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Terminologies and characteristics of natural mineral and thermal waters in selected European countries

Izrazoslovje in značilnosti naravnih mineralnih in termalnih voda v izbranih evropskih državah

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Abstract

This study discusses 1) the national legislative frameworks, terminologies, and criteria for the recognition of natural mineral waters and thermal waters in selected European countries (Austria, Bosnia and Herzegovina, Denmark, France, Hungary, Iceland, Italy, Lithuania, Poland, Portugal, Romania, Serbia, Slovenia, and Spain), and 2) it provides a first extensive multi-national overview of hydrogeological and hydrogeochemical characteristics of numerous water sources from those regions.

Natural mineral waters are well defined and regulated in the European Union by the Directives 2009/54/EC and 2003/40/EC that are implemented by national law regulations. In contrast, no legal definition exists for thermal waters on an EU level and national definitions commonly differ or are not present. Defining thermal waters by water temperatures of at least 20 °C at the outlet is commonly found (6 out of 15 countries), but other definitions like considering the difference to the average air temperature are also present. Furthermore, no definitions on a national level are quite frequent (5 out of 15 countries), those countries preferentially refer to expert recognitions.

We considered 678 natural mineral waters and 2,390 thermal waters in this study and collected information on practical use, hydrogeological settings and hydrogeochemical conditions. The comparison of the datasets shows commonalities like a predominance porous aquifers, especially sandy aquifers, and sedimentary carbonate rock aquifers (limestone, dolomite, chalk). Furthermore, natural mineral waters commonly show TDS contents of less than 1 g/l and alkaline-earth-HCO_3 water types. Surprisingly, 21 % of the considered sources bear water temperatures above 20 °C and could be considered as thermal waters as well. Thermal waters – the majority (above 30 °C) is found in Hungary - usually show water temperatures between 20 and 70 °C and TDS contents between 1 and 14.5 g/l. The hydrogeochemical properties show a larger variation in contrast to natural mineral waters, but Na-(HCO_3, Cl) waters seem to be most commonly found.

Izvleček

Študija razpravlja o: 1) nacionalnih zakonodajnih okvirjih, izrazoslovju in kriterijih za priznavanje naravnih mineralnih in termalnih voda v izbranih evropskih državah (Avstrija, Bosna in Hercegovina, Danska, Francija, Madžarska, Islandija, Italija, Litva, Poljska, Portugalska, Romunija, Srbija, Slovenia in Španija), ter 2) predstavlja prvi pregledni več-nacionalni pregled hidrogeoloških in hidrogeokemijskih značilnostih številnih vodnih virov v teh regijah.

Naravne mineralne vode v Evropski uniji so definirane in regulirane z Direktivama 2009/54/EC in 2003/40/EC, implementiranima z nacionalno zakonodajo. Nasprotno, na nivoju EU ne obstaja zakonodajna definicija za termalne vode, nacionalne definicije so različne ali pa celo ne obstajajo. Kot termalna voda so običajno opredeljene vode s temperaturo iztoka vsaj 20 °C (v 6 od 15 držav), vendar obstajajo tudi definicije, ki upoštevajo odstopanje od povprečne letne temperature zraka. Nadalje, ponekod nacionalnih definicij nimajo (5 od 15 držav), tam jih običajno priznavajo na podlagi strokovnih mnenj.

V raziskavo smo vključili 678 naravnih mineralnih voda ter 2.390 termalnih voda in zbrali podatke o rabi, hidrogeoloških osnovah in hidrogeokemijskih pogojih. Primerjava podatkov je pokazala, da prevladujejo medzrnski, še posebej peščeni vodonosniki, in vodonosniki v sedimentnih karbonatnih kamninah (apnenec, dolomit, kreda). Nadalje, naravna mineralna voda ima najpogosteje manj kot 1 g/l skupnih raztopljenih snovi ter je zemeljskoalkalijsko- HCO_3 tipa. Presenetljivo lahko kar 21 % naravnih mineralnih voda uvrstimo tudi med termalne vode, saj imajo temperaturo nad 20 °C. Termalne vode imajo temperaturo običajno med 20 in 70 °C in TDS med 1 in 14,5 g/l, večino (z nad 30 °C) pa najdemo na Madžarskem. Hidrogeokemične lastnosti termalnih voda so bolj spremenljive kot pri naravnih mineralnih vodah, najpogosteje pa so vode Na-(HCO_3, Cl) tipa.

Introduction

Thermal and mineral waters are special types of groundwater. They are well known for thousands of years and have an important role in society, well-being and health (e.g. EuroGeoSurveys, 2016, Stober & Bucher, 2012; Lund, 2001). From prehistoric use of natural thermal waters to Roman public baths – the evolution of societies is always accompanied by these waters. Today, as these waters are widely used in our society for societal and economic purposes, regulations have been drawn up at the national and international levels.

Today, natural mineral waters have an important role in the bottled water industry among EU's member states. According to the non-profit trade association, "Natural Mineral Waters Europe", 97 % of all bottled water sold in Europe comes from a natural mineral water or spring water source (Natural Mineral Waters Europe, 2021). The EU average consumption was approximately 118 liters per capita in 2019; and Italy, Germany, Portugal, Hungary and Spain were biggest consumers.

Thermal waters or geothermal waters – the water temperature is elevated due to geothermal heat and they are a source of clean energy as well as a valuable product with therapeutic, balneotherapeutic and recreational properties (Sowizdzal, 2018). For centuries, they are used for balneological purposes and wellness. There are numerous examples for famous spas in Europe, like Gellert, Széchenyi and Rudas in Hungary, Baden-Baden in Germany, Karlovy Vari in Czech Republic or Grindavik in Iceland, while natural mineral water sites e.g. Rogaška Slatina in Slovenia were used for drinking treatments for centuries. Furthermore, the geothermal energy sector has continuously grown over the last decades and geothermal water is directly used for heating and electric power generation. For example, already 1,028 megawatt (MWe) comes from 57 geothermal power plants across Europe (EGEC, 2019) and the Pannonian basin is one of most prominent and historic geothermal places (Rman et al., 2020).

Several studies about the hydrogeology and hydrochemistry of mineral and thermal waters have been published on a national level in recent years, e.g. Haas et al., 2018; Elster et al. 2016, 2018; Eftimi & Frasheri, 2016; Miošić & Samardžić, 2016; Rosca et al., 2016; Todorović et al., 2016; Burić et al., 2016; Benderev et al., 2016; Borović et al., 2016; Eggenkamp & Marques, 2013; Dinelli et al., 2012; Brenčič et al. 2010; Lourenço et al. 2010; Käss & Käss, 2008; Lapanje, 2006; Zötl & Goldbrunner, 1993; Minissale, 1991. However, less studies describe and compare sources from multiple countries and regions in Europe (Porowski, 2019; Bräuer, et al. 2016; Papić, 2016, Balderer et al., 2014; Borszéki, 2013; Szocs et al. 2013; Gros, 2003; LaMoreaux & Tanner, 2001; Albu et al., 1997; Michel, 1997; Carlé, 1975). Furthermore, the comprehensive study on European Bottled Waters by Reimann & Birke (2010) focuses on Natural Mineral Waters to some extent, as well as books by Evina (1992) and Kirschner (2009).

Certainly, extensive literature is available to deepen the understanding of this topic. However, used terminologies vary between countries and can lead to misinterpretations. Divergent or missing national legislative frameworks are commonly the reason besides legal adaptions in time. The generally used glossary comprises a large number of technical terms including mineral water, healing/curative water, natural mineral water and spring water in the bottling industry, and thermal water that have to be clearly distinguished.

This study aims to assess first the national legislative frameworks, terminologies, and criteria for the recognition of natural mineral waters and thermal waters in the following European and neighbouring countries: Austria, Bosnia and Herzegovina, Denmark, France, Hungary, Iceland, Italy, Lithuania, Poland, Portugal, Romania, Serbia, Slovenia, and Spain. All were involved in Hydrogeological processes and Geological settings over Europe controlling dissolved geogenic and anthropogenic elements in groundwater of relevance to human health and the status of dependent ecosystems GeoERA (HOVER) project. Second, it provides a first extensive multi-national overview of hydrogeological and hydrochemical characteristics of numerous water sources from those regions.

Methodology

An overview of the legal recognition of thermal and natural mineral waters was provided within the project GeoERA HOVER by the national geological surveys based on the analysis of each relevant national legislation (see supplement information).

Furthermore, a database with a harmonized structure was set up to collect the hydrogeological and hydrochemical information at a multi-national scale (Table 1 and supplement information). A focus was given to available vocabulary standards of Inspiring New Scientific Perspective in Research and Ethics (INSPIRE) and Geoscience Markup Language (GEOSCIML) to increase the level of transparency. The data collection comprises hydrogeological and hydrochemical information (names of sources, locations, type of sources, use, borehole depths, aquifer media and type, aquifer lithology and age, hydrochemistry and groundwater age) (see Table 1 for details). Only representative single hydrochemical analysis were collected instead of data series assuming stable hydrochemical conditions with negligible variations for both types of special groundwaters (thermal and natural mineral waters). Stable conditions are a prerequisite requirement of a natural mineral water definition, and in most cases observed at thermal waters also. However, the selection of the representative analysis is based on expert evaluation. Post processing of the dataset comprised a general data curation, critical checks for outliers and anomalies, ion balance calculations of representative analysis (charge balance error (%) = $100 \times \frac{(\sum \text{cations} - \sum \text{anions})}{(\sum \text{cations} + \sum \text{anions})}$; see Freeze and Cherry, 1979) and water type calculations (cations and anions > 20 eq%). Analyses

Table 1. Collected hydrogeological and hydrochemical information in the dataset.

General information
• name of source and country • classification: thermal water, natural mineral water (Directive 2009/54/EC), natural mineral water (national law recognition) • type of water source: single well, well field, single artesian well, artesian well field, single captured spring, captured spring group, single gallery, gallery group, single spring, combination of sources • use: bottled natural mineral water, natural mineral water publicly available, thermal water for balneology, thermal water for heating, thermal water for electricity production, other; multiple answers (up to 3) were possible. • yield classes in l/s: <5, 5-25, >25 • borehole depth and screen depths in m (true vertical depths) • Aquifer media type according to INSPIRE: http://inspire.ec.europa.eu/codelist/AquiferMediaTypeValue • Aquifer type according to INSPIRE: http://inspire.ec.europa.eu/codelist/AquiferTypeValue • Lithology of the aquifer according to INSPIRE: http://inspire.ec.europa.eu/codelist/LithologyValue • Proportion of the lithology according to GEOSCIML: http://resource.geosciml.org/classifier/cgi/proportionterm • Aquifer age according to INSPIRE: http://inspire.ec.europa.eu/codelist/GeochronologicEraValue/
Location
• the location is derived from 1 km and 10 km grids, https://www.eea.europa.eu/data-and-maps/data/eea-reference--grids-2 and no exact coordinates are provided
Information of a representative hydrochemical analysis
• water temperature classes at the outlet of the source in °C: <15, 15-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90, 90-100, >100. We chose those classes to provide detailed information on water temperature distributions. They may not connect to national legislative frameworks. • total dissolved solids (g/l): <1, 1-14.5, >14.5 • field parameters specific conductivity (µS/cm; 25°C), pH, redox potential (Eh), O_2 (mg/l) • hydrochemical compounds in mg/l: Na, K, Ca, Mg, Sr, Ba, Fe, Mn, NH4, HCO_3, CO_3, F, Cl, Br, I, SO_4, NO_3, HS, Al, Sb, As, Be, Pb, Cd, Cs, Cr, Co, Cu, Li, Mo, Ni, Hg, Rb, Se, U, V, Zn, Sn, H_2SiO_3, H_3BO_3, • gas phase dominance: Methane (CH4), Carbon dioxide (CO_2), Nitrogen (N_2), Hydrogen sulphide (H_2S) • Apparent residence time: younger than 60, 60-10,000 years, older than 10,000 years. Those threshold values for groundwater ages were estimated by available isotope data or estimated expert judgements, however no raw data on relevant isotopes for groundwater age dating was collected. The categories were chosen by common criteria connected to isotope interpretation: e.g. presence of ^{3}H, ^{14}C.

with a charge balance error above 10 % were not considered in the further data evaluation. Shares of hydrochemical analyses below detection limit (DL) were treated by DL/2 to consider them in basic statistical figures (e.g. boxplots).

Results

EU and national legislations

Natural mineral waters

The exploitation and marketing of natural mineral waters in the European Union is regulated in Directive 2009/54/EC (see Annex 1- legal norms) and it can be clearly distinguished from ordinary drinking water by the following criteria:

1. by its nature, which is characterised by its mineral content, trace elements or other constituents and, where appropriate, by certain effects;
2. by its original purity and constant level of minerals.

This Directive shall not apply to:

3. waters which are medicinal products within the meaning of Directive 2001/83/EC on the Community code relating to medicinal products for human use;
4. natural mineral waters used at source for curative purposes in thermal or hydromineral establishments.

An underground origin and protection from all risks of pollution are required to meet those criteria. The hydrochemical composition, temperature and other essential characteristics of natural mineral waters shall remain stable in time (±20 %) and should only show natural fluctuation. Furthermore, the extraction rate should also not affect the composition.

Expert practice prior to Directive 2009/54/EC (see also Directive 80/777/EEC, no longer in force and adopted before from some states cooperating in the project become EU Members) was that the requirement for the legal recognition was different especially for some of the States not yet EU Members at that time and dependent on the level of total dissolved solids (TDS) or the content of carbonic acid. Traditionally, mineral water source needed to show pharmacological, physiological and clinical properties or TDS of at least 1,000 mg/l at the source and after bottling or a minimum of 250 mg/l of free carbon dioxide.

Directive 2003/40/EC established a list of recognized sources that is regularly updated and sets concentration limits for public health purposes, labelling requirements and limited possibilities for water treatment (5 types of treatments are permitted). Natural mineral waters and spring waters may be treated at source to remove unstable elements and some undesirable constituents in compliance with the provisions laid down in Article 4 of Directive 2009/54/EC. Table 2 and 3 provide an overview of natural constituents, indications, and criteria for water quality. Finally, it should be mentioned that the hydrochemical composition needs to be present on the label of a bottled water as well.

Table 3. Criteria for natural mineral water indications according to Annex III of Article 9 in Directive 2009/54/EC.

