ANALYSIS OF RECLAIMED WATER APPLICATION FOR IRRIGATION USING MULTI-CRITERIA ANALYSIS

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EXECUTIVE SUMMARY

Approximately 60% of the population of the Cova da Beira region (Portugal) lives in rural communities with less than 2,000 inhabitants and the wastewater treatment plants (WWTP) in the region are mainly septic tanks, constructed wetlands and trickling filters. The daily reclaimed water discharged into streams could be mainly reused for landscape irrigation of public parks and lawns and golf courses, which often means offsetting potable water for nonpotable purposes. However, those applications may require a polishing treatment to remove mainly pathogens, and trace elements.

A one-year monitoring campaign was carried out in a biological aerated filter that treats the sewage of 4,000 inhabitants. The research included the measurement of the flow-rate and its characteristics in terms of pH, temperature, conductivity, BOD_5, COD, TSS, TN, NH_4, NO_2, NO_3, TP, Na, Mg, Ca, K, Cl, B, As, Cd, Cr, Cu, Hg, Ni, Pb, Zn, total coliforms (TC), faecal coliforms (FC), E. Coli and helminths eggs (HE). Results show that the effluent concentrations of BOD_5, COD, TN, TP, K, Ca and phytotoxic elements (Na, B and Cl) are compatible with the international guidelines for irrigation reuse (crop irrigation). Values of conductivity are not a risk to soil salinity, but TC, FC and E. Coli values are not compatible with the reuse guidelines and, therefore, a final disinfection must be implemented to decrease the pathogenic content. The low nitrate concentrations (<5 mg L^{-1}) are suitable for irrigation and constitute a very low risk for groundwater contamination.

GIS-based multi-criteria analysis was performed combining reclaimed water characteristics, the type and needs of the dominant crop production and environmental, technical and economic criteria. The results showed that approximately 170,000 m^3 of reclaimed water annually discharged in the local stream could be reused for irrigation of 30.53 ha fruits trees, corn, olive trees and vine, located at a distance of about 1.8 km from the WWTP.

The use of reclaimed wastewater in rural areas brings other advantages such as the reduction of the residual pollution load discharged in water streams and the reduction of water abstraction volumes for irrigation, which are important environmental and economics benefits, especially in periods of water shortage.

KEY WORDS: Agricultural irrigation, GIS, multi-criteria analysis, reclaimed water, reuse.

1 INTRODUCTION

1.1 Background

The Cova da Beira region (Portugal) is covered by an Irrigation Plan, which provides water from the dams systems Sabugal-Meimoa, for irrigation of approximately 14,400 ha of agricultural area. The severe drought occurred 5 years ago limited the availability of water in both dams, which are the water sources for the irrigation system of Covilhã-Fundão (the average volume of water stored in the Meimoa dam in 2006 ranged from 9% to 28% of the maximal allowed volume). This occurrence had negative effects on several uses, especially in the rainfed agriculture. On the other hand, the water in the Meimoa dam presented variable quality, reaching the eutrophic state in the months of July to September, which adversely impacted on the main uses of this water. Accordingly, the search for alternative sources of water such the reuse of reclaimed water can help to balance the needs, especially in water shortage periods.

Approximately 60% of the population of the Cova da Beira region lives in rural agglomerates with less than 2,000 inhabitants. The WWTP are mostly based on septic tanks, constructed wetlands and trickling filters, which produce a final effluent (reclaimed water) suitable for reuse (Marecos do Monte and Albuquerque, 2010; Pedrero *et al*., 2011a and 2011b). Nutrients in treated wastewater (reclaimed water) may be valuable as fertilizers for crop production (EPA, 2004). However, pathogens are harmful for humans. Therefore, the reclaimed wastewater reuse may require a polishing treatment, which may increase the costs of operation and maintenance of the WWTP.

The selection of agricultural parcels for irrigation with reclaimed water requires the collection, processing and analysis of complex information (*e.g*. characteristics of the reclaimed water, soils characteristics, type of crop production and maximum needs of water and nutrients, land use, environmental and legal restrictions, accessibility) and tools for multi-criteria analysis. Geographical information systems (GIS) allow the georeferentiation, organization, processing and analysis of such complex information, allowing the selection of the parcels more suitable for irrigation. GIS has been used for site selection for aquifer recharge (Kallali *et al*., 2007; Pedrero *et al*., 2011b), pulp mill sludge application (Ribeiro *et al*., 2010) and location of wastewater treatment plants (Gemitzia *et al*., 2007).

