Environ Geochem Health (2017) 39:483–496
DOI 10.1007/s10653-016-9829-x

ORIGINAL PAPER

Physicochemical fingerprinting of thermal waters of Beira Interior region of Portugal

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Received: 15 September 2015 / Accepted: 26 April 2016 / Published online: 3 May 2016

Abstract Mineral natural waters and spas have been used for therapeutic purposes for centuries, with Portugal being a very rich country in thermal waters and spas that are mainly distributed by northern and central regions where Beira Interior region is located. The use of thermal waters for therapeutic purposes has always been aroused a continuous interest, being dependent on physicochemical fingerprinting of this type of waters the indication for a treatment in a specific pathological condition. In the present work, besides a literature review about the physicochemical composition of the thermal waters of the Beira Interior region and its therapeutic indications, it was carried out an exhaustive multivariate analysis—principal component analysis and cluster analysis—to assess the correlation between different physicochemical parameters and the therapeutic indications claims described for these spas and thermal waters. These statistical methods used for data analysis enables classification of thermal waters compositions into different groups, regarding to the different variable selected, making possible an interpretation of variables affecting water compositions. Actually, Monfortinho and Longroiva are clearly quite different of the others, and Cró and Fonte Santa de Almeida appear together in all analysis, suggesting a strong resemblance between these waters. Thereafter, the results obtained allow us to demonstrate the role of major components of the studied thermal waters on a particular therapeutic purpose/indication and hence based on compositional and physicochemical properties partially explain their therapeutic qualities and beneficial effects on human health. This classification agreed with the results obtained for the therapeutic indications approved by the Portuguese National Health Authority and proved to be a valuable tool for the regional typology of mineral medicinal waters, constituting an important guide of the therapeutic armamentarium for well and specific-oriented pathological disturbs.

Keywords Thermal water · Physicochemical composition · Therapeutic indications · Beira Interior · Portugal · Multivariate analysis

Electronic supplementary material The online version of this article (doi:10.1007/s10653-016-9829-x) contains supplementary material, which is available to authorized users.

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Introduction

Portugal is one of the richest European countries in mineral medicinal waters, and the majority of the spas are located inland in the northern and central regions. Thermal waters originate from the subsoil, which are generated in specific geological conditions and present "physicochemical dynamism" and share three fundamental characteristics: natural origin from the earth "springs," bacterial purity and therapeutic potential (Ghersetich et al. 2000; Matz et al. 2003). Most thermal waters originate from the water resulting from precipitation, and with its deep infiltration, these waters acquire particular characteristics, depending on the mineralogical composition of the geological formations that the waters flow through. In fact, the geological variability in Portugal enables the occurrence of thermal waters with a high diversity properties (APRH 2014). One of the richest regions in respect with number and variety of natural springs is Beira Interior some of which with proven medicinal properties that were known since ancient times (Lepierre 1930).

Beira interior is located in central region of Portugal with an area of 28 199 km^2 that reaches from the international border with Spain to the Atlantic Ocean and integrates the Hesperian massif that emerged since the end of the Paleozoic and assumes as a vast mineral medicinal resources in its subsoil have been used, for therapeutic means, since Roman times (Picoto 1996; Rebelo et al. 2015).

Thermal waters are classified according to parameters such as temperature, osmotic pressure, radioactivity, chemical composition, and mineralization, with the latter two considered of greater importance (Alexandre and Malcata 2000). The various therapeutic effects described with thermal therapy have been attributed to its physicochemical composition, reason why they are usually classified as bicarbonated, sulfated, chlorided, sulfurous, hiposaline, and gasocarbonic waters, and this correlation has been the basis for the indication of the different thermal resorts for different disorders of several vital systems of the body, and it is precisely in this context that the existing data are more controversial. From a simplistic and reductionist point of view, most Portuguese thermal waters are described as weakly mineralized, sulfurous, bicarbonated or chlorinated and sodium type waters (Chambel et al. 2006; Lourenço and Ribeiro 2004; Lourenço et al. 2010). Although the physical–chemical characterization of thermal water is the better criteria to characterize the spa resorts, nowadays some of them are characterized according to their location (for example seaside or mountain area) (van Tubergen and van der Linden 2002).

In the past decades, an important change occur in the clinical use of thermal water for the treatment of several diseases in continental Europe, mainly due to the increase in randomized clinical trials mainly in the area of dermatology and rheumatology, which when supported by physicochemical and biological assays improves the prestige and the evidence-based practice all over the Europe (van Tubergen and van der Linden 2002). Several studies have been developed in the last decade correlating the different types of thermo-mineral waters used in European spas and its geochemistry and the indication for a specific therapeutic purpose (Rebelo et al. 2015). Although numerous studies on the origin and quality of Portuguese thermal waters based on hydrogeological characteristics have been made, none of them cross and correlates this information with the importance and therapeutic potential/indication of the region. In what concerns Portuguese mineral waters, and specifically Beira Interior thermal waters, only a few studies were carried out to characterize and describe the potential and hydrochemistry of these waters and its beneficial effects on human health (Araujo and Coutinho 2012; Rebelo et al. 2010, 2011, 2015).

In the present work, a literature review was undertaken in order to create an index of information of physicochemical composition of thermal waters of the Beira Interior region and its therapeutic indications, followed by an exhaustive statistical analysis to assess the correlation between the different physicochemical parameters and the therapeutic indications described for that thermal waters.

Materials and methods

The data of the physicochemical characterization and therapeutic indication of the thermal waters of Beira Interior region of Portugal were obtained from the responsible Portuguese organisms Direção Geral de Energia e Geologia (DGEG) and Direção Geral de Saúde (DGS). Data correspond to eight thermal spas: Caldas da Cavaca, Caldas de Manteigas, Cró, Fonte Santa de Almeida, Longroiva, Monfortinho, Penamacor and Unhais da Serra (Fig. 1).

