Hydromineral resources inventory mapping (NW Portugal and Galicia): outputs from TERMARED project (INTERREG IV-B SUDOE)

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Abstract

The TERMARED project supported the establishment and development of a thematic network of inter and trans-disciplinary transnational cooperation nature in the mineral and thermal water sectors. One of the main goals was to draw up a catalogue of a selected hydromineral resources in the SUDOE territory (in our case study the European regions involved were Galicia, NW Portugal, and SW of France). The selected natural springs has a potential background for balneotherapy/balneological purposes.

1 Introduction

Water resources have had an impact on the socioeconomic sustainability and development of society. The close relationship between water and human society has been essential throughout the history of civilizations (Mays [1]). Natural springs provide a source of valuable water resources at a regional level (e.g., LaMoreaux and Tanner [2], Carvalho and Chaminé [3], Margat, and van der Gun [4]). They are normally located in a singular geologic and morphotectonical framework, hydrogeochemical and isotopic signature, as well as exhibit distinctive gradients in rainfall and temperature.

Geographical Information Systems (GIS) based maps provide an accurate tool to improve the databases about hydromineral resources and the overall functioning of the groundwater systems, as well as supports the decision makers and managers to achieve an environmental sustainable use and management (e.g., Teixeira et al. [5], Chaminé et al. [6,7]). This approach is significant regarding the hydromineral systems of a given area, acting as resource of high economic importance considering its utilisation in the thermal spa and/or bottled water industry (e.g., LaMoreaux and Tanner [2], Carvalho [8,9,10], Carvalho and Chaminé [3], Carvalho et al. [11]).

2 TERMARED project

A comprehensive integrated hydromineral resources study has been carried out in the scope of the TERMARED project (INTERREG IV-B SUDOE programme) lead by "Xunta de Galicia". That project aimed the establishment of an interdisciplinary network of cooperation, focused on exchange and transfer knowledge in the thermal sector (in terms of medical hydrology); see details in TERMARED [12]. The main goal was the publication of an original catalogue of selected thermal waters in SUDOE region (Northern Portugal, Galicia and SW France). In addition, regional mapping studies were realized for inventorying hydromineral resources in northern-western of Iberian Peninsula, particularly in NW Portugal and Galicia regions. The regional hydrogeological framework of those areas are very similar (e.g., Carvalho [8,9], Delgado et al. [13], Corral et al. [14], and references therein).

To achieve the goal of identifying springs for further economic and tourism development, an extensive work was carried out, with collection and organisation of all previous data on the thermal occurrences in northern-western of Iberia (figure 1). Numerous bibliographic sources were used for both regions (e.g. NW Portugal: Henriques [15], Acciaiuoli [16], Almeida and Almeida [17], IGM [18], Calado [19], Carvalho [8,9], Bastos et al. [20], Carvalho et al. [11]; Galicia: Xunta de Galicia [21], Galdo [22], Rodríguez-Caro et al. [23], López-Geta et al. [24], Molinero et al. [25]; and references therein) and several fieldwork campaigns.

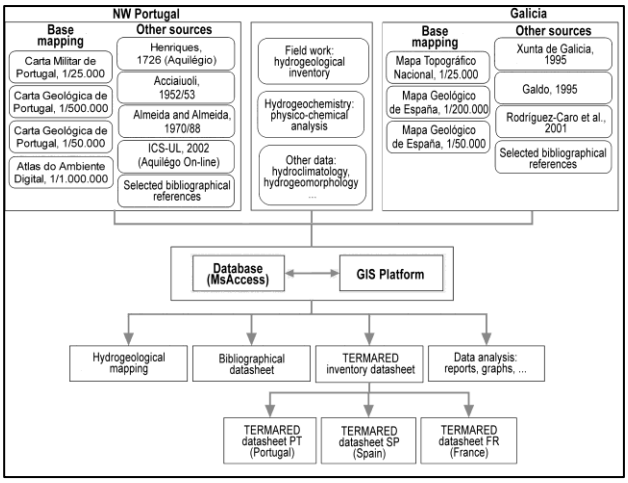

Figure 1. Methodological flow chart of mapping sources and inventory hydrological data of the site investigations (TERMARED project).