1.2 Research objectives

The main objective of the study was to identify the suitable agricultural land parcels for irrigation with reclaimed water from a small WWTP located in the area limited by the irrigation system of Covilhã-Fundão, taking into account the characteristics of the reclaimed water, the type and needs of the dominant crop production and environmental, technical and economical criteria. A GIS multi-criteria analysis was used to help in the selection of the agricultural parcels.

2 MATERIALS AND METHODS

2.1 Wastewater treatment plant and monitoring campaign

A small wastewater treatment plant serving 4000 inhabitants was selected. The treatment line is composed by preliminary treatment (bar racks and grit chambers), primary treatment (settlement tank) and biological aerated filter.

A 12-months monitoring campaign was setup between January and December of 2007 including the daily measurement of flow-rate and the collection of samples of raw influent and reclaimed water every two weeks. The samples were analyzed for the following parameters: pH, temperature, electrical conductivity (EC), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), total nitrogen (TN), ammonia (NH_4), nitrite (NO_2), nitrate (NO_3), total phosphorus (TP), sodium (Na), magnesium (Mg), calcium (Ca), potassium (K), chloride (Cl), boron (B), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), zinc (Zn), total coliforms (TC), faecal coliforms (FC), E. Coli and helminth eggs (HE). All the parameters were determined according to standard methods (APHA-AWWA-WEF, 1999).

2.2 Selection of areas for irrigation

This step included the delimitation of the study area taking in account the location of the WWTP, the river used as final discharge point, the Boidobra village and the A23 motorway as shown in **Figure 1**. The extract of the Military Map No. 235 (1/25,000 scale) in digital format, altimetry data (1/25,000 scale) and orthophotomps (photogrammetric flight of 2004, 1/5,000 scale) were used for delimiting the study area (406.6 ha) and other elements were georreferenced (*e.g*. location of the WWTP and agricultural parcels). The analysis of the information was carried out using the software ArcGIS 9.1 (ESRI, USA) and the ArcCatalog and ArcMap applications.