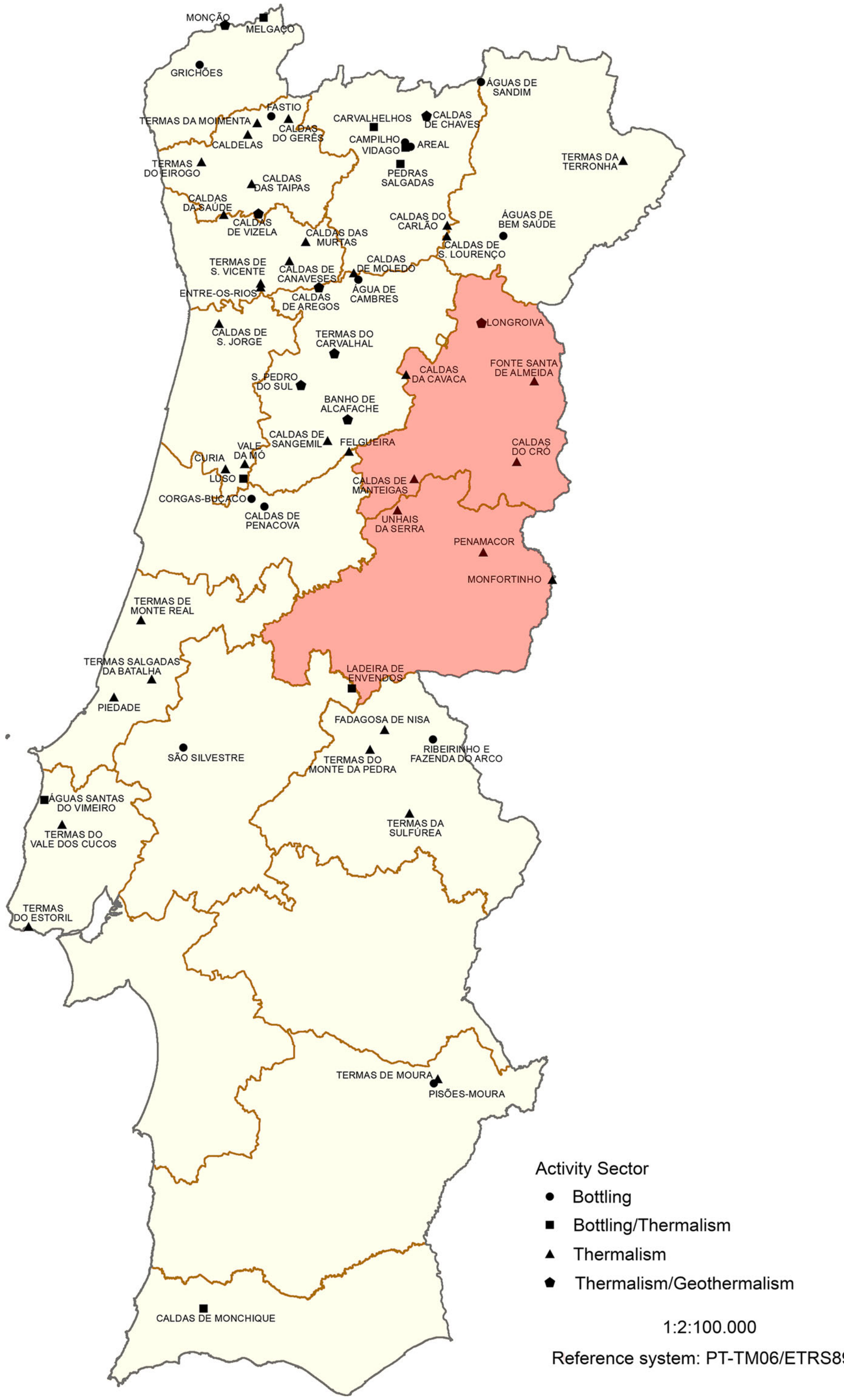


Fig. 1 Map with the distribution of the thermal spas in Portugal, including the eight thermal spas of the Beira Interior region of Portugal. Adapted from Direção Geral de Energia e Geologia

The data were analyzed and summarized in different tables considering the physicochemical composition and therapeutic indication.

The role of dominant components in those waters was carefully assessed, and putative correlations to specific therapeutic orientations were investigated by multivariate analysis. Principal component analysis (PCA) (Jolliffe 2002) and clusters analysis (Naes et al. 2002) were performed in order to evaluate the similarities and differences between the physicochemical composition as previously described for monitoring of water properties and interpretation of hydrogeochemical data (Rebelo et al. 2015).

For the PCA analysis the number of principal components (PCs) was chosen based on the Kaiser or eigenvalue criterion (Kaiser 1690) in which the number of PCs is chosen for an eigenvalue higher than 1, and as described by Jolliffe (2002).

The cluster analysis was made using the Ward's method after the reduction of the data to a small number of principal components using then the scores of the principal components as inputs to the cluster analysis (Naes et al. 2002).

Chemometric modeling was performed with MATLAB version 8.3 (MathWorks, Natick, MA, USA) and the PLS Toolbox version 7.5 (Eigenvector Research Inc., Wenatchee, WA, USA).

Results and discussion

Based on data collected it was possible to create and index with physicochemical composition of thermal waters of the Beira Interior region (Table 1) in order to characterize them and to highlight the role of the major components of the thermal waters to a particular therapeutic purpose and hence to obtain a useful tool for regional typology of the thermal waters in Portugal.

In Beira Interior region exists eight thermal spas with approved therapeutic indications by the DGS Portuguese authority (Table 2) namely endocrine metabolic, circulatory, respiratory, digestive, urinary, skin, rheumatic and musculoskeletal, in spite of the generic chemical cataloging attributed to these thermal waters (Table 3). In fact, most Portuguese thermal waters are described as weakly mineralized, sulfurous, bicarbonated or chlorided and sodium type waters as previously mentioned. The obtained results are in accordance with this classification with total mineralization between 41 and 402 mg/L. Cations are mostly represent by Na^+, followed by K^+ and Ca^{2+} Among the anions, HCO_3^- is the main dissolved specie, followed by Cl^-, F^- and SO_4^{2-}.

pH values range from 8.13 to 9.40, with exception of the Monfortinho thermal water (pH of 5.88), indicating alkaline nature thermal waters. The electrical conductivity ranges from 33.50 to 530 µS cm^{-1}.