Indications	Criteria
Low mineral content	Mineral salt content, calculated as a fixed residue, not greater than 500 mg/l
Very low mineral content	Mineral salt content, calculated as a fixed residue, not greater than 50 mg/l
Rich in mineral salts	Mineral salt content, calculated as a fixed residue, greater than 1,500 mg/l
Contains bicarbonate	Bicarbonate content greater than 600 mg/l
Contains sulphate	Sulphate content greater than 200 mg/l
Contains chloride	Chloride content greater than 200 mg/l
Contains calcium	Calcium content greater than 150 mg/l
Contains magnesium	Magnesium content greater than 50 mg/l
Contains fluoride	Fluoride content greater than 1 mg/l
Contains iron	Bivalent iron content greater than 1 mg/l
Acidic	Free carbon dioxide content greater than 250 mg/l
Contains sodium	Sodium content greater than 200 mg/l
Suitable for the preparation of infant food	—
Suitable for a low-sodium diet	Sodium content less than 20 mg/l
May be laxative	—
May be diuretic	—

Table 2. Constituents naturally present in natural mineral waters and maximum limits which, if exceeded, may pose a risk to public health according to Annex I in Directive 2003/40/EC.

Constituents	Maximum limit in mg/l
Antimony	0.005
Arsenic	0.01 (as total)
Barium	1
Boron	not fixed
Cadmium	0.003
Chromium	0.050
Copper	1.0
Cyanide	0.07
Fluorides	5.0
Lead	0.010
Manganese	0.50
Mercury	0.001
Nickel	0.02
Nitrates	50
Selenium	0.01

In 2021, 2.098 trade descriptions of natural mineral waters are recognised by member states including Northern Ireland (UK) and countries in the European Economic Area (EEA countries). Natural mineral waters are subject to an authorization procedure carried out by the competent authorities of the EU countries. The lists of natural mineral waters officially recognised are published by the European Commission in the Official Journal of the European Union. These lists are regularly updated. It has to be added that trade name can be associated with multiple sources (e.g. boreholes or springs). Germany leads the ranking with 827 accepted trade descriptions, followed by Italy (305), Hungary (173), Spain (160) and France (101). Another interesting note is that member states can recognize natural mineral water sources in third countries, for example Germany has accepted places of exploitation in Armenia, Bosnia and Herzegovina, Canada, China, Croatia, India, Iran, Kosovo, Macedonia, New Zealand, Russia, Serbia, Switzerland and Turkey. Therefore, sources of registered natural mineral waters in Europe can be imported from outside of Europe.

To avoid misunderstandings of used terms, natural mineral waters regulated by Directive 2009/54/EC have to be clearly separated from the following groundwater types:

- Bottled spring waters. They are intended for human consumption, usually from a single non-polluted groundwater source, are bottled at source and comply with the present drinking water regulations (Directive 2020/2184). However, the original purity may vary, what means that hydrochemical compositions do not need to remain stable as requested for mineral water (±20 % of variation not relevant) over a lengthy period of time. Certain provisions of the previously mentioned Directive 2009/54/EC are also applicable to

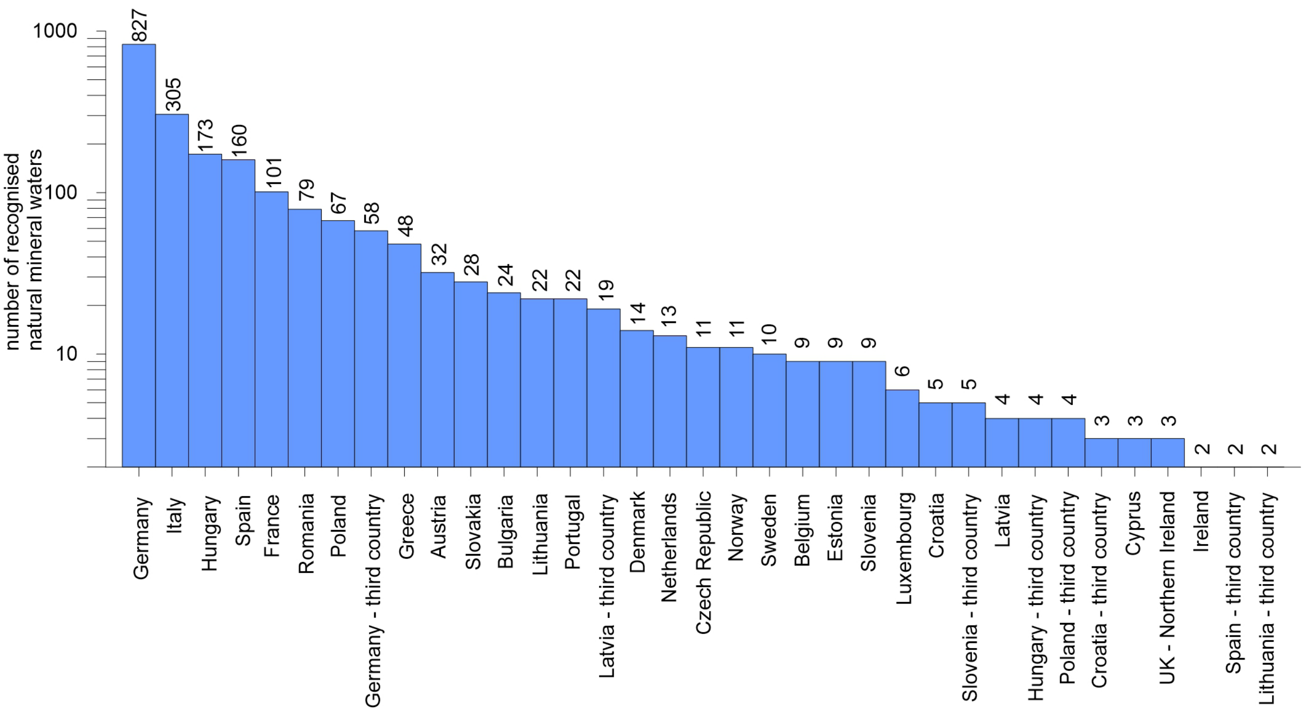

Fig. 1. List of natural mineral waters recognised by member states, United Kingdom (Northern Ireland) and EEA countries according to Directive 2003/40/EC, update from April 9th 2021 (see legal norms).

spring waters such as the microbiological parameters and labelling requirements.
- Bottled drinking water: A bottled drinking water not necessarily has to have an underground source, therefore bottling at a spring or borehole is not a requirement (Directive 98/83/EC) and additional water treatment are allowed to modify water quality. Its quality has to comply with the drinking water regulations.
- Healing/curative/therapeutic and geothermal or thermomineral water: There is no Directive applicable, but national legislative frameworks may consider from nation-to-nation divergent definitions for those types of groundwaters that are commonly based on specific criteria (e.g. TDS content, hydrochemical compounds and temperature, pharmacological, physiological and clinical properties).

The following national legal norms regulate natural mineral waters in selected countries of the dataset (see also Annex 1: Legal norms; no information was delivered for Iceland and Lithuania):

Austria	In Austria, natural mineral waters are defined in the mineral water and spring water regulation: Mineral- and spring water regulation, BGBl. II, Nr. 309/1999 However, the following laws and regulations have to be considered as well: 1) water rights act: WRG 1959, BGBl. Nr. 215/1959 idgF. 2) drinking water ordinance: TWV, BGBl. II Nr. 304/2001 idgF. 3) Health- and nutrition security law: GESG, BGBl. I Nr. 63/2002 idgF. 4) food security and consumer protection law: LMSVG, BGBl. I Nr. 13/2006 idgF. 5) Food labelling regulation: LMKV, BGBl. Nr. 72/1993 idgF. Relevant threshold values are found in the previously mentioned mineral water and spring water regulation and the Austrian food code: Chapter B 17 „Bottled waters“ (BMGF-75210/0005-II/B/13/2016).
Bosnia and Herzegovina	Natural mineral waters are defined in the Waters Act - Rulebook on natural mineral water, spring water and table water (Official Gazzette of the Bosnia and Herzegovina No. 26/10, 40/10).
Denmark	The groundwater source has to be approved by the Danish Veterinary and Food Administration under the Ministry of Environment and Food of Denmark and the following national legislation is relevant: 1) BEK nr 38 of 12/01/2016 Bekendtgørelse om naturligt mineralvand, kildevand og emballeret drikkevand; 2) VEJ nr 9105 of 10/04/2008 Vejledning om mærkning af naturligt mineralvand, kildevand og emballeret drikkevand.
France	It is defined by transposition of the EU Directive 2009/54/EC into the Public Health Code (articles L1322-1 to 13 et R.1322-1 to 1322-44-23) and in the following regulations: Decree No 2007-49 of 11 January 2007 on the safety of water intended for human consumption. Supplemented by five orders relating to the constitution of the authorisation application files for public interest declaration, assignment of a protection perimeter, water quality criteria, analyses of sanitary control and water monitoring, etc. Before the application of the EU Directive, french mineral waters were also recognised for their therapeutic properties by the French Academy of Medecine. By regulation, mineral water can be used packaged (bottled), distributed in a public water supply (buvette publique) or used for therapeutic uses in a spa establishment, each usage is cover by a strict legislation to ensure water quality and public health (maximum limits, water treatment).
Hungary	Mineral water according to Hungarian law LVII from 1995 on water management is defined as water which originates from a natural aquifer, which has a typically different mineral composition compared to those used as a source for regular human drinking water, and its water composition meets the (biological and chemical) criteria defined in the relevant legislation. The 65/2004 (IV. 27.) FVM-ESzCsM-GKM common ministerial decree (with its update according to the 59/2006 (VIII. 14.) FVM-EüM-SZMM common ministerial decree) defines the requirements of bottled natural mineral water, spring water, drinking water, and enriched, flavoured, or enriched and flavoured bottled water. This decree is the law adopting and implementing the 80/777/EEC, 96/70/EC and 2003/40/EC EU laws. This decree does not regulate those non-bottled natural mineral waters which are used at their abstraction location or are used for medicinal purposes in balneological, health recuperation institutes. Those waters which are recognised as medicinal waters, including recognised medicinal mineral waters, are regulated by the 74/1999 (XII. 25.) EüM ministerial decree on natural medical factors.
Italy	In Italy, natural mineral water is defined in the Italian Legislative Decree N.176 of 8 October 2011, which adopts the EU Directive 2009/54/EC. Article 2.1 defines it as water which originated from a groundwater body, crops out at one or more natural of artificial springs and has peculiar purity conditions and health relevant properties.
Poland	In Poland, natural mineral water is defined as groundwater which differs from water used for human consumption in its original chemical and microbiological purity, its characteristic stable mineral composition and, in certain cases, its properties can have beneficial effects on human health. The above definition of water comes from Act of 25 August 2006 on Food and Nutrition Safety (Jour. of Law 2006 No 171 item 1563). The requirements concerning the composition and physical properties of natural mineral water are set out in the Regulation of 31 March 2011 on natural mineral water, spring water and table water (Jour. of Law 2011 No 85 item 466).
Portugal	In Portugal, natural mineral water is defined in Law no° 54/2015 of 22 June (Geological Resources Law) and the following specific regulations: Decree-Law no. 86/90 of 16 March (natural mineral waters) and Decree-Law no. 84/90 of 16 March (spring water).
Romania	In Romania, natural mineral water is a pure microbiological water, originating in an underground aquifer, protected from any possible risk of pollution according to Annex no. 1 from Government Decision 1020/2005. It is exploited by one or more natural sources and it is characterized by a stable composition, temperature and other characteristics within the limits of natural fluctuation and in terms of source flow variations.

Serbia	In Serbia, natural mineral water is defined in the “Regulation on Quality and Other Requirements for Natural mineral water, Spring Water and Bottled Drinking Water” (Official Gazette of Serbia and Montenegro, number 53/05). Furthermore, the “Regulation on the Hygienic Acceptability of Potable Water (Official Gazette of FRY, number 42/98 and 44/99) have to be considered.
Slovenia	In Slovenia, natural mineral water is defined in the Rules on natural mineral water, spring water and table water (Official Gazette of Rep. of Slovenia No. 50/04, 75/05 in 45/08 – ZKme-1). Article 4 defines it as water which beside microbiological requirements from the 5th article also: has a source in a subsurface water source (is groundwater), protected from any possibility of contamination, and springs or is pumped at a spring from one or more natural outflows or wells; has properties which clearly distinguish it from drinking water and may be connected to content of dissolved solids, trace elements or other ingredients, and may have certain nutritional and physiological effects; has the same purity as at the source. The deviation from the mean annual measured values for the main constituents specific to the individual natural mineral water may not exceed ± 20%.
Spain	Natural mineral waters are regulated by the following legislation: 1) Law of Mines 22/1973, 21 of July (BOE number 189, de 24-07-1973); 2) Royal Law 2857/1978, 25 of August (BOE number 295, de 11-12-1978). Furthermore, natural mineral waters are also regulated by the Royal Law 1798/2010 regarding the exploitation and commercialization of bottled drinking natural mineral waters and spring waters. From the interpretation of this legislation, it can be understood that depending on the use or destination, mineral-medicinal waters could be classified into: 1) Natural mineral waters: Those are microbiologically-free and with a constant chemical composition over time regardless of the water flow. They have a specific mineral and trace elements composition and are characterized for its original purity and 2) Spring waters: Those are microbiologically-free but no constant chemical composition over time is required.

Thermal waters

In opposition to natural mineral waters, no European directives exist to define thermal waters. Most definitions for thermal water are based on water temperatures at the outlet. However, thermal waters are not recognized or defined by an EU legislative framework. National laws or directives may set the criteria.

Results from this study show, that the majority of countries define a thermal water by a minimum temperature of 20°C at the outlet of the source (Table 4). However, several member states don’t have any criteria on temperature, but apply expert / professional recognitions according to different water properties.

Detailed Information about the national legislation frameworks in considered countries is found in Annex 1- Legal norms. No legislation framework for the definition of thermal waters is present in Lithuania, Portugal and Iceland. In Denmark, no thermal waters are present as all groundwaters show temperatures at the outlet below 15 °C.