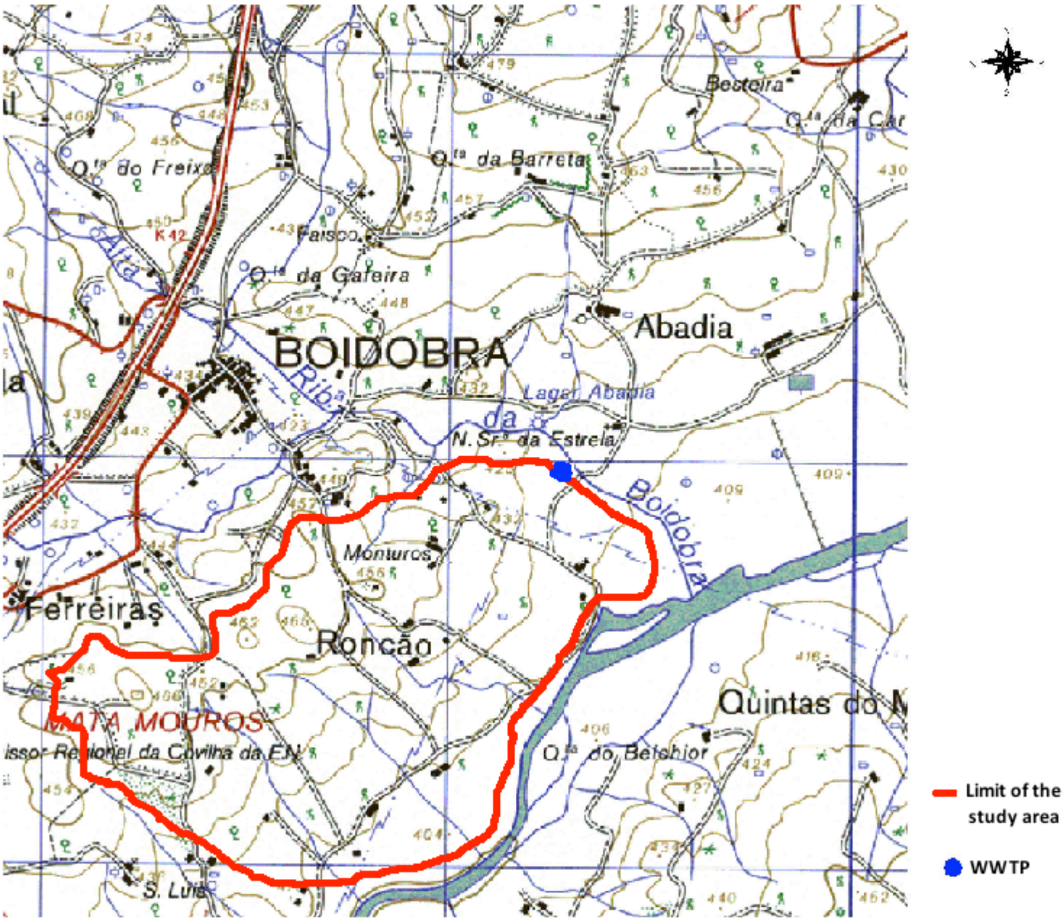

FIGURE 1 **Location of the study area**

The area is located in the central part of the Beira Interior region and is influenced by the moderate Mediterranean climate, with an average annual precipitation of 780 mm, annual average temperature of 14.5 ◦C and average evapotranspiration of around 700 mm. Therefore, a water deficit is expected during the period from June to October.

The following parcels with dominant crops were identified based on restrictions of the Portuguese Standard NP 4434 (IPQ, 2005), the land use map, as well as local information from local farmers it was identified:
- Fresh vegetables for raw consumption: 15.3 ha
- Lawns, parks and public gardens, lawns for sports, wooded areas with easy access to the public: 62.7 ha
- Vegetable crops for cooking, forage crops and grass cultivation, vineyards and orchards: 133.5 ha

The final selection of agricultural parcels for irrigation was based on environmental, technical and economic criteria selected based in other studies (Marecos do Monte and Albuquerque, 2010, Asano *et al*., 2007; Pedrero *et al*., 2011a). The criteria are as follows:

Environmental criteria

- A safety distance of 50 m from natural water resources;
- A safety distance of 100 m from water supply sources and water reservoirs used for human consumption;
- A distance of 200 m from urban residential areas.

Technical criteria

- Annually available volume of reclaimed water;
- water demand of the crops identified in the study area;
- The physical, chemical and microbiological characteristics of the reclaimed water;
- The nutrient demand of crops;
- The tolerance of crops to parameters associated to toxicity and salinity;
- Land uses (the Corine Land Cover map was used to evaluate the potential land use of the studied area);
- Slope (irrigation should be preferably applied in agricultural parcels with slope ranging between 0% and 12%, since higher slope increase runoff, soil erosion and thus soil instability, which risks basin safety and increases refilling costs);
- Groundwater table (aquifers should be sufficiently deep and transmissive to prevent excessive rises of the groundwater table due to infiltration, and the minimum static level accepted is 5 m in order to avoid groundwater contamination).

Economic criteria

- Maximum distance of 4 km (this criterion included water transfer cost from WWTP to the agricultural parcels).

All the elements defined as environmental, technical and economic criteria were located and georeferenced in the selected study area (Figure 1). Spatial analysis was carried out through a representation of each selected variable by a thematic layer (thematic map). The thematic layers were developed from geographical data obtained from official sources, georeferenced data and data generated using satellite images and orthophotos. Each point (cells representing 10 m × 10 m) in each layer took a value (0 or 1) according to exclusion and inclusion criteria. Map algebra was used to make a Boolean operation between grid cells of different thematic maps in order to generate a final map with the agricultural parcels for application of reclaimed water. The software ArcGIS 9.1 (ESRI, USA) and the ArcCatalog and ArcMap applications were used for all the operations, namely for the following main tasks:

- Integration and management of spatial and non-spatial data (Raster or Vector);
- Editing of both data and geographical entities;
- Overlaying thematic information topics;
- Spatial analysis (Spatial Analyst);
- Design of slope maps (3D Analyst);
- Definition of buffer zones on the border of geographical entities, using the buffer application;
- Query of databases according to predefined criteria;
- Georeferring of elements or entities;
- Geoprocessing of the information for mapping information in the selected study area;
- Determination of the agricultural parcels with higher suitability for reclaimed water application, using algebra of maps (Raster Calculator).

