# Urban sprawl in Zêzere watershed (Portugal) and the risk of reduction of the water quality

**Bruno M. MENESES**[1], Eusébio REIS[2], Maria José VALE[3], Rui REIS[4]

[1] Centre for Geographical Studies, Institute of Geography and Spatial Planning, Universidade de Lisboa. Rua Branca Edmée Marques, 1600-276, 1600-214, Lisboa, Portugal | General Directorate for Territorial Development. Rua da Artilharia Um, 107, 1099-052, Lisboa, Portugal, bmeneses@campus.ul.pt
[2] Centre for Geographical Studies, Institute of Geography and Spatial Planning, Universidade de Lisboa. Rua Branca Edmée Marques, 1600-276, 1600-214, Lisboa, Portugal, eusebioreis@campus.ul.pt
[3] General Directorate for Territorial Development. Rua da Artilharia Um, 107, 1099-052, Lisboa, Portugal, mvale@dgterritorio.pt
[4] General Directorate for Territorial Development. Rua da Artilharia Um, 107, 1099-052, Lisboa, Portugal, rui.reis@dgterritorio.pt

**Abstract:** This paper explores the Land Use and Land Cover Changes (LUCC) in the Zêzere watershed (Portugal) and the risk of reduction of surface water quality, with emphasis in urban sprawl, because the LUCC that took place in the past in this watershed showed the increase of this type of land use and land cover (LUC). This factor resulted in changes in shallow water quality in the main dam reservoir: Castelo de Bode. It was verified a tendency to an increase of urban areas through the analysis of Corine Land Cover (CLC) cartography for 1990, 2000, 2006, and 2012. It has been estimated the probability of urban sprawl in this watershed by bivariate statistical models (Fuzzy Logic-Gamma operator) and, using the previous results, we determined spatially the areas most likely to surface artificialization until 2018 and 2024. These results and the observations of variations of water quality parameters (WQP) in the past will serve to calculate the tendency for WQP variation in future. The results indicate that urban sprawl may increase the risk of deterioration in the quality of surface water.

**Keywords**: Urban sprawl, Water quality implications, risk, Zêzere watershed.

## 1. Introduction

Urban sprawl has been indicated as a factor that causes the reduction of water quality in some river basins, particularly that of surface waters (Fiquepron *et al*., 2013; Scatena, 2000; Teixeira *et al*., 2014; Yu *et al*., 2013). In the Zêzere watershed there is indication of implications of urban sprawl in the water quality of the main reservoirs, especially in those rivers where more pronounced process of urban sprawl is observed (Meneses *et al*., 2015; Vale *et al*., 2015). This watershed includes an important water reserve of Continental Portugal, namely the Castelo de Bode dam. This dam is relevant in the national context because it supplies water to the greater Lisbon region (accounting for more than a fifth of the Portuguese population). Anthropogenic interventions in the land use and land cover (LULC) of this watershed have implications with the quality of water stored in the main reservoirs, especially the artificialization of soil for housing construction, roads, or commercial and industrial infrastructures (Meneses *et al*., 2015).

In this context it is necessary to evaluate how urban sprawl influences a decrease in the quality of surface water due to the growing anthropogenic pressures in the catchment areas of drinking water reserves, a problem already discussed in some territories around the world (Fiquepron *et al*., 2013; Glavan *et al*., 2013; Li *et al*., 2008; Scatena, 2000; Vale *et al*., 2015; Vushe *et al*., 2014; Gottfried and Debano, 1983).

Water scarcity and the urban sprawl (without creation of preventive measures of waste water treatment) are two factors that lead to an increase of the risk of surface water quality reduction (Enderlein *et al.*,

1996), in particular because urban sprawl provides conditions for an increased input of pollutants or contaminants in surface water.

The availability of water in quantities is also important, particularly in the dilution of the elements or compounds, i.e., a lesser amount of water stored in reservoirs is the cause of an increase in the concentration of certain physical and chemical elements in these waters, thus reducing their quality (Meneses, 2013). Given the importance of this natural resource it is necessary to evaluate the resulting impacts of LUCC in order to minimize interference in its availability (quantity and quality).

