 15446 | 9016 | 4210 | 4020 | 4274 | 22100 | > 200 | / |
| $K^+$ | 133 | 73.0 | 93.9 | 88.1 | 157 | 518 | / | / |
| $Mg^{2+}$ | 1387 | 1166 | 1259 | 1400 | 417 | 1948 | > 50 | 150 |
| $Ca^{2+}$ | 3453 | 2800 | 1969 | 2080 | 1267 | 6302 | > 150 | 500 |
| Fe (total) | 18.0 | 6.42 | 0.31 | 0.30 | 0.11 | 10.1 | / | / |
| $Fe^{2+}$ | 16.8 | 0.9 | 0.09 | 0.26 | 0.04 | / | > 1 | 20 |
| Anions | | | | | | | | |
| $Cl^-$ | 32075 | 21000 | 12350 | 12500 | 8650 | 49900 | > 200 | 8.5 g |
| $SO_4^{2-}$ | 2642 | 1675 | 1673 | 2046 | 1862 | 1647 | > 200 | 1200 |
| $HCO_3^-$ | 46.6 | 92.5 | 110 | 29.9 | 119 | < 10 | > 600 | 1300 |
| $CO_3^-$ | < 0.01 | 0.01 | 0.05 | < 0.01 | 0.07 | < 0.01 | / | / |
| $Br^-$ | 81.8 | 52.5 | 46.2 | 46 | 47.5 | 270 | / | / |
| $F^-$ | / | / | / | 0.48 | / | / | > 1 | 1 |
| Others | | | | | | | | |
| $SiO_2$ | 6.1 | 8.2 | 8.3 | / | 7.2 | < 2 | / | / |
| Boron, B | 1.13 | 0.54 | 1.71 | / | 2.25 | 7.95 | / | / |
| $H_2S$ | < 0.05 | < 0.05 | < 0.05 | / | < 0.05 | < 0.05 | / | 1 |
| Overall mineralisation | 55221 | 35837 | 21667 | 22213 | 16750 | 82445 | / | / |
| Dry residue (180°C) | 55197 | 35791 | 21612 | 22198 | 16691 | 82445 | / | / |

/ – missing or not specified value.

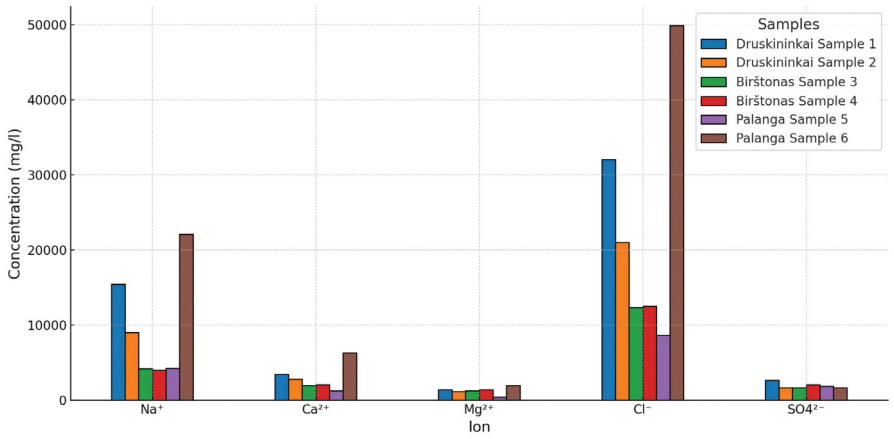


**Fig 2** Concentrations of ions in different samples

**Table 4** Classification of mineral water samples from Druskininkai, Birštonas, and Palanga based on their mineralization levels and chemical composition

| Location | Sample No | Mineral water type | TDS, g/l | Main chemical composition |
|---|---|---|---|---|
| Druskininkai | 1 | Very high mineralization /brine | > 35 | Chloride sodium water with high calcium, sulphate, magnesium, and ferrous content |
| | 2 | Very high mineralization /brine | > 35 | Chloride sodium water with high calcium, sulphate, and magnesium content |
| Birštonas | 3 | High mineralization | 15–35 | Chloride sodium water with calcium, sulphate, and magnesium content |
| | 4 | High mineralization | 15–35 | Chloride sodium water with calcium, sulphate, and magnesium content |
| Palanga | 5 | High mineralization | 15–35 | Chloride sodium water with high calcium, sulphate, and magnesium content |
| | 6 | Very high mineralization/brine | > 35 | Chloride sodium water with high calcium, sulphate, and magnesium content |

trast, the samples from Birštonas (samples 3 and 4) and Palanga's sample 5 are classified as highly mineralized waters (15-35 g/l), also contained significant amounts of calcium, magnesium, and sulfate. This classification (Table 4) was formed following the guidelines as referenced by Ziemska et al. (2019), Lithuanian hygiene norm HN 127:2010. The table summarizes the findings from the current study, comparing the mineralization and chemical composition of the water samples, which are essential for their balneological application.

