Supplementary Materials: Environmental Groundwater Vulnerability Assessment in Urban Water Mines (Porto, NW Portugal)

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Table S1. Groundwater potential contamination sources around *Paranhos* and *Salgueiros* spring galleries.

Category	Source Type	Usual Character (after [1]) Point (P); Diffuse (D); Line (L)	Inventory Numbers	Potential Groundwater Contamination Load (after [1]) H (High), M (Moderate), L (Low)
Urbanisation	Sewage network	L	107	H
	Hospital/Health Clinic	P	15, 16, 41, 55, 63, 73, 74, 83	M
	School/Social Care building	P	40, 45, 52, 53, 54, 58, 60, 78, 81, 82, 84, 86	M
	Urban garbage collection department	P	75	M
	Ventilation shaft	P	18, 19, 23, 30, 31, 32, 67, 68, 93, 94, 95, 96, 97, 98, 99, 102, 103	M
	Spring galleries entrance	P	24, 25, 28, 29, 34, 35, 69, 91, 92	M
	Ancient and/or canalized water courses	L	106	M
	Abandoned building/open country	P	37, 59, 89	L
	On-site sanitation	P	9, 33	L
Industrial	Garage	P	1, 2, 3, 5, 6, 8, 12, 14, 22, 36, 38, 39, 42, 43, 44, 46, 47, 49, 50, 56, 57, 65, 66, 71, 76, 79, 80, 88	H
	Petrol station	P, L	27	H
	Metallurgy	P	10	M
	Cable wire factory	P	13	M
	Lamp factory	P	48	M
	Socks factory	P	87	M
	Laundry office	P	70, 72	M
	Typography	P	77	M
Miscellaneous	Spring galleries	L	104	H
	Riding school	P, D	4	M-H
	Artificial lake	P, D	17	M-H
	Cemetery	P	64	L
	Kennel	P	26	L
	Washing place	P	101	L
	Old army factory	P	51	L
	Military headquarters	P	62, 105	L
Agricultural	Public garden with pond	P, D	7	M-H
	Cultivation field	D	100	M-H
	Public garden	P, D	11, 61	M
Water Mismanagement	Production well	P	20, 85, 90	M-H
	Abandoned well	P	21	M-H

Table S2. AVI parameters used in the surrounding area of *Paranhos* and *Salgueiros* spring galleries.

AROUND 1900				
GEOLOGICAL UNITS AND HYDROLOGICAL FEATURES	**AVI PARAMETERS DESCRIPTION AND CLASSIFICATION**			
	Thickness of unsatured zone, t (m) See *Depth to groundwater* description for *GODS*.	*Hydraulic conductivity of unsatured zone, K (m/d)* In the absence of quantitative data for this period of time, the same order of magnitude considered for the present time was assumed.	*Hydraulic resistance, c (d)* Parameter obtained by the computation of t and K (c = t/K). Indicates the approximate travel time for water to move by advection downward through the unsatured zone.	log(c)
Alluvia	1	1.5	0.7	−0.2
Two-mica granite, medium to fine grained, predominantly, moderately to highly weathered	12	1	12.0	1.1
PRESENT-DAY				
HYDROGEOTECHNICAL UNITS	**AVI PARAMETERS DESCRIPTION AND CLASSIFICATION**			
	Thickness of unsatured zone, t (m) See *Depth to groundwater* description for *GODS*.	*Hydraulic conductivity of unsatured zone, K (m/d)* Estimated through permeability tests (Lugeon and Lefranc) and pumping tests.	*Hydraulic resistance, c (d)* Parameter obtained by the computation of t and K (c = t/K). Indicates the approximate travel time for water to move by advection downward through the unsatured zone.	log(c)
Alluvia	3	1.5	2.0	0.3
Saprolite	3	0.1	30.0	1.5
Granite, medium to fine grained, $W_{4–5}$, $F_{1–2}$	8	0.3	26.7	1.4
Granite, medium to fine grained, W_3, F_3	12	0.6	20.0	1.3
Granite, medium to fine grained, $W_{1–2}$, $F_{1–2}$	15	0.8	18.8	1.3
References: Around 1900 [2–13]; Present-day [14–22]				

Table S3. GODS parameters used in the surrounding area of *Paranhos* and *Salgueiros* spring galleries.

