8-1-2014

GIS-Based Site Selection For Agricultural Irrigation With Reclaimed Water

Natalia Sardinha

Antonio Albuquerque

Flora Silva

Paulo Scalize

11th International Conference on Hydroinformatics
HIC 2014, New York City, USA

GIS-BASED SITE SELECTION FOR AGRICULTURAL IRRIGATION WITH RECLAIMED WATER

NATÁLIA SARDINHA (1), ANTÓNIO ALBUQUERQUE (2), FLORA SILVA (3), PAULO SCALIZE (4)

(1): Águas da Covilhã, Rua Ruy Faleiro, 111, Apartado 38, 6201-999 Covilhã, Portugal, Tel: +351-275310810, Fax: +351-275310819.

(2): Department of Civil Engineering and Architecture, University of Beira Interior, Edifício 2 das Engenharias, Calçada Fonte do Lameiro, 6201-001 Covilhã, Portugal, Tel: +351-275329981, Fax: +351-275-329969.

(3): School of Technology and Management, Polytechnic Institute of Bragança, Campus de Santa Apolónia, Apartado 1134, 5301-857 Bragança, Portugal, Tel: +351-273303000, Fax: +351-273313051.

(4): Civil Engineering School, Federal University of Goiás, Praça Universitária, s/n, Setor Universitário, Postal Code: 74605-220, Goiânia, Goiás, Brazil.

Abstract: Most of the treated wastewater produced in the Cova da Beira region (Portugal) is discharged into streams. It is believed this reclaimed water could be reused for agricultural irrigation since it is a sector with high water demand. However, it is necessary evaluating if its quality is suitable for irrigation. From flow rate data and physical-chemical analyses produced in the years 2009, 2010 and 2011, and from a supplementary monitoring campaign carried out in 2012, it was observed that the reclaimed water could be used for agricultural irrigation if the pathogenic load could be controlled. Based on 5 thematic maps and environmental and technical criteria, a Suitability Map was generated for the application of reclaimed water in 47.5 ha of corn, olive grove, orchard and vineyard, using GIS tools. This analysis involved the overlapping of exclusion and inclusion areas of thematic maps using algebraic operations (multicriteria analysis). The average volume of reclaimed water generated in the years between 2009 and 2011 would be sufficient to irrigate all the existent agricultural parcels in each year, after removing the areas with technical or environmental restrictions.

Keywords: Agricultural irrigation; GIS; multi-criteria analysis; reclaimed water; reuse

INTRODUCTION

The Cova da Beira region (Portugal) is normally affected by droughts, which decreases the water availability in quality and quantity for irrigation. The needs of water for irrigation is expected to increase in the region, which, along with the needs for public supply and industrial demand, will put supply problems due to the overexploitation of some natural water sources and the low quality observed in other sources. Thus, the search for alternative sources of water, such as the reuse of treated wastewater, may help to minimize this problem.

The application of the 2000/60/CE Directive constitutes an important step for the sustainable management of water resources. The water reuse becomes an important axis for the integrated management of water resources, particularly for uses such as agricultural irrigation, landscape irrigation, industry applications, groundwater recharge, recreational and environmental uses and even non-potable urban uses.

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, and 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 as also used in previous studies in the same region (Ribeiro et al., 2010; Pedrero et al., 2011).

The main objective of the study was to identify the suitable agricultural parcels for irrigation with reclaimed water from a local treatment plant, taking into account its characteristics, the type and needs of the dominant crop production, and environmental and technical criteria, using a GIS multi-criteria analysis.

MATERIAL AND METHODOS

In a first phase it was defined the study area, a vast rural area with 690 ha located in the Beira Interior region, in the parishes of Boidobra and Ferro (municipality of Covilhã, district of Castelo Branco, Portugal), and it was characterized the geological aspects, geomorphological, hydrogeological, socio-economic characteristics, land use and type of soil (Fig. 1).

Afterwards, a local wastewater treatment plant (WWTP) serving 65,000 inhabitants was selected. Quality monitoring data from 2009 to 2011 was collected and a supplementary sampling was carried out in order to have suitable information on the reclaimed water characteristics, namely for the parameters flow rate, pH, temperature, electrical conductivity, BOD_5, COD, TSS, TN, NH_4-N, NO_3-N, TP, B, Ca, Cl, Mg, Mn, K, Na, Cd, Pb, Cu, Cr, Ni, Zn, total coliforms, faecal coliforms and E. Coli.

