Paranhos spring galleries catchworks from Porto urban area (NW Portugal): a geoenvironmental approach

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ABSTRACT

This multidisciplinary study presents the preliminary results of the structural geology and geotechnical studies of a granitic rock-mass block delimitation. In addition, hydrogeological and ecotoxicological methods were used to assess the nature and suitability for use of groundwater from spring horizontal galleries catchworks located in Porto urban area. These springs represented one of the main water supplies of Porto city, for more than five centuries. For the characterisation of the granitic rock-mass, the scanline sampling technique of discontinuities has been applied to the study of granitic free rock-mass faces from Paranhos tunnels (Porto urban area). For that purpose, the underground area (*ca.* 3km extension and a -25m of depth) was studied using the following tools: subsurface geological and geotechnical mapping (scale: 1/1.000), structural geology and geotechnics/geomechanics techniques. Water samples were collected from several sampling sites for hydrogeological and ecotoxicological analyses. A geoenvironmental approach probably offers the best potential for reliable surface water and groundwater studies and characterisation of the geospatial parameters variability, such as, lithological heterogeneity, structural geology features, geomorphology, hydrogeology and geotechnics of a specific site. This study contributes to a better water management of the urban geo-space, either in historical and heritage terms, or for several purposes of public use.

RESUMO

Este trabalho apresenta, numa abordagem multidisciplinar, uma caracterização geológico-estrutural e geotécnica do subsolo granítico da cidade do Porto. Este estudo foi realizado ao longo de um sistema de galerias subterrâneas, com mais de 3 km, captando o antigo manancial de Paranhos (também conhecido como o manancial da Arca d'Água ou da Arca das Três Fontes), o qual constituiu, durante mais de cinco séculos, uma das principais fontes de abastecimento de água da população da cidade do Porto. O trabalho envolveu, numa fase inicial, a cartografia geológica e geotécnica subterrânea do traçado das galerias (escala 1/1.000), o levantamento geológico-geotécnico das superfícies de descontinuidades ao longo de todo o traçado subterrâneo e a realização de ensaios geomecânicos do material-rocha. Numa fase posterior, foi efectuado o estudo da compartimentação do maciço granítico com vista ao seu zonamento geotécnico e geomecânico. Por fim, procedeu-se à elaboração de mapas temáticos integradores da informação subterrânea (*e.g.*, mapa geológico-estrutural, mapa do grau de alteração, mapa de zonamento geotécnico) e da cartografia superficial disponível. Um estudo desta índole pretende contribuir para uma melhor gestão do geo-espaço urbano, quer em termos históricos e patrimoniais, quer no que toca ao aproveitamento da água para diversos fins de utilidade pública.

INTRODUCTION

Water is an integral part of the environment and its availability is indispensable to the efficient functioning of the biosphere. More than 50% of the world's population lives in urban areas, which cause a remarkable impact on the hydrological cycle due to impermeabilisation of the land surface, reducing direct infiltration and increasing surface runoff (*e.g.,* Chilton *et al*., 1997, 1999; Lerner, 2004). The increasing worldwide pressure on water resources under conditions of global anthropogenic and climatic change often requires an integrated multidisciplinary approach to address the scientific issues involving these resources. Moreover, hydrogeological data acquisition in urban areas is rather difficult and so the integration of geotectonical and geomorphological features is of crucial importance.

This work makes use of a multidisciplinary approach to address issues related to the hydrogeological processes, and its dynamics, of groundwater resources from Porto urban area. Through this approach the different phases of the hydrological cycle related to urban areas groundwater systems are faced as interrelated and not as isolated sub-systems. Furthermore, both surface water and groundwater resources are handled as a whole in their assessment, development and management in urban environment (*e.g.*, Legget, 1973; Foster, 1996; Chilton *et al*., 1997, 1999; Lerner, 2004). Therefore, more realistic conceptual models may be achieved. Additionally, scientific research results

are expected to have impact on human communities that make use of water and land at urban areas. So far, water has been managed in a split way. Surface water and groundwater are considered individually in development activities without due recognition of their interdependence.

