# Urban groundwater mapping techniques: importance on urban water cycle

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## Abstract

This work aims to present the importance of urban groundwater mapping techniques. In order to achieve that goal a GIS multi-technique approach, using hydroclimatology, geomorphology, hydrogeology, historical geography, hydrotoponymy and remote sensing, was performed to assess groundwater systems in urban areas of NW Portugal.

## 1 Introduction

An urban population demands high quantities of energy and raw materials, and removal of waste, some of which turns into environmental pollution (Marsalek et al. [1]). Urbanisation is a worldwide trend, with more than 50% of the world's population currently living in cities. Moreover, nearly 70% of the European population lives in urban areas (UN-Habitat [2]). The urban water cycle provides a worthy conceptual and unifying basis for studying the water balance and conducting water inventories of urban areas. The concept of the urban water cycle demonstrates the connectivity and interdependence of urban water resources and human activities, and the need for integrated sustainable management (Marsalek et al. [1]). In addition, currently is significant the study of the role of climate, geology, geomorphology, land use, among others features, as well as the man activities on urban areas (e.g., Sherlock [3], Leopold [4] Leggett [5], Ehlen et al. [6], Wilkinson [7]).

The need for provision of safe water, sanitation and drainage systems are key elements which are vital to the understanding and management of groundwater resources in urban environments. Human activity such as land-use change may exert a stronger influence on terrestrial hydrology than climate change (Taylor et al. [8]). Integrated water resources management poses not only scientific, but also technical, socio-economic, cultural and ethical challenges. In this context, integrated urban water resources management provides the opportunity to optimize the whole urban water system and to minimise water consumption, costs and energy and recognises that different types of water can be used for different purposes (e.g., Bahri [9], UNESCO [10], Braga et al. [11], Sharp and Hibbs [12], Schirmer et al. [13], Foster et al. [14]). This increasing pressure on groundwater resources under conditions of global anthropogenic and climatic variability and change often requires an integrated multidisciplinary approach to address the scientific issues concerning these resources. Besides, hydrogeological data acquisition in urban areas is rather difficult and so the integration of geotectonics, geomorphology and hydrogeography is of crucial importance. In that perspective urban geoscience needs to evolve to a new paradigm of a smart urban geoscience, particularly related to geology, hydrology, groundwater, rock and soil geotechnics, urban hydraulics, environment, geohazards, geoheritage and geoarchaeology issues (Chaminé et al. [15]).

This work intends to present urban groundwater systems, namely to evaluate the groundwater yields that might be available for non-potable uses, such as irrigation of parks and lawns, street cleaning and fire-fighting. To exemplify that approach Porto and

Penafiel urban areas located in NW Portugal were chosen. This can provide guidelines for the planning and management of water resources exploitation in an equitable, sustainable and ethical manner.

