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Coordenador da Edição:

Manuel José dos Santos Silva

Comissão Organizadora:

Manuel José dos Santos Silva
Ana Maria Carreira Lopes
José Mendes Lucas
Rogério Manuel Simões
Annabel Fernandes
Kátia Monteiro

Comissão Científica:

Manuel José dos Santos Silva
Ana Maria Carreira Lopes
José Mendes Lucas
Rogério Manuel Simões

Apoio Técnico:

Annabel Fernandes
Kátia Monteiro

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Characterization of Residual Soil used for Infiltration of Reclaimed Water

F. Silva¹, A. Albuquerque², A. Silva³, V. Cavaleiro²

¹ School of Technology and Management and FibEnTech, Polytechnic Institute of Bragança, Campus de Santa Apolónia, Apartado 1134, 5301-857 Bragança, Portugal

² Department of Civil Engineering and Architecture and FibEnTech, University of Beira Interior, Bloco II das Engenharias, Calçada do Lameiro, 6201-001 Covilhã, Portugal

³ Department of Eletromechanical Engineering, University of Beira Interior, Bloco II das Engenharias, Calçada do Lameiro, 6201-001 Covilhã, Portugal

Abstract

The effects of climate change and the growing demand for water for domestic, industrial, agricultural and recreational activities have led the use of treated wastewater (reclaimed water) for such applications. The artificial recharge of aquifers with treated wastewater can be an alternative way for restoring underground water volumes that can be used for satisfying some activities, particularly in water shortage areas or where their quality is not suitable for use. After a two-year monitoring period in the Vila Fernando WWTP (Guarda, Portugal), the characteristics of the treated effluent suggest that it could be used for infiltration for aquifer recharge. A multi-criteria analysis based on GIS was developed for site location of infiltration sites. The procedure has involved the combination of six thematic maps and environmental, technical and economic criteria, over an area of 6687.1 ha. About 6.4 ha were selected for suitable sites for infiltration and one of these sites (Quinta de Gonçalo Martins, Guarda) was selected for collecting soil samples. The characterization of the soil indicates that is favorable to the infiltration of treated wastewater for artificial recharge of aquifers.

Introduction

Reclaimed water reuse is a growing practice, which has been motivated primarily by the need to protect water resources from discharges from WWTP and also due to the water scarcity. There is thus the need for a sustainable management of water resources, which includes water conservation, and where the reuse of treated wastewater is an important strategic component [1]. Groundwater resources are an important source of water for urban, industrial and agricultural activities. However, when they are over-exploited, the uptaken volumes are not returned for aquifer recharge, lowering the water levels on soil, which can lead to the contamination by sea water or sources of diffuse pollution [2]. In Portugal, some regions of the Northeast, South and Beira Interior, particularly in arid and semi-arid areas have water deficit in the summer months.

One of the ways that could contribute for keeping water reserves in the soil would be by recharging aquifers with treated wastewater [3], using direct injection or infiltration into the soil (in this case, the wastewater has a natural polishing treatment provided by infiltration, sorption and biodegradation mechanisms in soil). Indirect recharge by infiltration is an interesting way to manage volumes extracted in areas of over-exploitation of the resource, besides acting as a polishing treatment process. Rapid infiltration basins allow the pitch of the effluent into the soil, working as a filter (this procedure is called Soil Aquifer Treatment (SAT)), removing organic pollutants, nitrogen, phosphorus, heavy metals and pathogens [4].

When the infiltration is performed on the soil surface or in the unsaturated zone (vadose zone), much of the organic matter, nitrogen forms, phosphorus and heavy metals are removed or converted in the first meter of soil [4]. The main concern is nitrate, ammonium and pathogenic load. However, if the infiltration area is located in permeable sandy soil with less than 10% of clay and with reactive properties, and with a minimum unsaturated height of 5 m [5], allowing infiltration rates between 0.2 and 1 m/day, the concentration of the pollutants and pathogens is significantly reduced.

The aim of this study focused on identifying areas with residual soils (soils resulting from "in situ" degradation of rocks) for the infiltration of reclaimed water produced at one WWTP, using a multi-criteria analysis based on GIS, as well as in characterizing the soil in order to evaluating its potential for polishing the wastewater.

Materials and Methods

The study area is located in the northeastern region of Beira Interior (Figure 1), between the WWTP of Vila Fernando and Perimeter Protection of Cró spa, dominated by granitic residual soils. The climate is continental, with an average annual rainfall of 780 mm, average evapotranspiration of 700 mm, and a water deficit in the period from June to September. The average temperature

is 10.7 °C. In the field study, the depth of the aquifer varies between 10 and 50 m [6].