Austria	In Austria, sources of thermal waters are not defined by a federal law, but by Acts on natural health-promoting substances and spas for each state in Austria except Vorarlberg. However, they share the definition that groundwaters with a temperature of 20°C or higher at the outlet are considered as thermal water.
Bosnia and Herzegovina	In Bosnia and Herzegovina thermal waters are defined in the Waters Act - Rolebook on the categorization, classification, the budget reserve of ground water and management of records about them (Official Gazette of the Bosnia and Herzegvoina No. 47/11). Thermal waters are defined by a total mineralization <1 g/l and a water temperature greater than the mean annual air temperature of the area were the source is located. Thermal waters with a total mineralization > 1g/l are considered as thermomineral waters. Several additional regulatory frameworks and laws are relevant for the definition of thermal waters.
France	In France, national regulations of thermal waters are based on the Public Health Code and the Decree 2007-49 11 January 2007 on the health safety of water intended for human consumption. There is no definition according to temperature at the outlet. A thermal water is defined as a natural mineral water used in a thermal establishment for its therapeutic properties (article R. 1322-52). Exploitation of thermal mineral water is covered by a legal authorisation and strict water quality controls overseen by the health authorities and covered by the Public Health Code. Thermal water is used on site or by direct adduction, for the internal or external treatment of the curists diseases, water from one or more regularly authorized mineral sources and/or sludges and/or gases. The therapeutic properties are recognized by the medicinal authorities (Académie de Médecine).
Hungary	In Hungary, thermal water according to the Hungarian law LVII from 1995 on water management is defined as (having its source from an aquifer) groundwater with an outflow temperature (at the surface) of 30°C or above. Its use is regulated as already mentioned under natural mineral waters, those waters which are recognised as medicinal waters, including recognised medicinal mineral waters, are regulated by the 74/1999 (XII. 25.) EüM ministerial decree on natural medical factors. Thermal water resource management, the management of used thermal water is regulated by the 147/2010. (IV. 29.) Government Decree under the general rules on the use, protection and damage control of waters, and water utilities. The Hungarian law XLVIII from 1993 on mining regulates when a geothermal energy usage requires concession rights, and defines the criteria for mining royalties related to geothermal energy usage.
Italy	In Italy, thermal water is mentioned in the Italian Governmental Law N.323 of 24 October 2000 but this act deals only with the exploitation permits and not with technical-scientific issues and, consequently, there is not a definition according to temperature at the outlet.
Poland	In Poland, thermal water is defined as groundwater with a temperature at the outflow not lower than 20°C. The above definition of thermal water comes from Act of 9 June 2011 Geological and Mining Law (Jour. of Law 2018 item 1563)
Romania	In Romania, thermal water is defined in the Governmental Decision no. 1154/2004.

Serbia	In Serbia, thermal water is groundwater which temperature is higher than the average annual temperature of a given place. To be considered as a thermal groundwater, it should meet certain requirements: to have a stable regime and to be heated from the temperature of the Earth's crust, not from the Sun's heat, which means that its temperature should be a consequence of geothermal processes in the Earth's crust. Nevertheless, in practice groundwater with an outlet water temperature > 20°C are commonly considered as thermal water. There are no precise terms from national laws or rulebooks.
Slovenia	In Slovenia, thermal water is defined in the Waters Act (Official Gazette of Rep. of Slovenia No. 67/02, 2/04 – ZZdrI-A, 41/04 – ZVO-1, 57/08, 57/12, 100/13, 40/14, 56/15). Row 6. of the article 7 defines it as a groundwater from a well, spring or a capture which is heated in geothermal processes in Earth's crust and has the temperature at the spring or wellhead at least of 20 °C.
Spain	In Spain, thermal waters are regulated by the following legislation: 1) Law of Mines 22/1973, 21 of July (BOE number 189, de 24-07-1973); 2) Royal Law 2857/1978, 25 of August (BOE number 295, de 11-12-1978). Furthermore, according to the Article 23.1 and 23.2 of the 22/173 Law of Mines and the Article 38.1 of the 2857/1978 Royal Law, thermal waters are defined as a Mineral Resource and are classified as a special type of "mineral water". In detail, mineral water is considered as thermal water when the outlet water temperature is 4°C greater than the mean annual air temperature in the same location where the water source is located.

Table 4. Minimum water temperatures at the outlet (°C) to define thermal waters in selected countries.

Minimum water temperatures at the outlet (°C) to define thermal water	**number of countries**	**names**
Average water temperature has to differ 4 °C in relation to average air temperature	1	Spain
water temperature greater than the mean annual air temperature of the area where the source is located	1	Bosnia and Herzegovina
20	6	Austria, Czech Republic, Italy, Poland, Romania, Slovenia
30	2	Hungary, Lithuania
no definition	5	France, Iceland, Latvia, Portugal, Serbia

Constitution of the dataset

The dataset comprises hydrogeological and hydrochemical information from 3,068 sources (e.g. springs or wells) from selected countries: Austria, Bosnia and Herzegovina, Denmark, France, Hungary, Iceland, Italy, Lithuania, Poland, Portugal, Romania, Serbia, Slovenia and Spain including Catalonia (see Table 5 and Fig. 3).

Limited data availability and missing rights of data uses are the restricting reasons for a complete dataset in some countries and regions leading to the consideration of 2,390 thermal

Table 5. Overview of considered sources in the dataset. Natural mineral waters trade descriptions recognised by member states derived from 2013/C95/03 (updated May 25th 2021).

	classification of considered sources in the dataset & data availability in the provided dataset				Natural mineral waters trade descriptions recognised by member states (2013/C95/03)
Sources in countries	Natural mineral water (Directive 2009/54/EC)	Thermal water	Natural mineral water (Directive 2009/54/EC)	Thermal water	
Austria	40	62	All	Yes	32
Bosnia and Herzegovina	0	28		Yes	None
Denmark	17	0	All	No thermal waters in Denmark	14
France	33	240	partially	Yes	101
Hungary	224	1,432	all	partially	173
Iceland	0	3	none	Yes	1
Italy	0	241	none	Yes	305
Lithuania	21	0	all		22
Poland	126	46	all	Yes	89
Portugal	17	121	partially	Yes	22
Romania	0	14	none	Yes	79
Serbia	30	82	all?	Yes	none
Slovenia	9	33	all	Yes	9
Spain	161	88	all	Yes	160
Total	**678**	**2,390**			

water sources and 678 natural mineral waters in this dataset. In a few cases – like in Hungary or France – natural mineral water sources can be also thermal waters if recognised according to Directive 2009/54/EC. Those waters are counted as natural mineral water source in the dataset.

Most important, no information on natural mineral waters is available for Italy and Romania and partial information is only available for France and Portugal. Also, no hydrochemical information, but TDS is reported for Hungarian thermal water sources. As it concerns Italy, this information is not reported here since it is not managed by the Geological Survey of Italy.

Hydrogeological characteristics of natural mineral waters

The natural mineral waters considered in the dataset are mostly used for bottling (*n=565* out of *678*), other uses like a public easements (free public access to a natural mineral water source; *n=21*) are rarely found (Fig. 2). The yield of the sources is usually below 5 l/s (*n=320*) or 5 to 25 l/s (*n=219*). Extraction rates above 25 l/s are rarely found (*n=16*), but present in Spain, Austria, Serbia and France.

Sources of groundwater extraction are usually single wells (*n=300* out of *678*), followed by well fields (*n=169*) and single artesian wells

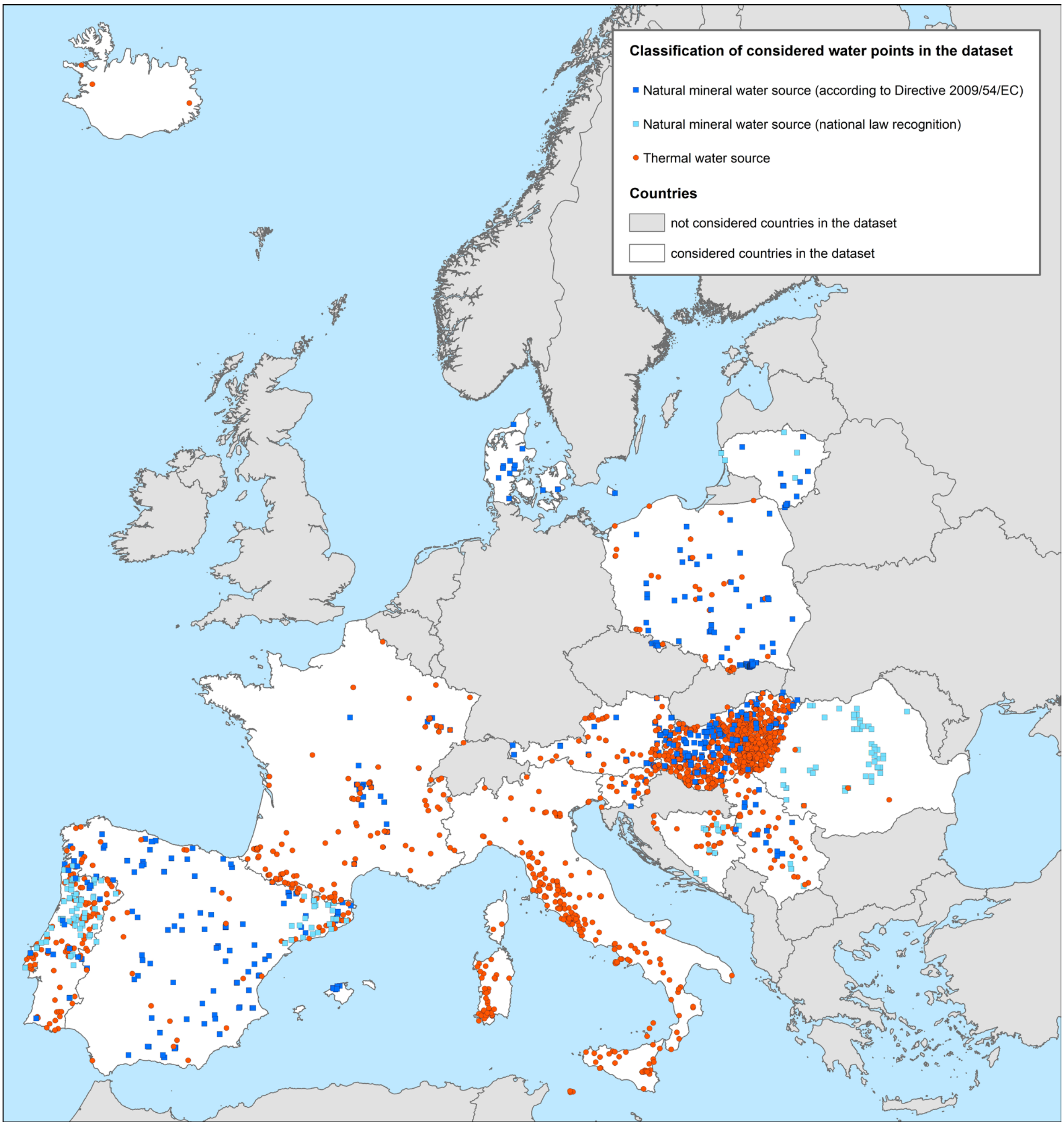

Fig. 2. Map of natural mineral waters and thermal waters found in the dataset.

(*n=74*). Captured springs (*n=54*) or captured spring groups are less widespread (*n=16*), which is expected as stable composition should prevail. Depths of wells are usually between approx. 85 and 250 m. Many sources are confined sub-artesian (*n=299*) and artesian (*n=114*). Unconfined conditions are uncommon (*n=24*) as they are not suitable to meet the regulation criteria on geological and hydrogeological conditions for mineral water: water characteristics have to be preserved intact because of the underground origin of such groundwater, which has been protected from all risk of pollution.

The aquifer media type (primary and secondary porosity) is in most cases porous (*n=275* out of *678*) or a combination of porous and fractured (*n=99*). Karstic and fractured (*n=78*), fractured (n=*31*) and entirely karstic (*n=2*) are less abundant. Karstic aquifers often have issues with microbiological pollution due to fast inflow of freshwater, therefore they rarely supply natural mineral waters resources. Porous aquifers with higher self-purification capabilities most often provide stable composition which is required for natural mineral waters.

The lithologies of the aquifers are often clastic sediments (*n=264* out of *678*) and sandy aquifers are prevailing. Carbonate sedimentary rock aquifers (*n=202*) are also numerous containing limestone, dolomite and chalk. Sources associated with pyroclastic rocks (*n=65*), metamorphic rocks (*n=27*), igneous rocks (*n=24*) or clastic sedimentary rocks (*n=17*) are less present. Most common aquifer ages are Neogene (*n=133* of *678*), Mesozoic (*n=120*) and Quaternary (*n=103*).

Most sources have temperatures of <15 °C at the outlet (*n=312* out of *678*) and 132 sources show temperatures between 15 and 20 °C (Table 7 and Fig. 3). Elevated temperatures above 20 °C are found for 117 natural mineral water sources, mainly in Hungary (*n=71*) and less frequent in Serbia (n=16), Spain. (*n=14*), Portugal (*n*=7), France (*n=4*), Austria (*n=3*), Slovenia (*n=1*) and Poland (*n=1*).

TDS are commonly below 1 g/l (*n=342*), less sources show a range between 1-14.5 g/l (*n=171*) and highly mineralized groundwaters with >14.5 g/l are very rare (*n=10*). Those highly mineralized natural mineral waters are entirely found in Hungary. The pH is usually in a range between 6.5 and 7.5 and EC mostly between 500 and 2,000 µS/cm (25 °C); green color intensity to show higher numbers / percentages.

Calculations of the water types (>20eq%) of major cations and anions for 462 sources show, that (Ca, Mg)-HCO_3 waters are dominating (*n=164*), followed by Na-HCO_3 waters (n=55), Ca-HCO_3 waters (*n=43*) and (Ca, Mg, Na)-HCO_3 waters (*n=26*). 30 different water types were identified in the dataset proving a wide range of hydrochemical characteristics. Exclusively Na bearing types are found for 91 sources. Furthermore, non HCO_3 types are rarely found (*n= 15* for Cl; *n=2* for SO_4). An overview of available hydrochemical analyses is found in Annex 2.

Under consideration of the indications of Directive 2009/54/EC for special labeling, 38 % of the sources are suitable for a low-Na diet, 33 % contain HCO_3, 31 % contain Fe, 26 % contain Na, 23 % contain Ca and Mg, 16 % contain F, 12 % contain Cl and 9 % contain SO4.

Qualitative information on groundwater residence times is unfortunately scarce. Most sources show groundwater retention times above 60

Table 6. Natural mineral waters found in countries according to their temperatures at the outlet. Elevated numbers are visualized by green color intensity.