3 RESULTS AND DISCUSSION

3.1 Analysis of reclaimed water for irrigation

The results of the monitoring campaign are presented in **Table 1**.

TABLE 1 **Characteristics of the raw influent and the reclaimed water**

Parameter	Raw influent [1)]	Reclaimed water [1)]	RE (%) [3)]
Flow-meter ($m^3\ d^{-1}$)	465 ± 56	-	-
Temperature (ºC)	13.5 ± 3.6	14.2 ± 2.4	-
pH	6.6 - 7.8	6.1 - 7.7	-
EC ($dS\ m^{-1}$)	0.41 ± 0.03	0.38 ± 0.04	7.3
BOD_5 ($mg\ L^{-1}$)	312.2 ± 25.4	23.1 ± 4.3	92.8
COD ($mg\ L^{-1}$)	518.3 ± 64.2	110.1 ± 24.2	78.8
TSS ($mg\ L^{-1}$)	120.6 ± 45.6	25.2 ± 4,.6	79.1
NH_4 ($mg\ L^{-1}$)	55.3 ± 9.7	18.5 ± 3.6	66.5
NO_2 ($mg\ L^{-1}$)	0.13 ± 0.02	< 0.01 [2)]	100
NO_3 ($mg\ L^{-1}$)	0.8 ± 0.2	4.1 ± 1.8	-
TN ($mg\ L^{-1}$)	68.3 ± 10.6	25.6 ± 3.8	62.5
TP ($mg\ L^{-1}$)	8.2 ± 2.2	6.1 ± 1.4	25.6
Na ($mg\ L^{-1}$)	105.3 ± 13.3	110.2 ± 28.5	-
Mg ($mg\ L^{-1}$)	3.2 ± 1.1	2.1 ± 0.8	34.4
Ca ($mg\ L^{-1}$)	14.5 ± 3.7	15.6 ± 4.2	-
K ($mg\ L^{-1}$)	36.7 ± 8.7	31.3 ± 5.0	14.7
Cl ($mg\ L^{-1}$)	43.1 ± 10.1	38.2 ± 6.7	11.4
B ($mg\ L^{-1}$)	0.14 ± 0.05	0.15 ± 0.05	-
As ($mg\ L^{-1}$)	0.01 ± 0	0.01 ± 0	-
Cd ($mg\ L^{-1}$)	0.04 ± 0.01	< 0.005 [2)]	100
Cr ($mg\ L^{-1}$)	1.88 ± 0.11	0.11 ± 0.03	94.1
Cu ($mg\ L^{-1}$)	0.01 ± 0,0	< 0.005 [2)]	100
Hg ($mg\ L^{-1}$)	0.01 ± 0.0	< 0.005 [2)]	100
Ni ($mg\ L^{-1}$)	0.15 ± 0.03	0.11 ± 0.04	26.3
Pb ($mg\ L^{-1}$)	0.1 ± 0.02	0.08 ± 0.01	20
Zn ($mg\ L^{-1}$)	0.28 ± 0.05	0.21 ± 0.05	25
TC (NTU per 100 mL)	$2.2x10^6$ ± 1200	$1.1x10^5$ ± 850	$1.1x10^1$
FC (NTU per 100 mL)	$2.1x10^5$ ± 850	$1.0x10^4$ ± 900	$1.1x10^1$
E. Coli (NTU per 100 mL)	$2.4x10^5$ ± 950	$2.0x10^4$ ± 700	$0.4x10^1$
HE (eggs per 10 L)	ND	ND	-

1) Average ± confidence intervals (calculated for a confidence level of 95% and 24 samples)
2) Below the detection limit
3) Pathogen removal in logs