This paper also attempts to synthesise the surface water/groundwater interactions in order to understand the Porto environmental urban systems. In addition, the necessity to meet the rapidly expanding urban, industrial, and agricultural water requirements is also analysed. These crucial urban aquifers are also the most susceptible to depletion and contamination, with the recharge rate and dominant processes determining their level of vulnerability. In fact, Porto urban area is strongly related to regional morphotectonic, palaeoweathering, biogeochemistry and climate framework.

PORTO URBAN AREA: A CASE STUDY

Main goals

The overall aim of this research "*GROUNDURBAN R&D Project*" is to assess the role of the regional geotectonical and hydrogeotechnical mapping on the sustainable management of groundwater resources from Porto urban area (NW Portugal, near the Atlantic shoreline), where groundwater is an important resource for local water supply (Afonso, 1997, 2003; Afonso *et al.*, 2004).

The main objectives of the *GROUNDURBAN* Project can be summarised as follows (figure 1): i) to adopt important technological capabilities to perform an integrated geoenvironmental multi-approach water resources assessment; ii) to update knowledge on the inter-relations between climate, hydrology and biology in urban areas; iii) to assess the quality/quantity based in hydrogeochemical, isotopic geochemistry and ecotoxicological parameters; iv) to characterise the main fissured geological and morphotectonical systems related with the recharge and underground circulation; v) to provide information to support water management and land use planning.

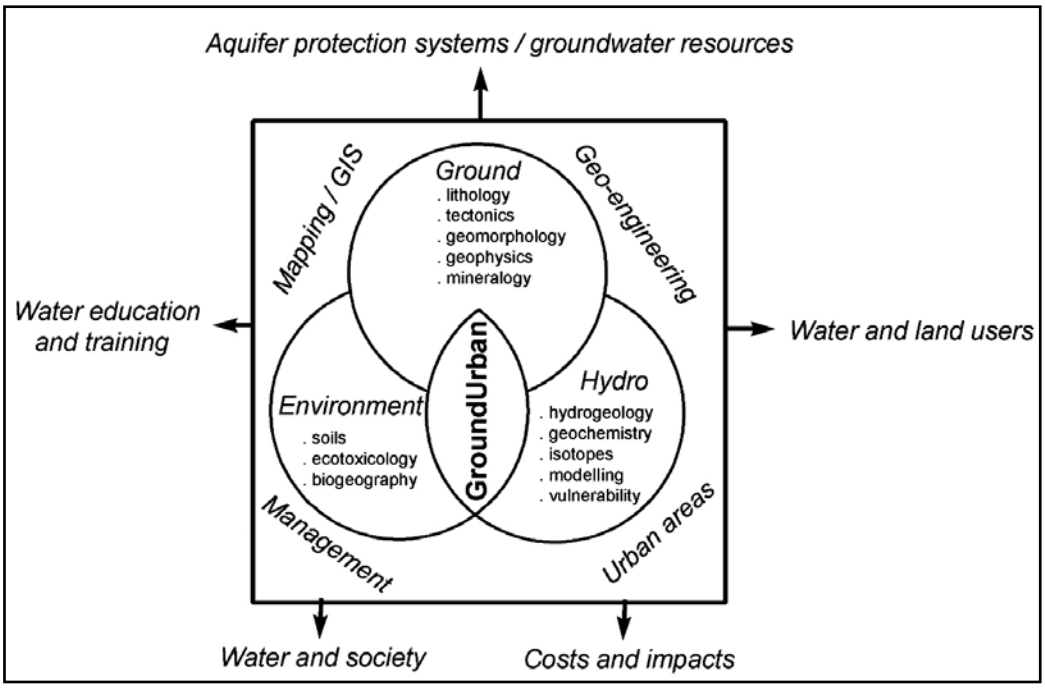

Figure 1. Conceptual framework for the management and protection of urban groundwater resources: the *GROUNDURBAN* project.

The *GROUNDURBAN* Project is strongly connected with one of the most crucial water-related research issues at the turn of the millennium "Water and Society" such as indicated by the UNESCO International Hydrological Programme (Aureli, 2002). Special emphasis will be dedicated to "Land habitat hydrology in urban areas" and their role and environmental impact on surface water/groundwater recharge and circulation. The referred topic is based on the fundamental principle that groundwater is as essential to sustainable development as it is to life and that water, beyond its geological, hydrochemical and biological function in the hydrological cycle, has social, economic and environmental values that are inter-linked and mutually supportive. The multidisciplinary approach of this project comprises the use of methods of: hydrogeology, isotope geochemistry and hydrogeochemistry, ecotoxicology, clay mineralogy and palaeoweathering, applied geophysics, remote sensing and tectonics, structural geomorphology and environmental geotechnics.