Temperature class at the outlet (°C) (n=561 of 678)	<15	15-19.9	20-29.9	30-39.9	40-49.9	50-59.9	60-69.9	70-79.9	Total number
Austria	33	4	1	2					40
Denmark	14								14
France	16	10	4						30
Hungary	66	81	37	12	12	4	3	3	218
Lithuania	20	1							21
Poland	125				1				126
Portugal	1	9	6	1					17
Serbia	4	10	14	2					30
Slovenia	7	1	1						9
Spain	26	16	9	1	1	3			56
Total number	312	132	72	18	14	7	3	3	561

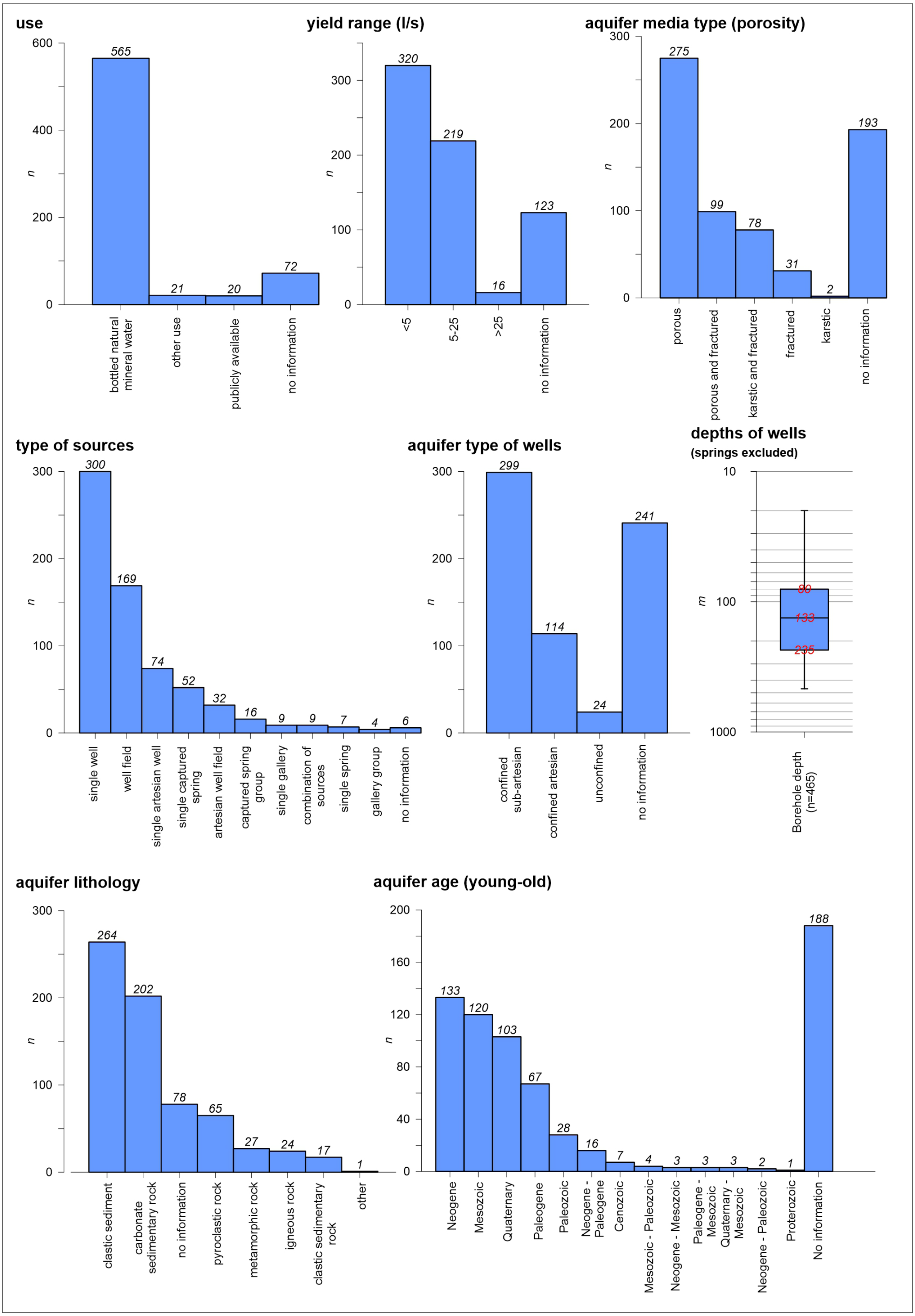

Fig. 3. Characteristics of natural mineral waters found in the dataset.

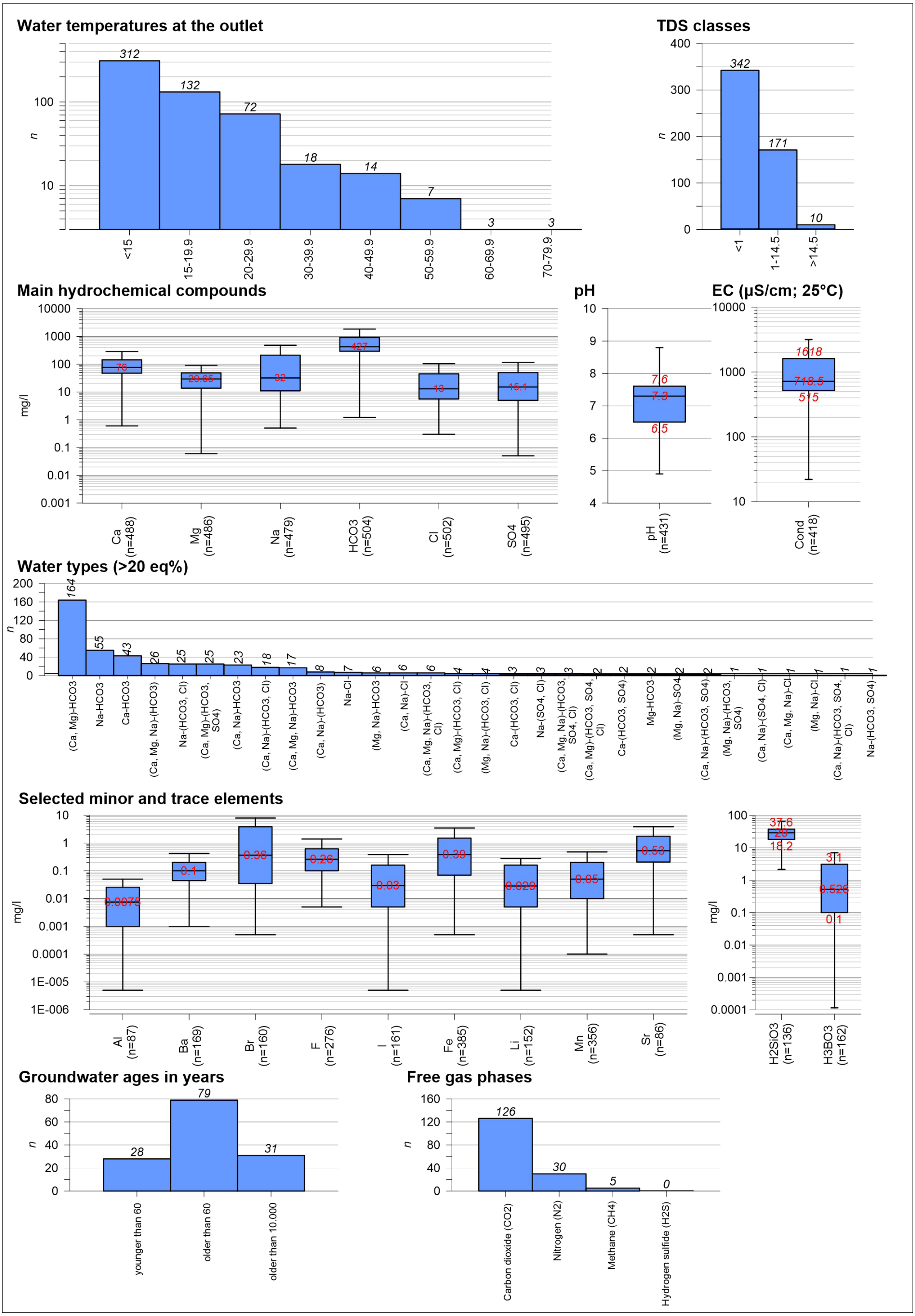

Fig. 4. Hydrochemical characteristics of natural mineral waters found in the dataset.

years (*n=79*), however old groundwaters with ages above 10,000 years (*n=31*) are present as well as groundwaters with less than 60 years (*n=28*).

Data availability is also limited for free gas phases, however, groundwaters rich in carbon dioxide seem to be relatively common (*n=126*). This is expected as historically mineral waters were enriched in CO_2.

Hydrogeological characteristics of thermal waters

Thermal waters found in the dataset (not including waters above 20 °C from the natural mineral water dataset) are mainly used for balneological purposes (*n=859* out of 2,390) and heating (n=380). However, other uses (*n=512*) are very common. Sources that are entirely used for energy production are not present except for one site in Italy. Other uses may comprise agricultural purposes, aquaculture or in rare cases drinking water if no other water resource are available. Agricultural purpose is not uniformly classified by all countries as some included this use into the heating category. Extraction rates between 5 and 25 l/s (*n=1,011*) outweigh the yield class <5 l/s (*n=598*) and rates above 25 l/s (*n=288*). This may occur as yield information is uncertain due to variable values with time.

Sources of thermal groundwater extraction are mostly wells (*n=946* out of 2,390) or artesian wells (*n=860*). Captured springs (*n=302*), captured spring groups (*n=98*) and uncaptured springs (*n=78*) are less common. The true vertical depth of wells is usually within the range of 465 to 1,298 m (25th to 75th percentile); it has to be added that absolute numbers were collected for data on borehole depths. The deepest artesian well that is used for heating is found in Poland with a depth of 3,943 m, however thermal water is extracted from a screen between 2,960 and 2,776 m at this site. Accordingly, the majority of sources are confined artesian (*n=902*) or sub-artesian (*n=694*).

The abundant aquifer media type (primary and secondary porosity) is porous (*n=1,185* out of 2,390) and a combination of porous and fractured (*n=127*) is less common compared to the previously described natural mineral water sources. Karstic and fractured (*n=316*), fractured (*n=246*) and compound (*n=167*) are also frequently present, but entirely karstic (*n=16*) is rarely found.

The lithologies of aquifers are predominated by clastic sediments (*n=1,383* of *2,390*), especially by sandy aquifers. Carbonate sedimentary rock aquifers (*n=460*) containing limestones, dolomites and chalk are followed by clastic sedimentary rocks (*n=356*), mainly sandstones. Sources associated with igneous rocks (*n=267*) and metamorphic rocks (n=138) are less present and other types like chemical sedimentary (evaporitic materials) (*n=17*), tuffite (*n=10*), pyroclastic rocks (*n=5*) and biogenic sediments (*n=2*) are rarely found. Most common aquifer ages are Neogene (*n=1,064* of 2,390), Mesozoic (*n=362*) and Quaternary (*n=187*).

Most frequent classes of water temperatures at the outlet are 30–40°C (*n=638*), 40–50 °C (*n=424*) and 20–30 °C (*n=355*) (Fig. 5). A distribution of

Table 7. Thermal waters found in countries according to their temperatures at the outlet; green colour intensity shows higher numbers.

Temperature class at the outlet (°C) (n=2,340 of 2,390)	**<15**	**15-19.9**	**20-29.9**	**30-39.9**	**40-49.9**	**50-59.9**	**60-69.9**	**70-79.9**	**80-89.9**	**90-99.9**	**>100**	**Total number**
Austria			18	17	12	2	4	2	4		3	62
Bosnia and Herzegovina	1	11	8	4		3				1		28
France	39	26	37	38	32	29	14	4	1			220
Hungary			88	466	312	199	167	87	63	47	3	1,432
Iceland								1	1		1	3
Italy			121	58	34	13	3	4	4	3		240
Poland	2		21	2	4	5	5	6	1			46
Portugal	1	96	16	2								115
Romania				1	5	2		1	1	2	2	14
Serbia			24	22	6	8	8	10				78
Slovenia			7	9	3	5	8	1				33
Spain	2	4	16	19	16	11		1				69
Total number	45	137	356	638	424	277	209	117	75	53	9	2,340

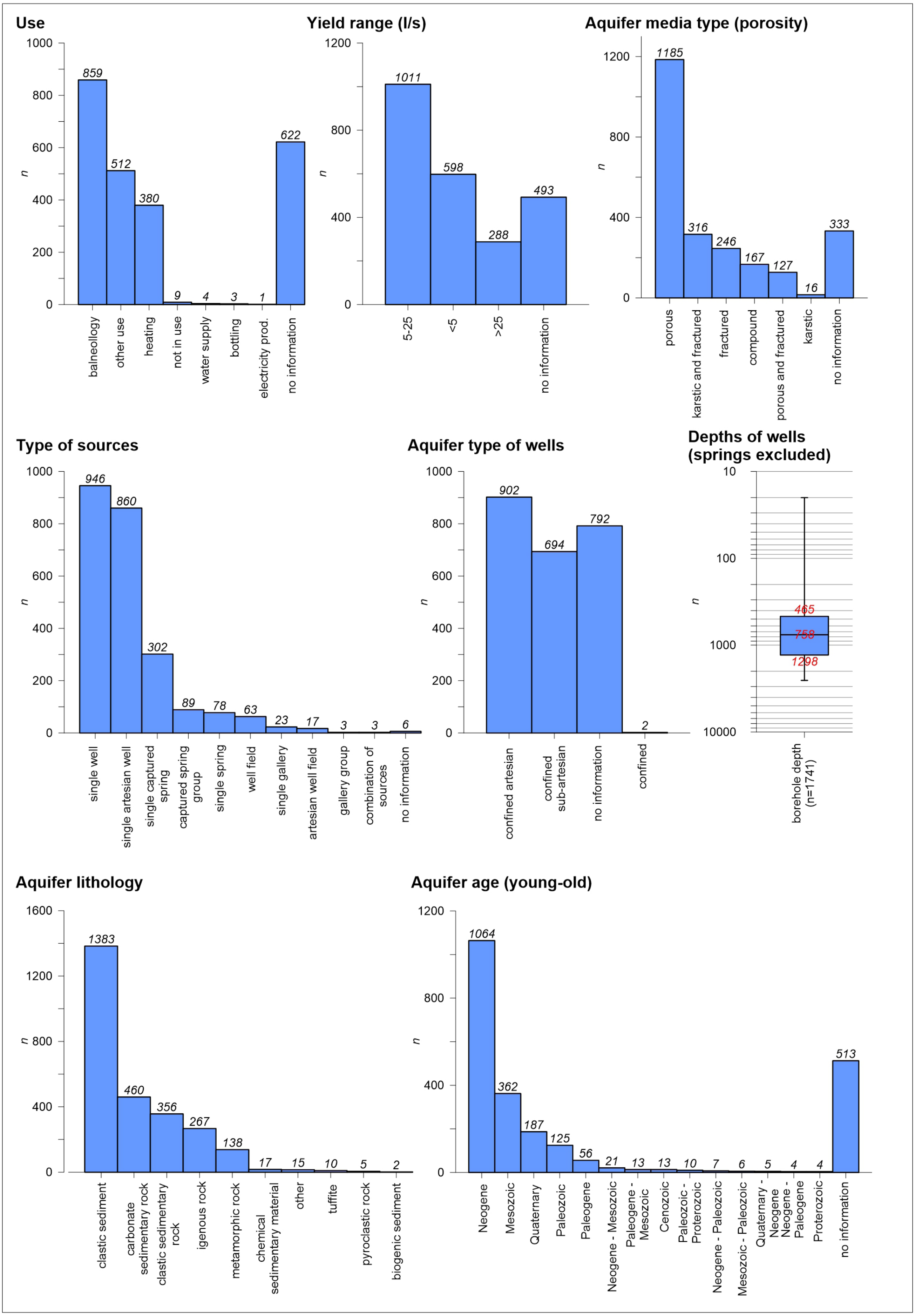

Fig. 5. Characteristics of thermal waters found in the dataset.