## 2. Main objectives

The main objective of this research is to evaluate the risk of water quality reduction in the Castelo de Bode dam (Zêzere watershed) as a function of the urban sprawl that has occurred in the last two decades. Based on the predictions of surface artificialization in the future determined by bivariate statistical models. The risk of water quality reduction in the future was assessed, considering that the conditions responsible in the past, for the reduction of water quality still remain.

Given the vulnerability of this natural resource to degradation, the hazard resulting from the process of urban sprawl and its consequences on water quality, and bearing in mind the elements mentioned, particularly the population relying on this natural resource, we intended to determine the risk implied by the process of urban sprawl in the reduction of water quality.

## 3. Materials and methods

### 3.1 Study area and data

The study area is Zêzere watershed (Potugal), with an area covering 5063.9 $Km^2$. This watershed comprises one of the main reservoirs of drinking water in Continental Portugal which supplies various municipalities in the Lisbon region (area with the highest population density in the Portuguese territory) (Fig. 1).

For the assessment of urban sprawl, land use and land cover changes (LUCC) were accounted using the Corine Land Cover cartography (CLC 1990, 2000, 2006 and 2012 in Figure 1) and the results obtained were later crossed with the water quality parameters of the Castelo de Bode dam (information provided by National System of Hydrological Resources of Portugal - SNIRH). With the trends of urban sprawl and the variations of the parameters of water quality in the past, it was determined the probability of surface water quality deterioration, assuming the existence of a cause-and-effect relationship that will be determined by establishing correlations with the above mentioned results.

CLC 1990 was used to model the probability of urban sprawl. CLC 2000 and CLC 2006 were used to calibrate the model, and CLC 2012 was used to validate the results.

The natural variables that have integrated this probability modeling of urban sprawl were: slope, elevation, precipitation, humidity, soil type, insolation (hours), distance to main urban centers, and distance to road network.

The water quality parameters (WQP) were selected on the basis of the data available for the stations located in dam reservoir, Castelo de Bode, currently available on the website of the SNIRH. We selected: pH, total ammoniacal nitrogen (TAN), 5-day biochemical oxygen demand (BOD5), fecal coliforms (FC), total coliforms (TC), total mercury (Hg), electric conductivity in field (20 °C) (ECF), total nitrate ($NO_3^-$), total nitrite ($NO_2^-$) and total suspended solids (TSS).

The data series of WQP selected lack some data, in this sense we considered the three-year average (year corresponds to the CLC data and the two previous years), admitting that LUCC observed at a given time are also a result of LUCC dynamics that occurred in previous years.