The research team includes members of several different institutions, namely from University of Aveiro, ISEP (School of Engineering, Porto Polytechnical Institute), CIIMAR (Interdisciplinary Centre for Marine and Environmental Research), University of Porto, University of Lisbon and ITN (Instituto Tecnológico e Nuclear).

Brief history of the Porto city

Porto is located on the banks of the Douro River, in Northern Portugal, being one of the oldest cities in Europe. The history of Porto City dates back at least to the 6th century, since the days of Suevians. The conquest of the so-called *Portucale*, the previous designation for the Porto area, in 868 A.D. is duly considered as an event of the most ancient history of Porto. However, as of 868 A.D. it became the centre of the movement of Christians re-conquest of Iberian Peninsula. The Porto City became an important conurbation since the 12th century and has been developed on granitic hill slopes of Douro riverside. The old neighbourhoods, bearing a striking picture of architectural and historical attributes of Porto City, led its recognition by UNESCO as a World Heritage Site in 1996.

Geological and geomorphological setting

The Porto urban area is located in a complex geotectonic domain of the Iberian Massif (Ribeiro et al., 1990), between the Porto–Coimbra–Tomar shear zone and the Douro–Beira Carboniferous Trough (Chaminé *et al.*, 2003a,b). The crystalline bedrock of Porto city consists of granites in the eastern part and gneisses-micaschists complex in the western part (figure 2). A major fault zone — Porto-Coimbra-Tomar shear zone (Chaminé *et al*. 2003a,b) — trending NNW-SSE, defines the boundary between these two major geological units. Variscan granitic rocks, representing the Porto granite facies and Ermesinde porphyritic facies underlay the Porto site (*s.str.*).

The regional geotectonical framework of Porto urban area (*e.g.*, Sharpe, 1849; Barata, 1910; Rosas da Silva, 1936; Carríngton da Costa, 1958; Chaminé, 2000; Almeida, 2001; Chaminé *et al*., 2003a,b; and references therein) comprises a crystalline fissured basement complex which is strong deformed and overthrusted Late Proterozoic/Palaeozoic metasedimentary rocks and granites. The Porto granite consists of two-micas, coarse grained, and greyish in colour, changing to yellowish when weathered. The granite is, generally, weathered to different grades, from fresh-rock to residual soil, showing highly variable conditions, resulting in arenisation and kaolinisation, which may reach depths of more than 100m (*e.g.*, Begonha & Sequeira Braga, 1995; Begonha, 2001; Gaj *et al*., 2003; COBA, 2003). The chemical palaeoweathering took place during the Cenozoic times under a tropical/subtropical climate conditions (Araújo *et al.*, 2003). The geomorphologic framework of the region corresponds to a wide flat area dipping gently to South and West. There are ubiquitous evidences for neotectonic activity, such as (Araújo *et al.*, 2003): a) abundant faults

(mainly reverse) affecting the higher deposits of this littoral platform; b) same marine levels seems to appear at different altitudes, developing an irregular pattern with a general trend dipping from North to the South.

Hydrogeological framework

The regional hydrogeological units described in Porto urban area are presented in table 1, together with an outline of the Vila do Conde-Porto-Ovar hydrogeological map (figure 2), facing their future use as an important tool for the sustainable management of local water resources. The negative impact on the quality of groundwater resources can take considerable time to be detected, since the response time of groundwater systems is the longest of all components of the urban hydrological cycle. Thus, in these areas, hydrogeological data acquisition namely structural, morphotectonical and geological, is, generally, the key to predict the possible negative impacts of surface water–groundwater interaction. The intensity of the impacts is usually dependent on the vulnerability to pollution of underlying aquifers and directly connected with the type and stage of urban development.

Table 1. Main hydrogeological features from Porto urban area (adapted from Afonso *et al*., 2004).