AROUND 1900				
	GODS **PARAMETERS DESCRIPTION AND CLASSIFICATION**			
GEOLOGICAL UNITS AND HYDROLOGICAL FEATURES	***G**roundwater confinement* *Evaluation based on the hydrological knowledge through bibliographical data and on the land cover extrapolated throughout topographic survey from the 19th century.*	***O**verlying strata* *Lithological characterization based on the dugwells and spring galleries descriptions from the late 19th century and the beginning of the 20th century.*	***D**epth to groundwater (m)* *Data obtained from groundwater surveys (dugwells and springs) specially those from the period 1890–1910.*	***S**oil cover type* *Characterization based mainly on the dugwells descriptions.*
Alluvia	unconfined	alluvial sands and gravels	<5	coarse sand and gravel
Two-mica granite, medium to fine grained, predominantly, moderately to highly weathered	semi-confined to unconfined	igneous formations to residual soils	5–20	silty sand to silty clay
PRESENT-DAY				
	GODS **PARAMETERS DESCRIPTION AND CLASSIFICATION**			
HYDROGEOTECHNICAL UNITS	***G**roundwater confinement* *Evaluation based on typical hydrogeological cross-section in this area, storage coefficient values obtained through pumping tests, and land cover.*	***O**verlying strata* *Data obtained from the log description of geotechnical and hydrogeological boreholes, dugwells and piezometers. Due to the sparse availability of water-wells with water level records, the water-well logs provided adequate information to understand the lithological sequences encountered above the water table.*	***D**epth to groundwater (m)* *Data obtained from geotechnical and hydrogeological boreholes, dugwells, piezometers and springs.* *Since water-wells were spatially inhomogeneous, interpolation methods could not be applied to depth to water values recorded in the water-well database.*	***S**oil cover type* *Data obtained from the log description of geotechnical and hydrogeological boreholes, dugwells and piezometers and also by soil maps of the region.*
Alluvia	unconfined (covered)/ unconfined	alluvial sands and gravels	<5	thin/absent
Saprolite granite, W_5 to W_6	confined/ semi-confined	kaolinitic deposits/residual soils	<5	silty clay
Granite, medium to fine grained, $W_{4–5}$, $F_{1–2}$	semi-confined/ unconfined (covered)	igneous formations/residual soils	5–20	silt
Granite, medium to fine grained, W_3, F_3	semi-confined	igneous formations	5–20	silty sand
Granite, medium to fine grained, $W_{1–2}$, $F_{1–2}$	confined/ semi-confined	igneous formations	5–20	thin/absent
References: Around 1900 [2–13]; Present-day [14–22]				

Table S4. DRASTIC parameters used in the surrounding area of *Paranhos* and *Salgueiros* spring galleries.