The results are compared with the hygiene norms applied in Lithuania for water pools where balneotherapy procedures are performed (Table 5). The pH of mineral water ranged from 5.71 (6th centre) to 7.54 (5th centre). According to HN 127:2010, the mineral water is classified as low acidic from the 1st and 6th centres, neutral from the 2nd, and low alkaline from the 3rd, 4th, and 5th centres. The pH values met the pool requirements in the balneological therapy. Regarding the parameters set for the pools, the smell was acceptable and the permanganate number of mineral water did not exceed the normal limit (it was lower in the 6th centre, possibly because the water was more acidic). The water of the studied samples differed in colour (more colourful, natural), all samples had a higher ammonia concentration, and the 1st, 2nd, and 6th samples exhibited higher turbidity, while the 3rd, 4th, and 5th samples showed lower pH values.

The study highlighted that the amounts of heavy metals in the investigated mineral water (Table 5) only partially met the safety requirements of natural mineral water. Elements such as As, Cd, Ni, Pb, Sb, Se, and Hg were below the minimal measurable limit. Ba, Cr, and Cu fluctuated more between the centres, but none was above the threshold concentration value according to hygiene standards HN 28:2003 (V–758, 2003). According to this Lithuanian hygiene norm, the highest concentration of Mn was found in SPA centre No. 1 (2300 µg/l), which exceeds the maximum limit (500 µg/l) by four times. Elevated concentrations of Mn were also found in centres No. 2, 4, and 6, containing 740 µg/l, 600 µg/l, and 520 µg/l of Mn, respectively. In most cases, the lowest heavy metal content was in centre 3 (except for Cu) and centre 5 (except for Ba).

This study of mineral water facilitates a more accurate planning for the use of mineral water in SPA centres. The applicability of mineral water was reviewed based on its appropriate mineralization for the

**Table 5** Organoleptic, physical, and chemical pollution parameters in mineral water

| Parameters \ Centres/water samples | 1 | 2 | 3 | 4 | 5 | 6 | Parameters for pool water (HN, 2005; HN 2016) |
|---|---|---|---|---|---|---|---|
| Colour, mg/l Pt | 3 | 6 | 4 | 3 | 4 | 4 | 0.5 |
| Smell points (acceptable, no significant changes, +) | + | + | + | + | + | + | < 3 (moderate) on a 5-point scale |
| Hydrogen ion concentration, pH | 6.53 | 6.84 | 7.49 | 7.27 | 7.54 | 5.71 | Recommended pH: 7.2–7.8 with chlorine compounds, 7.2–8.0 with bromine compounds |
| Turbidity, NTU | 37 | 25 | 1 | 1 | < 1 | 12 | Less than 0.5 |
| Ammonia (by NH4+), mg/l | 2.58 | 1.8 | 2.19 | 1.22 | 5.41 | 25.2 | Not more than 0.5 |
| Permanganate index, mg/l $O_2$ | 4.09 | 3.39 | 4.02 | 2.98 | 1.65 | < 0.5 | 2.0–6.5 |
| Bromide, mg/l $Br^-$ | 81.8 | 52.5 | 46.2 | 46 | 47.5 | 270 | From 1.5 to 2.0 mg/l when mineral water is diluted with fresh water in mineral water or seawater pools |

treatment of rheumatic diseases, respiratory diseases, mental stress, and other conditions. The benefits expected from the tested mineral water are summarized in Table 6.

Certainly, the thermal mineral water of the western part of Lithuania (Fig. 1) with more than 150 g/l mineralization can be highly beneficial for human health and well-being. Unfortunately, these natural mineral water resources are underutilized in SPAs. The physical properties and chemical effects of thermal mineral water therapy may play an important role in the treatment of various diseases. Warm or hot mineral water can have numerous positive effects: muscle relaxation and pain relief, improved circulation, reduced stress and tension, and enhanced skin condition. Mineral water can positively affect the skin and improve its condition and appearance. Warm or hot mineral water can help reduce muscle tension, alleviate joint pain, and improve mobility, which is particularly important for people suffering from joint diseases or engaging in intense physical activity. Warm temperatures can help dilate blood vessels and improve blood circulation, potentially reducing blood pressure and enhancing overall circulation. Warm mineral water can also help reduce stress, alleviate mental tension, and improve overall mood due to its calming and relaxing effects. Overall, thermal stress has an immunosuppressive effect, and immersion in thermal mineral water therapy has numerous physiological effects, causing changes in the neuro-immuno-endocrine system (Fioravaniti *et al*. 2012).