RE: removal efficiency
ND: not detected

The annual net volume of reclaimed water produced at the WWTP is approximately 170,000 m^3, based on the average flow-rate. The average removal efficiency (RE) for COD (78.8%), NH_4 (66.5%) and TN (62.5%) are lower than the values expected for BAF reactors (Tchobanoglous *et al.*, 2002; Asano *et al.*, 2007; Albuquerque *et al.*, 2011): >85% (COD), >70% (NH_4 and TN). The average effluent concentrations for NH_4, TN and TP are higher than the goals set-up in the Directive 271/91/EEC and in the Portuguese Decree-Law No. 236/98: maximum allowed values of 10 mg L^{-1} (NH_4), 15 mg L^{-1} (TN) and 3 mg L^{-1} (TP). The removal of heavy metals and nitrate are quite good and the respective effluent concentrations were below the limits for both the discharge in water bodies (Portuguese Decree-Law No. 236/98) and irrigation (Portuguese Decree-Law No. 236/98; EPA, 2004; Portuguese Standard NP 4434, 2005; Marecos do Monte, 2007; Asano *et al.*, 2007; UNESCO, 2009).

The suitable characteristics of the reclaimed water for crop irrigation are (Murcott, 1995): moderate organic content, high nutrient content (N, P), low pathogen content, and low metal and phytotoxic elements (Na, Cl and B). There is no risk of groundwater contamination by nitrate, the EC is below 0.7 dS m^{-1} (higher values are a risk for soil salinity), and the concentration of heavy metals and phytotoxic compounds are below the recommend values for crop irrigation (Portuguese Decree-Law No. 236/98; EPA, 2004; Portuguese Standard NP 4434, 2005; Bixio and Wintgens, 2006; Asano *et al.*, 2007; UNESCO, 2009). However, the pathogenic content (TC, FC and E. Coli) is not suitable for irrigation (Portuguese Decree-Law No. 236/98, WHO, 2006).

Therefore, the WWTP needs to be upgraded to increase the removal of ammonia and phosphorous if the final effluent is discharged in water streams, or a final disinfection to remove pathogens if the final application is crop irrigation. However, the content in nutrients of the reclaimed water may be beneficial for agricultural irrigation, since it can act as fertilizers for crops (EPA, 2004). This practice may also reduce the amount of synthetic fertilizers that might be applied (Lazarova and Barhi, 2005; EPA, 2004).

3.2 Agricultural land parcels for irrigation

For each environmental, technical and economic variable the exclusion areas were coded as 0 and the inclusion areas as 1. By overlapping all the criteria associated to each variable to the parcels with dominant crops (mainly fruit trees, corn, olive trees and vine) in the studied region the more suitable agricultural parcels for irrigation were obtained as shown in **Figure 2**. A GIS in raster format was used to create the map with the location of the agricultural parcels and the results were processed according to the algebra of maps (maps overlapping for the different variables, operated in 10 m × 10 m cells sized).

Taking in account the annual volume of water needed for each type of crop (fruit trees, corn, olive trees and vine) and the annual volume of reclaimed water produced at the WWTP, the area of each crop to be used for irrigation are presented in **Table 2**. Therefore, a total of 30.53 ha of crops may be irrigated with the annual volume of reclaimed water produced at the WWTP, located at less than 1.8 km from the WWTP.

The volume of heavy metals and nutrients to be incorporated in soil was computed from the their effluent concentrations in the reclaimed water, the total volume of reclaimed water to used annually ad the potential area for irrigation. The results are presented in **Table 3**.

