Scenarios of land use change and soil erosion at the Alqueva reservoir area

Vera Ferreira, André Samora-Arvela, Thomas Panagopoulos
*Research Centre for Spatial and Organizational Dynamics (CIEO), University of Algarve, Gambelas Campus, 8000 – Faro, Portugal, tpanago@ualg.pt

Abstract

Mediterranean landscapes are under enormous pressures towards its alteration, reflecting more and more rapid changeable dynamics. The Alqueva reservoir surrounding in the Alentejo Region, south of Portugal, is an example of remarkable landscape change due to water availability. The Land Use/Cover Change (LUCC) can affect the water erosion problem, an environment and economic problem that can increase sediment yield at the reservoir. The purpose of this article was to create future LUCC scenarios, as a complementary way to investigate the impact on soil erosion using RUSLE model, through the study of the C factor (vegetation cover change) and P factor (management practices). The MAS/LUCC methodology is used to obtain scenarios taking into account the following four prospective directions: production of biomass for bioenergy, agricultural intensification by means of irrigation, increasing rural tourism and development of golf resorts, and climate change. The scenarios created, allowed the study of soil erosion scenarios, showing that the expected LUCC can effectively increase this problem through changes on vegetation cover. The use of sustainable land management (SLM) is a good approach to decrease soil erosion, contributing to the prevention of silting up in the Alqueva reservoir and safeguarding of landscape sustainability. The back casting approach used in this study, showed to be an advantage basis to create decision support system for the region, through the knowledge of the expected LUCC and the impact of them on soil erosion and the understanding of the role of SLM facing these LUCC.

Keywords: Land-use change, soil erosion, reservoir, RUSLE.

1. INTRODUCTION

Mediterranean landscapes are under enormous pressures towards its alteration, reflecting more and more rapid changeable dynamics. Such land use/cover change (LUCC) greatly affects the soil erosion problem (Yang et al. 2003) due to changes in vegetation and management techniques which greatly affect the intensity and frequency of overland flow and surface wash erosion (Kosmas et al. 1997, Wang et al. 2003, Cerdan et al. 2010). Soil erosion, which has become a threat to sustainability, is characterized by the decline of soil depth and quality in one place and deposition in another, due to the increase of runoff (Lal 2001; Prasannakumar et al. 2011). Therefore, it often causes negative downstream impacts, such as the sedimentation in rivers and reservoirs that reduces their storage capacity and life span (Pandey et al. 2007).

The empirical Universal Soil Loss Equation (USLE) is one of the most widely used models for estimating annual soil loss (Wischemeier and Smith 1978) and its modifications include the Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997). RUSLE is defined as:

$$A=R\times K\times L\times S\times C\times P \qquad (1)$$

where A is the potential erosion (annual average soil loss in t ha^{-1} $year^{-1}$), R denotes the rainfall and runoff erosivity factor, K represents soil erodibility factor, L and S are slope length and gradient factor, C symbolizes the vegetation cover factor and P the vegetation control practice factor.

The modelling of LUCC is important with respect to the prediction of soil degradation and its consequences. Over the last few decades, numerous researchers have improved measurements of LUCC and understanding of their causes, and some predictive models have been developed (Koomen et al. 2007). One valuable class of models to simulate and analyze LUCC are multi-agent system models of land-use/cover change (MAS/LUCC models) that combined with, in many cases, the technology of Geographic Information Systems (GIS), represents an useful tool to analyze the modification of the landscape in the past, simulate future land use change and predict potential implications (Parker et al., 2003; Koomen et al., 2007).

This special class of LUCC models combines a Cellular Automata (CA) model that represents landscape, with agent-based representations of decision-making, integrating the two components through specification of interdependence and feedbacks between agents and their environment (Parker et al. 2003). The CA models are based on the interaction between contiguous cells whose change between states (land use types), according the conditions of the neighborhood and adopting transition rules in defined time period (Samora-Arvela and Panagopoulos, 2013). Usually, the CA models resort to Markov chains, constructing Transition Matrices (quantitative analysis of LUCC areas), presenting trend dynamics that, after, are projected in order to simulate future LUCC.

The quantification of land-use changes cannot be restricted to the projection of trend dynamics (forecasting approach), so it’s frequent to combine these cellular models with Multi-criteria Evaluation (MCE), in order to study, by the landscape factors (slope, soils, water resources, scenic attributes, among others), the prospective influence of human demand on the process of LUCC (backcasting approach). Thus, multi-criteria evaluation is a method that analyses the suitability for potential transition of a certain area to maintain or change its land use given the human intentions or objectives, unfolding the influence and importance (hierarchy) of each criteria (landscape factors and constraints) by the Analytical Hierarchy Process (AHP) (Samora-Arvela and Panagopoulos, 2013). In other words, AHP permits to attribute weights among different criteria based on decisions and objectives for some area (Saaty 2004).

In the 50s, the idea of unproductivity in south of Portugal was related to the predominance of non-irrigated agriculture, and the solution plan was the Alqueva dam’s construction to create the largest artificial lake in Western Europe (Sanches and Pedro 2007). Nowadays, the Alqueva surrounding landscape has been rapidly changing due to water availability, which is evident in the recent plantation of irrigated olive groves and vineyards, the cultivation of vegetables and the development of some natural tourism/golf projects. Furthermore there is in the region a great potential to biomass production for bioenergy due to irrigation conditions but also due to proximity to a bioenergy production central.

Additionally to these LUCC there is the inevitable climate change. Therefore, the main study objective is to make LUCC future scenarios, as a complementary way to investigate the impact on soil erosion using RUSLE model, through the study of the C factor (vegetation cover) and P factor (management practices). The MAS/LUCC methodology is used to obtain backcasted scenarios of land-use/cover change (BS/LUCC) taking into account the following aspects/directions:

- Increasing of biomass production for bioenergy;
- Intensification of irrigated agriculture;

- Increasing of rural tourism and development of golf resorts;
- Climate change.

2. STUDY AREA

The Alqueva reservoir is located on the Guadiana river in Alentejo, a semiarid region in the south of Portugal (8º30' W, 38º30' N). It is the largest artificial lake in Western Europe with a total surface area of 250 km^2 (from which 35 km^2 is in Spain), a total capacity of 4.15 km^3, a total shoreline of approximately 1100 km and an extension of 83 km in length (Ferreira et al. 2015a). The complex project was constructed during 1998-2002, and the main objective was to create a strategic water reserve, for supply water to the populations, for irrigation in the surrounding area (about 110000 ha), to produce hydroelectric power and a large lake where several tourist projects can be built. Excluding the area submerged by the lake, the research area, where are expected LUCC resulting from the recent water availability, corresponds to the Alqueva lake Surroundings (Fig. 1), which integrates six municipalities of Alentejo region: Alandroal, Reguengos de Monsaraz, Portel, Mourão, Moura and Barrancos. Still, this is the territorial area of a landscape management plan specifically focused on this territory, namely the Regional Plan for the Surroundings of Alqueva Lake PROZEA (CCDRA 2001).