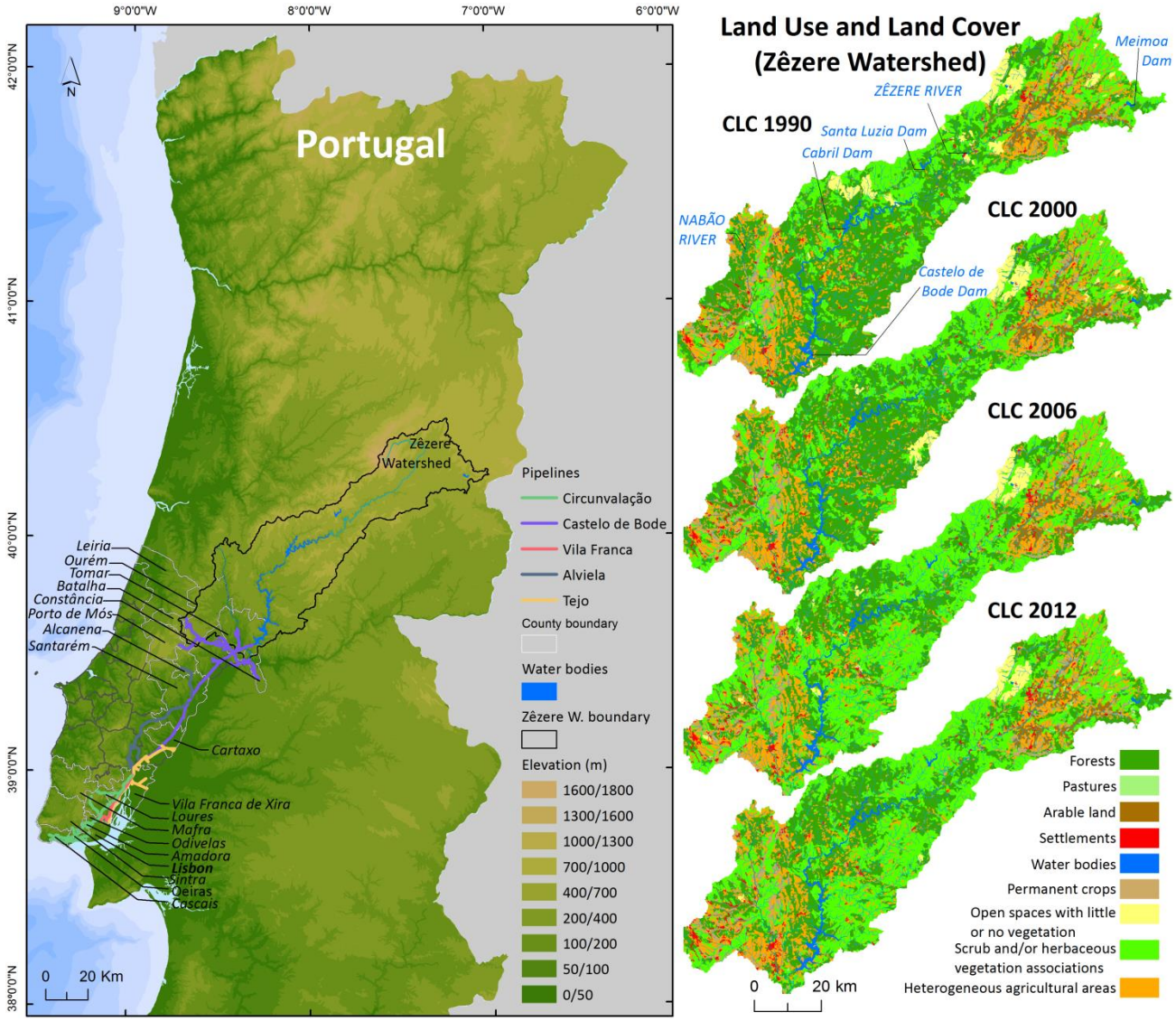


**Figure 1** – Land use and land cover of Zêzere watershed in different years (CLC data) and the counties supplied with drinking water of the Castelo de Bode Dam.

3.2 Numerical modelling of the urban sprawl and determination of the risk of reduction of the water quality

The predictions of urban sprawl were determined by a bivariate statistical model. First we crossed urban areas with natural variables and objectively determined the *a priori* probability and conditional probabilities (for each class of independent variables). These results were converted through the *fuzzification* process for further integration of the Spatial Data Modeller (Arc-SDM) in ArcGIS 10.2. The following process was the determination of the probability of urban space sprawl through the *Fuzzy* Logic (*Gamma* Operator in Eq. 1) (Chen *et al.*, 2013; Zadeh, 1965).

$$Fuzzy\ Gamma = \left(1 - \prod_{i=1}^{n}(1-\mu_i)\right)^{y} \left(\prod_{i=1}^{n}\mu_i\right)^{1-y} \quad (1)$$

In Eq. (1), $\mu i$ is the *fuzzy* association values ($i$=1, 2, 3, …, n) for the variables 1, 2, 3, …, n; $n$ corresponds to the number of variables considered, and $y$ the parameter set by the operator.

The risk of water quality reduction in Zêzere watershed was evaluated as a function of the probability of urban sprawl, because the increase of this LUC type during the last decade had interference in the quality of surface water (Meneses *et al*., 2015; Vale *et al*., 2015). In this way, the urban sprawl is considered one of the main factors associated with the degradation of the water quality in this watershed.

## 4. Results and discussion

4.1 LUC transitions of last years and the probability of urban sprawl

The LUCC in Zêzere watershed in the last decades was significant, namely forest transitions to other LUC types. In the case of settlements, the area of this LUC type increased between 1990 and 2012, this being the result of the urban sprawl increase, especially for heterogeneous agricultural areas and forest areas (Table 1).