The results were presented first by the therapeutic indications of the thermal waters and secondly the multivariate analysis was performed.

Therapeutic indications of Beira Interior thermal waters

Respiratory and rheumatic and musculoskeletal systems

Considering the Table 2, it is possible to infer that all these thermal waters exhibit as therapeutic indications the respiratory and rheumatic and musculoskeletal systems. These associations could be explained since they are all sulfurous waters, with the exception of the Monfortinho thermal water. Actually, the sulfur content, due to its antiseptic properties, justifies the application of these waters in the respiratory mucosa and its action on injured cartilage in certain rheumatic affections (Costantino et al. 2006; Jaltel 2001; Petraccia et al. 2004; Vu and Mitsunobu 2004, 2005). Salami et al. (2008) demonstrated the effectiveness of the application of the sulfurous thermal water in treatment of the recurrent upper respiratory infections, owing to their known mucolytic activity, trophic and antioxidant effects on respiratory mucosa. Also they pointed out that this type of water has an immunomodulant activity that contributes to the therapeutic effects of the water in upper airway inflammatory diseases (Salami et al. 2008). In addition, there is a set of musculoskeletal diseases which showed clinical improvement with thermal waters, such as rheumatoid arthritis, ankylosing spondylitis, fibromyalgia, osteoarthritis, low back pain and chronic pain (Ardıç et al. 2007; Bálint et al. 2007; Cantarini et al. 2007; Codish et al. 2005; Forestier 1999; Gaál et al. 2008; Guillemin et al. 2001; Gutembrunner et al. 2001; Karagülle et al. 2007a; Pittler et al. 2006; Silva et al. 2008; Verhagen et al. 2008). There is also evidence that these type of waters have a beneficial effect, namely on the amelioration of pain associated with those diseases (Falagas et al. 2009). Different

Table 1 Detailed physicochemical composition of thermal waters of the Beira Interior region (Data obtained from Direcção-Geral de Energia e Geologia)

Physicochemical composition	Caldas da Cavaca	Caldas de Manteigas	Cró	Fonte Santa de Almeida	Longroiva	Monfortinho	Penamacor	Unhais da Serra
Physicochemical constants and non-dissociated substances								
Temperature emergency (°C)	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*
pH	8.35	9.4	8.13	8.51	8.84	5.88	8.23	8.36
Conductivity (μS/cm)	343	208	437	446	530	33.5	310	281
Total alkalinity (in HCl 0.1 N)	129	12.7	27.5	31.1	152	6.9	154	71.1
Total hardness (in $CaCO_3$)	15	0,8	1.0	1.0	7.0	7.4	2.4	9.1
Silica (mg/L)	56	34.7	47.8	38.1	65	18.6	38	51
Total sulfur (in I_2 0.01 N)	3.6	6.8	16.9	12.1	46	–	13	11
Dry residue (mg/L)	262	168	302	314	384	36	231	219
Cations (mg/L)								
Litium (Li^+)	0.44	0.12	0.69	0.35	0.76	–	1.1	0.30
Sodium (Na^+)	80	47.1	103	109	128	3.4	77	66
Potassium (K^+)	2.8	0.9	2.7	1.8	7.5	0.62	1.3	2.2
Magnesium (Mg^{2+})	0.11	<0.05	0.21	0.17	<0.10	1.2	0.19	0.14
Calcium (Ca^{2+})	5.9	3.0	3.5	3.8	2.8	0.98	0.66	3.4
Iron (Fe^{2+})	<0.03	–	–	–	<0.03	<0.003	<0.03	<0.03
Ammonium (NH_4^+)	0.06	<0.04	0.06	0.11	0.7	<0.05	0.20	0.08
Anions (mg/L)								
Fluoride (F^-)	14	10.8	15.7	15.0	23	<0.1	3.9	14
Chloride (Cl^-)	21	6.8	33	36.9	45	3.8	13	24
Bicarbonate (HCO_3^-)	155	45	157	177	148	8.5	183	81.4
Sulfate (SO_4^{2-})	2.1	11.8	14.1	11.4	12	1.3	1.6	13
Nitrates (NO_3^-)	<0.3	<0.10	<0.20	0.21	<0.3	1.9	<0.3	<0.3
Nitrites (NO_2^-)	<0.010	<0.01	<0.01	<0.01	<0.010	<0.010	<0.010	<0.010
Total mineralization (mg/L)	285	190	381	402	493	41	285	209

nd not determined

studies confirm that sulfur can be absorbed through the skin and may have an analgesic effect as reviewed by Bender et al. (2005).

These thermal waters are also bicarbonated, which reinforce the therapeutic indication for respiratory system. Bicarbonate ions modify the acidic environment of tissues with phlogosis, promoting the removal of inflammation (Faílde 2006).

Skin

Two thermal waters from Monfortinho and Cró Spas present dermatologic therapeutic effects. Monfortinho thermal water is an oligomineral water whose main components are bicarbonate, sodium and silica, which together represent more than 50 % of their total mineralization that can justified its potential for dermatologic purpose. The Cró thermal water is a medium mineral water, being a sulfurous water and also being rich in silica and certain cations with important functions for the skin (K^+, Na^+ and Ca^{2+}) (Faílde and Mosqueira 2006). Thermal waters have demonstrated different effects on the skin, from cellular renewal, skin hydration, recovery of cutaneous barrier and keratolytic effects to antimicrobial activity, detergent property, antioxidant capacity and anti-inflammatory activity (Nunes and Tamura 2012), and also have been applied in the treatment with balneotherapy for different dermatologic diseases, such as atopic dermatitis, contact dermatitis, seborrhea, seborrheic dermatitis, psoriasis, and ichthyoses (Brockow et al. 2007; Chevutschi et al. 2007; Faílde

Table 2 Therapeutic indications of thermal waters of the Beira Interior (Direção Geral da Saúde 2014)