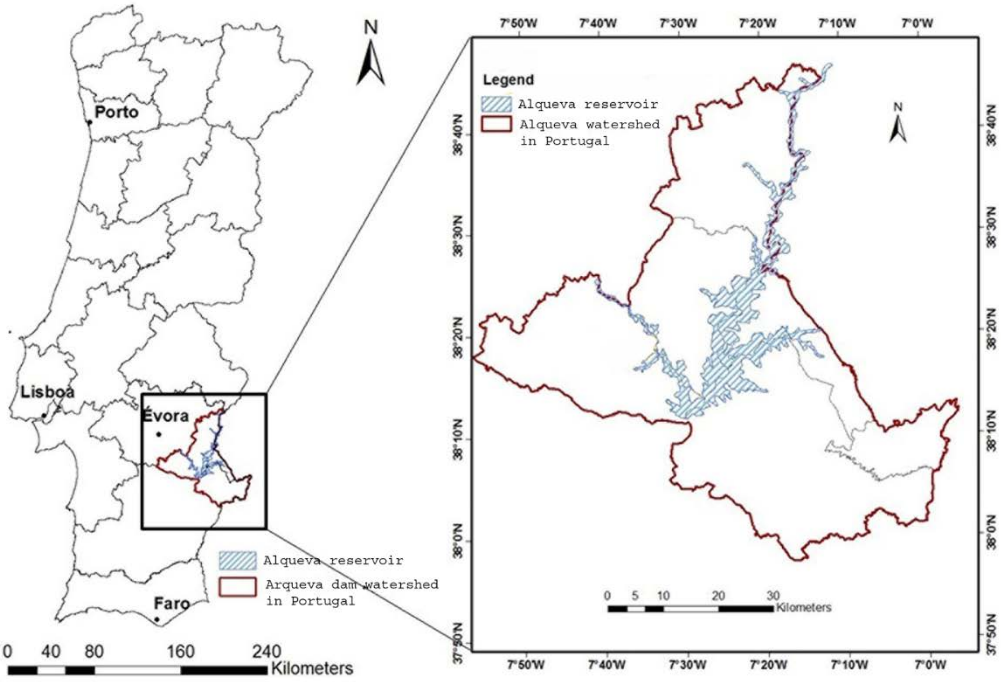


Figure 1 – The study area map.

In this area, the climate is continental Mediterranean (type Csa, according to Koppen classification), with mild winters and very hot and dry summer (Sanches and Pedro 2007). The annual average temperature ranges from 24 to 28 °C in hot months (July/August), and from 8 to 11 °C in cold months (December/January). The average annual precipitation on the nearest meteorological station, for the last 30 years, is approximately 500 mm (Ferreira and Panagopoulos 2014). The region is affected by intense dry periods without precipitation, since 80% of the precipitation occurs from October to April.

The soils are mainly leptosols and luvissols (FAO 2006), with low percentage of organic matter. The landscape is characterized by its hilly topography with significant altitude variations (mainly between 50 and 570 meters). Before the dam implementation the Alqueva landscape was characterized by dryness and immensity, reflecting the predominance of non-irrigated cultures, olive groves, vineyards and, especially, a typical agro-silvo-pastoral system, “o Montado”, mostly *Quercus rotundifolia* (holm oak) and some *Quercus suber* (cork oak) woodlands (Jones et al. 2011; Borges et al. 2010).

Demographically, Alentejo Region has been marked by the declining of population derived from rural exodus, having lost 20% of its population between 1950 and 1960 (Sanches and Pedro 2007). Currently, the population loss continues at - 9% rate for the 2001-2011 period (Panagopoulos and Barreira 2012).

3. MATERIAL AND METHODS

This study work was divided into three phases. The first was the land-use change/cover (LUCC) scenarios based on MAS/LUCC methodology. The second comprised the influence of these land-use changes, which affect soil vegetation cover and management, on C factor and consequently on soil erosion (estimated by RUSLE method). The third part is the study of the implementation of common sustainable land management (SLM) practices that affects P factor and consequently also soil erosion.

3.1. Land-use change/cover (LUCC)

Through MAS/LUCC, the modeling of land-use change and the simulation of future land-use scenarios in the Alqueva watershed was guided by the following steps:

1. Creation of transition matrices by a cellular automata (CA) LUCC model. These matrices calculate land use change before and after the construction of the dam. These probabilities were used to define change in individual land uses and to build future scenarios. The Corine Land Cover (CLC) data from the years 2000 and 2006 was used as input data in the process, since the reservoir filling began in 2002, and only the changes between these years can reflect the influence of dam construction.
2. Elaboration of suitability maps of criteria trough Multi-criteria Evaluation (MCE) and Analytic Hierarchy Process (AHP), resorting to digitized landscape factors and constraints in Geographic Information Systems (GIS), and weighing their influence in defining the most suitable areas for backcasting land use transition, according to four prospective directions: biomass production for bioenergy, agriculture intensification, rural and golf tourism development and climate change impact in vegetation cover. The studied factors were the planning intentions of Governamental Landscape Planning (PROZEA - Regional Plan for the Surroundings of Alqueva lake; PROTA - Regional Plan of the Alentejo Region; POAAP - the Plan for the Alqueva and Pedrogão dams lakes), slope, proximity of accessibilities, villages and historic elements, and constraints like protected areas. Combination of criteria and their respective weights define the areas more suitable to change.
3. Conjugation of transition probabilities (2000-2006) and suitability maps in order to allocate LUCC in the landscape future scenarios (BS/LUCC).

The studied temporal points/marks are the year of 2006 (assumed as the present situation by the lack of more updated land use data), 2050 and 2100 (BS/LUCC accounting the stated prospective directions together).

The elaboration of these landscape scenarios, in terms of land use, enables the reflection about the implications of these thematic land use/cover change on soil erosion by the variation of C factor (refers to soil cover) of Revised Universal Soil Loss Equation (RUSLE).