The high anthropic interventions or activities in Zêzere watershed contributed to the high transitional LUCC area of certain LUC types evaluated in this investigation, namely LUCC for agricultural, grassland and settlements. In this case, the settlements encompass several LUC types: urban fabric; industrial, commercial and transport units; mines, dump and construction sites; and artificial, non-agricultural vegetated areas.

These LUCC have implications on the quality of surface water, on the one hand due to the reduction of infiltration by the soil sealing, which provides greater surface runoff, contributing to increase the level of certain elements and compounds drawn by this water (e.g. suspended solids with physical implications and also in the organoleptic characteristics). On the other hand, population increase lead to the development of human activities in the areas of runoff leading to the dam reservoir, can induce variation of certain WQP, increasing the levels of fecal coliforms, and BOD5, due to poor sewerage and wastewater treatment systems efficiency.

For the period 2012-2018 can be estimated an increase of 9494.5 ha in urban areas and for the period 2018-2024 an increase of 1012.4 ha. Analyzing the results point out an increase in urban areas between 1990 and 2012 (Fig. 2), but analyzing growth trends for the aforementioned periods, we highlight the absolute variations of urban areas with an increase until 2024 (very similar to the one observed between 1990 and 2000), when compared with the increase observed between 2012 and 2016.

**Table 1** – LUC changes in Zêzere watershed (area ha) between 1990 and 2012 (CLC data).

| CLC 2012 / CLC 1990 | Arable land | Forests | Heterogeneous agricultural areas | Open spaces with little or no vegetation | Pastures | Permanent crops | Scrub and/or herbaceous vegetation associations | **Settlements** | Water bodies | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Arable land | 14166.5 | 50.7 | 1675.9 | 0 | 334.8 | 642.6 | 487.6 | **154.0** | 0 | 17512.0 |
| Forests | 131.4 | 113603.7 | 1027.4 | 508.5 | 8.3 | 218.5 | 92775.9 | **652.7** | 9.8 | 208936.3 |
| Heterogeneous agricultural areas | 2668.8 | 1079.0 | 82490.2 | 0 | 331.4 | 3185.4 | 2264.0 | **1408.5** | 31.7 | 93458.9 |
| Open spaces with little or no vegetation | 0 | 4599.8 | 16.6 | 8926.7 | 0 | 0 | 5830.7 | **0** | 0 | 19373.7 |
| Pastures | 50.7 | 0.5 | 144.0 | 0 | 28.2 | 0 | 22.7 | **0** | 0 | 246.1 |
| Permanent crops | 353.2 | 10.5 | 918.8 | 0 | 20.1 | 16102.4 | 60.8 | **238.8** | 0 | 17704.5 |
| Scrub and/or herbaceous vegetation associations | 374.4 | 31907.1 | 1063.8 | 219.3 | 392.5 | 195.7 | 103477.4 | **347.4** | 58.2 | 138035.7 |
| **Settlements** | **0** | **1.5** | **30.7** | **0** | **0.2** | **3.1** | **74.1** | **6006.8** | **0** | **6116.3** |
| Water bodies | 0 | 7.9 | 1.6 | 0 | 0 | 0 | 3.0 | **0** | 4990.0 | 5002.4 |
| Total | 17744.9 | 151260.6 | 87369.0 | 9654.5 | 1115.4 | 20347.7 | 204996.1 | **8808.2** | 5089.6 | 506386.1 |