Thermal spas	Endocrine-metabolic	Circulatory system	Respiratory system	Digestive system	Urinary system	Skin	Rheumatic and musculoskeletal
Caldas da Cavaca			X	X			X
Caldas de Manteigas			X				X
Cró			X			X	X
Fonte Santa de Almeida			X				X
Longroiva			X				X
Monfortinho	X	X	X	X	X	X	X
Penamacor			X				X
Unhais da Serra		X	X	X			X

Table 3 Generic chemical attributes of the thermal waters of the Beira Interior region

Thermal spas	Weakly mineralized	Sulfurous	Bicarbonated	Sodic
Caldas da Cavaca	x	x	x	x
Caldas de Manteigas		x	x	x
Cró	x	x	x	x
Fonte Santa de Almeida	x	x	x	x
Longroiva	x	x	x	x
Monfortinho			x	x
Penamacor	x	x	x	x
Unhais da Serra	x	x	x	x

Adapted from the Direcção-Geral de Energia e Geologia

and Mosqueira 2006; Gambichler 2007; Ghersetich et al. 2000; Halevy and Sukenik 1998; Léauté-Labreze et al. 2001; Lotti and Ghersetich 1996; Matz et al. 2003; Merial-Kieny et al. 2011; Nunes and Tamura 2012; Panico and Imperato 2009; Tabolli et al. 2009). There are studies that show that sulfur can be absorbed through the skin and evokes various physiologic responses in the skin, such as vasodilation in the microcirculation, an analgesic effect, and inhibition of the immune response. Besides that, it also interacts with oxygen radicals in the deeper layers of the epidermis, producing sulfur and disulfur hydrogen, which may be transformed into pentathionic acid, and this may be the source of the antibactericidal and antifungal activity of this element (Matz et al. 2003).

Digestive system

Some of the studied thermal waters also exhibit therapeutic indication to the digestive system, namely Caldas da Cavaca and Unhais da Serra (Table 2). The bicarbonate ion is by excellence the key component for this indication, due to its antacid and inflammatory properties. However, crossing the physicochemical composition of these thermal waters, it is not possible to draw a correlation with this indication.

Other systems

Some thermal waters from Beira Interior region also exhibit therapeutic indications to endocrine-metabolic, circulatory, and urinary systems, namely Monfortinho thermal water. In fact, bicarbonate ion could contribute to other therapeutic orientations, namely endocrine-metabolic diseases and nephro-urinary system (Karagülle et al. 2007b), besides to the respiratory system (Diegues and Martins 2010). Moreover, the Unhais da Serra thermal water is indicated for circulatory and digestive systems as other authors describe for other SPAs (Carpentier and Satger 2009; Gutenbrunner et al. 2001; Ippolito et al. 2008; Mancini et al. 2003; Paran et al. 1998) .

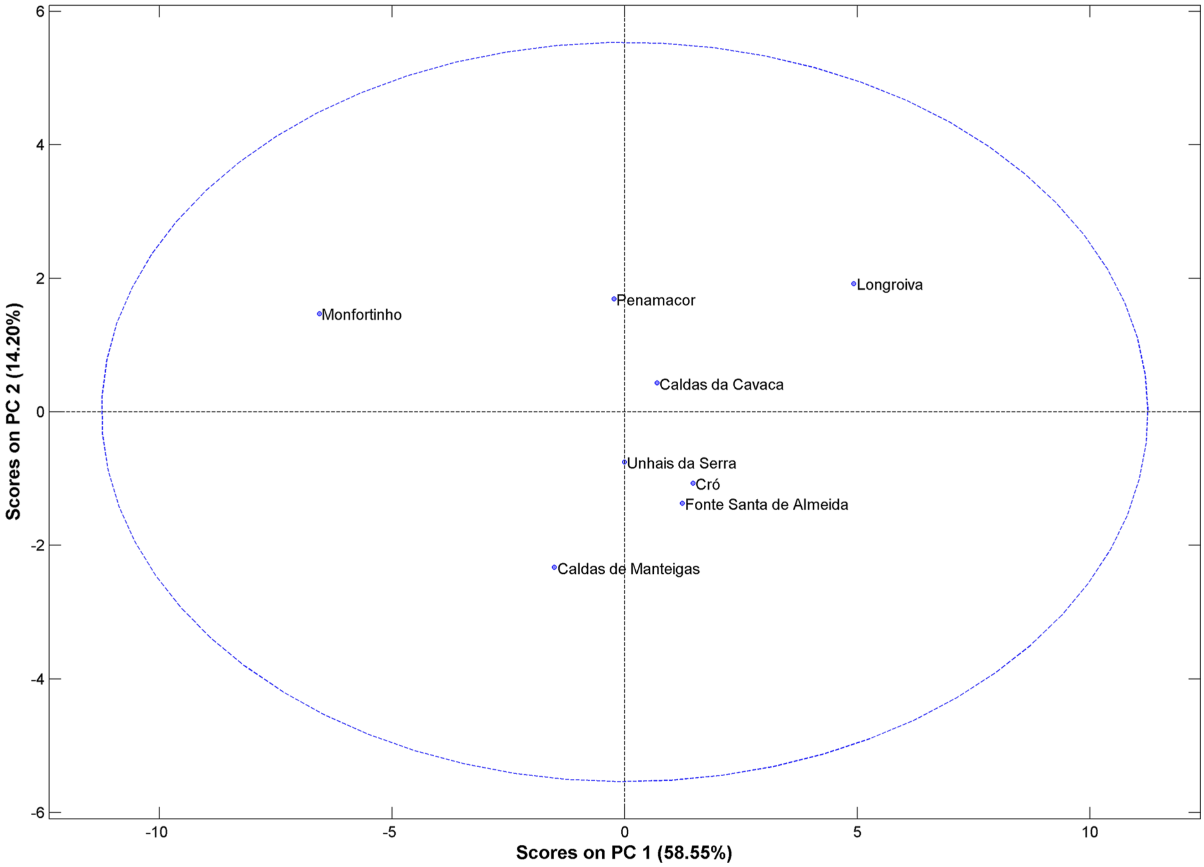


Fig. 2 PCA score plot of the first two components of the thermal waters with all variables included in absolute value (with the exception of the ion iron). The PCA retains 83.33 % of variance in the first three components. The data was autoscaled before the PCA analysis