3.2. Soil erosion scenarios

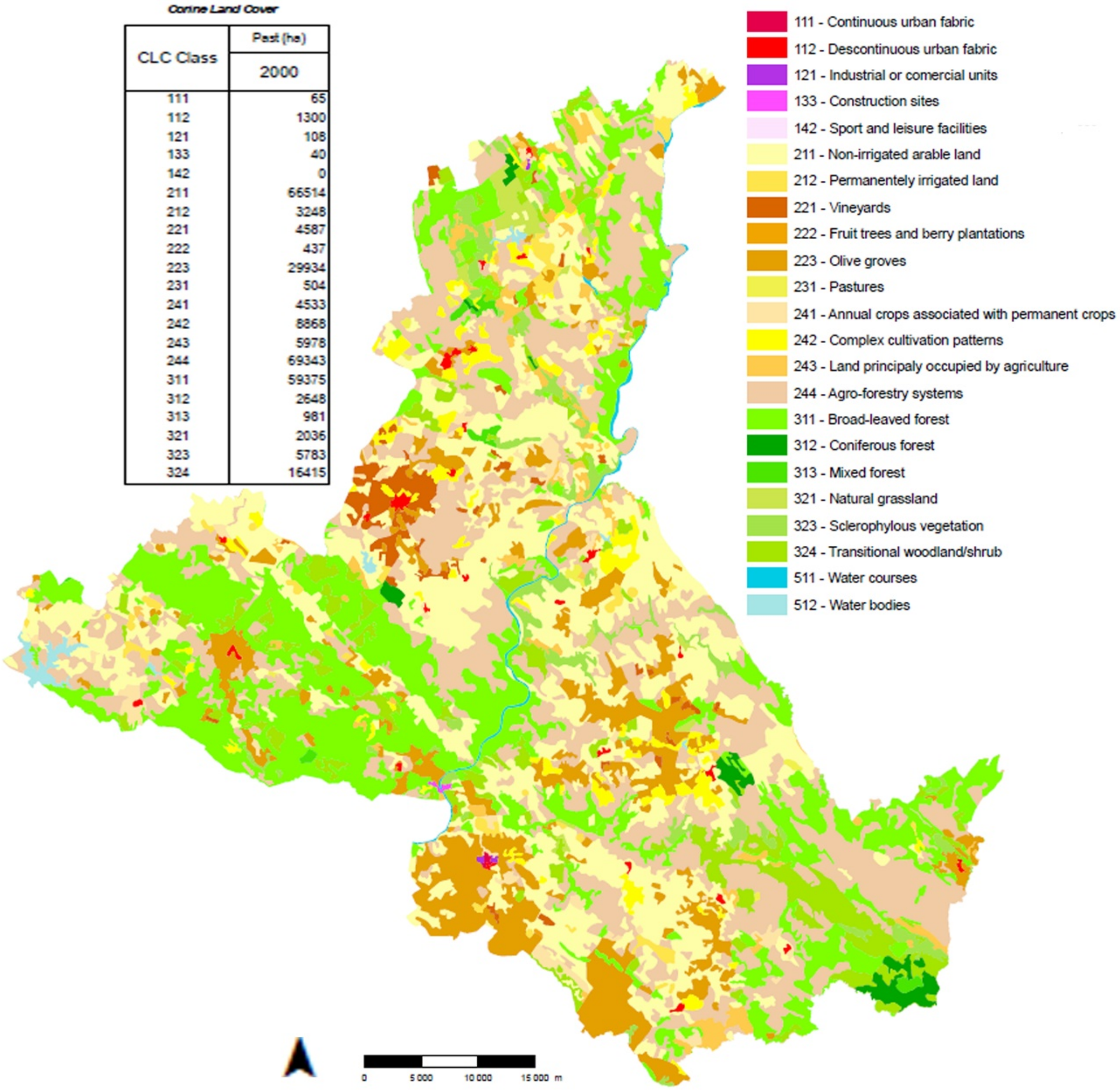
To obtain soil erosion scenarios, each factor considered by RUSLE approach was studied. Geographic Information Systems (GIS) and geostatistics have been effectively used with these models since they make soil erosion prediction and its spatial distribution possible, with reasonable expenses and accuracy. The methodology about how to use geostatistics and create maps for each of the RUSLE factors was described in previously reported research (Ferreira and Panagopoulos, 2010; Ferreira and Panagopoulos, 2013; Ferreira et al., 2015a).

The climate change is expected to modify the precipitation amounts and intensities that affect erosivity (Nearing 2004). According to model HadRM2, which is a Regional Climate Model driven by Global Circulation Models (GCMs) (Santos et al. 2002), in South of Portugal (which is including Alqueva area), the total amount of precipitation is expected to decrease (-11%) and the temperature is expected to increase (+5.9ºC) by 2100. The precipitation may be concentrated in the winter, decreasing especially during summer and autumn, and the region may register an increase of the number of days with precipitation above 50 mm by 2100. Alpert et al. (2002) point out an increase in torrential rainfall despite a decrease in annual rainfall observed in the western Mediterranean region. For south of Portugal is expected an increase between 0 to 50% in annual runoff related to strong rainfall intensity due to concentration of precipitation in a small number of events. Considering this, a mean increase of 12.5% on rainfall erosivity is expected in the study region according to Santos et al. (2002).

According to RUSLE literature, the C factor reflects the effect of vegetation on erosion rate (Renard et al. 1997). Vegetation cover protects the soil by dissipating the raindrop energy before it reaches the soil surface. As such, soil erosion can be effectively limited with proper management of vegetation, plant residue, and tillage (Lee 2004). This factor ranges between 0 for well-protected soil to 1 for bare soil, and it has a close linkage to land use types. In the present study the C factor values were assigned to each corresponding Corine CLC classes according some authors (Wischmeier and Smith 1978; Morgan 2005) and the Corine classes of the study area are shown in figure 2.

The support practice factor *P* represents the effects of control practices such as contouring, strip cropping, terracing, etc. that help to prevent soil erosion by reducing the rate of water runoff. These techniques are considered SLM practices since it ensure the soil conservation. The P factor was assigned 1 (no support practice factor), because the support practices are insignificant in this area until 2006. However for the year 2100 it was developed a scenario that was considering the application of soil conservation practices.

The present research will improve the understanding of soil erosion on the Alqueva region and the influence of different factors. This knowledge will be used as a basis for setting up a decision support system that promotes sustainable planning of land-use in the region. Therefore a scenario was created considering the application of some SLM practices particularly on the uses that are expected to increase in the region and that have high C factor (namely irrigated land, vineyards, fruit trees and olive groves, and xerophytic vegetation). SLM practices were considered for each land-use and the P factor value was taken from tables according to Wischmeier and Smith (1978) and Morgan (2005).