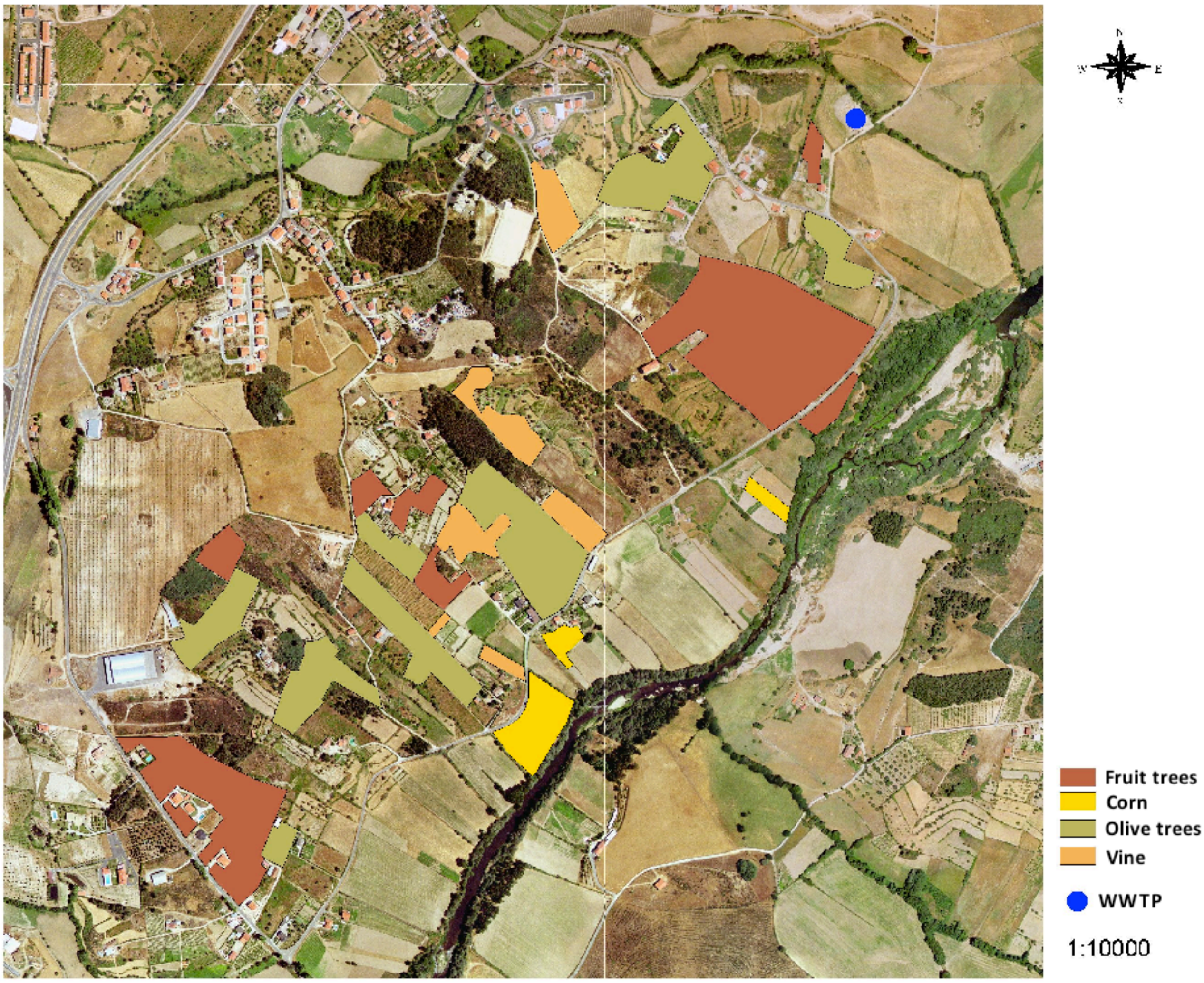

FIGURE 2 **Selected agricultural parcels for irrigation with reclaimed water**

TABLE 2 **Areas for irrigation for each crop**

Type of crop	Needs of water for each crop ($m^3\ ha^{-1}\ ano^{-1}$)	Volume of reclaimed water to be used ($m^3\ ha^{-1}\ ano^{-1}$)	Area for irrigation	
			(ha)	(%)
Fruit trees	7500	85200	11.36	37.2
Corn	2500	11300	4.52	14.8
Olive trees	5300	46100	8.70	28.5
Vine	4600	27400	5.96	19.5
Total		**170000**	**30.53**	**100**

TABLE 3 **Load of nutrients and heavy metals associated to the reclaimed water**

Parameter	Load to be applied on soil (kg ha^{-1} $year^{-1}$)	Directive 86/278/EEC [1)]	MADRP (1997), DELG (2008) USDA-SCS (1994) [2)]
TN	142.5		170 - 210
TP	34		157
As	0.06		
Cd	0.11	0.15	
Cr	0.84	4.5	
Cu	0.06	12	
Hg	0.06	0.1	
Ni	0.61	3	
Pb	0.45	15	
Zn	1.17	30	

[1)] Limit values for amounts of heavy metals that may be added to agricultural soils (also adopted in the Portuguese standard NP 4434 (IPQ, 2005)
[2)] Limit values for amounts of TN and TP that may be added to agricultural soils

As shown in **Table 3**, the quantities of heavy metals to be incorporated in the soil are much lower than the limits defined in both the Directive 86/278/EEC and the Portuguese standard NP 4434 (IPQ, 2005). However, the risks for leaching and surface runoff should be previously evaluated.