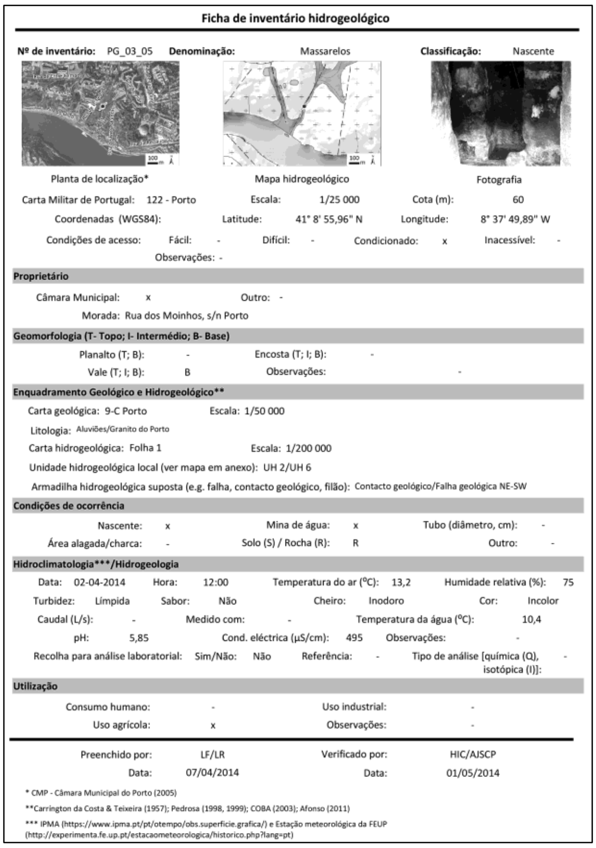
## 2 Urban groundwater mapping

Several techniques were integrated in this study, hydroclimatology, geomorphology, hydrogeology, historical geography, hydrotoponymy and remote sensing. Field and desk techniques for hydrogeological mapping, surface and subsurface geological fieldwork were applied and cartographic issues were developed through the application of GIS based tools (e.g., Struckmeier and Margat [16], Zaporozec [17], Witkowski et al. [18], Howard [19], Assaad et al. [20], Teixeira et al. [21], and references therein).

A comprehensive bibliographical analysis of historical documents related to groundwater use was performed and a groundwater inventory, related to the early 20th century, was compiled and cross-checked from historical sources. Moreover, recent hydrogeologic and hydrotoponymical inventories have been performed (e.g., Afonso et al. [22, 23], Freitas et al. [24]), Figure 1.


Figure 1. Several aspects of the fieldwork campaigns (Porto and Penafiel urban areas): Measuring temperature, pH and electrical conductivity in a fountain (a); georeferencing public washing places (b and c); measuring the piezometric level in a dug-well (d); georeferencing fountains (e) locating a water mine (f).

Recently several groundwater and hydrohistorical inventories have been performed in Porto urban area, supported by field and desk techniques for urban hydrogeology and GIS-based mapping (e.g., Afonso et al. [23], Chaminé et al. [25], Freitas et al. [24], Chaminé et al. [15], and references therein), Figure 2. These studies in Porto city, for example, were supported by a comprehensive cross-check and analysis of historical sources and old mapping related to groundwater use. In addition, more than 410 water sites were inventoried and over 100 sites are currently being monitored for field hydrogeology, hydrogeochemistry, groundwater ecotoxicology, geomicrobiology, engineering geosciences, subterranean geology, and radiological studies regarding a smart urban geoscience approach.



**Ficha de inventário hidrogeológico**

**Nº de inventário:** PG_03_05 **Denominação:** Massarelos **Classificação:** Nascente

Planta de localização* | Mapa hidrogeológico | Fotografia

Carta Militar de Portugal: 122 - Porto Escala: 1/25 000 Cota (m): 60
Coordenadas (WGS84): Latitude: 41° 8' 55,96" N Longitude: 8° 37' 49,89" W
Condições de acesso: Fácil: - Difícil: - Condicionado: x Inacessível: -
Observações: -

**Proprietário**
Câmara Municipal: x Outro: -
Morada: Rua dos Moinhos, s/n Porto

**Geomorfologia (T- Topo; I- Intermédio; B- Base)**
Planalto (T; B): - Encosta (T; I; B): -
Vale (T; I; B): B Observações: -

**Enquadramento Geológico e Hidrogeológico****
Carta geológica: 9-C Porto Escala: 1/50 000
Litologia: Aluviões/Granito do Porto
Carta hidrogeológica: Folha 1 Escala: 1/200 000
Unidade hidrogeológica local (ver mapa em anexo): UH 2/UH 6
Armadilha hidrogeológica suposta (e.g. falha, contacto geológico, filão): Contacto geológico/Falha geológica NE-SW

**Condições de ocorrência**
Nascente: x Mina de água: x Tubo (diâmetro, cm): -
Área alagada/charca: - Solo (S) / Rocha (R): R Outro: -

**Hidroclimatologia***/Hidrogeologia**
Data: 02-04-2014 Hora: 12:00 Temperatura do ar (ºC): 13,2 Humidade relativa (%): 75
Turbidez: Límpida Sabor: Não Cheiro: Inodoro Cor: Incolor
Caudal (L/s): - Medido com: - Temperatura da água (ºC): 10,4
pH: 5,85 Cond. eléctrica (μS/cm): 495 Observações: -
Recolha para análise laboratorial: Sim/Não: Não Referência: - Tipo de análise [química (Q), isotópica (I)]: -