Corine Land Cover

CLC Class	Past (ha)
	2000
111	65
112	1300
121	108
133	40
142	0
211	66514
212	3248
221	4587
222	437
223	29934
231	504
241	4533
242	8868
243	5978
244	69343
311	59375
312	2648
313	981
321	2036
323	5783
324	16415

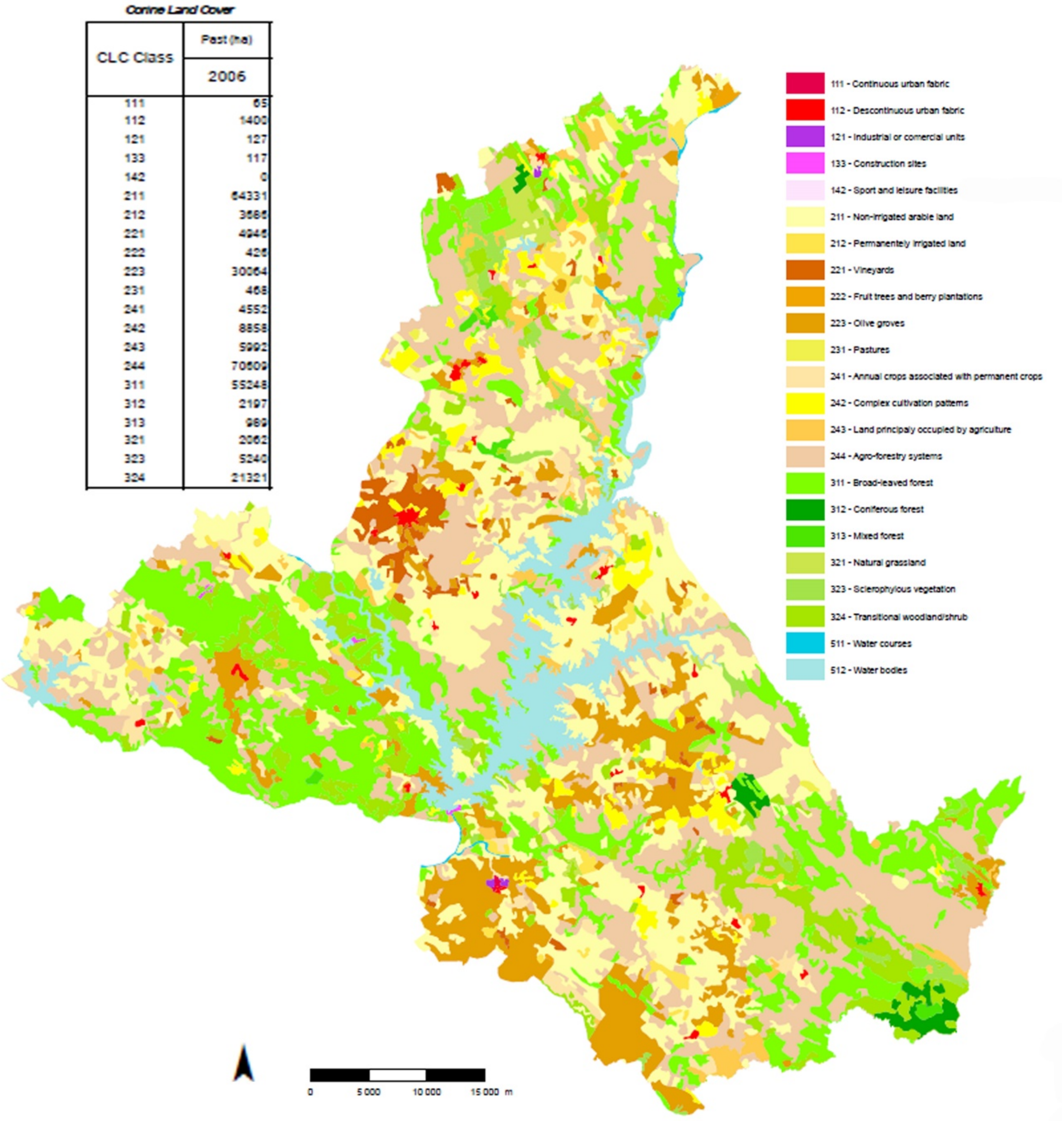
Figure 2 - Land-use in 2000 according to Corine Land Cover.

4. RESULTS AND DISCUSSION

4.1. Land use change scenarios

The Figure 3 illustrates the land-use according Corine Land Cover at the 2006 (assumed as the present situation). Most part of the study area was covered by agroforestry land (CLC class 244), non-irrigated arable land (CLC class 211) and olive groves (CLC class 223), the typical land-uses in the Alentejo region (Jones et al. 2011; Borges et al. 2010) until the challenges created by water availability from Alqueva reservoir.