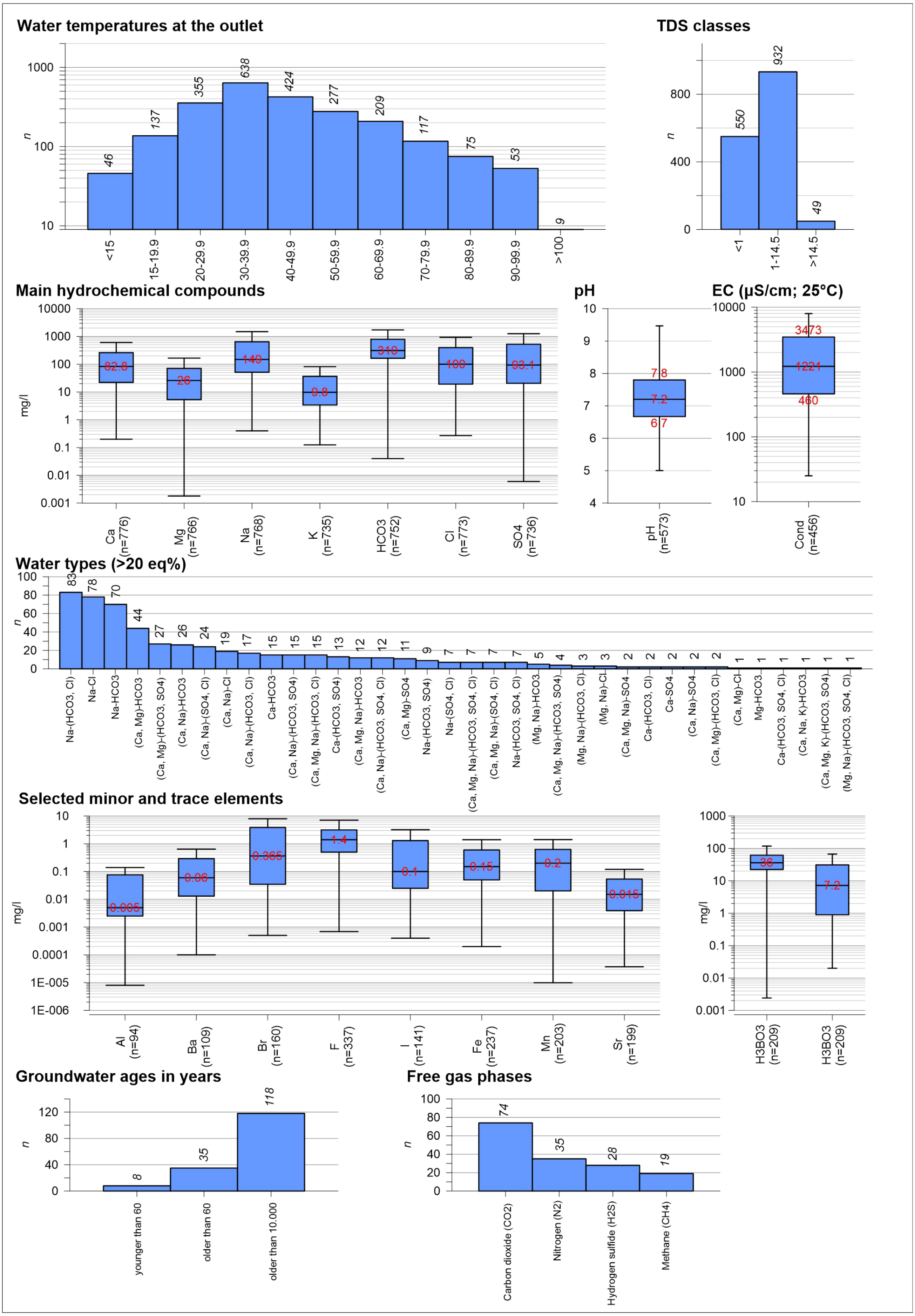

Fig. 6. Hydrochemical characteristics of thermal waters found in the dataset.

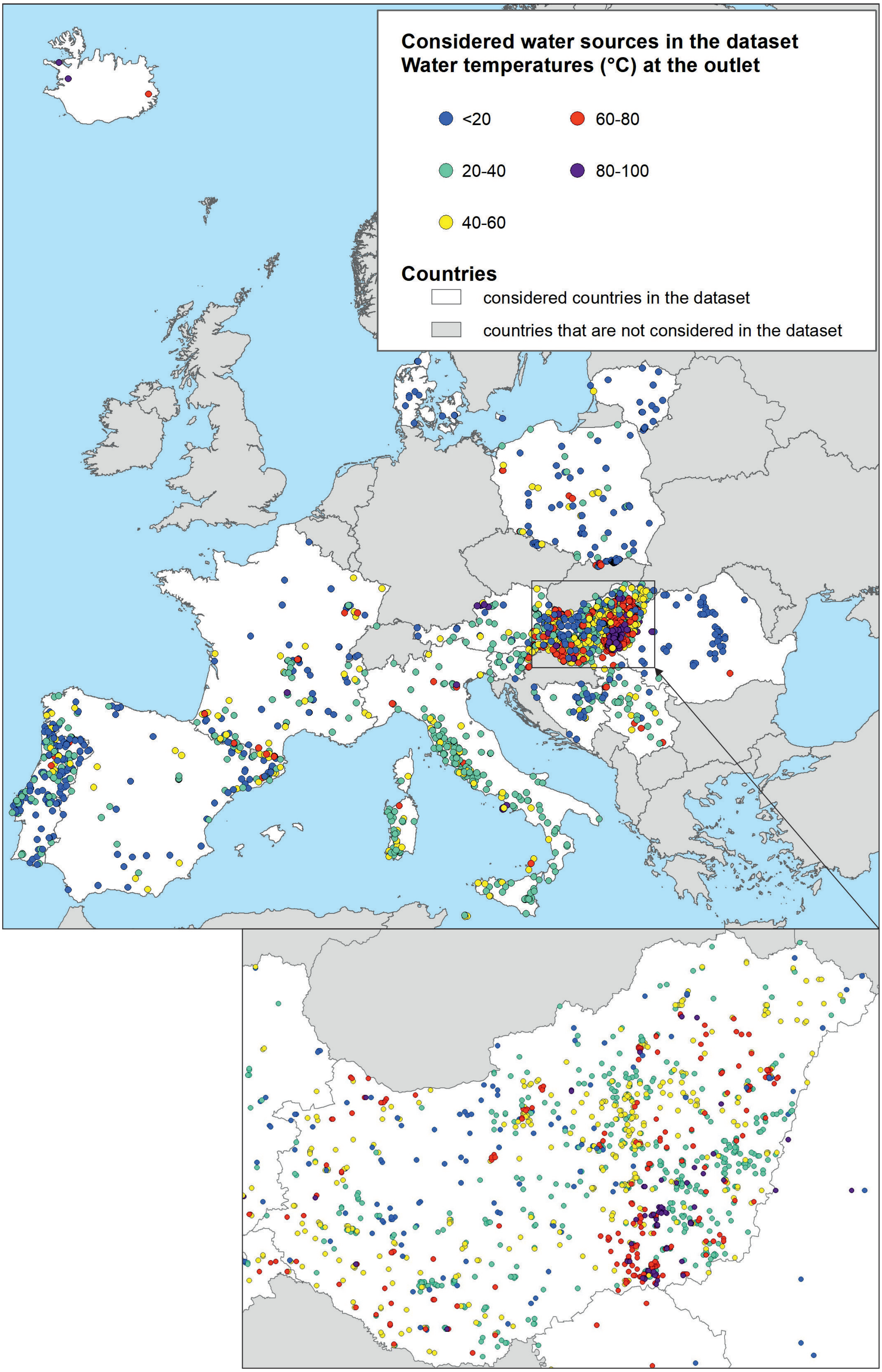

Fig. 7. Water temperatures at the outlet of sources found in the dataset of thermal and natural mineral waters; due to better visualisation, the classes are 20 degrees and not 10, as discussed in tables and text.

the temperature classes is found in Table 6 and it shows that the majority of sources are found in Hungary (*n=1,432*). Sources with a temperature below 15 °C are included due to national criteria in some countries. Rarely existing thermal waters with >100 °C (*n=9;* no exact temperature was gathered, only ranges) at the outlet are reported from Austria, Hungary, Romania and Iceland and can be usually associated with deep boreholes with depths between 1,500 and 2,800 m. However, a captured spring group in Iceland extracting from a basalt aquifer is an exception.

The common TDS range is 1 to 14.5 g/l (*n=932*) and thermal waters with a mineralisation below 1 g/l (*n=550*) are less prevailing. Highly mineralized thermal brines with a TDS content above 14.5 g/l are rather rare (n=49), located in several countries: Austria, Spain, Romania, Bosnia and Herzegovina, Poland, Italy and Hungary. The common EC range of the considered thermal waters is overall between approx. 450 and 2,700 µS/cm (25 °C) and pH is usually neutral to slightly alkaline.

Calculations of the water types (>20eq%) excluding the Hungarian dataset where no information is available show, that Na-(HCO_3, Cl) waters (*n=83*) are most common followed by Na-Cl waters (*n=78*), Na-HCO_3 (*n=70*) and (Ca, Mg)-HCO_3 (*n=44*). However, the hydrochemical composition of the considered sources is highly diverse, this is shown by 34 present water types in the dataset. An overview of available hydrochemical analyses is found in Annex 2.

Qualitative information on groundwater residence times is rare. Most sources show ages above 10,000 years (*n=118*) and groundwaters older than 60 years but younger than 10,000 years (*n=35*) are less frequent. Data availability is also limited for free gas phases, however, groundwaters rich in CO_2 seem to be common (*n=126*).

Discussion

Natural mineral waters are well defined and regulated in the European Union by the Directives 2009/54/EC and 2003/40/EC. Those directives are implemented by national law regulations.

Datasets for natural mineral and thermal waters comprise a large number of data, but also exhibit large numbers of missing or partially missing information due to missing data availability or limited data access. For example, data on trace elements and groundwater retentions times are not available in most cases. However, considering available information, the comparison of the datasets from a hydrogeological point of view shows common characteristics but also obvious differences.

Porous aquifer media types are dominant in both datasets and aquifer lithologies are mostly clastic sediments, especially sandy aquifers followed by carbonate sedimentary rocks that may contain limestones, dolomites and chalk. Most important, unconfined conditions are rarely present in the dataset. They are due to faster recharge and more responsive dynamics less capable of providing ground waters with stable composition or warmer water.

Temperatures at the outlet of thermal waters are commonly between 20 and 70 °C (82 %) and temperatures above 70 °C are less common (11 %) (Table 8). Furthermore, only 7% of sources that are classified as thermal waters show temperatures below 20 °C. In comparison, 79 % of natural

Table 8. Comparison of the datasets of natural mineral and thermal waters regarding temperatures at the outlet and total dissolved solids; green colour intensity to show higher percentages.

	TDS (g/l)	T (°C) at the outlet of source											%
		<15	15-19.9	20-29.9	30-39.9	40-49.9	50-59.9	60-69.9	70-79.9	80-89.9	90-99.9	>100	*of n sources*
natural mineral water	<1	35	18	9	2	1	0	0	0	0	0	0	***64***
(Directive 2009/54/EC)	1-14,5	21	4	4	1	2	1	1	1	0	0	0	***35***
(n=490 out of 678)	>14,5	0,4	0,2	0	0,2	0,2	0	0	0	0	0	0	***1***
	% of n sources	***56,4***	***22,2***	***13***	***3,2***	***3,2***	***1***	***1***	***1***	***0***	***0***	***0***	***100***
thermal waters	<1	0,2	5	8	13	6	2	1	1	0	0	0	***36***
(n=1,523 out of 2,390)	1-14,5	0,3	1,2	7	11,5	12,5	9,4	9	4,3	3,1	2,4	0,3	***61***
	>14,5	0	0,3	1,2	0,3	0,3	0,5	0,2	0,1	0,2	0,1	0,1	***3***
	% of n sources	**0,5**	**6,5**	**16,2**	**24,8**	**18,8**	**11,9**	**10,2**	**5,4**	**3,3**	**2,5**	**0,4**	**100**