The GIS-based mapping methods that support the hydromineral inventory of the project TERMARED is presented from two key-regions, NW Portugal and Galicia. In addition, the general assessment permitted to record and map over 590 groundwater occurrences for NW of Iberia (figure 2). That inventory was supported by a carefully selected bibliographical analysis, fieldwork and desk studies.

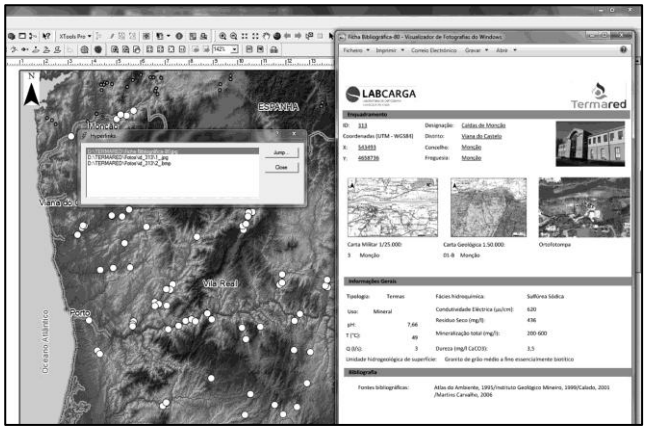

Figure 2. An example of the GIS output for the NW Portugal (adapted from Teixeira et al. [26]): 1. Application tool to create hyperlinks between features (line, point or polygon) and other files; 2. Hyperlink addressed to a file (image or text); 3. Visualisation of photo details for the water inventory; 4. Hydrogeological inventory datasheet (field and desk data); 5. Regional hydrogeological mapping.

A Geographical Database (GDB) was created to support the TERMARED project, and some of the results achieved with the creation of this database, combined with Geographical Information System (GIS) platform. The results of the field inventories were integrated into a database and simultaneously into a GIS platform, based on ArcGIS 9.3 software. This combined methodology allowed to cross-check and analyse several levels of information, namely climatology, geology, geomorphology, hydrogeology, hydrogeochemistry, as well as hydrohistorical issues, useful informations about hydromineral economy.

Figure 3. Hydrological datasheet of a selected site: Angueiro site (Monção), Minho/Miño River, on the NW Portugal and South Galicia border (adapted from TERMARED [12]).

Data from field inventories were integrated into a database that coupled GIS mapping and hydromineral water occurrences. The combined methodology allowed cross-checking and analysis of

several levels of features. The multi-analysis approach provided useful information regarding the coupling of hydromineral resources and GIS mapping.

At this stage, the data were loaded into a spatial database, which allowed the creation and autofill of a bibliographical datasheet for each point. It was also created a field datasheet, which were filled during the visit to the inventoried water points. The field data of these points were collected: accessibility, hydrogeological and hydroclimatological conditions, geomorphological features and conditions of use. This sheet included also the systematic recording of various water parameters at each sampling point, namely: water temperature (ºC), air temperature (ºC), pH, electric conductivity (µS /cm), relative humidity (%), flow rate, among others. Wherever possible this information was compared to data from regional and local reference literature.

The figure 4 shows the cover of the catalogue of the thermal springs of SUDOE region.

Figure 4. The book cover of the "Catálogo de manantiales termales del espacio SUDOE / Catálogo de nascentes termais do espaço SUDOE / Catalogue des sources thermales de l'espace SUDOE" edited by "Xunta de Galicia" (see the full reference in TERMARED [12]).