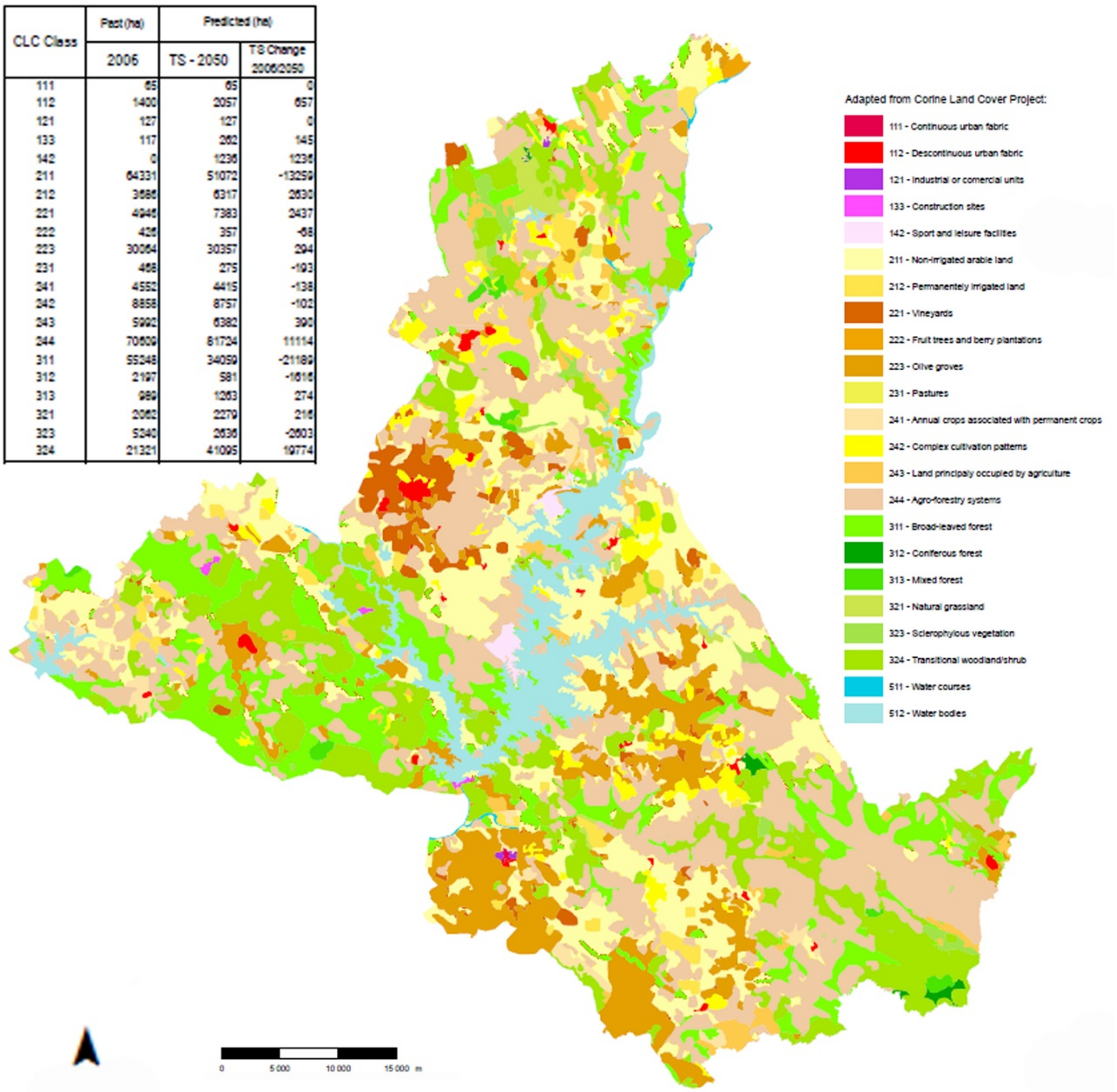
The Alqueva landscape lost between 2000 and 2006, in terms of area of land use types, essentially broad-leaved forest (CLC class 311) by more than 4000 ha and non-irrigated arable land (CLC class 211) in almost 3000 ha. These quantitative changes are presented on the figure 4. Between these two years the gains in terms of area are fundamentally transitional woodland/shrub (CLC class 324), agroforestry area (CLC class 244), permanently irrigated land (CLC class 212) and vineyards (CLC class 221).



Corine Land Cover

CLC Class	Past (ha)
	2006
111	65
112	1400
121	127
133	117
142	0
211	64331
212	3686
221	4946
222	426
223	30064
231	468
241	4552
242	8858
243	5992
244	70609
311	55248
312	2197
313	989
321	2062
323	5240
324	21321

Figure 3 - Land-use in 2006 according to Corine Land Cover.



CLC Class	Past (ha)	Predicted (ha)	
	2006	TS - 2050	TS Change 2006/2050
111	65	65	0
112	1400	2057	657
121	127	127	0
133	117	262	145
142	0	1236	1236
211	64331	51072	-13259
212	3686	6317	2630
221	4946	7383	2437
222	426	357	-68
223	30064	30357	294
231	468	275	-193
241	4552	4415	-138
242	8858	8757	-102
243	5992	6382	390
244	70609	81724	11114
311	55248	34059	-21189
312	2197	581	-1616
313	989	1263	274
321	2062	2279	216
323	5240	2636	-2603
324	21321	41095	19774

Figure 4 - Projective scenario of land-use/cover change for 2050 if business as usual.

Business as usual Scenarios

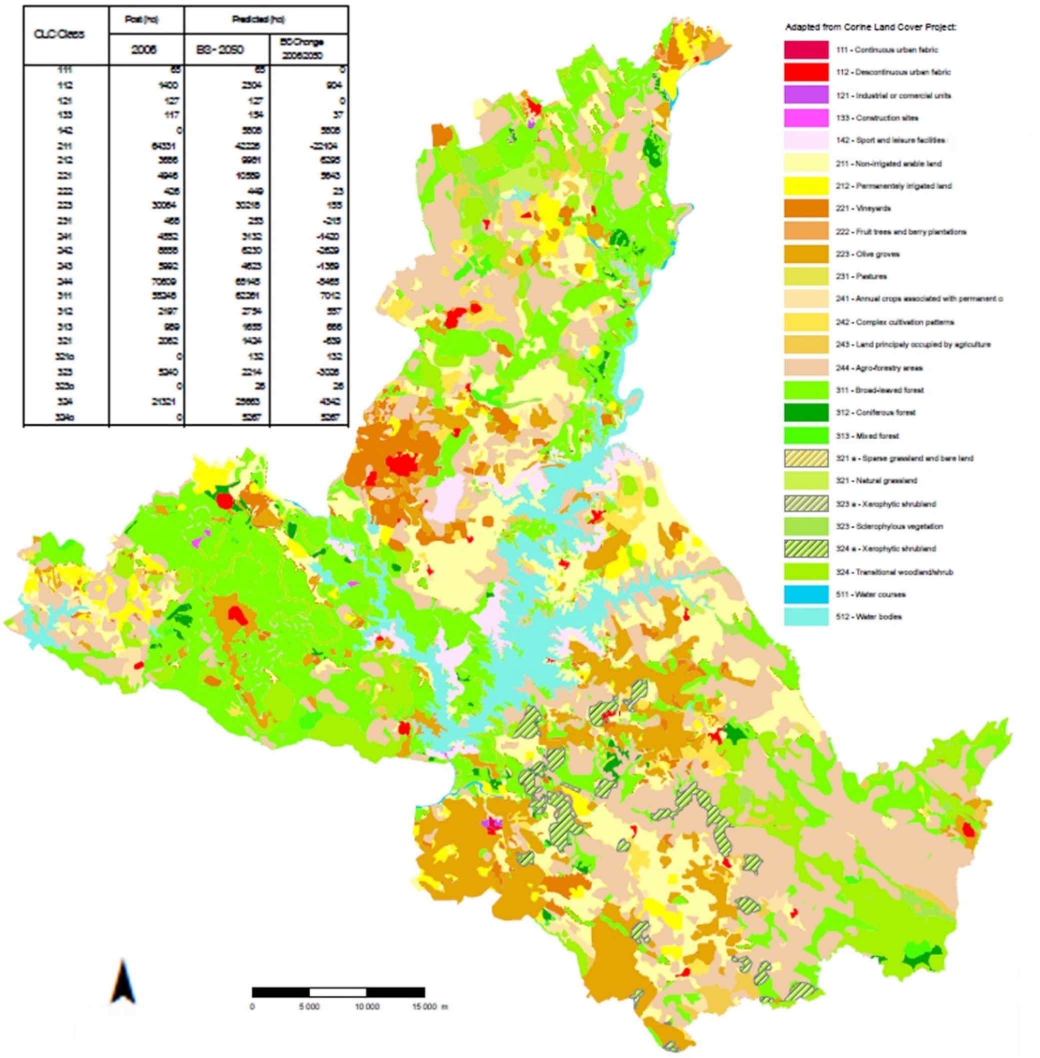
The scenarios of land use change for 2050 and 2100 were created based on the transition matrix of LUCC between 2000 and 2006 and by the addition and retraction of CLC land use areas related to the different prospective directions of land use change (production of biomass for bioenergy, agricultural intensification by means of irrigation, increasing rural tourism and development of golf resorts, and climate change). Climate change is expected to alter land-use in some areas by the intervention of human decision or to modify the vegetation in others natural land-uses, due to changes in air temperature and water availability. New classes were added accounting the effect of climate change on existing land-use classes based on Santos et al. (2002) predictions. The new classes were transition to sparse vegetation cover (CLC classes): 321-Natural grassland to 321a- Sparse herbaceous vegetation and/or bare land; 323-Sclerophyllous vegetation and 324-Transitional woodland/shrub to 323a and 324a-Xerophytic vegetation.