The main criteria in the assessment of natural mineral water are not only the confirmation of their original chemical purity and quality but also their beneficial effects on human health. In many European countries, hydrotherapy, balneotherapy using mineral water is widely used, it is included in the national health systems; in other countries it is distinguished as a type of complementary medicine or does not belong to either traditional or complementary medicine, it is used only in the field of wellness. Thus, various SPA treatments using natural resources, such as mineral or geothermal water could help restore or improve human physical and mental health.

## CONCLUSIONS

Lithuanian mineral waters are characterized by high mineralization and unique chemical composition, making them suitable for extensive use in balneology. Their composition meets and exceeds many European and local health standards, making them valuable for both therapeutic and scientific applications.

Mineral waters and their use for human health have deep traditions in Lithuania, as a green country with rich natural resources. Mineral water used in Lithuanian medical SPAs is highly mineralized sodium chloride mineral water with significant calcium, magnesium, and sulphate. The tested mineral water is claimed to be effective against chronic diseases and could be used for the complementary treatment of nervous, rheumatic, skin, respiratory, cardiovascular, and metabolic disorders. In Lithuania, part of the natural mineral water has been scientifically proven as beneficial for the prevention and treatment of various conditions so it can be considered curative.

Research findings suggest that the thermal mineral waters (with mineralization > 150 g/l) found in SPA centres in the western part of Lithuania can provide significant health benefits, as indicated by their primary biological functions and applications in balneotherapy. However, their thermal properties are currently practically unused.

This study could increase the interest of scientists in a deeper study of these highly mineralized sodium chloride (salt) mineral waters with significant calcium, magnesium, and sulphate and other distinctive

**Table 6** The main biological functions of the chemical elements and mineral substances found in the studied waters and possible application. Compiled by the authors according to Lithuanian SPA Research Centre (2008), Gomes (2013), and Quattrini *et al*. (2016)

| Chemical elements and mineral substance | Main biological function in body (oral and/or external use) | Possible applications | Centres sorted by ascending amount of mineral substance |
|---|---|---|---|
| Chloride | – increases the secretion of stomach (hydrochloric acid formation) and pancreas,<br>– balance of intestine, bile ducts, and liver,<br>– reduces blood glucose level,<br>– laxative effect,<br>– increases skin circulation,<br>– reduces inflammation,<br>– maintains electrolyte balance,<br>– controls muscle contraction and nerve conduction | Inflammatory skin diseases<br>Rheumatic diseases<br>Nervous disorders<br>Digestive tract diseases (oral)<br>Respiratory diseases (COPD, saltwater inhalations) (Khaltaev *et al*. 2020) | 6, 1, 2, 4, 3, 5 |
| Sodium | – regulates cell permeability,<br>– regulates body fluids,<br>– stimulates and cleanses the lymphatic system and helps with arthritis | Nervous disorders<br>Inflammatory skin diseases<br>Intense physical activity<br>Respiratory diseases | 6, 1, 2, 5, 3, 4 |
| Calcium | – regulate bone, teeth development,<br>– regulates muscle contraction and myocardium activity, nerve impulses transmission,<br>– important for blood clotting,<br>– regulates cell permeability,<br>– necessary for epithelization, basal layer keratinocyte differentiation, regulates skin barrier homeostasis | Rheumatic diseases (Fioravanti *et al*. 2012; Gáti *et al*. 2018)<br>Nervous disorders<br>Inflammatory skin diseases<br>Atopic dermatitis (Huang *et al*. 2018)<br>Psoriasis<br>Cardiovascular disorders (hypertension)<br>Mental status improvement (Zámbó *et al*. 2008)<br>Wound healing<br>Beneficial for adolescents, pregnant women, subjects who do not consume dairy products, elderly | 6, 1, 2, 4, 3, 5 |
| Sulphur | – detoxifying agent,<br>– reduces purulent process,<br>– stabilizes metabolic reactions, glucose levels, and gastric secretion,<br>– reduces allergies,<br>– stimulates nervous reactions,<br>– keratoplastic activity (hair, nail, cartilage, ligaments, tendons),<br>– anti-inflammatory action,<br>– antipruritic activity,<br>– lightly laxative | Rheumatic diseases<br>Peripheral nerve injury<br>Inflammatory skin reactions<br>Allergic skin diseases<br>Skin diseases (psoriasis<br>Atopic, contact dermatitis, acne)<br>Wound healing (Davinelli *et al*. 2019)<br>Mental status improvement<br>Digestive tract diseases (oral)<br>Respiratory diseases (inhaled) (Khaltaev *et al*. 2020) | 1, 4, 5, 2, 3, 6 |
| Magnesium | – important for bone formation,<br>– regulates nervous and muscular activities,<br>– regulates lipid metabolism and protein synthesis,<br>– regulates the passage of chemical elements through membranes, replication,<br>– promote digestion,<br>– regulates skin restoration, barrier function,<br>– regulates nerve and muscle functioning,<br>– supports hormone levels,<br>– cardiovascular protection activities,<br>– pain management | Nervous disorders<br>Rheumatic disorders<br>Mental stress<br>Skin diseases (inflammatory, atopic, contact dermatitis, psoriasis<br>Digestive tract disorders | 6, 4, 1, 3, 2, 5 |
| Potassium | – regulates muscles and myocardium activities, lower blood pressure,<br>– acts on neuromuscular excitability,<br>– regulates acid-base balance,<br>– maintains fluid balance, eliminates body toxins,<br>– nourishes skin | Rheumatic diseases<br>Nervous diseases<br>Cardiovascular diseases<br>Inflammatory skin diseases<br>Atopic dermatitis<br>Psoriasis | 6, 5, 1, 3, 4, 2 |