3 Concluding remarks

This work highlights the importance of hydromineral resources inventory and GIS based mapping as useful tools to support hydrological conceptualisation, as well as for a balanced decision-making focus on sustainable hydromineral resources management.

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References

[1] Larry Mays. Ancient water technologies. Springer, Dordrecht, 2010.

[2] Philip E. LaMoreaux, Judy Tanner. Springs and bottled waters of the world: ancient history, source, occurrence, quality and use. Springer, Berlin, 2003.

[3] Jean Margat, Jac van der Gun. Groundwater around the world: a geographic synopsis. CRC Press, Boca Raton, Florida, 2013.

[4] José Martins Carvalho, Helder I. Chaminé. Uma perspectiva sobre o valor acrescentado das Ciências da Terra nas indústrias do termalismo e do engarrafamento de água. In: Helder I. Chaminé, José Martins Carvalho (editores), O valor acrescentado das Ciências da Terra no termalismo e no engarrafamento da água. Artigos seleccionados do II Fórum Ibérico de Águas Engarrafadas e Termalismo. Edição do Departamento de Engenharia Geotécnica / Laboratório de Cartografia e Geologia Aplicada, Instituto Superior de Engenharia do Porto, Porto, pp. 11-23, 2007.

[5] José Teixeira, Helder I. Chaminé, José Martins Carvalho, Augusto Pérez-Alberti, Fernando Rocha. Hydrogeomorphological mapping as a tool in groundwater exploration. Journal of Maps, 9(2):263–273, 2013.

[6] Helder I. Chaminé, José Martins Carvalho, Maria José Afonso, José Teixeira, Liliana Freitas. On a dialogue between hard-rock aquifer mapping and hydrogeological conceptual models: insights into groundwater exploration. European Geologist Magazine, Journal of European Federation Geologists, 35:26–31, 2013.

[7] Helder I. Chaminé, Maria José Afonso, Liliana Freitas. From historical hydrogeological inventory through GIS mapping to problem solving in urban groundwater systems. European Geologist Magazine, Journal of European Federation Geologists, 38:33–39, 2014.

[8] José Martins Carvalho. Mineral and thermal water resources development in the Portuguese Hercynian Massif. In: David Banks, Sheila

Banks (editors), Hydrogeology of Hard Rocks, International Association of Hydrogeologists, IAH, Oslo, 24(1):548-561, 1993.

[9] José Martins Carvalho. Mineral water exploration and exploitation at the Portuguese Hercynian Massif. Environmental Geology, 27:252–258, 1996.

[10] José Martins Carvalho. Prospecção e pesquisa de recursos hídricos subterrâneos no Maciço Antigo Português: linhas metodológicas. Universidade de Aveiro. (PhD Thesis), 2001.

[11] José Martins Carvalho, Luís Coelho, João Carlos Nunes, Maria do Rosário Carvalho, João Garcia, Rita Cerdeira. Portugal Country Update 2015. Proceedings World Geothermal Congress, Melbourne, Australia, 2015.

[12] TERMARED. Catálogo de manantiales termales del espacio SUDOE / Catálogo de nascentes termais do espaço SUDOE / Catalogue des sources thermales de l'espace SUDOE. Xunta de Galicia, Santiago de Compostela, 2011.

[13] Jordi Delgado, Ricardo Juncosa, Rosa Meijide, A. Vázquez, V. Barrientos. Características termohidrogeoquímicas de las aguas subterráneas en Galicia. In: Helder I. Chaminé, José Martins Carvalho (editores), O valor acrescentado das Ciências da Terra no termalismo e no engarrafamento da água. Artigos seleccionados do II Fórum Ibérico de Águas Engarrafadas e Termalismo. Edição do Departamento de Engenharia Geotécnica / Laboratório de Cartografia e Geologia Aplicada, Instituto Superior de Engenharia do Porto, Porto, pp. 281-299, 2007.