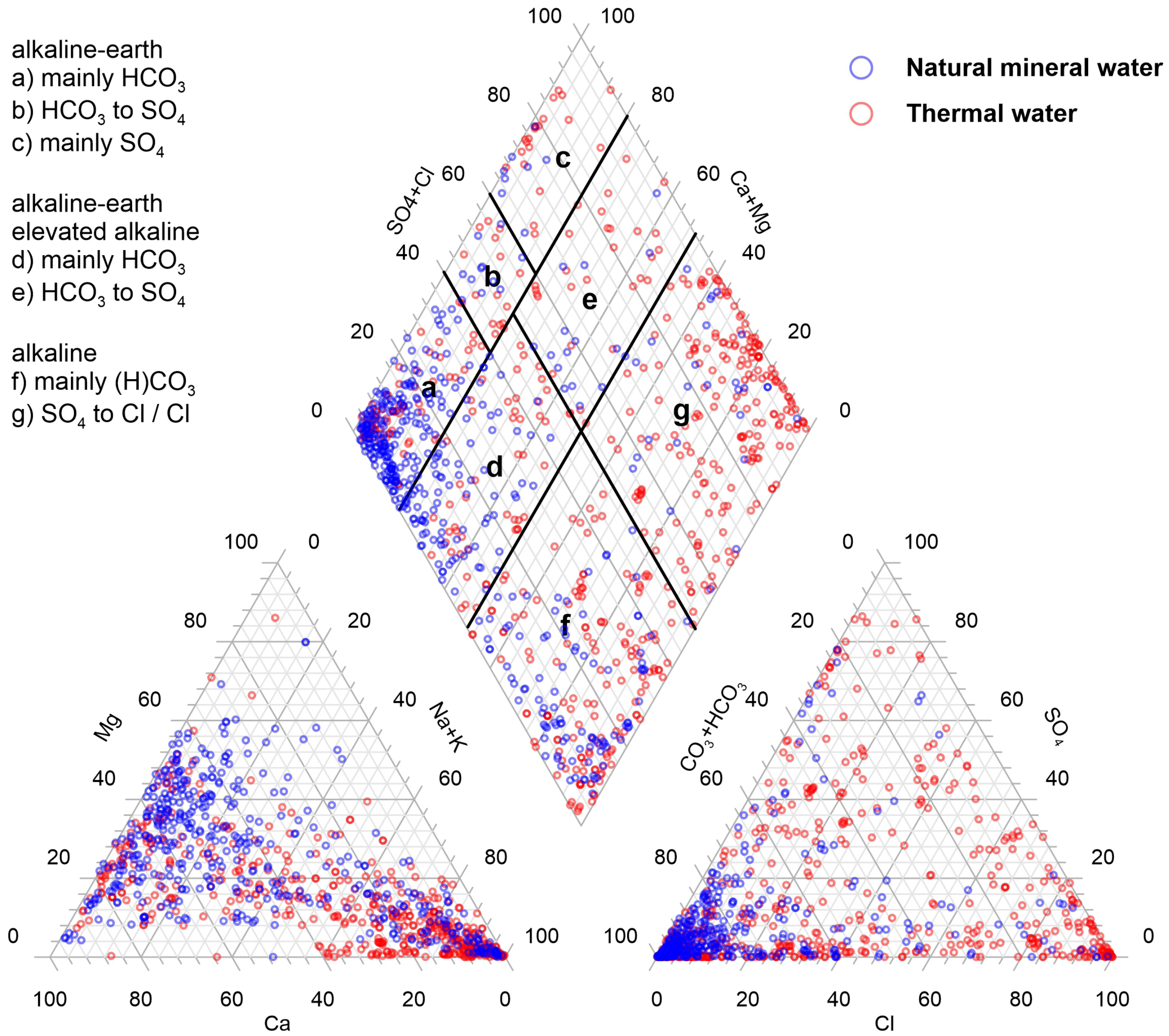

Fig. 8. Piper diagram to compare the datasets of natural mineral waters (n=423 out of 678) and thermal waters (n=518 of 2,390).

Table 9. Water types versus water temperatures at the outlet of natural mineral waters; green colour intensity to show higher percentages.

Natural mineral waters (n= 423 out of 678)	**Water temperature at the outlet (°C)**								**% of n sources**
	<15	**15-19.9**	**20-29.9**	**30-39.9**	**40-49.9**	**50-59.9**	**60-69.9**	**70-79.9**	
(Ca)-(HCO_3)	7,1	0,9	0,5	0,0	0,0	0,0	0,0	0,0	8,5
(Ca)-(HCO_3,Cl)	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,7
(Ca)-(HCO_3,SO_4)	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2
(Ca,Mg)-(HCO_3)	19,4	12,8	3,5	1,2	0,2	0,0	0,0	0,0	37,1
(Ca,Mg)-(HCO_3,Cl)	0,2	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,5
(Ca,Mg)-(HCO_3,SO_4)	3,1	0,7	0,7	0,7	0,0	0,0	0,0	0,0	5,2
(Ca,Mg)-(HCO_3,SO_4,Cl)	0,0	0,0	0,2	0,2	0,0	0,0	0,0	0,0	0,5
(Ca,Mg,Na)-(Cl)	0,0	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,2
(Ca,Mg,Na)-(HCO_3)	3,1	3,8	1,2	0,0	0,2	0,0	0,2	0,0	8,5
(Ca,Mg,Na)-(HCO_3,Cl)	0,2	0,2	0,5	0,5	0,0	0,0	0,0	0,0	1,4
(Ca,Mg,Na)-(HCO_3,SO_4,Cl)	0,2	0,0	0,0	0,0	0,5	0,0	0,0	0,0	0,7
(Ca,Na)-(Cl)	1,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,7
(Ca,Na)-(HCO_3)	4,3	1,4	1,2	0,0	0,2	0,0	0,0	0,0	7,1
(Ca,Na)-(HCO_3,Cl)	2,1	0,2	0,7	0,2	0,0	0,0	0,2	0,2	3,8
(Ca,Na)-(HCO_3,SO_4)	0,2	0,0	0,2	0,0	0,0	0,0	0,0	0,0	0,5

(Ca,Na)-(SO_4,Cl)	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2
(Mg)-(HCO_3)	0,0	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,5
(Mg,Na)-(Cl)	0,0	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,2
(Mg,Na)-(HCO_3)	0,5	0,2	0,5	0,0	0,0	0,0	0,0	0,0	1,2
(Mg,Na)-(HCO_3,Cl)	0,2	0,0	0,2	0,0	0,0	0,0	0,0	0,0	0,5
(Mg,Na)-(HCO_3,SO_4)	0,0	0,0	0,2	0,0	0,0	0,0	0,0	0,0	0,2
(Na)-(Cl)	0,2	0,7	0,0	0,0	0,0	0,2	0,0	0,0	1,2
(Na)-(HCO_3)	3,5	5,0	3,3	0,0	0,9	0,2	0,2	0,0	13,2
(Na)-(HCO_3,Cl)	0,0	0,5	2,1	0,5	1,2	1,2	0,0	0,2	5,7
(Na)-(HCO_3,SO_4)	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2
(Na)-(SO_4,Cl)	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2
% of n sources	47,5	27,7	15,1	3,3	3,3	1,7	0,7	0,7	100,0

Table 10. Water types versus water temperatures at the outlet of thermal waters; green colour intensity to show higher percentages.

thermal waters (n= 518 out of 2,390)	**<15**	**15-19.9**	**20-29.9**	**30-39.9**	**40-49.9**	**50-59.9**	**60-69.9**	**70-79.9**	**80-89.9**	**90-99.9**	**>100**	**% of n sources**
(Ca)-(HCO_3)	0,6	0,6	1,5	1,2	0,4	0,0	0,0	0,0	0,0	0,0	0,0	4,2
(Ca)-(HCO_3,Cl)	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2
(Ca)-(HCO_3,SO_4)	0,8	0,0	0,6	0,0	0,4	0,2	0,0	0,0	0,0	0,0	0,0	1,9
(Ca)-(HCO_3,SO_4,Cl)	0,0	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2
(Ca)-(SO_4)	0,0	0,0	0,2	0,0	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,4
(Ca,Mg)-(HCO_3)	2,1	0,6	3,1	1,9	0,2	0,0	0,6	0,0	0,2	0,0	0,0	8,7
(Ca,Mg)-(HCO_3,Cl)	0,0	0,0	0,0	0,0	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,2
(Ca,Mg)-(HCO_3,SO_4)	1,0	0,6	1,5	0,8	0,4	0,2	0,0	0,0	0,0	0,2	0,0	4,6
(Ca,Mg)-(SO_4)	0,0	0,2	0,2	0,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,0
(Ca,Mg,K)-(HCO_3)	0,0	0,0	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2
(Ca,Mg,Na)-(HCO_3)	0,2	0,2	0,8	0,6	0,0	0,2	0,0	0,0	0,0	0,0	0,0	1,9
(Ca,Mg,Na)-(HCO_3,Cl)	0,0	0,4	1,5	0,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	2,3
(Ca,Mg,Na)-(HCO_3,SO_4)	0,0	0,0	0,6	0,0	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,8
(Ca,Mg,Na)-(HCO_3,SO_4,Cl)	0,0	0,2	0,0	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,0
(Ca,Mg,Na)-(SO_4)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,0	0,0	0,0	0,2
(Ca,Mg,Na)-(SO_4,Cl)	0,0	0,0	0,2	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,0
(Ca,Na)-(Cl)	0,0	0,0	0,2	0,6	1,9	0,6	0,0	0,2	0,2	0,0	0,0	3,7
(Ca,Na)-(HCO_3)	0,2	0,8	2,3	0,6	0,0	0,2	0,6	0,0	0,0	0,0	0,0	4,6
(Ca,Na)-(HCO_3,Cl)	0,4	0,2	1,5	0,6	0,0	0,0	0,0	0,4	0,0	0,0	0,0	3,1
(Ca,Na)-(HCO_3,SO_4)	0,0	0,0	0,6	0,4	1,7	0,0	0,0	0,0	0,0	0,0	0,0	2,7
(Ca,Na)-(HCO_3,SO_4,Cl)	0,2	0,2	0,4	0,6	0,4	0,6	0,0	0,0	0,0	0,0	0,0	2,3
(Ca,Na)-(SO_4)	0,0	0,0	0,0	0,0	0,2	0,2	0,0	0,0	0,0	0,0	0,0	0,4
(Ca,Na)-(SO_4,Cl)	0,6	0,0	1,2	1,2	1,2	0,4	0,0	0,4	0,2	0,0	0,0	5,0
(Ca,Na,K)-(HCO_3)	0,0	0,0	0,0	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2
(Mg)-(HCO_3)	0,0	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2
(Mg,Na)-(Cl)	0,0	0,0	0,2	0,0	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,4
(Mg,Na)-(HCO_3)	0,0	0,0	0,0	0,6	0,4	0,0	0,0	0,0	0,0	0,0	0,0	1,0
(Mg,Na)-(HCO_3,Cl)	0,0	0,0	0,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,6
(Na)-(Cl)	0,4	1,0	4,2	1,7	1,9	2,9	1,4	0,8	0,6	0,2	0,0	15,1
(Na)-(HCO_3)	0,4	1,2	2,5	3,1	1,4	1,7	1,2	1,0	0,2	0,0	0,0	12,5
(Na)-(HCO_3,Cl)	0,0	0,2	4,1	3,9	2,5	1,7	1,5	0,2	0,4	0,2	0,6	15,3
(Na)-(HCO_3,SO_4)	0,0	0,0	0,4	0,2	0,4	0,4	0,4	0,2	0,0	0,0	0,0	1,9
(Na)-(HCO_3,SO_4,Cl)	0,0	0,0	0,6	0,4	0,2	0,0	0,0	0,0	0,0	0,0	0,0	1,2
(Na)-(SO_4,Cl)	0,2	0,0	0,4	0,0	0,6	0,0	0,0	0,0	0,0	0,0	0,0	1,2
% of n sources	7,1	6,6	29,5	20,8	14,9	9,3	5,6	3,3	1,7	0,6	0,6	100,0

mineral waters possess water temperatures below 20 °C, but the remaining 21 % of source bear temperatures above 20 °C and could be considered as thermal waters as well. However, those sources are evaluated as natural mineral waters in our approach. The mineralisation of natural mineral waters is usually below 1 g/l (64 %), whereas 1-14.5 g/l are common for thermal waters (61 %). Highly mineralized waters above 14.5 g/l are very rare in both datasets.

Natural mineral waters show primarily alkaline-earth bicarbonate water types (Fig. 7). In detail, 37 % of (Ca, Mg)-HCO_3 water type and 8.5 % a Ca-HCO_3 types are present (Table 9). On the other hand, Na-HCO_3 type waters are less abundant (13 %). The hydrochemical compositions of thermal water found in the dataset clearly exhibit a larger variation compared to natural mineral waters, but Na-Cl as well as Na-(HCO_3, Cl) types are commonly found (43 %). This indicates that more complex hydrochemical settings – e.g. ion exchange waters and diluted brines are often found.

Conclusions

This overview paper discussed legal framework and criteria for recognition of natural mineral water and thermal water in selected countries in Europe. It pointed out that especially for thermal waters, there is no uniform approach, despite the fact that most countries are within the European Union. This might cause misunderstandings not only among consumers of such goods but also for scientific research, due to varying definitions of classifications and threshold limits. In contrast, for natural mineral water it has to be mentioned that the definition is based on legislative definitions (Directive 2009/54/EC and Directive 2003/40/EC within the European Union, and national legislations in Bosnia and Herzegovina, Serbia).

This research provides a summary including a geological-hydrogeological statistical overview of recognised sources of natural mineral and thermal waters where comparison of both types reveals evident differences. Natural mineral waters are, usually, colder and less mineralized as thermal, but some can also be classified as thermal due to national definitions. Both are mostly tapped from confined aquifers, providing enough stable chemical composition. (Ca, Mg)-HCO_3 water type is prevailing at natural mineral water group while Na-(HCO_3, Cl) at thermal waters. This latter is a result of more pronounced and longer water-rock interaction having older water ages and hotter which results also in higher mineralization, while in some cases can represent diluted brines.

The collected and classified dataset is freely published at a webservice developed within the GeoERA project HOVER: https://data.geus.dk/egdi/?mapname=hover_wp3_d35c#baslay=baseMapGEUS&extent=-4366900,-1320100,11512740,6181370. We strongly encourage to use this research as a basis for further data collection which can be later supplemented to this webportal.

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The Final Report for HOVER WP3.1 is available here: https://repository.europe-geology.eu/egdidocs/hover/hover_d3-1_report_v2.pdf

The webservice for natural mineral and thermal waters (HOVER WP3.5) is available here: https://data.geus.dk/egdi/?mapname=hover_wp3_d35c#baslay=baseMapGEUS&extent=-4366900,-1320100,11512740,6181370

References

Albu, M., Banks, D. & Nash, H. 1997: Mineral and Thermal Groundwater Resources. Springer, Dordrecht: 447 p. https://doi.org/10.1007/978-94-011-5846-6

Balderer, W., Porowski, A., Idris, H. & Lamoreaux, J. W. 2014: Thermal and Mineral Waters. Origin, Properties and Applications. Springer, Berlin: 135 p. https://doi.org/10.1007/978-3-642-28824-1

Borović, S., Marković, T., Larva, O., Brkić, Z. & Mraz, V. 2016: Mineral and Thermal Waters in the Croatian Part of the Pannonian Basin. In: Papic, P. (ed.): Mineral and Thermal Waters of Southeastern Europe. Springer, Berlin: 31-45. https://doi.org/10.1007/978-3-319-25379-4_2

Borszéki, B. (eds.) 2013: Mineral and medicinal waters of the Carpathian Basin (in Hungarian). Budapest: 320 p.