The average ammonia effluent concentration (18.5 mg L^{-1}) is not high for crop irrigation and some of it will be oxidized to nitrate through nitrification in the upper part of the soil. Organic nitrogen is also of concern since it converts (mineralizes) into plant-available inorganic forms (ammonia nitrite and nitrate nitrogen). Ammonia and nitrate are readily available for plant uptake. However, if the reclaimed water is applied on the soil surface and not quickly incorporated, considerable ammonia may be lost to the air as gas (volatilization). The excess of ammonia not volatilized may therefore be oxidized to nitrate through nitrification, which may be subject to leaching loss (Ribeiro *et al*., 2010).

According to Portuguese and international guides for good agricultural practices (MADRP, 1997; DELG, 2008) the application rate of total nitrogen should not exceed 210 kg ha^{-1} $year^{-1}$ in non sensitive areas and 170 kg ha^{-1} $year^{-1}$ in areas sensitive to nitrate leaching according to the Directive 91/676/EEC (Nitrates Directive). Results show that the amount of nitrogen to be introduced in the soils of the study area (142.5 kg ha^{-1} $year^{-1}$) is lower than the limits recommended by Portuguese and international guides even for areas sensitive to nitrate leaching.

Total phosphorus concentration is low (6.1 mg L^{-1}) and will enter the soil in mineral forms, which tend to be retained by mineral colloids or to form phosphates (*e.g.* calcium phosphates, aluminium and iron) with low solubility (Ribeiro *et al*., 2010). The research carried out in Portugal has observed that the application of an average rate of approximately 75 kg P_2O_5 ha^{-1} $year^{-1}$ is enough to increase by 10 mg kg^{-1} the content of assimilative P in soil (LQARS, 2000). The amount of phosphorus to be incorporated in the soils (34 kg ha^{-1} $year^{-1}$) is much lower than the recommended value (USDA-SCS, 1994), and therefore may be classified of very low risk for phosphorus movement.

The use of GIS allowed the georeferencing, storage, processing and manipulating of complex information, in order to select agricultural parcels for reclaimed water application. This study also shows that small WWTP located in rural areas may provide a small, but important contribution of water for irrigation, which is very useful in regions with water scarcity as the Cova da Beira region in Portugal.

4 CONCLUSIONS

A one-year monitoring campaign is a small WWTP located in a rural area of the Cova da Beira region showed that the characteristics of the reclaimed water in terms of pH, EC, BOD_5 , COD, nitrogen, phosphorous, K, Ca, Mg, heavy metals and phytotoxic elements (Na, B and Cl) were suitable to be used for the irrigation of 30.53 ha of the dominant crops (fruits trees, corn, olive trees and vine), after a final disinfection to eliminate pathogens. The amount of nutrient and heavy metals to be incorporated in the agricultural soils are much lower than the goals set-up in international and national guides, laws and standards. GIS multi-criteria analysis was very useful for selecting the agricultural parcels to be irrigated, which involved Boolean operations and map algebra operation with several environmental, technical and economic criteria. The use of reclaimed water from small WWTP may represent an important water source for irrigation reuse in rural regions with water shortage, with important environmental and economics benefits.

REFERENCES

Albuquerque, A.; Makinia, J.; Pagilla, K. (2011): Influence of aeration on nitrogen removal in a submerged biological aerated filter for residuals removal. In *WEF Nutrient Recovery and Management 2011 Conference*. Miami, USA 9-12 January. WEF: Alexandria, USA, 931-944.

Albuquerque, A., Arendacz, M., Gajewska, M., Obarska–Pempkowiak, H., Randerson, P., Kowalik, P. (2009). *Removal of organic matter and nitrogen in a HSSF constructed wetland under transient loads*. Water Science and Technology, 60(7): 1677–1682.