[14] María del Mar Corral, Elena Galindo, C. Ontiveros, J. Díaz Muñoz. Hydrogeochemical areas as background for specific mineral and thermal waters of Spain. Environmental Earth Sciences, 73(6):2683-2697, 2015.

[15] Francisco da Fonseca Henriques. Aquilégio medicinal, em que se dá notícia das agoas de Caldas, de fontes, rios, poços, lagoas e cisternas do Reyno de Portugal e dos Algarves que, ou pelas virtudes medicinaes que tem, ou por outra alguma singularidade, são dignas de particular memória. Edição Officina de Musica, Lisboa (*http://purl.pt/22614*), 1726.

[16] Luiz de Menezes Acciaiuoli. Le Portugal hydrominéral. Direction Générale des Mines et des Services Géologiques, 2 volumes, Lisbonne, 1952/1953.

[17] Amaro de Almeida, João Duarte de Almeida. Inventário hidrológico de Portugal. Instituto de Hidrologia de Lisboa, 3 volumes (Trás-os-Montes e Alto Douro, Beira Alta; Minho), Lisboa, 1970/1988.

[18] IGM – Instituto Geológico Mineiro. Catálogo de recursos geotérmicos. Instituto Geológico Mineiro, Lisboa (Edição CD-rom), 1999.

[19] Carlos M. A. Calado. A ocorrência de água sulfúrea alcalina no Maciço Hespérico: quadro hidrogeológico e quimiogénese. Universidade de Lisboa (PhD Thesis), 2001.

[20] Cristiana Bastos, Maria Manuel Quintela, António Perestrelo de Matos. O novo aquilégio. Instituto de Ciências Sociais, Universidade de Lisboa. (*http://www.aguas.ics.ul.pt/*), 2002.

[21] Xunta de Galicia. Las aguas minerales en Galicia. Conselleria de Industria e Comercio, Santiago de Compostela, 1995.

[22] Fausto Galdo. Introducción a la historia de las aguas minerales de Galicia. Publicaciones do S.E.G./Grupo Interdisciplinar de Traballo R.M. Aller de Historia das Ciencias e das Técnicas en Galicia, Edicios do Castro, 1995.

[23] Juana Baeza Rodríguez-Caro, Juan Antonio López-Geta, Antonio Ramírez Ortega. Las aguas minerales en España: visión histórica, contexto hidrogeológico y perspectiva de utilización. Instituto Geológico y Minero de España, Madrid, 2001.

[24] Juan Antonio López-Geta, María del Mar Corral, Miguel Abolafia de Llanos, José Sánchez Guzmán, Laura Sanz López, Bárbara Sánchez Márquez. Mapa de las características físico-químicas de las aguas minerales y termales de España. In: Helder I. Chaminé, José Martins Carvalho (editores), O valor acrescentado das Ciências da Terra no termalismo e no engarrafamento da água. Artigos seleccionados do II Fórum Ibérico de Águas Engarrafadas e Termalismo. Edição do Departamento de Engenharia Geotécnica / Laboratório de Cartografia e Geologia Aplicada, Instituto Superior de Engenharia do Porto, Porto, pp. 265-280, 2007.

[25] Jorge Molinero, Felip Ortuño, Margarida Valverde (editores). Las aguas subterráneas en España antes las Directivas Europeas: retos y perspectivas. Instituto Geológico y Minero de España. Madrid, 2008.

[26] José Teixeira, Catarina Rodrigues, Patrícia Moreira, Rui Santos Silva, Ana Pires., Liliana Freitas, José Martins Carvalho, Helder I. Chaminé. A importância das bases de dados geográficas na inventariação de recursos hidrominerais: o projecto TERMARED (INTERREG IV-B SUDOE). In: Carlos Bateira, Laura Soares, Alberto Gomes, Helder I. Chaminé (editores), Proceedings/Actas do V Congresso Nacional de Geomorfologia,

Associação Portuguesa de Geomorfólogos, Porto. pp. 427- 429, 2010.