The final step has involved the identification of agricultural areas with potential for reuse of the reclaimed water, the adaptation of three existing digital maps (land use (OS), soil type (TS) road network (RV)), as well as the production of 6 new thematic maps (urban agglomerations (AU), digital terrain model (DTM), slopes (D), water streams network (LA), wells (P) and type of culture (TC)). Based on environmental, technical and public health protection criteria and on the 5 thematic maps produced it was generated the Suitability Map for agricultural application of the reclaimed water.

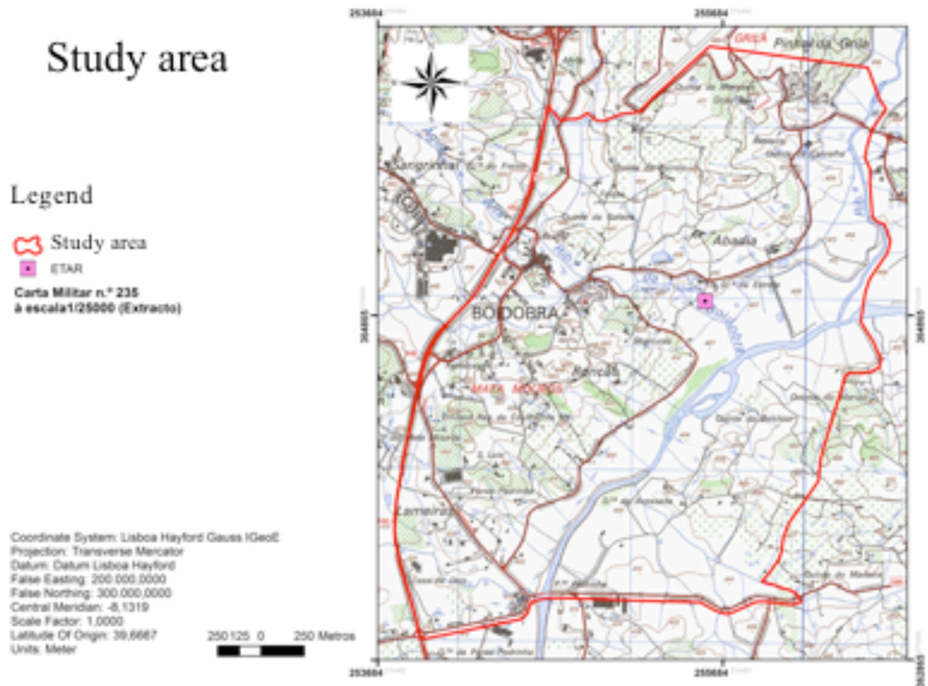

Figure 1 Location of the study area

RESULTS AND DISCUSSION

The characteristics of the reclaimed water are presented in Table 1. The results on physical, chemical and microbiological analysis suggest that there is no risk for groundwater contamination by nitrate. The average EC (0.4 dS m^{-1}) is not a risk for soil salinity. Looking at the compounds with potential phytotoxicity (B, Cl, Na), only boron presents higher concentration than the maximum suggested limit setup by international organisations for irrigation (0.7 mg B/L, 140 mg Cl/L and 140 mg Na/L, according to Westcot and Ayers (1985), Asano et al. (2007) and UNESCO (2009)). However, the toxicity of boron only is significant if the concentration of Cl and Na also are high.

The average heavy metals concentrations (Cd, Cr, Cu, Ni, Pb and Zn), which can be incorporated on soil do not present risk for its contamination, since they are lower than the values recommended by Asano et al. (2007) and UNESCO (2009). These values are similar to those observed by Pedrero (2010) in the region of Murcia (Spain) and Silva et al. (2012) in the region of Vila Fernando (Guarda, Portugal). As the TSS, Ca and Mg concentrations are low, according to Westcot and Ayers (1985), the risk for altering the permeability of the soil is low. However, the pathogenic content is not suitable for irrigation (Asano et al., 2007; UNESCO, 2009) and disinfection is needed before the application of the reclaimed water as also noted in previous studies in the same region (Marecos do Monte e Albuquerque, 2010; Pedrero et al., 2011).

The three existing digital maps (land use (OS), soil type (TS) road network (RV)) were adapted according the area of Fig. 1. Using the available digitalized-based maps (military maps, ortophoto maps, Corine land cover map, type of soil map and digital elevation model) and environmental, technical and public health protection criteria (Table 2), 6 new thematic maps (urban agglomerations (AU), digital terrain model (DTM), slopes (D), water streams network (LA), wells (P) and type of culture (TC)) were produced taking in account the procedure carried out by Pedrero et al. (2011) and Silva et al. (2012).