APHA-AWWA-WEF (1999): *Standard methods for the examination of water and wastewater*. 20th edition. American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC, USA.

Asano, T., Burton, F., Leverenz, H., Tsuchihashi, R., Tchobanoglous, G. (2007): *Water reuse*. First ed., New York, USA: McGrawHill.

Bixio, D., Wintgens, T. (2006): *Water reuse system management – Manual AQUAREC*. Brussels, Belgium: Directorate-General for Research, European Commission.

DELG (2008). *The code of good agricultural practice for the prevention of pollution of water, air and soil*. Department of Agricultusre and Rural Development; Dublin, Ireland, 165 pp.

EPA (2004): *Guidelines for water reuse*. Report EPA/625/R-04/108, Environmental Protection Agency, Washington, USA.

Gemitzia, A., Tsihrintzis, V., Christouc, O., Petalas, C. (2007): *Use of GIS in siting stabilization pond facilities for domestic wastewater treatment*. Journal of Environmental Management, 82: 155-166.

IPQ (2005): *Portuguese standard 4434 - Reuse of wastewater in irrigation*. Monte Caparica, Portugal: Portuguese Institute for Quality; 2005, 30 pp. [in Portuguese].

Lazarova, V., Bahri, A. (200). *Irrigation with recycled water*. Agriculture, Turfgrass and Landscape. CRC Press, Boca Raton, Florida, USA.

Kallali, H., Anane, M., Jellali, S., Tarhouni, J. (2007): *GIS-based multi-criteria analysis for potential wastewater aquifer recharge sites*. Desalination, 215: 111-119.

LQARS (2000): *Manual for culture fertilization*. Ministério da Agricultura, do Desenvolvimento Rural e das Pescas, Lisbon, Portugal [in Portuguese].

MADRP (1997): *Guide for good agriculture practices: protection of water streams against the nitrate pollution*. Ministério da Agricultura, do Desenvolvimento Rural e das Pescas, Lisbon, Portugal, 53 pp. [in Portuguese].

Marecos do Monte, H. (2007): *Guidelines for Good Practice of Water Reuse for Irrigation: Portuguese Standard NP 4434*. In *Wastewater Reuse – Risk Assessment, Decision-Making and Environmental Security*. edited by M. K. Zaidi, Springer, Dordrech, Neetherland.

Marecos do Monte, H., Albuquerque, A. (2010): *Analysis of constructed wetland performance for irrigation reuse*. Water Science and Technology, 61 (7): 1699–1705.

Murcott, T. (1995): *Ecatepec pilot plant and jar test results with aluminum sulfate and polymer*. Report, Massachusetts

Institute of Technology, Cambridge, USA.

Pedrero, F., Albuquerque, A., Amado, L., Marecos do Monte, H., Alarcón, J. (2011b): *Analysis of the reclamation treatment capability of a constructed wetland for reuse*. Water Practice and Technology, 6(3): 7 pp.

Pedrero, F., Albuquerque, A., Marecos do Monte, H., Cavaleiro, V., Alarcón, J. (2011a): *Application of GIS-based multi-criteria analysis for site selection of aquifer recharge with reclaimed water*. Resources, Conservation & Recycling, 56(1): 105–116.

Ribeiro, P., Albuquerque, A., Quinta-Nova, L., Cavaleiro, V. (2010): *Recycling of pulp mill sludge to improve soil fertility using GIS tools*. Resources, Conservation & Recycling, 54:1303-1311.

Tchobanoglous, G.; Burton, F.; Stensel, H. (2002): *Wastewater engineering. Treatment and reuse*. 4th Ed. McGraw-Hill, New York, USA.

UNESCO (2009): *Water in a changing world (WWDR-3)*. 3rd United Nations World Water Development Report, UNESCO, Butler, Tanner & Dennis, UK, 320 pp.

USDA-SCS (1994): *Phosphorus assessment tool*. Technical note, series number 1901, South National Technical Center, Forth Worth, Texas, USA.

WHO (2006). *Guidelines for the safe use of wastewater, excreta and greywater*. Vol. 2: Wastewater use in agriculture, World Health Organization, Geneva, Switzerland.