AROUND 1900							
	DRASTIC **PARAMETERS DESCRIPTION AND CLASSIFICATION**						
GEOLOGICAL UNITS AND HYDROLOGICAL FEATURES	***D**epth to water (m)* See *Depth to groundwater* description for *GODS*.	*Net **R**echarge (mm/y)* *Net recharge was evaluated considering the annual mean precipitation for the period 1900–1930 and an infiltration rate for each unit, considering an environment predominantly rural (i.e., non-urbanized).*	***A**quifer media* *Lithological characterization based on the dugwells and spring galleries descriptions from the late 19th century and the beginning of the 20th century.*	***S**oil media* See *Soil cover type* description for *GODS*.	***T**opography (% slope)* Slope was determined by "topographic" cartography from the 19th century.	***I**mpact of the vadose zone media* See *Overlying strata* description for *GODS*.	*Hydraulic **C**onductivity (m/d)* In the absence of quantitative data for this period of time, the same order of magnitude considered for the present time was assumed.
Alluvia	<1.5	>255	sand and gravel	sandy loam	The rating for this parameter is variable since slope values are calculated for each pixel of the ArcGIS raster dataset.	sand and gravel with significant silt and clay	<4
Two-mica granite, medium to fine grained, predominantly, moderately to highly weathered	9–15	100–180	igneous to weathered igneous	silty to clay loam		igneous	<4
PRESENT-DAY							
	DRASTIC **PARAMETERS DESCRIPTION AND CLASSIFICATION**						
HYDROGEOTECHNICAL UNITS	***D**epth to water (m)* See *Depth to groundwater* description for *GODS*.	*Net **R**echarge (mm/y)* *Annual rates of net groundwater recharge were derived from water-balance models, including urban recharge.*	***A**quifer media* *Aquifer media was based on the lithologies and hydrogeotechnical characteristics of the defined units.*	***S**oil media* See *Soil cover type* description for *GODS*.	***T**opography (% slope)* Slope was determined by topographic maps and digital elevation models.	***I**mpact of the vadose zone media* See *Overlying strata* description for *GODS*.	*Hydraulic **C**onductivity (m/d)* Based on permeability tests (Lugeon and Lefranc) and pumping tests. The locations of water-wells were too sparse to create an interpolated map of hydraulic conductivities.
Alluvia	1.5–4.5	>255	sand and gravel	thin or absent	The rating for this parameter is variable since slope values are calculated for each pixel of the ArcGIS raster dataset.	sand and gravel with significant silt and clay	<4
Saprolite granite, W_5 to W_6	1.5–4.5	50–100	very weathered igneous	clay loam		silt/clay	<4
Granite, medium to fine grained, $W_{4–5}$, $F_{1–2}$	4.5–9	100–180	weathered igneous	silty loam		igneous	<4
Granite, medium to fine grained, W_3, F_3	9–15	180–255	igneous	loam		igneous	<4
Granite, medium to fine grained, $W_{1–2}$, $F_{1–2}$	9–15	180–255	igneous	thin or absent		igneous	<4
References: Around 1900 [2–13]; Present-day [14–22]							

Table S5. SINTACS parameters used in the surrounding area of *Paranhos* and *Salgueiros* spring galleries.

AROUND 1900							
GEOLOGICAL UNITS AND HYDROLOGICAL FEATURES	***SINTACS* PARAMETERS DESCRIPTION AND CLASSIFICATION**						
	Soggicenza (depth to groundwater) (m) See *Depth to groundwater* description for *GODS*.	*Infiltrazione* (effective infiltration) (mm/y) See *Net Recharge* description for *DRASTIC.*	*Non saturo* (unsatured zone attenuation capacity) See *Impact of the vadose zone media* description for *DRASTIC*.	*Tipologia della cobertura* (soil/overburden attenuation capacity) See *Soil cover type* description for *GODS*.	*Acquifero* (satured zone characteristics) See *Aquifer media* description for *DRASTIC.*	*Conducibilità* (hydraulic conductivity) (m/s) See *Hydraulic conductivity* description for *DRASTIC.*	*Superficie topografica* (topographic surface slope) (%) See *Topography* description for *DRASTIC*.
Alluvia	<2	250–300	coarse to medium-fine alluvial deposit	sandy loam	coarse to medium-fine alluvial deposit	$<5 \times 10^{-5}$	The rating for this parameter is variable since slope values are calculated for each pixel of the ArcGIS raster dataset.
Two-mica granite, medium to fine grained, predominantly, moderately to highly weathered	10–15	100–200	fissured plutonic rock	silty to clay loam	fissured plutonic rock	$<5 \times 10^{-5}$	

Table S5. SINTACS parameters used in the surrounding area of *Paranhos* and *Salgueiros* spring galleries (continued).