Multivariate analysis

Principal component analysis (PCA)

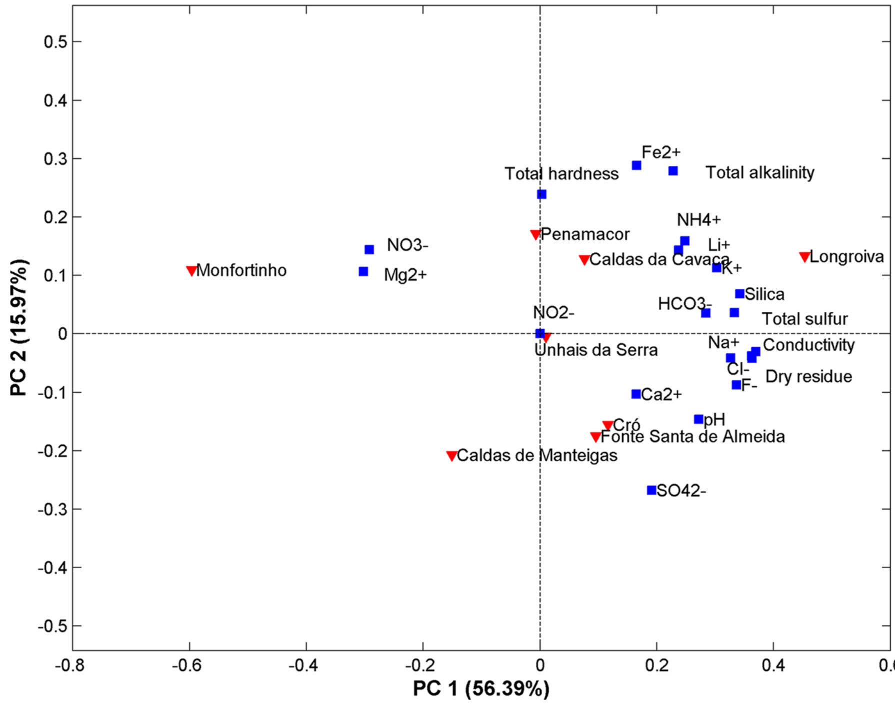
With the aim to evaluate potential closeness in terms of physicochemical composition between the thermal waters from the eight thermal spas, a multivariate analysis was carried out. The data used in the analysis comprised all the data from Table 1. In the cases that a variable was missing it was considered as not a number (NaN) and in the cases that appeared less than (<) the maximum value was considered.

When the data used was in absolute values, the data were autoscaled, i.e., the data matrix was autoscaled to mean zero unit variance, meaning that autoscaling subtracts the mean of each column (i.e., variable) of an input matrix and then divides each column by its standard deviation. If the values were used in percentages the data were mean centered, meaning that the data were centered in its average by subtracting the column (variable) mean from the value of each data entry (Martens and Naes 1992).

Initially, the analysis was performed using the entire data set with the exception of the iron since there were not enough data for this ion. A PCA with three principal components encompassing 83.33 % of the total variability was obtained. In the score plot presented on Fig. 2 the first two principal components can be seen. It can be observed that there is a clear separation of Monfortinho, Longroiva, and Penamacor thermal spas from the others indicating that the thermal waters in this spas are somewhat different.

To determine which variables have more influence in the categorization of thermal spas a biplot was performed (Fig. 3). The separation of Monfortinho thermal water is mainly due to the content in nitrate

Fig. 3 Biplot of the first two components of the PCA made with all variables in absolute value (with the exception of the ion iron)



and magnesium. Cró and Fonte de Almeida are more influenced by variables such as the pH, F^-, Ca^{2+} and SO_4^{2-}. By other side, Monfortinho thermal water exhibits a negative correlation with these parameters.

Remarkably, it can be seen that the Caldas da Cavaca thermal water, which presents therapeutic indication for the digestive system, is clearly influenced by bicarbonate ion, that could partially explain its vocation.

Other conclusions that can be drawn are that Caldas de Manteigas do not have any positive correlation with any of these variables.

The next step for the analysis was the use of only eight variables (silica, total sulfur, Na^+, K^+, Ca^{2+}, Cl^-, HCO_3^- and SO_4^{2-}) that were considered by us as more relevant for therapeutic purposes. A PCA was made with three components encompassing 98.44 % of the total variability. Results show a more evident differentiation of Longroiva thermal water as can be observed in Fig. 4. Identical results were obtained when total sulfur was excluded from the analysis (Supplementary Fig. 1). In fact, this thermal water exhibits the underlined above-described components in concentration levels higher than found in the other thermal waters, and therefore we believe that this thermal water could be used with efficacy for other therapeutic purposes.

Analyzing the biplot (Fig. 4), Longroiva thermal water is positively influenced by total sulfur, K^+, Cl^- and SO_4^{2-}. Cró, Fonte Santa de Almeida and Caldas da Cavaca thermal waters are positively affected by silica, Na^+, Ca^{2+} and HCO_3^-, and do not present correlation with Cl^-, total sulfur, K^+ and SO_4^{2-}. By other side, Monfortinho, Caldas de Manteigas, and Penamacor thermal waters exhibit a negative correlation with above referred variables.

Considering the biplot analysis performed excluding total sulfur (Fig. 5), and using percentages of the total mineralization, different results were obtained. Monfortinho thermal water is positively influenced by silica, strengthening the role of this element in such water. Cró and Fonte Santa de Almeida thermal waters are positively affected by Na^+. Caldas da Cavaca and Penamacor thermal waters are positively affected by HCO_3^- and negatively by SO_4^{2-}. Caldas de Manteigas and Longroiva thermal waters are positively affected by SO_4^2 and negatively by HCO_3^-.