**Utilização**
Consumo humano: - Uso industrial: -
Uso agrícola: x Observações: -

Preenchido por: LF/LR Verificado por: HIC/AJSCP
Data: 07/04/2014 Data: 01/05/2014

* CMP - Câmara Municipal do Porto (2005)
**Carrington da Costa & Teixeira (1957); Pedrosa (1998, 1999); COBA (2003); Afonso (2011)
*** IPMA (https://www.ipma.pt/pt/otempo/obs.superficie.grafica/) e Estação meteorológica da FEUP (http://experimenta.fe.up.pt/estacaometeorologica/historico.php?lang=pt)

Figure 2. Hydrogeological field inventory datasheet: an example for the so-called *Nascente de Massarelos* spring, Porto urban area.

In the case of Porto city the groundwater inventory comprised 34 springs, 32 springs/fountains, 64 fountains, 147 dug-wells, 55 boreholes, 16 masonry reservoirs and 65 shallow underground water galleries (Figure 3). "In situ" measurements covered 13 springs, 20 springs/fountains, 31 fountains, 2 dug-wells, 23 boreholes and 1 shallow underground water gallery. The temperature of these waters has a median value of 15.7ºC. These waters are slightly acidic with a median pH value of 6.9 (pH values ranged from 4.6 to 8.2), having boreholes the lowest values (median 5.8). Electrical conductivity measurements ranged from 185 to 663µS/cm, which indicate the presence of medium mineralised waters. Springs showed the highest levels, with a median value of 505µS/cm. Concerning flow rates, these are generally very low, less than 216m$^3$/day, being 26m$^3$/day the median value. Boreholes showed the highest values (median 52m$^3$/day). Although these flow rates are low, they can contribute to the city water supply (details in Afonso et al. [23, 24, 26]).

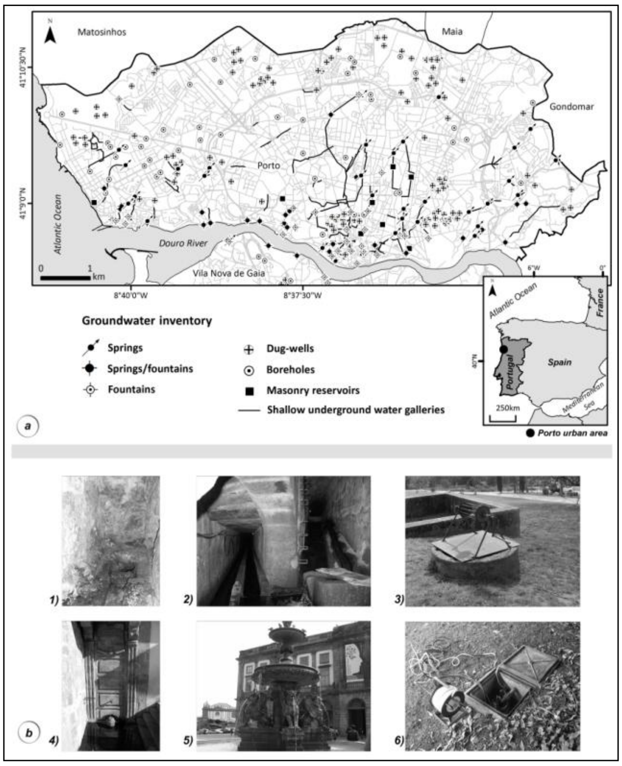



Figure 3. An example of urban groundwater inventory (a) and several aspects of the water sampled points (b): b1 - *Bicas de Massarelos* spring, b2 - *Paranhos* and *Salgueiros* underground water galleries, b3 - *Bonjóia* dug-well, b4 - *Colher* spring/fountain, b5 - *Leões* fountain, b6 - private borehole (Adapted from Afonso et al. [26], Chaminé et al. [15], Freitas et al. [24]).

## 3 Concluding remarks

New challenges are emerging related to the mapping, assessment, abstracting and modelling of the urban water cycle. Developing these types of inventories mapping in urban centres is a major challenge and vital to develop a comprehensive inventory of urban utility groundwater use, in order to water resources planning, to assess water supply security, and for investment strategies. In addition, must be highlighted the concept of the urban water cycle stress a holistic integrated sustainable management related to climatic, physiographic, environmental, and sociocultural conditions.

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