Bräuer, K, Geissler, W.H., Kämpf, H., Niedermannn, S. & Rman, N. 2016: Helium and carbon isotope signatures of gas exhalations in the westernmost part of the Pannonian Basin (SE Austria/NE Slovenia): Evidence for active lithospheric mantle degassing. Chemical Geology, 422/1: 60-70. https://doi.org/10.1016/j.chemgeo.2015.12.016

Brenčič, M., Ferjan, T. & Gosar, M. 2010: Geochemical survey of Slovenian bottled waters. Journal of Geochemical Exploration, 107/3: 400-409. https://doi.org/10.1016/j.gexplo.2010.09.007

Burić, M., Nikic, Z. & Papić, P. 2016: Mineral Waters of Montenegro. In: Papic, P. (ed.): Mineral and Thermal Waters of Southeastern Europe. Springer, Berlin: 65-79, https://doi.org/10.1007/978-3-319-25379-4_4

Carlé, W. 1975: Die Mineral- und Thermalwässer von Mitteleuropa. Stuttgart, Wiss. Verlagsgesellschaft mbH: 643 p.

Dinelli, E., Lima, A., Albanese, S., Birke, M., Cicchella, D., Giaccio, L. et al. 2012: Comparative study between bottled mineral and tap water in Italy. Journal of Geochemical Exploration, 112, 368-389. https://doi.org/10.1016/j.gexplo.2011.11.002

Eftimi, R. & Frashëri, A. 2016: Thermal Waters of Albania. In: Papic, P. (ed.): Mineral and Thermal Waters of Southeastern Europe. Springer, Berlin: 115-130. https://doi.org/10.1007/978-3-319-25379-4_7

EGEC, 2019: EGEC Geothermal Market Report, Full Report. European Geothermal Energy Council 2019, Brussels: 58 p.

Eggenkamp, H. G. M. & Marques, J. M. 2013: A comparison of mineral water classification techniques: Occurrence and distribution of different water types in Portugal (including Madeira and the Azores). Journal of Geochemical Exploration, 132: 125-139. https://doi.org/10.1016/j.gexplo.2013.06.009

Elster, D., Goldbrunner, J., Wessely, G., Niederbacher, P., Schubert, G., Berka, R., Philippitsch, R. & Hörhan, T. 2016: Erläuterungen zur geologischen Themenkarte Thermalwässer in Österreich 1:500.000. Geologische Bundesanstalt, Wien: 296 p.

Elster, D., Fischer, L., Hann, S., Goldbrunner, J., Schubert, G., Berka, R., Hobiger, G., Legerer, P. & Philippitsch, R. 2018: Österreichs Mineral- und Heilwässer. Geologische Bundesanstalt, Wien: 448 p.

EuroGeoSurveys, 2016: "Wonder water - the value of water", A geological journey around Europe's mineral springs, spas and thermal baths. Brussels, Belgium: 135 p.

Evina, E. 1992: La Giude du Buveur d'Eau. Solar, France: 263 p.

Freeze, A. & Cherry, J. 1979: Groundwater, 604 p.

Gros, N. 2003: The comparison between Slovene and Central European mineral and thermal waters. Acta Chimica Slovenica, 50/1: 57-66.

Haas, J., Brezsnyánszky, K., Budai, T., Fodor, L., Gál, N., Gombárné Forgács, G., Gyalog, L., Katona, G., Kovács, G., Kövér, Sz., Lesták, F., Nádor, A., † Nagymarosy, A., Prakfalvi, P., Rotárné Szalkai, Á., Scharek, P., Síkhegyi, F., Szepessy, G., Szőcs, T., Török, Á., Vatai, J., Vikor, Zs. & Zilahi-Sebess, L. 2018: Geology. In: Kocsis, K. (ed.): National Atlas of Hungary: Natural environment. Budapest, MTA CSFK Geographical Institute: 16-35.

Käss, W. & Käss, H. 2008: Deutsches Bäderbuch. Vereinigung für Bäder- und Klimakunde e.V., Schweizerbart, Stuttgart: 232 p.

Kirschner, C. 2009: Glossar Kur, Heilbad, Rehabilitation = Glossary Cure, Spa, Rehabilitation. Schweizerbart Verlag, Germany: 352 p.

LaMoreaux, P. & Tanner, J. 2001: Springs and Bottled Waters of the World: Ancient History, Source, Occurence, Quality and Use. Springer, Berlin: 315 p. https://doi.org/978-3-642-56414-7

Lapanje, A. 2006: Origin and chemical composition of thermal and thermomineral waters in Slovenia. Geologija, 49/2: 347–370. https://doi.org/10.5474/geologija.2006.025

Lourenço, C., Ribeiro, L. & Cruz, J. 2010: Classification of natural mineral and spring bottled waters of Portugal using Principal Component Analysis. Journal of Geochemical Exploration, 107/3: 362-372. https://doi.org/10.1016/j.gexplo.2010.08.001

Lund, J. 2001: Balneological use of thermal waters. In: International Geothermal Days Germany 2001, Bad Urach, Germany.

Michel, G. 1997: Mineral- und Thermalwässer. Allgemeine Balneogeologie. Borntraeger, Stuttgart: 398 p.

Minissale, A. 1991: Thermal springs in Italy: their relation to recent tectonics. Applied Geochemistry, 6/2: 201-212. https://doi.org/10.1016/0883-2927(91)90030-S

Miošić, N. & Samardžić, N. 2016: Mineral, Thermal and Thermomineral Waters of Bosnia and Herzegovina. In: Papic, P. (ed.): Mineral and Thermal Waters of Southeastern Europe. Springer, Berlin: 147-171. https://doi.org/10.1007/978-3-319-25379-4_9

Natural Mineral Waters Europe, 2021: https://naturalmineralwaterseurope.org/ (25.10.2021)

Nikic, Z. & Papić, P. 2016: Thermal Waters in Bulgaria. In: Papic, P. (ed.): Mineral and Thermal Waters of Southeastern Europe. Springer, Berlin: 47-64. https://doi.org/10.1007/978-3-319-25379-4_3

Papić, P. (ed.) 2016: Mineral and Thermal Waters of Southeastern Europe. Environmental Earth Sciences. Springer Verlag, Berlin: 174 p.

Porowski, A., Rman, N., Fórizs, I. & LaMoreaux, J. 2019: Introductory Editorial Thematic Issue: "Mineral and thermal waters". Environmental Earth Sciences, 78/16: 2p. https://doi.org/10.1007/978-1-4939-2493-6_978-1

Reimann, C. & Birke, M. (eds.) 2010: Geochemistry of European Bottled Water. Borntraeger, Stuttgart: 268 p.

Rman, N., Bălan, L., Bobovečki, I., Gál, N. Jolovic, B., Lapanje, A., Marković, T., Milenić, D., Skopljak, F., Rotár-Szalkai, Á., Samardžić, N., Szőcs, T., Šolaja, D., Toholj, N., Vijdea A. & Vranješ, A. 2020: Geothermal sources and utilization practice in six countries along the southern part of the Pannonian basin. Environmental Earth Sciences, 79/1. https://doi.org/10.1007/s12665-019-8746-6

Rosca, M., Bendea, C. & Vîjdea, A. 2016: Mineral and Thermal Waters of Romania. In: Papic, P. (ed.): Mineral and Thermal Waters of Southeastern Europe. Springer, Berlin: 97-114. https://doi.org/10.1007/978-3-319-25379-4_6

Sowizdzal, A. 2018: Geothermal energy resources in Poland – Overview of the current state of knowledge. Renewable and Sustainable Energy Reviews, 82/3: 4020-4027. https://doi.org/10.1016/j.rser.2017.10.070

Stober, I. & Bucher, K. 2012: Geothermie. Springer Verlag, Berlin: 287 p. https://doi.org/10.1007/978-3-642-24331-8

Szocs, T., Rman, N., Süveges, M., Palcsu, L., Tóth, G. & Lapanje, A. 2013: The application of isotope and chemical analyses in managing transboundary groundwater resources. Applied Geochemistry, 32: 95–107. https://doi.org/10.1016/j.apgeochem.2012.10.006

Todorović, M., Štrbački, J., Ćuk, M., Andrijašević, J., Šišović, J. & Papić, P. 2016: Mineral and Thermal Waters of Serbia: Multivariate Statistical Approach to Hydrochemical Characterization. In: Papic, P. (ed.): Mineral and Thermal Waters of Southeastern Europe. Springer, Berlin: 81-95, https://doi.org/10.1007/978-3-319-25379-4_5

Zötl, J. & Goldbrunner, J. E. 1993: Die Mineral- und Heilwässer Österreichs. Geologische Grundlagen und Spurenelemente. Springer, Wien: 331 p. https://doi.org/10.1007/978-3-7091-6652-9

Annex 1 - Legal norms

Europe

Directive 2009/54/EC of the European Parliament and of the Council of 18 June 2009 on the exploitation and marketing of natural mineral waters. Internet: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32009L0054 (25.10.2021)

Directive 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption. Internet: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32020L2184 (25.10.2021)

Directive 80/777/EEC of 15 July 1980 on the approximation of the laws of the Member States relating to the exploitation and marketing of natural mineral waters. Internet: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A31980L0777 (25.10.2021)

Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption. Internet: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31998L0083 (25.10.2021)

Directive 2003/40/EC of 16 May 2003 establishing the list, concentration limits and labelling requirements for the constituents of natural mineral waters and the conditions for using ozone-enriched air for the treatment of natural mineral waters and spring waters. Internet: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32003L0040 (25.10.2021)

List of natural mineral waters recognised by member states. Internet: https://eur-lex.europa.eu/legal--content/EN/TXT/HTML/?uri=CELEX:52013XC0403(04)&from=EN (25.102.2021)

Austria

Austrian food code: Chapter B 17 „bottled waters“ BMGF-75210/0005-II/B/13/2016. Internet: https://www.lebensmittelbuch.at/lebensmittelbuch/b-17-abgefuellte-waesser.html (25.10.2021)

Drinking water regulation – TWV, BGBl. II Nr. 304/2001 idgF. Internet: https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=Bundesnormen&Gesetzesnummer=20001483 (25.10.2021)

Food labelling regulation:– LMKV, BGBl. Nr. 72/1993 idgF. Internet: https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=Bundesnormen&Gesetzesnummer=10010723&FassungVom=2014-12-12 (25.10.2021)

Health- and nutrition security law– GESG, BGBl. I Nr. 63/2002 idgF. Internet: https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=Bundesnormen&Gesetzesnummer=20001896 (25.10.2021)

Mineral and spring water regulation, BGBl. II, Nr. 309/1999. Internet: https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=Bundesnormen&Gesetzesnummer=20000003 (25.10.2021)

Wasserrechtsgesetz 1959 – WRG 1959, BGBl. Nr. 215/1959 idgF. Internet: https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=Bundesnormen&Gesetzesnummer=10010290 (25.10.2021)

Medicinal occurrence and health resort law of Burgenland (state in Austria). HeiKuG, LGBl. Nr. 15/1963, zuletzt geändert durch LGBl. Nr. 79/2013. Internet: https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=LrBgld&Gesetzesnummer=10000048 (25.10.2021)

Medicinal occurrence and health resort law of Carinthia (state in Austria). LGBl. Nr. 157/1962, zuletzt geändert durch LGBl. Nr. 85/2013. Internet: https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=LrK&Gesetzesnummer=10000024 (25.10.2021)

Medicinal occurrence and health resort law of Lower Austria (state in Austria). LGBl. Nr. 272/1978, zuletzt geändert durch LGBl. Nr. 219/2001. Internet: https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=LrNO&Gesetzesnummer=20000627 (25.10.2021)

Medicinal occurrence and health resort law of Upper Austria (state in Austria). LGBl. Nr. 47/1961, zuletzt geändert durch LGBl. Nr. 90/2013. Internet: https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=LrOO&Gesetzesnummer=10000048 (25.10.2021)

Medicinal occurrence and health resort law of Salzburg (state in Austria). LGBl. Nr. 101/1997, zuletzt geändert durch LGBl Nr. 106/2013. https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=LrSbg&Gesetzesnummer=10001039 (25.10.2021)

Medicinal occurrence and health resort law of Styria (state in Austria). LGBl. Nr. 161/1962, zuletzt geändert durch LGBl. 87/2013. Internet: https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=LrStmk&Gesetzesnummer=20000421 (25.10.2021)

Medicinal occurrence and health resort law of Tyrol (state in Austria). LGBl. Nr. 24/2004, zuletzt geändert durch LGBl. Nr. 130/2013. Internet: https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=LrT&Gesetzesnummer=20000191 (25.10.2021)

Medicinal occurrence and health resort law of Vienna (state in Austria). LGBl. Nr. 29/2013. Internet: https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=LrW&Gesetzesnummer=20000303 (25.10.2021)

Bosnia and Herzegovina

Waters Act - Rulebook on natural mineral water, spring water and table water. Official Gazette of the Bosnia and Herzegovina No. 26/10, 40/10.

The law on Waters. Official Gazette of the Federation BiH No. 70/06.

The law on Geological Surveys. Official Gazette of FBiH, No. 9/10.

The law on Bottled Water in Bosnia and Herzegovina, No. 45/04.

The law on Concessions on Water and Public Property. Official Gazette of the Federation BiH, No. 8/00.

Rulebook on natural mineral and natural spring waters. Official Gazette of BiH No. 26/10

Rulebook on the categorization, classification, calculation of groundwater reserves and keeping records on them. Official Gazette of the FBiH, No. 47/11.

Rulebook on conditions for determining sanitary protection zones and protective measures for water sources used or planned to be used for drinking. Official Gazette of the Federation BiH, No. 51/02.

Rulebook on minimum technical, technological and personnel requirements for the production of refreshing soft drinks, fruit juices and syrups and bottled waters. Official Gazette of the Federation BiH, no. 81/06.

Rulebook on table water. Official Gazette of BiH No. 40/10.

Rulebook on the health safety of drinking water. Official Gazette of BiH No. 40/10.

Rulebook on the manner of keeping records and creating Cadastre of deposits of mineral raw materials, geological phenomena and approved investigative areas. Official Gazette of the Federation of BiH, no.38/11.