Figures 5 and figure 6 represent these scenarios of land-use in 2050 and 2100, respectively. The expected LUCC for 2050 and 2100 (when comparing with 2006) were:

- Increasing of discontinuous urban area (CLC class 112);

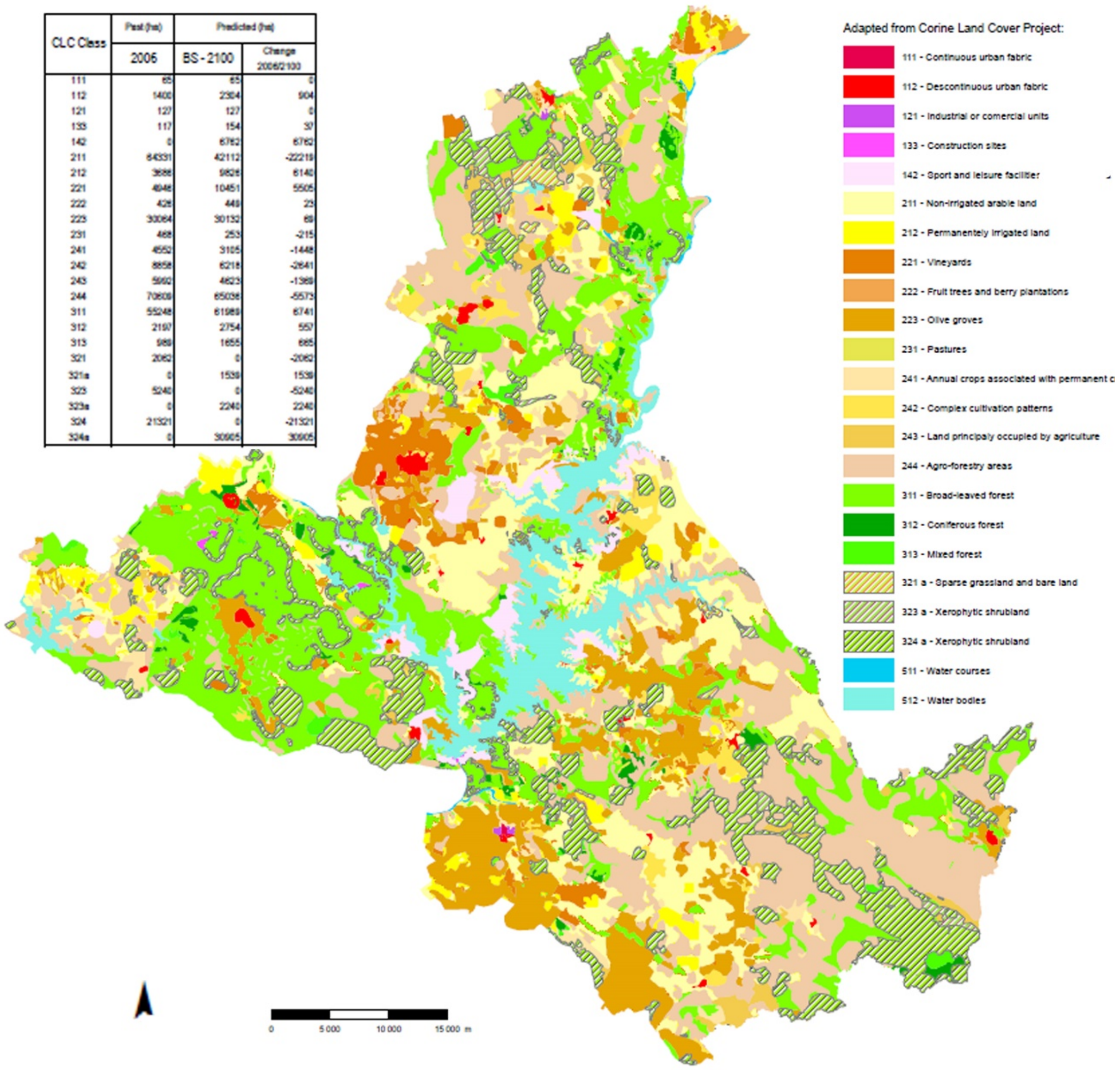
- Decreasing of non-irrigated arable land (CLC class 211) and increasing of permanently irrigated land (CLC class 212);
- Increasing sport and leisure facilities (rural tourism/golf courses) (CLC class 142);
- Increasing of vineyards, olive groves, fruit trees and berry plantations (CLC classes 221,222 and 223);
- Decreasing of pastures, annual crops, complex cultivation patterns, agriculture with natural areas and agroforestry systems (CLC classes 231, 241, 242, 243 and 244);
- Increasing of forested area (CLC classes 311, 312, 313);
- Decreasing of herbaceous natural vegetation (CLC class 321) and sclerophyllous vegetation (CLC class 323) and increasing of xerophytic vegetation and sparse vegetation (CLC class 321a, 323a and 324a);
- Increasing of transitional shrub/woodland (CLC class 324) at 2050 and decreasing until 2100.