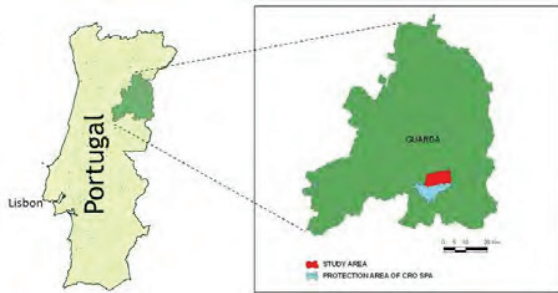


Figure 1. Location of the study area

As a source of treated wastewater, it was selected the WWTP of Vila Fernando, having been used flow-rate data and physical, chemical and microbiological data from a previous monitoring campaign [7], namely data on pH, temperature, biochemical oxygen demand (BOD₅), chemical oxygen demand (COD), total suspended solids (TSS), ammonia nitrogen (NH₄-N), nitric nitrogen (NO₃-N), total nitrogen (TN), total phosphorus (TP), electrical conductivity (EC), sodium (Na), calcium (Ca), potassium (K), chlorine (Cl), total coliforms (TC), fecal coliforms (FC), E. coli and helminth eggs (OH). In the last 3 samples, it was also determined magnesium (Mg), boron (B), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn).

To perform the suitability map for infiltration (Figure 2) with location of potential areas for infiltration of treated wastewater, it was used a multi-criteria analysis with the application of a Boolean overlay method [5]. The procedure consisted in the reclassification of variables (thematic maps) in binary form (0/1), which were then combined according to logic intersection operations and inclusiveness union (areas of possible application) and exclusive (without fitness areas) [7].

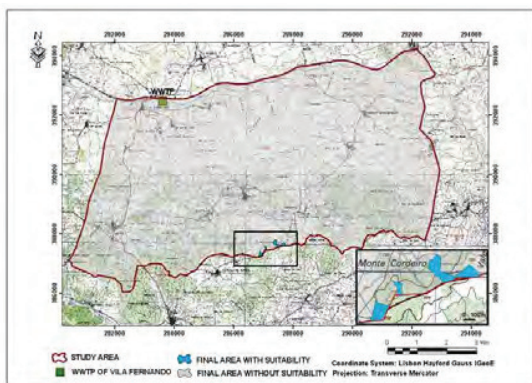


Figure 2. Suitability map of soils for the infiltration of reclaimed water

In one of the sites considered appropriate for treated wastewater infiltration (Figure 3-a), several soil samples were collected (Figure 3-b) for the determination of physical-chemical and mineralogical characteristics.



Figure 3. a) Selected site; b) sample of residual soil

The particle size distribution analysis of the soil was made by sieving method [8] and the examination of the fraction < 0,075 mm was performed by the sedimentation method [9]. The soil was classified according to the Unified classification [10]. The determination of the specific gravity of solids (G_s) was taken by the pycnometer method [11]. It was also determined the water content (w₀) [12] and the unit weight (γ₀) [13], and also the dry unit weight (γ_d), the voids (e) and the porosity (n), using the procedure described in [14]. The permeability was determined "in situ" using a Guelph permeameter and in the laboratory using the constant head permeameter, following the methodology described in [13]. The specific surface of the fine soil components (less than 0.075 mm fraction) was determined by laser diffraction using a Coulter LS200 equipment.

The qualitative mineralogical composition of the soil was determined by X-ray diffraction (XRD), with a Rigaku equipment DMAXIII model (USA). For the morphological and microstructural analysis, it was used an electronic microscope (SEM) (Hitachi S-2700 model; RONTEC, USA). The chemical composition (oxides and elemental analysis) was determined by an energy dispersive spectrometer (EDS), which is coupled to SEM.

The cation exchange capacity was determined by the method of ammonium acetate buffered to pH 7 as described in [15]. The organic matter was quantified by Walkley-Black method described by [16] and the pH of the soil was determined by the suspension potentiometric method [17].

Results and Discussion

Table 1 presents identifying characteristics, physical and chemical soil. The XRD pattern of Figure 4 shows that the mineralogical composition is ground quartz, muscovite, illite, kaolinite and smectite, constituting the kaolinite about 60% of clay mineral present in the soil. Figure 5 shows an example of the morphology of the soil particles.