Regional Hydrogeological Groups	**Hydrogeological Units**	**HYDROGEOLOGICAL FEATURES**										
		Connectivity to the drainage network			**Type of flow**		**Weathering**				**More suitable exploitation structures**	
		with	without	possible	porous medium	fissured medium	low thickness	high thickness	clayey	sandy	dug-wells, galleries and springs	boreholes
Sedimentary cover	sands and alluvium	**x**			**x**		**n. a.**	**n. a.**	**n. a.**	**n. a.**	**x**	
	sandstones and conglomerates	**x**			**x**		**n. a.**	**n. a.**	**n. a.**	**n. a.**	**x**	
Metasedimentary rocks	quartz-phyllites, micaschists and black shales			**x**		**x**	**x**	**x**		**x**		**x**
	quartzites and slates		**x**	**x**		**x**	**x**			**x**		**x**
	schists, graywackes and metaconglomerates			**x**		**x**		**x**	**x**			**x**
Granitic rocks	granite, medium to coarse grain, with megacrystals			**x**		**x**		**x**		**x**	**x**	
	granite, medium to fine grain, essentially biotitic			**x**		**x**		**x**		**x**	**x**	
	gneisses and migmatites			**x**		**x**	**x**	**x**		**x**	**x**	

n.a.= not applicable

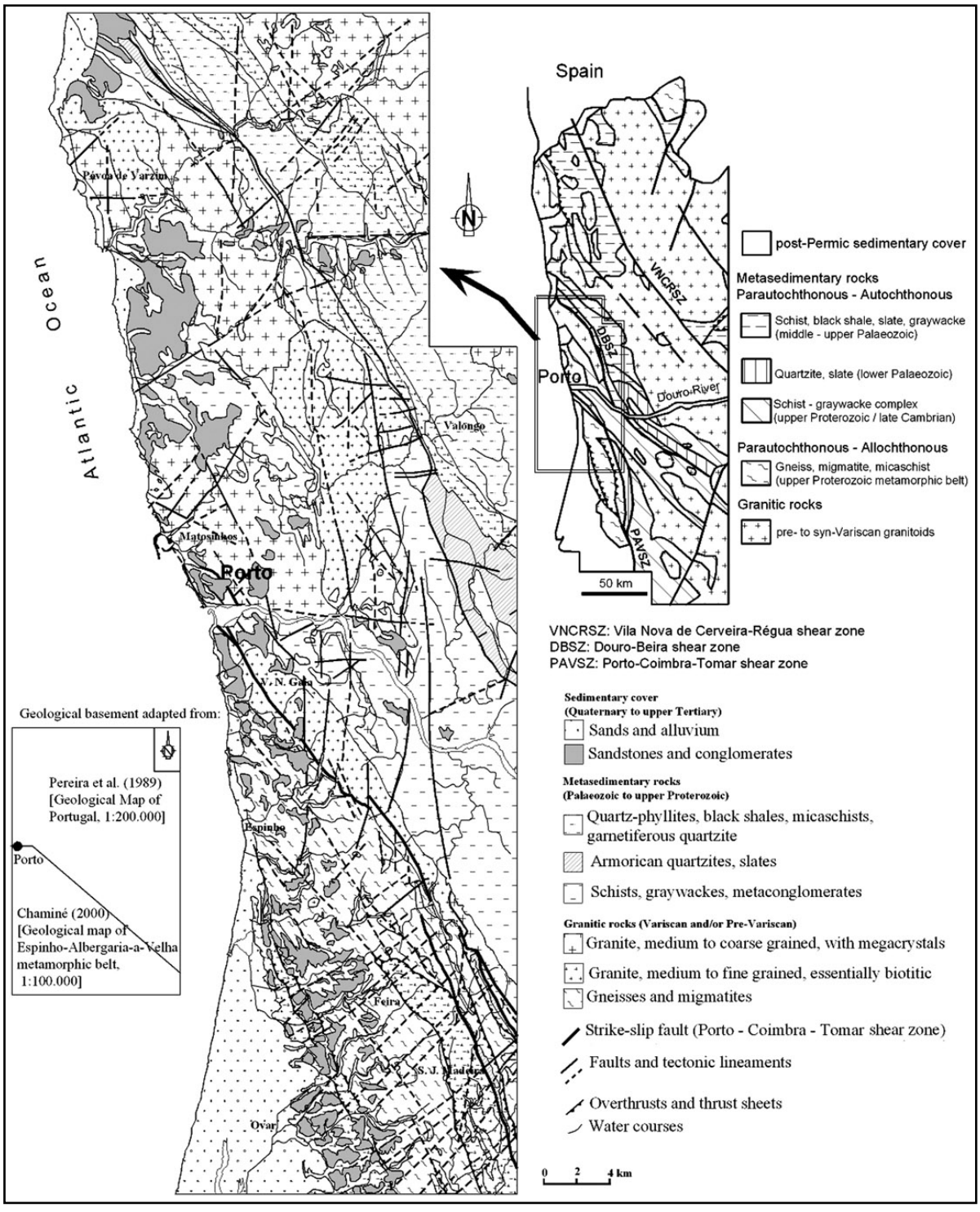

Figure 2. Geological setting from Porto metropolitan area (adapted from Chaminé *et al.*, 2003a)

Spring galleries catchworks: a geoenvironmental approach

Paranhos spring horizontal galleries catchworks constituted for more than five centuries one of the main water supplies to Porto city (*e.g.*, Ferreira da Silva, 1919; SMAS, 1961; Amorim & Pinto, 2001; Reis, 2002). This work presents the preliminary results of structural geology and geotechnics studies of block delimitation of granitic rock-masses. For this characterisation, the scanline sampling technique of discontinuities has been applied to the study of granitic free rock-mass faces from Paranhos spring galleries catchworks (Porto urban area). For that purpose, the underground area (*ca.* 3km extension and a -25m of depth) was studied using the following tools: subsurface geological and geotechnical mapping (scale: 1/1.000), structural geology, geotechnics/geomechanics and hydrogeological techniques (*e.g.