Water availability in Alqueva region will permit the increase of irrigated cultures, including the biomass cultivation for bioenergy. In the region has been noticed the increase of vineyards and olive groves using irrigation systems. The increase of rural tourism and golf areas is also increasing and development projects already started.



CLC Class	Past (ha)	Predicted (ha)	
	2006	BS - 2050	BS Change 2006/2050
111	65	65	0
112	1400	2304	904
121	127	127	0
133	117	154	37
142	0	5505	5505
211	64331	42226	-22104
212	3666	9961	6295
221	4946	10589	5643
222	426	449	23
223	30064	30218	155
231	468	253	-215
241	4552	3132	-1420
242	8858	6230	-2629
243	5992	4623	-1369
244	70609	65145	-5465
311	55248	62261	7012
312	2197	2754	557
313	989	1655	666
321	2062	1424	-639
321a	0	132	132
323	5240	2214	-3026
323a	0	26	26
324	21321	25663	4342
324a	0	5267	5267

Figure 5 – Back casting scenario of land-use/cover change for 2050 considering sustainable land management practices.



CLC Class	Past (ha)	Predicted (ha)	
	2006	BS - 2100	Change 2006/2100
111	65	65	0
112	1400	2304	904
121	127	127	0
133	117	154	37
142	0	6762	6762
211	64331	42112	-22219
212	3688	9828	6140
221	4946	10451	5505
222	426	449	23
223	30064	30132	68
231	468	253	-215
241	4552	3105	-1448
242	8858	6218	-2641
243	5992	4623	-1369
244	70608	65036	-5573
311	55248	61989	6741
312	2197	2754	557
313	990	1655	665
321	2062	0	-2062
321a	0	1538	1538
323	5240	0	-5240
323a	0	2240	2240
324	21321	0	-21321
324a	0	30905	30905

Figure 6 - Back casting scenario of land-use/cover change for 2100 considering SLM practices.

The transitional shrub/woodland is expected to increase between 2006 and 2050 especially due to abandonment of some agriculture with natural vegetation, pastures agroforestry systems and especially areas of non-irrigation. The increase of forest area in 2050 and 2100 derives from the future expectation of forest planting to bioenergy production. Between 2050 and 2100 the transitional shrub/woodland and slightly the forested area is expected to decrease due to the conversion of some to xerophytic vegetation and more golf course areas, an expected result of climate change and continuous touristic development.

4.2. Soil erosion scenarios

Based on the land-use scenarios and using the RUSLE model it was obtained soil erosion for 2006 and a scenario if “business as usual” for 2100. On the soil erosion scenario for 2100, as mentioned, we account the influence of climate change on rainfall erosivity (R factor). The annual mean of soil erosion for 2006 was 1.78 t ha^{-1}, and the highest values are associated with olive grove plantations (CLC class 223) looking at the LUCC scenario for the same year, associated to great altitudes and high LS factor (high and long slopes). Traditionally the olive groves tillage is done to control weeds and the soil is kept bare between trees, which contributes to increase soil erosion. Other small areas in 2006 presented also great soil erosion values due to construction activities where soil is frequently bare. As already investigated (Ferreira and Panagopoulos 2014) the traditional land-use, the agroforestry area, have some places with high annual soil erosion (higher than 30 t ha^{-1}), confirmed with the present maps.

Looking at the scenario for 2100 it was calculated that soil erosion will increase in some areas, comparing with 2006. The annual mean for soil erosion in 2100 in the surrounding area of Alqueva reservoir, is predicted to be 3.65 t ha^{-}, representing an increase of more than 100% when comparing with the mean value of 2006. The areas that are projected to experiment the highest increase are in the southeast part of surrounding area. This increase in southeast part is mainly associated with the change of transitional woodland/shrub and Sclerophyllous vegetation to Xerophytic vegetation cover and the decrease of some forest density. On the other hand in the west part of the reservoir the forest density is expected to increase. Additionally the increase of some land-uses such as vineyards, olive groves and irrigated cultures according to the scenario for 2100, contributes to intensify soil erosion in the future.

Sustainable Land Management (SLM) Scenario

The scenario for 2100 was developed considering the SLM implementation and then a comparison with the business as usual scenario was done. It was found that the use of soil conseervation practices can effectively decrease soil erosion if applied on the land-uses with low vegetation cover, and consequently low soil protection. Comparing scenarios it was perceived that the areas with more than 50 t ha^{-1} per year decrease when using SLM practices. The estimated mean value of annual soil erosion for 2100 with SLM was 2.27 t ha^{-1}, decreasing about 38% comparing with the 2100 scenario without SLM. Although these decrease for 2100 with SLM the mean value of soil erosion is greater than in 2006 scenario (1.78 t ha^{-1}), explained by the higher rainfall erosivity value (R factor), that increases soil erosion even for soils better protected. The SLM practices were assumed specially for the new land-uses with low vegetation protection, but facing the climate change and as showed in Ferreira et al. (2015b) the impact of the expected changes on soil erosion, it is imperative to implement some SLM on the current land-uses (specially the pastures, annual crops, complex cultures and other agriculture with natural vegetation). Other different SLM practices have been applied on Mediterranean areas and the advantage results have been reported by WOCAT databases (Schwilch et al. 2012). Some of these SLM can be incorporated in a decision support system in these study area, involving collaboration with both local people and governmental institutions, to mitigate the climate and LUCC impacts on soil erosion (Panagopoulos et al. 2015).

5. CONCLUSION

Scenarios of climate and land use/cover change were studied to predict their impact on soil erosion. The land-use changes were based on the years between 2000 and 2006 and according to different planning constrains, scenarios for 2050 and 2100 were developed. According to the prospective directions studied, the intensification of irrigated area including vineyards, olive groves and other cultures associated to climate change, are the main enhancers to increase soil erosion in the Alqueva surrounding area. The vulnerability on soil erosion, especially at those land-uses urges the SLM implementation. However the expected climate change will inflict the concern of applying SLM on almost all land-uses in the area. Using the erosion scenarios the areas of high erosion were rapidly identified, and management efforts can be directed at these high priority areas. The generated scenarios will be used as a basis to create a decision support system for the watershed of Alqueva region, through the knowledge of the expected land-use changes and the impact of them. The present study was an effective way of awareness and empowerment of decision-makers and landscape planners.