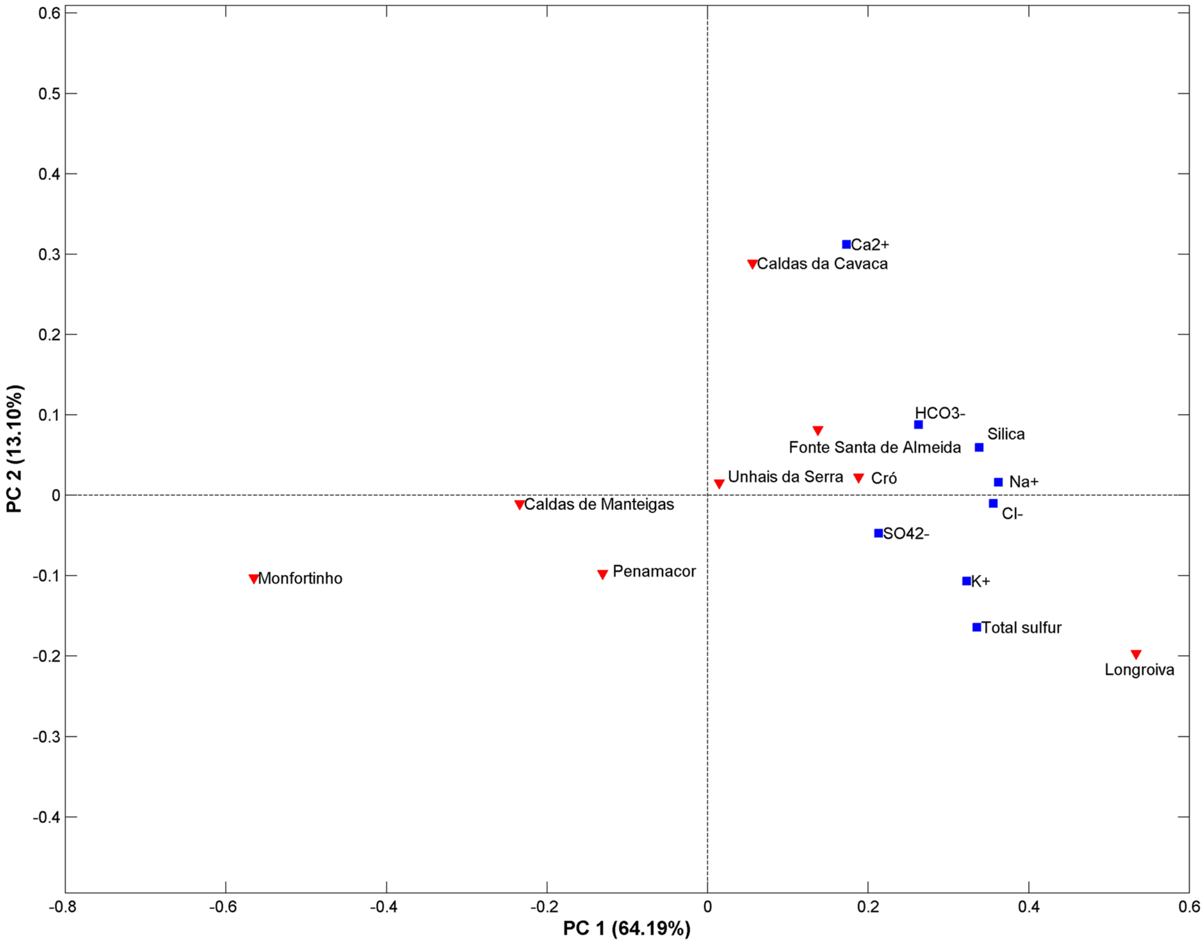


Fig. 4 Biplot of the first two components of the PCA made with 8 variables in absolute value

Cluster analysis

Next, a cluster analysis was performed using the Ward's method and based on the PCA first three components. In Fig. 6 the dendrogram of the cluster analysis shows that Longroiva, Monfortinho, and Penamacor thermal waters are more different from the others. Furthermore, there is a first group (red) that includes Caldas da Cavaca and Unhais da Serra and a second group (green) composed by the thermal waters of Cró, Fonte Santa de Almeida, and Caldas de Manteigas.

A cluster analysis using the cations (Fig. 7) and the anions (Fig. 8) were also performed using in this case the values in percentages of total mineralization. When considering the cations, it was verified that there is a big group that included the thermal waters of Longroiva, Penamacor, Fonte Santa de Almeida, Cró, Caldas de Manteiga and Caldas da Cavaca. Unhais da Serra, and surprisingly, Unhais da Serra appears alone. Therefore, it can be carried out the content of cations is similar between the majority of thermal waters. By the other side, in the cluster analysis using only the anions three groups can be found that comprise the thermal waters of Unhais da Serra, Fonte Santa de Almeida, and Cró; Longroiva and Caldas de Manteiga; and Penamacor and Caldas da Cavaca. The Monfortinho thermal water continues to present a peculiar composition. In this context, the contribution for the differentiation of the different thermal waters of Beira Interior could be attributed to the anions content.

Considering the eight variables above-mentioned, two different groups were obtained. The first one includes Fonte Santa de Almeida, Cró, Caldas da