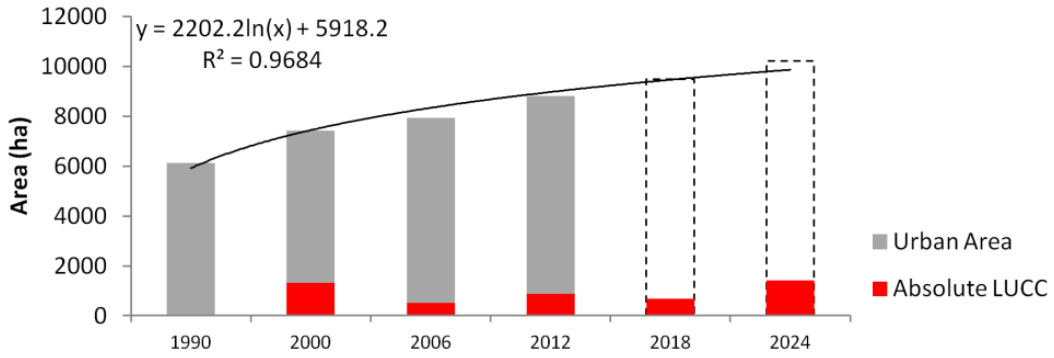


**Figure 2** – Urban areas in Zêzere watershed (CLC data) and the projection of urban sprawl to 2018 and 2024.

In Figure 3 we present the findings of the probability of spatial urban sprawl, obtained through the Fuzzy Gamma model. The most probable areas of urban sprawl are located in the Nabão sub-basin. Based on this probability and using the calculation of the trend of increase in urban areas determined from the CLC cartography for different years, because we located the areas that will, with greater probability, be the next ones to be affected by the process of urban sprawl (higher Fuzzy Gamma values).

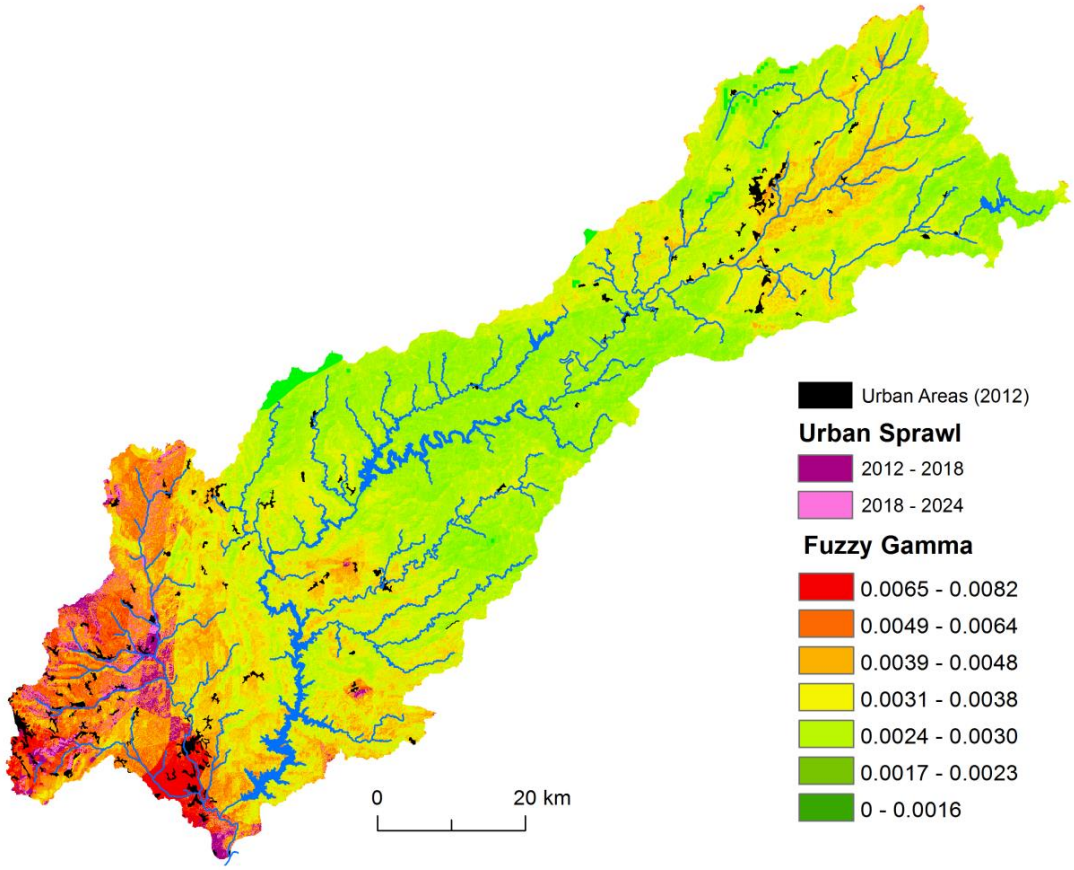


**Figure 3** – Probability of urban surface in Zêzere watershed determined by Fuzzy Gamma, and the projection of urban sprawl to 2018 and 2024.