Table 1 Characteristics of the reclaimed water

Parameters	Values
Flow rate (m^3/month)[1)]	272 581 ± 52 242
pH[1)]	6.0 – 7.8
BOD_5 (mg/L) [1)]	14.3 ± 2.3
COD (mg/L) [1)]	42.5 ± 6.7
TSS (mg/L) [1)]	13.2 ± 2.2
NO_3 N (mg/L) [1)]	10.3 ± 3.3
TN (mg/L) [1)]	20.1 ± 1.9
TP (mg/L) [1)]	2.3 ± 0.5
EC (mS/m) [2)]	396.8 ± 96.4
Na (mg/L) [2)]	34.7 ± 1.7
Mg (mg/L) [2)]	1.6 ± 0.1
Ca (mg/L) [2)]	34.7 ± 1.7
K (mg/L) [2)]	12.4 ± 1.0
Cl (mg/L) [2)]	39.1 ± 3.3
B (mg/L) [2)]	5.5 ± 0.8
Cd (mg/L) [2)]	0.9 ± 0.3
Cr (mg/L) [2)]	1.7 ± 0.4
Cu (mg/L) [2)]	3.2 ± 0.3
Ni (mg/L) [2)]	44.5 ± 16.1
Pb (mg/L) [2)]	3.0 ± 1.1
Zn (mg/L) [2)]	0.4 ± 0.2
E. Coli (NTU/100 mL) [2)]	6.5×103 ± 2.9×103
TC (NTU/100 mL) [2)]	6.9×104 ± 3.0×104
FC (NTU/100 mL) [2)]	6.1×104 ± 3.6×104

[1)] Average and confidence interval calculated for a confidence level of 95% and the following number of samples: 36 (flow rate), 72 (other parameters).

[2)] Average and confidence interval calculated for a confidence level of 95% and for 10 samples.

The thematic maps are matrixes of cells, each cell representing 10m × 10m and taking the value 0 (restriction point – exclusion cell) or 1 (non-restriction point – inclusion cell) according to the exclusion and inclusion criteria presented in Table 2. Map algebra was used to make Boolean operations between grid cells of the different thematic maps in order to generate a final suitability map for the infiltration of reclaimed water. All the data were collected and treated in vector format or raster format, using the software ArcGIS 9.2 (ArcCatalog, ArcMap and ArcToolbox applications). The digital elevation model (DEM) was built from altimetry data (elevation data) using a triangular irregular network (TIN).

Therefore, the setup of the Suitability Map (Fig. 2) for reclaimed water application has involved a multi-criteria analysis using the method of Boolean overlapping 5 thematic maps (water sources, land uses, slopes, urban areas and crops), and the environmental and technical criteria

(Table 2) to the parcels with dominant crops (fruit trees, corn, olive trees and vine), as suggested by Zhao et al. (2009) and Ribeiro et al. (2010).

Table 2 Environmental, technical and public health protection criteria

Criteria	Restrictions
Environmental and public health	- A safety distance of 50m away from water resources for irrigation or for human use was considered to prevent water contamination (P, LA); - A distance of 70m way from urban residential areas was considered enough for public health protection (AU); - Only agricultural parcels with fruit trees, corn, olive trees and vine were considered, since the risk of human contamination is low.
Technical	- Annually available volume of reclaimed water; - Land use (the Corine Land Cover map was used to evaluate the potential land use of the studied area) (OS, TC); - Slopes (irrigation should be preferably applied in agricultural parcels with slopes ranging between 0% and 12%, since higher slopes increase runoff, soil erosion and thus soil instability, which risks basin safety and increases refilling costs) (D, DTM); - Type of soil (the soil for reclaimed water irrigation should have the top section without soil rock) (TS).