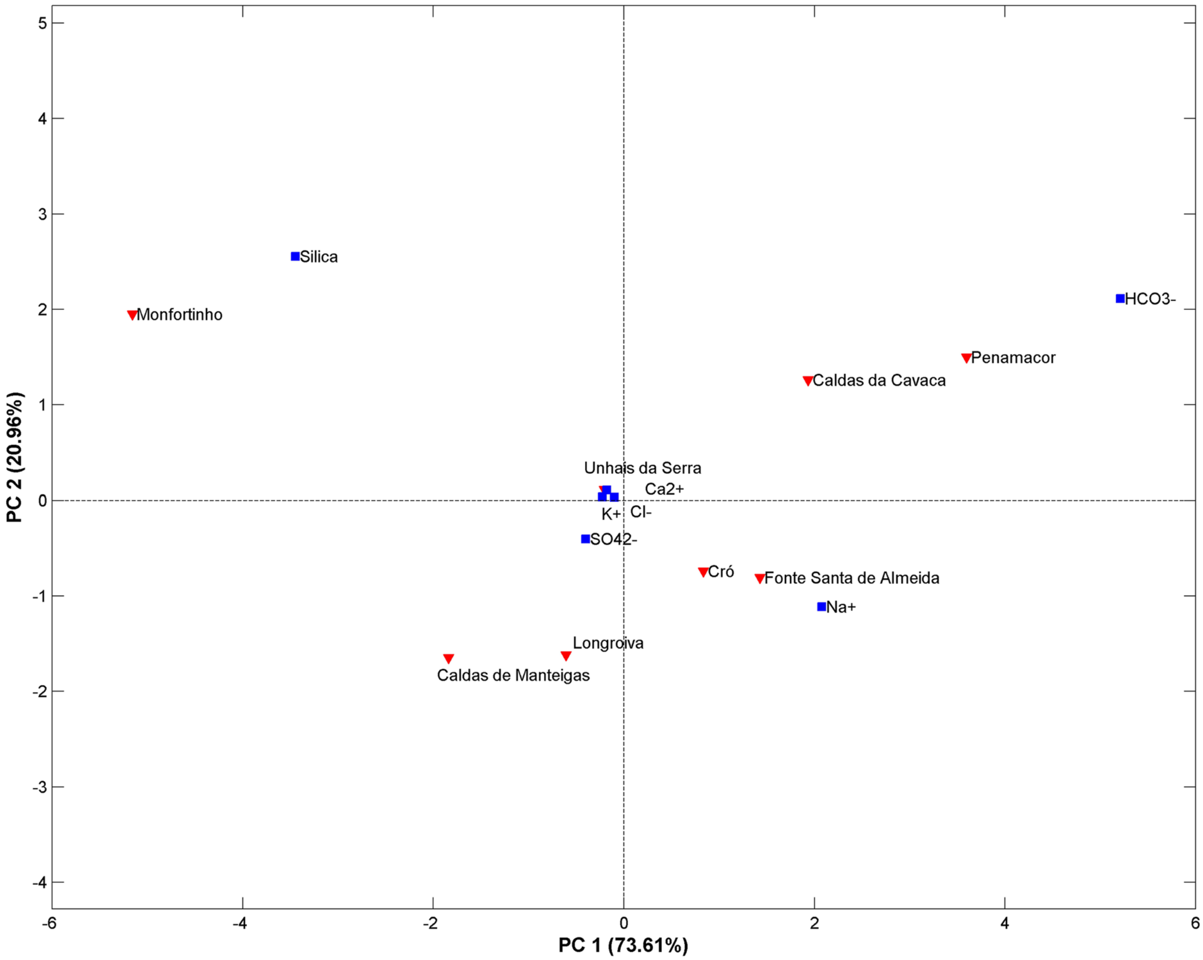


Fig. 5 Biplot of the first two components of the PCA made with 7 variables in percentage in relation to the total mineralization

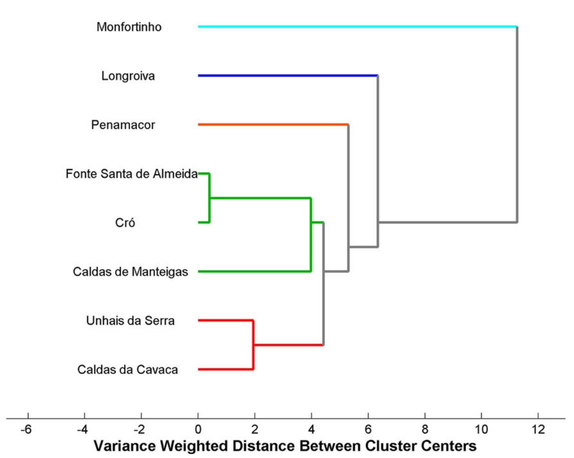


Fig. 6 Dendrogram of the Ward's method for cluster analysis when using all the variables in absolute value

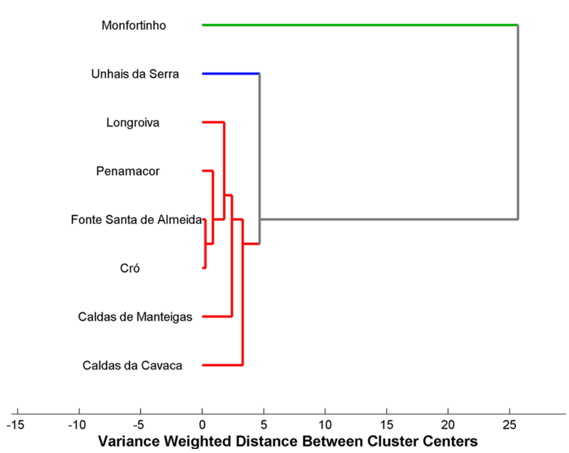


Fig. 7 Dendogram of the cluster analysis performed with the Ward's methods using the cations values in percentage in relation to the total mineralization

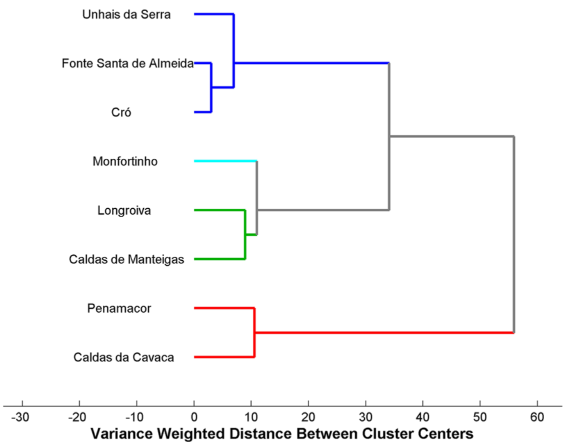


Fig. 8 Dendogram of the cluster analysis performed with the Ward's methods using the anions values in percentage in relation to the total mineralization