Most areas of urban sprawl identified for the two periods considered in this research have no direct implications on the quality of water of the Castelo de Bode dam, because they fall, mostly, on the Nabão Sub-basin. However, there is an increasing urban areas demand from the surrounding of the reservoirs of dams included in the Zêzere watershed, this fact, pointed out since 2002 (Vale, 1994) is also confirmed in this research, when we identify using CLC cartography for different years the appearance of new urban areas within this watershed. In the surrounding areas of the Castelo de Bode dam the highest probability of

urban sprawl point out by the model is within the Vila de Rei and Cernache de Bonjardim villages areas All these human interventions in the vicinity of such a relevant drinking water reservoir might be a risk of surface water quality degradation, mainly due to insufficient sewerage system for treatment of domestic waste water, leading to the increase of certain WQP.

4.2 Risk of degradation of the water quality surface

This research point out a truly concerning tendency for an increase in the concentrations of most WQP in the Castelo de Bode dam water reservoir, with exception of $NO_3^-$ and $NO_2^-$ (Fig. 4).

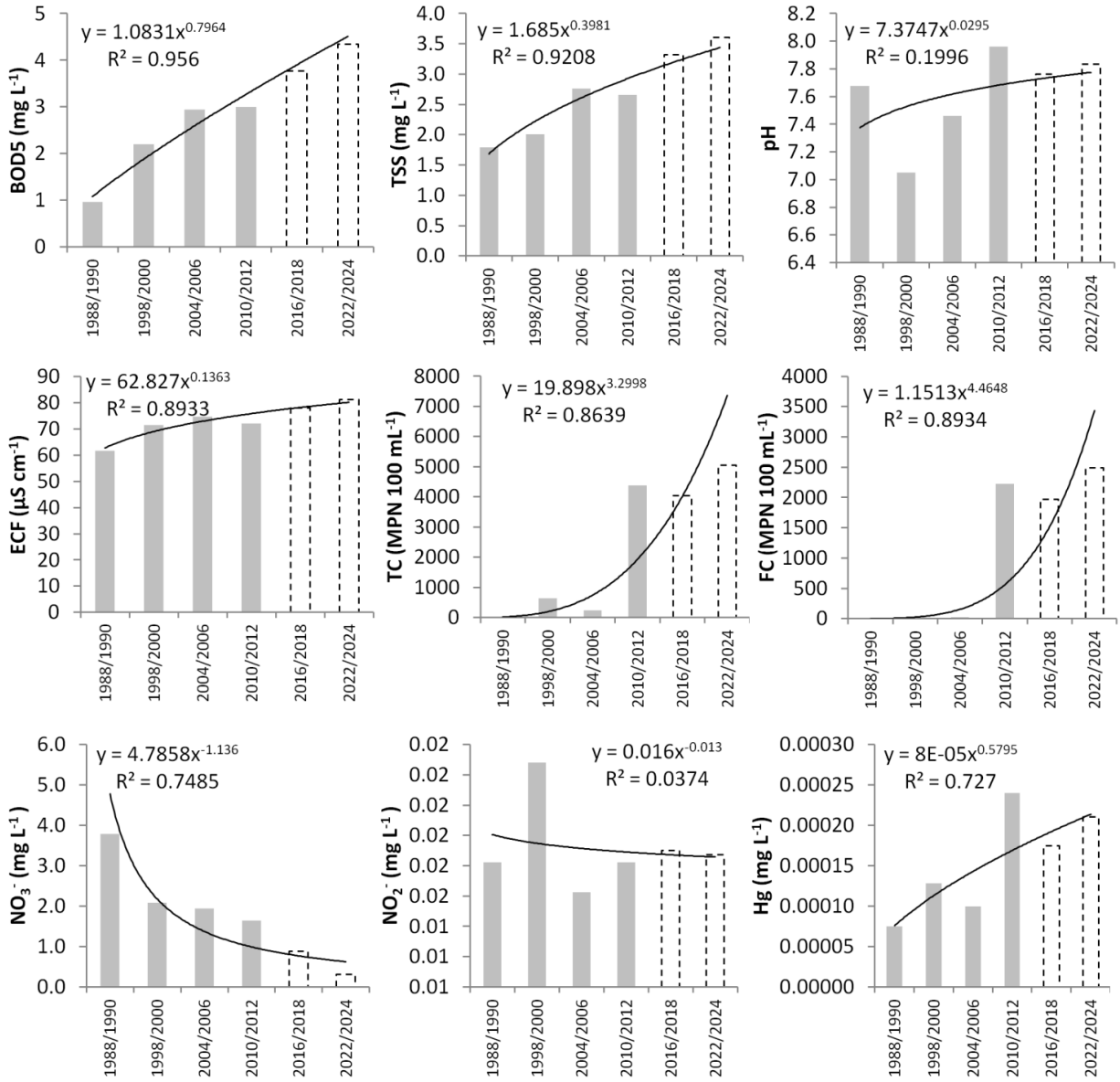


**Figure 4** – WQP of Castelo de Bode Dam in different times and tendencies of variations in future derived of urban sprawl.

Analyzing in detail the variations of WQP obtained from data at stations located on this dam reservoir, we observed different variations of WQP for different periods. With the probabilities of urban sprawl and the variations of WQP, we calculated the trend of variation in the concentration of WQP to 2016-2018 periods and 2022-2024 (with the linear regression).

The BDO5 always increases along the different periods, with a slowdown between 2004-2006 and 2010-2012. This is an important WQP for the definition of water quality, but the trend of urban sprawl in the Zêzere watershed may contribute to the increase of BDO5, contributing to the risk of reduction in the

quality of surface water. The case of TSS also increases between the periods analyzed, except for 2010-2012, which may be related to increased surface waterproof, but also with the consequent loss of forest area due to forest fires and deforestation causing increased water erosion (Baker, 1988). The case of the ECF increase can also be related to these LUCC, demonstrating the tendency to an increase of soluble salts in the water of the dam reservoir. In the first period pH was higher, in the second it reduced but has been increasing over time, hence the tendency is to increase in the future.