| Chemical elements and mineral substance | Main biological function in body (oral and/or external use) | Possible applications | Centres sorted by ascending amount of mineral substance |
|---|---|---|---|
| Bromide | – decreases the sensitivity of the central nervous system,<br>– important for collagen development | Nervous diseases<br>Inflammatory skin diseases<br>Atopic dermatitis<br>Psoriasis<br>May improve the health of patients on dialysis or total parenteral nutrition | 6, 1, 2, 5, 3, 4 |
| Bicarbonate | – stimulates secretion of sputum,<br>– promote digestion,<br>– reduces cholesterol,<br>– alkalizes urine and blood,<br>– improving peripheral circulation, lowering blood pressure,<br>– better glycaemic control (consumed) (Murakami *et al*. 2015),<br>– improved mental stress, sleep quality, and immune function (Ushikoshi-Nakayama *et al.* 2024),<br>– pain management (Gáti *et al*. 2018), (Fioravanti *et al*. 2012) (bathed) | Digestive tract disorders<br>Metabolic disorders (gout, uremia, diebetes)<br>Urinar disorders<br>Nervous diseases<br>Mental stress<br>Sleep quality<br>Cardiovascular diseases<br>Skin problems | 5, 3, 2, 1, 4, 6 |
| Silica | – increase in bone density,<br>– help make collagen for skin integrity, cartilage, tendons,<br>– supports immune response, control inflammation,<br>– orthosilicic acid is found in numerous tissues including bone, tendons, aorta, liver and kidney (Martin 2007) | Skin lesions (chronic wounds, ulcers, and abscesses)<br>Atopic, contact dermatitis<br>Psoriasis<br>Rheumatic disorders<br>Immunity problem | 3, 2, 5, 1, 6 |
| Boron | Might be beneficial for<br>– reproduction and development,<br>– calcium metabolism, bone formation,<br>– brain function,<br>– insulin and energy substrate metabolism,<br>– immunity, and the function of steroid hormones (vitamin D, estrogen) (ODS 2022) | Rheumatic diseases<br>Nervous diseases<br>Metabolic disorders | 6, 5, 3, 1, 2 |
| Ferrum | – essential for blood production,<br>– supports healthy skin, nail, hair (procollagen-proline oxidase),<br>– increases resistance to stress and diseases,<br>– helps convert blood sugar to energy,<br>– important for the immune system,<br>– aids cognitive function,<br>– pain management, specifically gynecological pain, improvement of mental status | Ferodeficitic anemia<br>Skin, hair, nail disorders<br>Immunodeficiency<br>Mental stress | 1, 6, 2, 4, 3, 5 |
| Manganese | – important for the synthesis of several enzymes involved in the metabolism of proteins, fats and sugars,<br>– important for bone development,<br>– may give protection against oxygen-free radicals,<br>– nourishes the nerve cells | Metabolic diseases<br>Rheumatic diseases<br>Nervous diseases<br>Atopic dermatitis<br>Contact dermatitis<br>Psoriasis | 1, 2, 4, 6, 3, 5 |

qualities of Lithuanian mineral water for the treatment of specific diseases and their inclusion in the list of medicinal mineral water resources in Lithuania. The natural resources of mineral water with varied physical–chemical characteristics can offer new opportunities for their hydrological and therapeutic exploitation. They are also consistent with the existing trajectory of WHO priorities in investments for environment and health cohesion, which can lead to a significant reduction in the burden of diseases and enable better health and well-being for all (WHO 2009). It is necessary to continue scientific research in the field of balneology with the analysis of the composition of natural resources and their impact on human health.

As the utilization of mineral water represents a beneficial form of natural therapy, gaining a deeper understanding of their composition, uniqueness, and potential health effects leads to a more effective mineral water use in the development of medical SPA services.

By comparing these results to the established standards, we can affirm that Lithuanian mineral waters meet and often exceed the criteria for medicinal waters, making them valuable for both therapeutic use and further scientific study.

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