*, Struckmeier & Margat, 1995; Assaad *et al.*, 2004). Surface and subsurface fieldwork surveys were first carried out to identify major tectonic accidents responsible for groundwater circulation paths, and to assess lithological and structural heterogeneity. The results achieved at different scales were compared in order to detect the presence of a multiscale fracture network pattern. Figure 3 shows the geological and hydrogeological mapping of one of Paranhos' galleries (Jardim de Arca d'Água — Rua Nova do Regado sector).

In hydrogeological investigations of urban areas, chemical analyses and ecotoxicological assessment of waters collected from springs, dug-wells and boreholes can provide important information concerning the evaluation of mixing processes between surface waters and groundwaters. In fact, in urban areas, the chemical composition, and so the potential toxicity, of local groundwaters is often conditioned by human activities, since the intense urbanisation and agricultural practices control the conditions occurring at shallow levels. In this study, a combination of hydrogeological, hydrogeochemical and ecotoxicological methods has been used to assess the nature and suitability for use of groundwater from spring galleries catchworks located in Porto urban area. Hydrogeological fieldwork campaigns were first performed, and *in situ* determinations included: temperature (ºC), pH and electrical conductivity (μS/cm). Several sampling sites were then established, based on the surface activities located on the course of the springs, and water samples were collected for hydrochemical and ecotoxicological analyses. All water samples have been analysed for major element concentrations. For ecotoxicological evaluation standard bioassays with *Daphnia magna* were performed. For each sample, two 48-LC50 bioassays were simultaneously performed: one with pH correction and the other without pH correction. In each