The case of TC and FC is more problematic, mainly due to the sharp increase between 2010-2012, compared to previous periods. These WQP are very related to the increase of urban surfaces in this watershed. This fact was verified in previous work establishing the correspondence between increasing artificialization of the soil and increasing concentrations of certain WQP on this dam reservoir (Meneses *et al*., 2015). The increase of these two WQP is very much related to the appearance of new urbanizations around reservoirs in the last two decades (Vale, 2002) and with the consequent loss of drainage sewer system for subsequent treatment of waste water and solid waste. In most cases this still refers to the construction of septic tanks, adding to the already existing in the vicinity of houses, very dispersed along the surrounding areas of reservoirs, in the absence of a strict pollution discharges control, thus leading to possible contamination of downstream waters. These facts contribute to an increased risk of reduction of the quality of surface water.

The variations on the concentrations of $NO_3^-$ and $NO_2^-$ is largely related to agricultural crops and agricultural chemicals used to increase the profitability of soils (Cordovil, 2004). However, the land use for pursuing these anthropogenic activities is increasingly sustainable, due to the creation of more sustainable agricultural measures, in particular due to restrictions that lead to the reduction of agrochemical applications that can be dragged or leached by surface water. Hence the tendency is for the levels of $NO_3^-$ and $NO_2^-$ concentrations to reduce over time.

In general, most WQP have a tendency to increase in the coming years (Fig. 4) due to urban sprawl. Even considering that the most likely areas of urban sprawl were identified in this research, considering the relevance of this water reservoir for drinking supply, all watershed (particular the areas upstream of Castelo de Bode dam) should be the subject to preventive measures in order to minimize the risk of water quality degradation.

## 5. Conclusions

The results of this research are innovative once deeply explore and establish a cause-effect relationship between urban sprawl and the reduction of water quality in the Zêzere watershed. Furthermore they allow the determination of future trends for the two processes and their relationships, allowing the adoption of mitigation measures for the risk of water quality degradation.

The monitoring and maintenance of the LUC in Zêzere watershed is essential so that the surface water maintains an acceptable quality for public supply. Preventing degradation of these waters is essential, since there is a tendency for urban sprawl on basins of the main reservoirs of Zêzere watershed. Associated with this urban areas increase, there is the risk of degradation of surface water quality, derived from the increase of certain WQP, as for example the TC and FC. The correct management of this territory, with emphasis on preventing urban sprawl in the vicinity of the reservoirs, will contribute to the improvement of water quality, assure good quality of drinking water supply for present and future generations, and contribute to reduce the risk of diseases, assuring population health.