Table 1. Characteristics of soil

Parameter	Value
Clay (< 0.002 mm)	4.9 %
Silt (0.002 – 0.06 mm)	16.6 %
Sand (0.06 – 2 mm)	56.8 %
Gravel (2 – 60 mm)	21.7 %
Unified classification	Silty sand with gravel
Specific gravity (G_s)	2.65
Water content (w_0)	10.45 %
Unit weight (γ_0)	17.52 KN/m ³
Dry unit weight (γ_d)	16 KN/m ³
Void ratio	0.63
Porosity	38.5 %
Permeability in laboratory (k)	3.23 x 10 ⁻⁵ m/s
Permeability "in situ" (k)	4.5 x 10 ⁻⁵ m/s
Specific surface (fraction < 0,075 mm)	0.29 m ² /g
Oxides:	
SiO ₂	58.64 %
Al ₂ O ₃	33.17 %
Fe ₂ O ₃	3.96 %
K ₂ O	4.23 %
Cation Exchange Capacity (pH=7)	6.09 cmol.kg ⁻¹
Organic matter content	0.25 %
pH	4.91

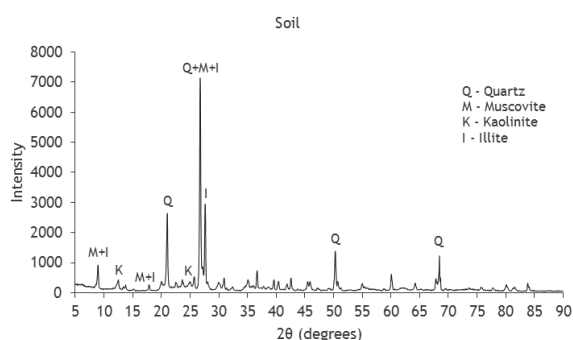


Figure 4. XRD of soil particles

The results of physical-chemical and microbiological analysis on treated wastewater [7] show that the concentrations of NT, NH₄-N and PT would be high for discharge into watercourses or for use in agricultural irrigation. The concentrations of inorganic compounds and microbiological load are similar to the secondary effluent characterized by [1]. If the application were for agricultural irrigation, or urban, industrial and landscape activities, taking into account the allowable limits in several studies [1,4], the treated wastewater would need a polishing treatment for reducing nitrogen and phosphorus loads, and pathogens. Thus, the infiltration of this reclaimed water into the soil, besides allowing a polishing

treatment in the vadose zone and aquifer recharge, would also avoid investments in the WWTP for adding a polishing treatment.

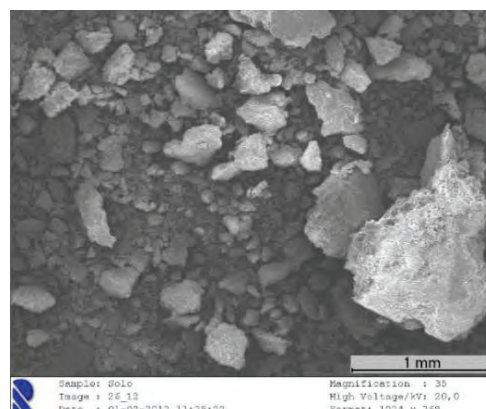


Figure 5. SEM image of the residual soil (35x)

The soil is classified as silty sand (SM) with gravel (G) [10], with a considerable percentage of sand. The percentage of clay is very low, less than 5%, which means that most of the fines are essentially silty. According to [5], to prevent clogging of soil and ensuring the polishing treatment of wastewater, the soil must have a low fraction of clay, in particular less than 10%. The water content is relatively low (10.45% (height-dependent parameter of the year in which samples are collected), with a void ratio of 0.63 and porosity of 38.5%. The specific gravity of the solid particles is 2.65, which is typical of granitic residual soils. The permeability (k) determined in laboratory has a value of 3,23x10⁻⁵ m/s, which increases "in situ" (4.496x10⁻⁵ m/s) what was expected, because in laboratory tests the permeability of discontinuities is not taken into account. It should be noted that soils with permeability of about of 25 mm/h are suitable for infiltration of treated wastewater [18].

The soil analysed in this study mainly contains silica and alumina, which was expected, since the clays and silts have an aluminosilicated structure with less high content of iron and potassium. The high amount of Al₂O₃, indicates the predominance of kaolinite, evidenced by the XRD. It should be noted that the clay-colloidal complex of the soil has reactive properties that allow removing pollutants by sorption mechanisms, as well as a suitable specific surface area for biofilm development with capacity for removing pollutants and pathogens through biodegradation and filtration mechanisms. The capacity of cationic exchange of the soil is low [19] favoring more the removal of the Ca²⁺, compared to Mg²⁺, K⁺ and Na⁺. The low organic matter content and acidity (low pH) of the soil is in agreement with other analysis observed for soils in the Beira Interior region [20].

Conclusions

Using thematic maps and environmental, technical and economic criteria, and a multi-criteria analysis in GIS, it was obtained a suitable map indicating a favorable area of 6.4 ha for the infiltration of treated wastewater for aquifer recharge in residual granitic soils of the Quinta de Gonçalo Martins (Guarda, Portugal). The treated wastewater produced at a close WWTP serving a small rural community (Vila Fernando, Guarda, Portugal) can constitute an alternative source of water for artificial recharge of aquifers. The results of the soil analysis indicates that it has reactive properties which gives it a good capacity for removing pollutants and pathogens, allowing it to act as a barrier against groundwater contamination during artificial recharge of aquifers.

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