Denmark

Executive Order on natural mineral water, spring water and bottled drinking water: BEK nr 38 of 12/01/2016. Internet: https://www.retsinformation.dk/eli/lta/2016/38 (25.10.2021)

Guidance on the labeling of natural mineral water, spring water and bottled drinking water: VEJ nr 9105 of 10/04/2008. Internet: https://www.retsinformation.dk/eli/retsinfo/2008/9105 (25.10.2021)

France

Public Health Codes, articles L1322-1 to 13 et R.1322-1 to 1322-44-23

Safety of water intended for human consumption, Decree No 2007-49 of 11 January 2007

https://www.legifrance.gouv.fr/codes/article_lc/LEGIARTI000021940425/

https://www.legifrance.gouv.fr/codes/article_lc/LEGIARTI000021940425/2010-02-26/

https://www.legifrance.gouv.fr/codes/article_lc/LEGIARTI000006909666#:~:text=Une%20eau%20min%C3%A9rale%20naturelle%20est,fix%C3%A9es%20par%20l'article%20R.&text=l'une%20et%20l'autre,de%20tout%20risque%20de%20pollution

Décret n° 2007-49 du 11 janvier 2007 relatif à la sécurité sanitaire des eaux destinées à la consommation humaine - Légifrance (https://www.legifrance.gouv.fr) (https://www.legifrance.gouv.fr/loda/id/LEGIARTI000006259300/2007-01-12/)

National regulation on thermal waters. Article R. 1322-52 of the Public Health Code and the Decree 2007-49 11 January 2007 https://www.legifrance.gouv.fr/codes/article_lc/LEGIARTI000006909777

Hungary

59/2006 (VIII. 14.) FVM-EüM-SZMM. Internet: https://net.jogtar.hu/jogszabaly?docid=A0600059.FVM&txtreferer=A0400065.FVM (12.10.2021)

65/2004 (IV. 27.) FVM-ESzCsM-GKM. Internet: https://net.jogtar.hu/jogszabaly?docid=a0400065.fvm (12.10.2021.)

Mineral water according to Hungarian law LVII from 1995. Internet: https://net.jogtar.hu/jogszabaly?docid=99500057.tv (12.10.2021.)

Ministerial decree on natural medical factors, 74/1999 (XII. 25.). Internet: https://net.jogtar.hu/jogszabaly?docid=99900074.eum (12.10.2021)

National law implementing 2003/40/EC. Internet: https://eur-lex.europa.eu/legal-content/EN/

ALL/?uri=CELEX%3A32003L0040 (12.10.2021)
National law implementing 80/777/EEC. Internet: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A31980L0777 (12.10.2021.)
National law implementing 96/70/EC. Internet: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31996L0070 (12.10.2021)

Italy

Implementation of Directive 2009/54/EC on the use and marketing of natural mineral waters. Decree N.176 of 8 October 2011. Official Gazette of Italian Republic, General Serie n.258, 1-13 (05/11/2011)
Reorganization of the thermal water sector. Law N.323 of 24 October 2000. Official Gazette of Italian Republic, General Serie n.261, 4-14 (08/11/2000)

Poland

Act of 25 August 2006 on Food and Nutrition Safety. Jour. of Law 2006 No 171 item 1563. Internet: http://prawo.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20061711225 (25.10.2021)
Regulation of 31 March 2011 on natural mineral water, spring water and table water. Jour. of Law 2011 No 85 item 466. Internet: http://prawo.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20110850466 (25.10.2021)
Jour. of Law 2018 item 1563

Portugal

Geological Resources Law. Law noº 54/2015 of 22 June. Internet: https://dre.pt/pesquisa/-/search/67552498/details/maximized (25.10.2021)
Decree for natural mineral waters. Decree-Law no. 86/90 of 16 March. Internet: https://dre.pt/web/guest/pesquisa/-/search/333159/details/normal?l=1 (25.10.2021)
Decree for spring waters. Decree-Law no. 84/90 of 16 March. Internet: https://dre.pt/web/guest/pesquisa/-/search/333157/details/maximized?jp=true (25.10.2021)

Romania

Definition of natural mineral water. Government Decision 1020/2005.
Definition of thermal water. Governmental Decision no. 1154/2004.

Serbia

Regulation on Quality and Other Requirements for Natural mineral water, Spring Water and Bottled Drinking Water. Official Gazette of Serbia and Montenegro, number 53/05.
Regulation on the Hygienic Acceptability of Potable Water. Official Gazette of FRY, number 42/98 and 44/99.

Slovenia

Rules on natural mineral water, spring water and table water. Official Gazette of Rep. of Slovenia No. 50/04, 75/05 in 45/08 – ZKme-1. http://www.pisrs.si/Pis.web/pregledPredpisa?id=PRAV5392 (11.11.2021)
Water Act. Official Gazette of Rep. of Slovenia No. 67/02, 2/04 – ZZdrI-A, 41/04 – ZVO-1, 57/08, 57/12, 100/13, 40/14, 56/15, 65/20. http://pisrs.si/Pis.web/pregledPredpisa?id=ZAKO1244 (11.11.2021)

Spain

Law of Mines 22/1973 (BOE number 189, de 24-07-1973). Internet: https://www.boe.es/buscar/doc.php?id=BOE-A-1973-1018 (25.10.2021)
Royal Law 2857/1978 (BOE number 295, de 11-12-1978). Internet: https://www.boe.es/buscar/doc.php?id=BOE-A-1978-29905 (25.10.2021)
Royal Law 1798/2010. Internet: https://ec.europa.eu/growth/tools-databases/tris/en/search/?trisaction=search.detail&year=2018&num=67 (25.10.2021)

Annex 2- Hydrochemical dataset

Thermal waters - Number of considered analyses

number of analyses / number of analyses below detection limit	Sodium (Na)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	Strontium (Sr)	Barium (Ba)	Iron (Fe total)	Manganese (Mn total)	Ammonium (NH_4)	Bicarbonate (HCO_3)	Carbonat (CO_3)	Fluoride (F)	Chloride (Cl)	Bromide (Br)	Iodide (I)	Sulfate (SO_4)	Nitrate (NO_3)	Hydrogen Sulfide (HS)	Aluminium (Al)	Antimony (Sb)	Arsenic (As)	Beryllium (Be)	Lead (Pb)	Cadmium (Cd)	Cesium (Cs)	Chrome (Cr)	Cobalt (Co)	Copper (Cu)	Lithium (Li)	Molybdenum (Mo)	Nickel (Ni)	Mercury (Hg)	Rubidium (Rb)	Selenium (Se)	Uranium (U)	Vanadium (V)	Zinc (Zn)	Tin (Sn)	m-Silic acid (H_2SiO_3)	o-Boric acid (H_3BO_3)
Austria	61/0	59/0	62/0	62/0	41/2	37/6	45/9	29/9	44/4	60/0	9/2	51/1	61/0	26/2	22/10	60/2	19/18	21/1	20/12	4/13	26/3	2/8	10/20	3/23	3/1	18/13	5/12	19/11	40/0	9/1	7/16	8/13	11/0	4/16	8/9	8/4	17/7	1/10	49/0	44/0
Bosnia and Herzegovina	25/0	21/0	27/0	26/0	20/0	5/1	19/1	17/2	15/2	27/0	10/1	14/2	27/0	10/2	12/1	26/1	21/2	3/0	13/2	2/2	9/2	0/2	13/5	8/5	1/1	12/3	4/1	14/3	15/2	0/3	6/2	7/4	8/2	6/3	3/0	0/3	17/1	1/1	4/0	1/1
France	220/0	214/0	219/0	220/0	0/0	0/0	0/0	0/0	0/0	211/0	0/0	0/0	219/0	0/0	0/0	215/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Iceland	3/0	3/0	3/0	3/0	3/0	3/0	2/1	3/0	0/0	3/0	0/0	3/0	3/0	3/0	3/0	3/0	1/0	3/0	3/0	3/0	3/0	0/0	1/2	1/2	0/0	1/2	0/3	3/0	3/0	3/0	1/2	1/2	3/0	3/0	0/3	3/0	3/0	1/2	0/0	0/0
Italy	225/0	225/0	229/0	227/0	23/0	0/0	0/0	0/0	32/0	218/0	10/0	65/0	227/0	11/0	0/0	225/0	5/1	16/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	25/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	199/0	98/0
Poland	40/0	40/0	40/0	37/3	31/0	25/7	40/0	31/8	25/6	40/0	7/8	37/0	40/0	29/7	22/12	40/0	19/16	11/8	16/15	7/13	12/13	3/8	11/13	4/18	0/0	6/14	8/19	18/12	34/1	8/6	12/15	5/15	0/0	3/18	0/2	5/11	25/5	0/1	30/0	25/3
Portugal	17/0	9/0	16/0	16/0	5/0	6/1	10/0	5/1	3/2	16/0	4/0	13/0	17/0	5/0	2/0	14/2	11/0	7/1	5/0	1/1	3/2	2/1	4/0	2/1	4/1	4/1	1/2	3/1	8/0	5/0	1/2	0/1	4/1	3/1	2/1	4/1	4/0	0/2	17/0	8/0
Romania	8/0	7/0	8/0	8/0	0/0	0/0	1/0	0/0	1/0	9/0	0/0	1/0	9/0	0/0	1/0	8/0	0/0	5/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Serbia	40/0	38/0	40/0	39/1	22/0	9/0	28/3	23/6	13/6	39/0	6/4	25/4	40/0	11/8	12/2	22/3	4/0	4/7	3/1	19/4	3/1	5/7	3/8	6/0	7/2	3/1	6/6	22/2	3/1	5/6	2/8	12/1	2/3	3/0	5/0	16/6	3/0	5/0	4/0	0/0
Slovenia	33/0	32/1	33/0	33/0	29/0	0/0	18/14	22/9	20/13	33/0	0/0	27/3	31/2	17/11	10/19	31/2	6/26	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	28/1	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	33/0	24/5
Spain	85/0	79/0	85/0	85/0	9/0	0/0	54/0	43/0	75/0	85/0	52/0	73/0	85/0	0/0	0/0	84/0	76/0	13/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	38/0	0/0	0/0	0/0	0/0	0/0	0/0W	0/0	0/0	0/0	0/0	0/0

Natural mineral waters - Number of considered analyses

number of analyses / number of analyses below detection limit	Sodium (Na)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	Strontium (Sr)	Barium (Ba)	Iron (Fe total)	Manganese (Mn total)	Ammonium (NH_4)	Bicarbonate (HCO_3)	Carbonat (CO_3)	Fluoride (F)	Chloride (Cl)	Bromide (Br)	Iodide (I)	Sulfate (SO_4)	Nitrate (NO_3)	Hydrogen Sulfide (HS)	Aluminium (Al)	Antimony (Sb)	Arsenic (As)	Beryllium (Be)	Lead (Pb)	Cadmium (Cd)	Cesium (Cs)	Chrome (Cr)	Cobalt (Co)	Copper (Cu)	Lithium (Li)	Molybdenum (Mo)	Nickel (Ni)	Mercury (Hg)	Rubidium (Rb)	Selenium (Se)	Uranium (U)	Vanadium (V)	Zinc (Zn)	Tin (Sn)	m-Silic acid (H_2SiO_3)	o-Boric acid (H_3BO_3)
Austria	26/0	24/0	28/0	28/0	11/0	12/2	18/6	12/6	10/7	28/0	1/3	20/3	27/1	6/1	5/7	28/0	18/5	0/1	7/7	0/7	8/6	0/4	1/13	1/13	2/1	4/10	0/6	8/7	11/0	1/5	3/7	0/10	4/0	2/7	7/0	0/6	7/8	0/4	12/0	9/2
Bosnia and Herzegovina	10/0	6/0	10/0	10/0	7/0	3/1	8/0	8/0	5/0	10/0	4/0	7/0	9/0	3/0	3/0	9/1	8/0	0/0	3/1	0/0	1/1	0/1	3/2	2/2	0/0	3/2	2/0	7/0	4/0	0/1	2/0	1/1	2/0	1/0	0/0	1/1	5/0	0/0	1/0	2/0
Denmark	9/0	8/0	9/0	9/0	1/0	3/0	6/3	4/5	9/0	9/0	0/1	9/1	11/0	1/0	1/0	12/0	6/5	0/1	1/0	1/0	2/2	0/1	1/0	0/1	0/0	0/1	1/2	1/0	0/0	0/0	5/2	1/0	0/0	0/1	0/0	0/0	1/0	0/0	1/0	1/0
France	30/0	30/0	30/0	30/0	0/0	0/0	0/0	0/0	0/0	31/0	0/0	0/0	31/0	0/0	0/0	31/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Hungary	200/0	172/0	205/0	204/0	24/0	104/0	219/0	207/0	214/0	220/0	28/0	124/0	213/0	103/0	103/0	213/0	217/0	88/0	35/0	85/0	150/0	17/0	99/0	109/0	4/0	104/0	22/0	110/0	79/0	23/0	96/0	97/0	15/0	90/0	17/0	18/0	106/0	1/0	92/0	190/48
Lithuania	40/0	40/0	40/0	40/0	24/0	33/0	40/0	37/0	40/0	40/0	38/0	39/0	40/0	30/6	10/7	40/0	1/39	5/5	21/7	1/35	2/35	0/4	6/34	0/40	0/5	4/35	5/12	10/28	9/7	3/12	4/35	10/28	0/0	1/33	0/8	7/9	12/19	0/8	9/0	25/2
Poland	56/0	56/0	56/0	56/0	3/0	3/0	53/0	56/0	3/0	56/0	8/21	3/0	61/0	0/3	2/1	57/1	2/1	0/0	1/2	1/2	1/2	0/3	0/3	0/3	0/0	1/2	3/0	1/2	2/1	0/3	3/0	1/2	0/0	1/2	0/0	1/2	3/0	0/3	3/0	3/0
Portugal	17/0	17/0	17/0	17/0	2/0	8/4	12/0	10/2	4/8	17/0	1/0	12/4	17/0	12/0	8/4	16/0	10/6	1/0	3/0	6/3	7/5	7/3	9/3	9/2	0/2	5/7	3/9	6/6	12/0	7/3	7/5	0/1	0/1	0/1	0/0	0/10	12/0	1/9	17/0	12/0
Serbia	14/0	14/0	15/0	15/0	9/0	6/0	11/3	8/2	5/1	15/0	0/1	10/1	14/0	7/0	8/0	12/1	0/0	8/0	7/0	10/2	7/0	7/1	5/0	8/0	8/0	4/0	8/1	9/0	7/0	8/0	0/1	8/0	8/0	7/0	8/0	11/1	7/0	0/0	0/0	0/0
Slovenia	8/0	7/0	8/0	8/0	2/0	0/0	3/1	3/0	3/0	8/0	0/0	7/0	8/0	7/0	0/0	7/1	2/2	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	2/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	6/0	1/0
Spain (including Catalonia)	57/0	57/0	58/0	58/0	1/0	0/0	51/0	38/0	49/0	58/0	50/0	51/0	58/0	0/0	0/0	58/0	56/0	15/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	37/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0