PRESENT-DAY							
HYDROGEOTECHNICAL UNITS	***SINTACS* PARAMETERS DESCRIPTION AND CLASSIFICATION**						
	Soggicenza (depth to groundwater) (m) See *Depth to groundwater* description for *GODS*.	*Infiltrazione* (effective infiltration) (mm/y) See *Net Recharge* description for *DRASTIC*.	*Non saturo* (unsatured zone attenuation capacity) See *Impact of the vadose zone media* description for *DRASTIC*.	*Tipologia della cobertura* (soil/overburden attenuation capacity) See *Soil cover type* description for *GODS*.	*Acquifero* (satured zone characteristics) See *Aquifer media* description for *DRASTIC*.	*Conducibilità* (hydraulic conductivity) (m/s) See *Hydraulic conductivity* description for *DRASTIC*.	*Superficie topografica* (topographic surface slope) (%) See *Topography* description for *DRASTIC*.
Alluvia	2–5	250–300	coarse to medium-fine alluvial deposit	thin or absent	coarse to medium-fine alluvial deposit	$<5 \times 10^{-5}$	The rating for this parameter is variable since slope values are calculated for each pixel of the ArcGIS raster dataset.
Saprolite granite, W_5 to W_6	2–5	50–100	plutonic rock	clay	plutonic rock	$<5 \times 10^{-5}$	
Granite, medium to fine grained, $W_{4–5}$, $F_{1–2}$	5–10	100–200	fissured plutonic rock	silty loam	fissured plutonic rock	$<5 \times 10^{-5}$	
Granite, medium to fine grained, W_3, F_3	10–15	200–250	fissured plutonic rock	loam	fissured plutonic rock	$<5 \times 10^{-5}$	
Granite, medium to fine grained, $W_{1–2}$, $F_{1–2}$	10–15	200–250	fissured plutonic rock	thin or absent	fissured plutonic rock	$<5 \times 10^{-5}$	
References: Around 1900 [2–13]; Present-day [14–22]							