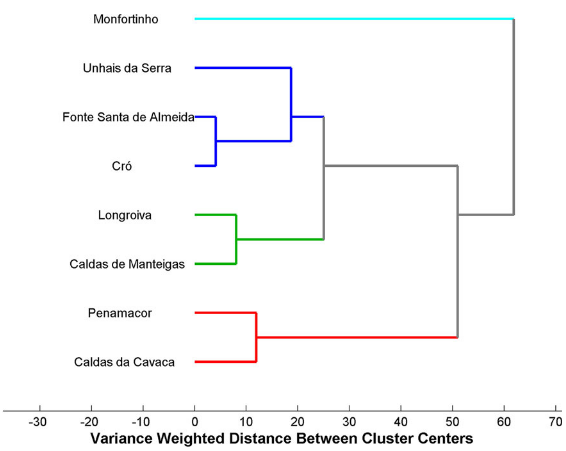


Fig. 9 Dendogram of the cluster analysis performed with the Ward's methods 7 variables in absolute values

Cavaca and Unhais da Serra, and the second one with Monfortinho and Caldas de Manteiga (Supplementary Fig. 2).

Excluding the variable total sulfur from the cluster analysis, three different groups were registered, composed by: Penamacor and Caldas da Cavaca; Caldas de Manteigas and Longroiva; Cró, Fonte Santa de Almeida and Unhais da Serra. Monfortinho thermal waters continue to be more different from all the others (Fig. 9).

It can be settled from this multivariate analysis that the waters from the thermal spas of Longroiva and Monfortinho are different from each other and from all the rest. In fact, some authors studied the relationship between the composition of the waters with the geographical situation of the springs (Gil et al. 1999), and in this particular case, these springs are located in opposite sites, namely Longroiva at north and Monfortinho at south of the Beira Interior region. Additionally, it is worth to mention that Fonte de Santa Almeida and Cró thermal waters of always appear together in the analysis indicating a strong resemblance, which is in line with the described correlations. The geographic proximity between the two springs could substantiate this association.

Conclusions

From this study, we can conclude that the thermal waters used to treat different disorders present different physicochemical identities. The mechanisms by which these diseases are treated in spa therapy are nowadays more fully justified and scientifically supported by the biological activities attributed to different chemical elements.

Based on our analysis, we suggests the role of the chemical elements that are essential to support a specific therapeutic indication. However, it is still not clear what are the ideal concentrations of such elements in order to attain a foreseeable response to treatment.

The common therapeutic indications of the thermal waters of Beira Interior region of Portugal (respiratory and rheumatic and musculoskeletal systems) are justified by the presence of dominant components, namely sulfur and bicarbonate (which also exhibits effects in the digestive, endocrine-metabolic diseases and nephro-urinary systems). The dermatologic therapeutic indications are clearly invoked by the presence of sulfur, silica and different cations, such as sodium, calcium and potassium. However, two special cases in Beira Interior should be highlighted, in compliance with the results generated from the multivariate analysis, which demonstrated that Monfortinho and Longroiva thermal waters have peculiar properties. Actually, Monfortinho thermal water is indicated for different therapeutic purposes, and in a certain extension it could be attributed to its low mineralization content (hyposaline water) and to the major components (bicarbonate, sodium and silica). The second case, the Longroiva thermal water that represents the water with higher content of key elements referred throughout this paper, surprisingly, only exhibits the classical therapeutic indications of the Beira Interior region of Portugal, that are respiratory and rheumatic and musculoskeletal systems The geographical situation could explain the extremes of the behavior of such thermal waters.

Another point that must not be forgotten is that the composition of each thermal water of the spas is a characteristic of that spa resort, and the extrapolation of the results to other spa resorts should be carried out cautiously. Additionally, the comparison with well-known French thermal waters is very difficult once those compositions are quite distinct to the thermal waters of our country, as also the classification system applied.

Furthermore, the idea to catalog generally the Portuguese thermal waters as being weakly mineralized, sulfurous, bicarbonate or chloride and sodium type waters is clearly wrong once these waters presents particular compositions. More specifically, the thermal waters of the Beira Interior region of Portugal have its own physicochemical behavior, which significantly influences the therapeutic vocations attributed to them. However, it is also difficult to directly assess the correlation between a specific therapeutic indication and the difference in its content in cations and anions, for example. It is also worth to mention that other factors should always bearing in mind when allocating the benefits of the thermal therapy: mechanical, thermal and other effects, such as undifferentiated general stimulation, resulting from a dietary care, physical and mental rest, including avoidance of everyday stress, and task-oriented exercises. Another important issue to an efficacious treatment is the duration of the thermal treatment implemented that must be studied and described in clinical protocols for each purpose or disease situation.

Thermal water therapy is safe and pleasant for patients and there are almost no side effects during or after treatment. As previously analyzed, different studies have shown that this therapy is effective to different indications and most of them deal with disorders of the locomotor system, but also skin diseases, respiratory affections, metabolic syndromes, and gastrointestinal conditions, or even with proved beneficial effect in cardiovascular disorders. In this perspective, and in our opinion, properly designed, sample-sized, and controlled clinical trials are required in various system affections to corroborate the approved therapeutic indications of these thermal waters and even add/suspend other therapeutic vocations.

In conclusion, the performed data analysis demonstrated to be an effective tool in the identification of the main structural interrelationships among the physicochemical parameters of thermal waters, enhancing their similarities and dissimilarities. The achieved categorization of the thermal of the Beira Interior region of Portugal could be used as a useful approach of therapeutic armamentarium to direct for well and specific-oriented pathological disturbs, besides the promotion of well-being associated with the thermalism.

Acknowledgments The authors would like to acknowledge the financial support provided by the Portuguese Foundation for Science and Technology (FCT) (PEst-OE/EGE/UI4056/2014) and Mais Centro "UDI/Transferência de IDT e Desenvolvimento do Produto" da UDI-IPG (CENTRO-07-CT62-FEDER-005026).

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