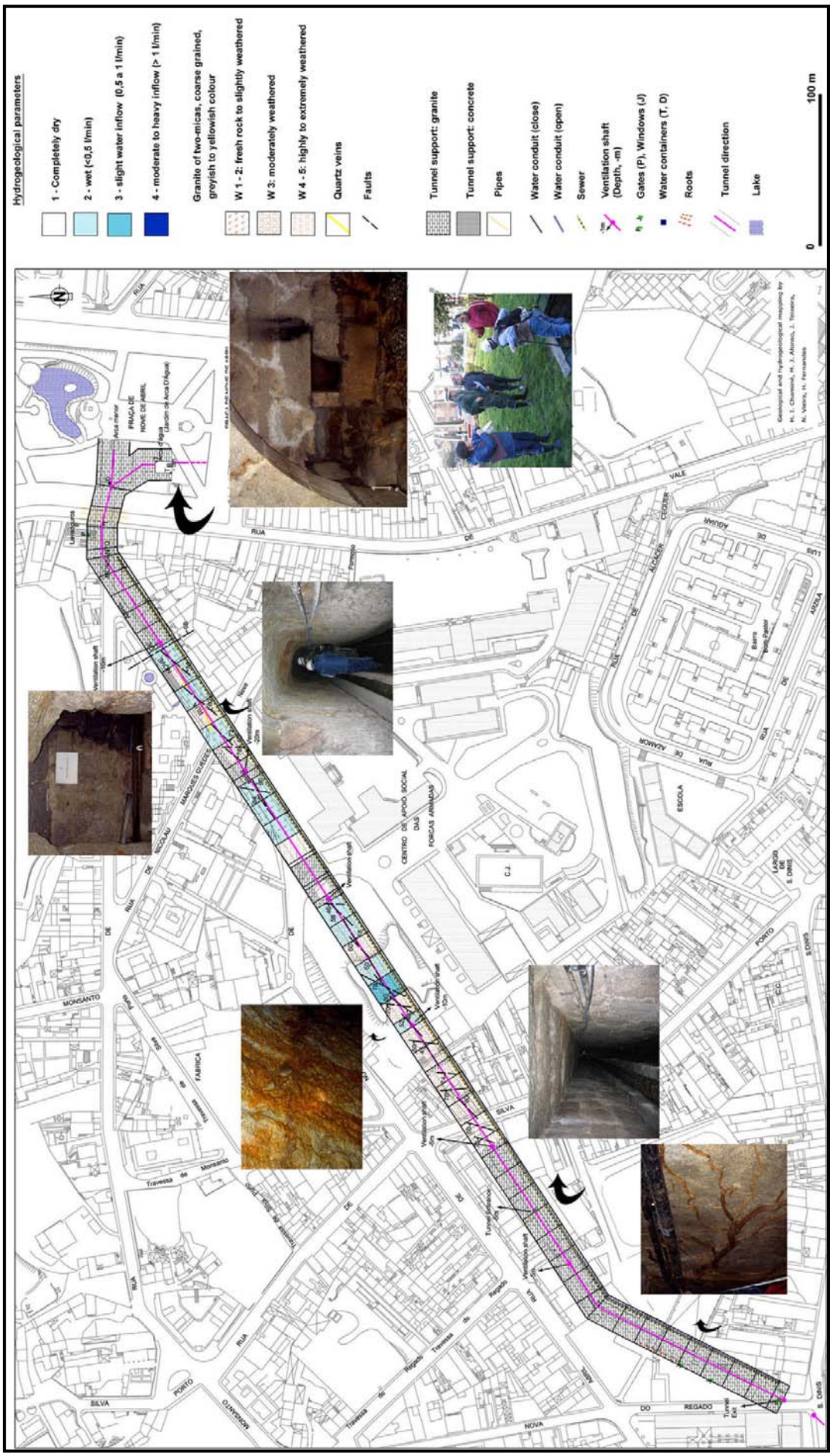

Figure 3. Geological and hydrogeological mapping of one of the Paranhos galleries (Jardim de Arca d'Água – Rua Nova do Regado sector).

bioassay, five concentrations of groundwater were prepared by dilution of the original sample with ASTM hard water (ASTM, 1980). Preliminary hydrochemical analyses showed a nitrate and sulphate-enriched composition for these groundwaters, probably resulting from intense urbanisation, sewer leakage and some agricultural practices. Concerning the ecotoxicological analyses, no mortality was observed in any of the tests performed. The results obtained in this study suggest that part of Porto urban groundwater could be suitable for irrigation and even potable uses, but additional tests must be carried out to verify its compliance with existing standards of quality. Specifically, geoenvironmental and ecotoxicological studies are required to assess potential variations in water composition and toxicity associated with seasonal changes in climate and human activities.

CONCLUDING REMARKS

Characterisation of groundwater resources in urban areas seeks to address several important questions related to the sustainable management of local/regional such resources. This usually provides important methodologies and tools to assess the interaction between surface/ground waters, supporting prevention and mitigation of possible environmental problems.

Geoengineering multidisciplinary approaches probably offer the best potential for reliable groundwater and surface water studies and for assessment of geospatial parameters' variability, such as, lithological heterogeneity, structural geology features, geomorphology and geotechnics of a specific site. So, the combination of consistent local data, remote sensing and GIS technology offers promise for a better understanding over large urban areas.

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