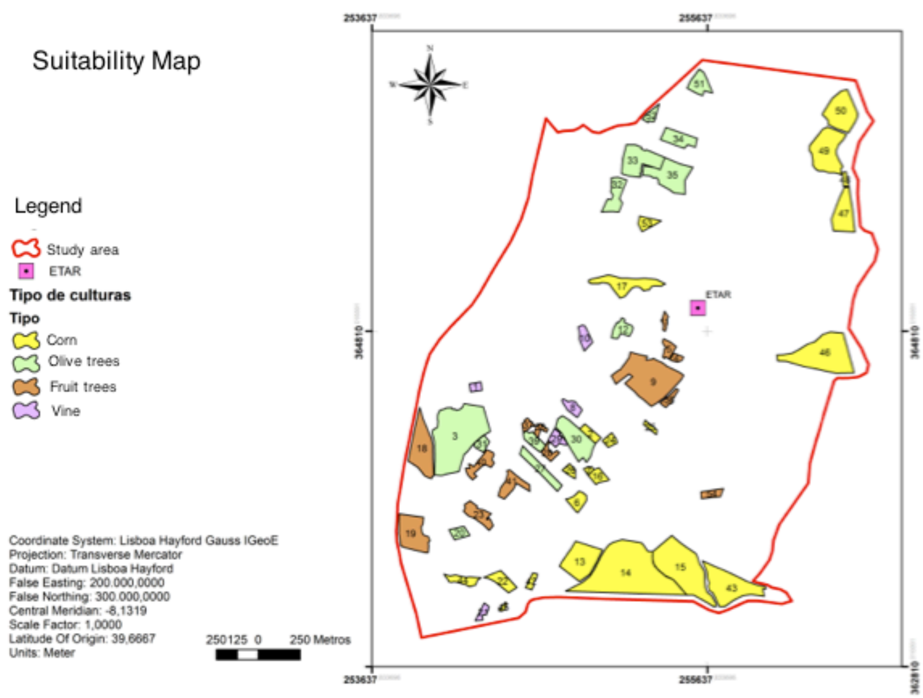

Figure 2 Suitable map for agricultural irrigation with reclaimed water

The value of each cell of the Suitability Map (Figure 2) has resulted, therefore, from the sum of the multiplication of the weights assigned to each thematic map by the value stored in each of its cells. Therefore, a total of 47.5 ha of crops can be irrigated with the annual volume of reclaimed water produced at the WWTP.

CONCLUSIONS

The qualitative and quantitative data collected at a local WWTP showed that the characteristics of the reclaimed water is suitable to be used for the annual irrigation of 47.5 ha of fruits trees, corn, olive trees and vine, after a final disinfection to eliminate pathogens. 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 and technical criteria.

AKNOWLEDMENTS

The authors wish to thank Águas da Serra for its help in providing data on the characteristics of the reclaimed water from the wastewater treatment plant of Covilhã.

REFERENCES

[1] Asano T., Burton F., Leverenz H., Tsuchihashi R. and Tchobanoglous G., *“Water Reuse: Issues, Technologies and Applications”,* McGraw-Hill, New York, USA (2007).

[2] Marecos do Monte H., Albuquerque A., “Analysis of constructed wetland performance for irrigation reuse”, *Water Science and Technology,* Vol. 61, No. 7 (2010), pp. 1699–1705.

[3] Pedrero F., Albuquerque A., Marecos do Monte H., Cavaleiro V., Alarcón J.,”Application of GIS-based multi-criteria analysis for site selection of aquifer recharge with reclaimed water”, *Resources, Conservation &* Recycling, Vol. 56, No. 1 (2011), pp. 105–116.

[4] Pedrero F., *“Sustainable irrigation management with reclaimed water”,* PhD Thesis. Consejo Superior de Investigaciones Científicas (CSIC), Murcia, Spain (2010), 155 pp.

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

[6] Silva F., Albuquerque A., *Marecos do Monte H., Cavaleiro V. e Carvalho A., “Site selection for reclaimed water infiltration using GIS tools”, Proc. of the IWA Regional Conference on Wastewater Purification and Reuse,* 28-30 March 2012, Creta, Greece (2012), 12 pp.

[7] UNESCO, “*Water in a Changing World (WWDR-3)”,* 3rd United Nations World Water Development Report, UNESCO, Butler, Tanner & Dennis, UK (2009), 320 pp.

[8] Westcot D., Ayers R., *“Irrigation water quality criteria”,* In: Irrigation with Reclaimed Municipal Wastewater – A Guidance Manual, Pettygrove G. and Asano T. (edts), Lewis Publishers, Inc., Chelsea, USA (1985),

[9] Zhao Y., Qin Y., Chen B., Zhao X., Li Y., Yin X., Chen G., “GIS-based optimization for the locations of sewage treatment plants and sewage outfalls – a case study of Nansha District in Guangzhou City, China”, *Communications in Nonlinear Science and Numerical Simulation,* Vol. 14 (2009), 1746–57.