## Acknowledgments

This work was supported by a grant from Institute of Geography and Spatial Planning and Universidade de Lisboa (BD2015).

## References

Baker, J.M. (1988). Hydrologic and water quality effects of fire. In *Effects of fire management of Southwestern Natural Resouces* (pp. 31–42).

Chen, X., Yu, S. X., Zhang, Y. P. (2013). Evaluation of Spatiotemporal Dynamics of Simulated Land Use/Cover in China Using a Probabilistic Cellular Automata-Markov Model. *Pedosphere*, *23*(2), 243–255.

Cordovil, C. (2004). *Dinâmica do azoto na reciclagem de resíduos orgânicos aplicados ao solo*. Alfragide, Portugal.: Instituto do Ambiente.

Enderlein, U.S., Enderlein, R.E., Peter, W.W. (1996). Water Quality Requirements. In D. Chapman (Ed.), *Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring* (Sc. editio). Cambridge: E&FN Spon.

Fiquepron, J., Garcia, S., Stenger, A. (2013). Land use impact on water quality: valuing forest services in terms of the water supply sector. *Journal of Environmental Management*, *126*, 113–21.

Glavan, M., Miličić, V., Pintar, M. (2013). Finding options to improve catchment water quality—Lessons learned from historical land use situations in a Mediterranean catchment in Slovenia. *Ecological Modelling*, *261-262*, 58–73.

Gottfried, G. J., DeBano, L.F. (1988). Streamflow and water quality responses to preharvest prescribed burning in an undisturbed ponderosa pine watershed. In *Proceedings of the Effects of Fire in Management of Southwestern Natural Resources* (pp. 222–228).

Li, S., Gu, S., Liu, W., Han, H., Zhang, Q. (2008). Water quality in relation to land use and land cover in the upper Han River Basin, China. *Catena*, *75*(2), 216–222.

Meneses, B.M. (2013). *The influence of forest fire on water quality of São Domingos stream located in the Western Region of Portugal*. High Institute of Agronomy of University of Lisbon, Lisbon.

Meneses, B.M., Reis, R., Vale, M. J., & Saraiva, R. (2015). Land use and land cover changes in Zêzere watershed ( Portugal ) — Water quality implications. *Science of the Total Environment*, *527-528*, 439–447.

Scatena, F.N. (2000). Drinking water quality. In G. E. Dissmeyer (Ed.), *Drinking water from forests and grasslands. A Synthesis of the scientific literature* (pp. 7–25). Asheville, North Carolina: USDA Forest Service. Southern Research Station.

Teixeira, Z., Teixeira, H., Marques, J.C. (2014). Systematic processes of land use/land cover change to identify relevant driving forces: implications on water quality. *The Science of the Total Environment*, *470-471*, 1320–35.

Vale, M.J. (1994). *Sistemas de Informação Geográfica e Planeamento: Construção de um Sistema de Informação Geográfica para Avaliação e Implementação do Plano de Ordenamento da Albufeira de Castelo de Bode*. ISEGI-UNL.

Vale, M.J. (2002). *Web-based Collaboration to Support Water Resource Management and Land Use Integrated Planning*. ISEGI, UNL.

Vale, M.J., Meneses, B.M., Reis, R., Saraiva, R.A., Villegas, J., Cruz, M. (2015). Water Quality Impact Assessment of Land Use and Land Cover Changes. A dynamic IT model for territorial integrated management. In *GEOProcessing 2015: The Seventh International Conference on Advanced Geographic Information Systems, Applications, and Services* (pp. 38–42). Lisbon: IARA.

Vushe, A., Haimene, E.P., Mashauri, D. (2014). Namibian Land Use Changes and Nutrient Water Quality of the Okavango River. *Journal of Agriculture and Environmental Sciences*, *3*(2), 219–239.

Yu, D., Shi, P., Liu, Y., Xun, B. (2013). Detecting land use-water quality relationships from the viewpoint of ecological restoration in an urban area. *Ecological Engineering*, *53*, 205–216.

Zadeh, L.A. (1965). Fuzzy Sets. *Information and Control*, *8*, 338–353.