References

1. Zaporozec, A. (Ed.) *Groundwater Contamination Inventory: A Methodological Guide with a Model Legend for Groundwater Contamination Inventory and Risk Maps*; UNESCO, IHP-VI, Series on Groundwater, 2; UNESCO: Paris, France, 2004.
2. Von Eschwege, W.L. Geognostische Verhältnisse der Gegend von Porto, nebst einer Beschreibung des bei S. Pedro da Cova gelegenen Steinkohlenlagers, welches die Uebergangsbildung von der Urbildung trennt. *Arch. Miner. Geognos Bergbau Hüttenkd* **1833**, *6*, 264–276.
3. Sharpe, D. On the geology of the neighbourhood of OPorto, including the Silurian coal and slates of Vallongo. *Q. J. Geol. Soc. Lond. Proc.* **1849**, *5*, 142–153.
4. Bourbon e Noronha, T. As Aguas do Porto. Bachelor's Thesis, Escola Médico-Cirúrgica do Porto, Porto, Portugal, 1885. (In Portuguese)
5. Telles Ferreira, A.G. *Carta Topográfica da Cidade do Porto*; Direcção-Geral dos Trabalhos Geodésicos, Topográficos, Hidrográficos e Geológicos do Reino: Lisboa, Portugal, 1892.
6. Ferreira da Silva, A.J. O *Exame das Águas Potáveis sob o Ponto de Vista Hygienico e as Águas dos Poços do Porto*; O Instituto de Coimbra, Universidade de Coimbra: Coimbra, Portugal, 1895; 83–95 (p1); 141–152 (p2); 213–225 (p3); 449–463 (p4); 518–527 (p5).
7. Delgado, J.F.N.; Choffat, P. *Carta Geológica de Portugal, Escala 1/500.000*, 3rd ed.; Direcção dos Trabalhos Geológicos: Lisboa, Portugal, 1899.
8. Delgado, J.F.N.; Choffat, P. *La Carte Géologique du Portugal*; Comptes Rendues VIII Congrès Géologique Internationale: Paris, France, 1901; Volume 2, pp. 743–746.
9. Carteado Mena, J. *Contribuição Para o Estudo da Hygiene do Porto: Analyse Sanitaria do seu Abastecimento em Água Potável. III. Estudo Sobre os Poços do Porto*; Unpublished Report; Laboratório de Bacteriologia do Porto e Laboratório de Hygiene do Porto: Porto, Portugal, 1908.
10. Fontes, A. Contribuição para a Hygiene do Porto: Analyse Sanitaria do seu Abastecimento em Água Potável. I. Estudo dos Mananciaes de *Paranhos* e *Salgueiros*.Bachelor's Thesis, Escola Médico-Cirúrgica do Porto, Porto, Portugal, 1908. (In Portuguese)
11. Bahia Junior, J. Contribuição Para a Hygiene do Porto: Analyse Sanitaria do seu Abastecimento em Agua Potavel. Porto: II—Mananciaes do Campo Grande, Bispo e Freiras, Cavaca, Camões, Virtudes, Fontaínhas, Praça do Marquês de Pombal e Burgal: Fontes suas Derivadas de Nascente Privativa. Bachelor's Thesis, Escola Médico-Cirúrgica do Porto, Porto, Portugal, 1909. (In Portuguese)
12. Barata, J.M.P. Contribuição Para o Estudo das Rochas do Porto. Bachelor's Thesis, Faculdade de Philosophia Natural, Universidade de Coimbra, Coimbra, Portugal, 1910. (In Portuguese)
13. Carríngton da Costa, J. *O Pôrto: Geografia-Geologia*; Bastos, C., Ed.; Nova Monografia do Porto, Companhia Portuguesa do Porto: Porto, Portugal, 1938; pp. 3–32.
14. Afonso, M.J. Hidrogeologia de Rochas Graníticas da Região do Porto. Master's Thesis, Universidade de Lisboa, Lisboa, Portugal, 1997. (In Portuguese)
15. Afonso, M.J. Hidrogeologia de rochas graníticas da região do Porto (NW de Portugal). *Cadernos Laboratorio Xeolóxico Laxe* **2003**, *28*, 173–192.
16. Begonha, A.; Sequeira Braga, M.A. Weathering of the Oporto granite: Geotechnical and physical properties. *Catena* **2002**, *49*, 57–76.
17. COBA—Consultores de Engenharia e Ambiente, SA. *Carta Geotécnica do Porto*, 2nd ed.; COBA/FCUP/CMP: Porto, Portugal, 2003.
18. Viana da Fonseca, A.; Carvalho, J.; Ferreira, C.; Santos, J.A.; Almeida, F.; Pereira, E.; Feliciano, J.; Grade, J.; Oliveira, A. Characterization of a profile of residual soil from granite combining geological, geophysical and mechanical testing techniques. *Geotech. Geol. Eng.* **2006**, *24*, 1307–1348.
19. Afonso, M.J.; Marques, J.M.; Guimarães, L.; Costa, I.; Teixeira, J.; Seabra, C.; Rocha, F.; Guilhermino, L.; Chaminé, H.I. Urban hydrogeology of the *Paranhos* sector, Porto city (NW Portugal): A geoenvironmental perspective. In *Aquifer Systems Management: Darcy's Legacy in a World of Impending Water Shortage*; Chery, L., Marsily, G., Eds.; Selected Papers on Hydrogeology; IAH/Taylor & Francis CRC Press: London, UK, 2007; SP10, pp. 391–406.
20. Afonso, M.J.; Chaminé, H.I.; Marques, J.M.; Carreira, P.M.; Guimarães, L.; Guilhermino, L.; Gomes, A.; Fonseca, P.E.; Pires, A.; Rocha, F. Environmental issues in urban groundwater systems: A multidisciplinary study of the *Paranhos* and *Salgueiros* spring. *Environ. Earth Sci.* **2010**, *61*, 379–392.

21. Chaminé, H.I.; Afonso, M.J.; Robalo, P.M.; Rodrigues, P.; Cortez, C.; Monteiro Santos, F.A.; Plancha, J.P.; Fonseca, P.E.; Gomes, A.; Devy-Vareta, N.F.; et al. Urban speleology applied to groundwater and geo-engineering studies: Underground topographic surveying of the ancient Arca D'Água galleries catchworks (Porto, NW Portugal). *Int. J. Speleol.* **2010**, *39*, 1–14.
22. Afonso, M.J. Hidrogeologia e Hidrogeoquímica da Região Litoral Urbana do Porto, Entre Vila do Conde e Vila Nova de Gaia (NW de Portugal): Implicações Geoambientais. Ph.D. Thesis, Universidade Técnica de Lisboa, Lisbon, Portugal, unpublished work.