REFERENCES

Alpert P., Ben-Gai T., Baharad A., Benjamini Y., Yekutieli D., Colacino M., Diodato L., Ramis C., Homar V., Romero R., Michaelides S., Manes A. 2002. The paradoxical increase of Mediterranean extreme daily rainfall in spite of decrease in total values. Geophys. Res. Lett. 29, 31.1 – 31.4.

Borges P. J., Fragoso R., Garcia-Gonzalo J., Borges J. G., Marques S., Lucas M. R. 2010. Assessing impacts of common agricultural policy changes on regional land use patterns with a decision support system: an application in Southern Portugal. Forest Policy and Economics, 12, 111-120.

CCDRA. 2001. Regional Plan for the Surroundings of Alqueva Lake. Évora: Comissiono of Cordination and Development of Alentejo Region.

Cerdan O., Govers G., Bissonnais Y.L., Van Oost K., Poesen J., Saby N., Gobin A., Vacca A., Quinton J., Auerswald K. et al. 2010 Rates and spatial variations of soil erosion in Europe: a study based on erosion plot data. Geomorhology, 122, 167–177

FAO 2006. World reference base for soil resources. A framework for international classification, correlation and communication. World Soil Resources Reports, 103. FAO, Rome.

Ferreira, V. Panagopoulos, T. 2010. Soil erodibility assessment at the Alqueva dam watershed. In Panagopoulos, T. (ed) *Advances in Climate Change, Global Warming, Biological Problems and Natural Hazards*, WSEAS press, Faro, Portugal, pp: 112-118.

Ferreira V. and Panagopoulos T. 2013. Risco de erosão do solo na área envolvente à Barragem do Alqueva. 10th CNA-XII CNEA: Repensar o Ambiente: Luxo ou inevitabilidade. 6-8 November 2013, Aveiro University, Aveiro, Portugal.

Ferreira V. and Panagopoulos T. 2014. Seasonality of soil erosion under Mediterranean conditions at the Alqueva dam watershed. *Environmental Management*, 54, 67-83.

Ferreira, V., Panagopoulos, T., Cakula, A., Andrade, R., Arvela, A. 2015a. Predicting soil erosion after land use changes for irrigating agriculture in a large reservoir of southern Portugal. *Agriculture and Agricultural Science Procedia*, 4, 40-49. http://dx.doi.org/10.1016/j.aaspro.2015.03.006

Ferreira, V., Samora Arvela, A., Panagopoulos, T. 2015b. Soil erosion vulnerability in scenarios of climate land use changes after the development of a large reservoir in a semi-arid area. *Journal of Environmental Planning and Management* http://dx.doi.org/10.1080/09640568.2015.1066667

Jones N., de Graaff J., Rodrigo I., Duarte F. 2011. Historical review of land use changes in Portugal (before and after EU integration in 1986) and their implications for land degradation and conservation, with a focus on Centro and Alentejo Regions. *Applied Geography*, 31, 1036–1048

Koomen E., Stillwell J., Bakema A., Scholten H.J. 2007. Modeling land-use change: Progress and Applications, GeoJournal Library, Vol. 90, 398p

Kosmas C., Danalatos N., Cammeraat L.H., Chabart M., Diamantopoulos J., Farand R., Gutierrez L., Jacob A. 1997. The effect of land use on runoff and soil erosion rates under Mediterranean conditions. Catena 29, 45-59

Lal R 2001. Soil degradation by erosion. Land Degradation & Development 12, 519–539.

Lee S. 2004. Soil erosion assessment and its verification using the universal soil loss equation and geographic information system: A case study at Boun, Korea. Environmental Geology, 45, 457–465.

Morgan R. P. C.. 2005. Soil Erosion and Conservation. Oxford: Blackwell Publishing.

Nearing M.A., Pruski F.F., O'Neal M.R. 2004. Expected climate change impacts on soil erosion rates: a review. Journal of Soil and Water Conservation, 59 (1), 43–50.

Panagopoulos T. and Barreira A.P. 2012. Shrinkage perceptions and smart growth strategies for the municipalities of Portugal. *Built Environment*, (38), 276-292.

Panagopoulos, T., A. Cakula, V. Ferreira, and A. Arvela. 2015. “Simulation model for predicting soil erosion in a large reservoir of southern Portugal”. *International Journal of Sustainable Agricultural Management and Informatics*: 1(1), 3-25. http://dx.doi.org/10.1504/IJSAMI.2015.069043

Pandey A., Chowdary V.M., Mal B.C. 2007. Identification of critical erosion prone in the small agricultural watershed using USLE, GIS and remote sensing. Water resources management, 21, 729-746.

Parker D.C., Manson S.T., Janssen M.A., Huffmann M.J., Deadman P. 2003. Multi-agent systems for the simulation of land-use and land-cover change: a review. Annals of the Association of American Geographers, 93 (2), 314-337.

Prasannakumar V., Vijith H., Abinod S., Geetha N. 2011. Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology. Geoscience Frontiers, 3 (2), 209–215.

Renard K.G., Foster G.R., Weesies G.A., McCool D.K., Yoder D.eastC. 1997. Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Agric. Handbook No 703. USDA, Washington, DC.

Saaty T. L. 2004. Decision Making – The Analytic Hierarchy and Network Process (AHP/ANP). Journal of systems science and systems engineering, 13 (1), 1-35.

Samora-Arvela, A., Panagopoulos, T. 2013. Landscape change following the Alqueva dam construction. In: C. Newman, Y. Nussaume & B. Pedroli (Eds) Landscape & Imagination: towards a new baseline for education in a changing world. UNISCAPE, Bandecchi & Vivaldi, Pontedera, Italy. pp: 539-544. ISBN: 978-88-8341-548-7

Sanches R. and Pedro J.O. 2007. Empreendimento de Fins Múltiplos de Alqueva. Empresa de Desenvolvimento de Infra-estruturas do Alqueva (EDIA), Beja, Portugal.

Santos F.D., Forbes K., Moita R. 2002. Climate Change in Portugal. Scenarios, Impacts and Adaptation Measures — SIAM Project. Gradiva: Lisbon.

Schwilch G., Hessel R., Verzandvoort S. 2012. DESIRE for greener land. Options for Sustainable Land Management in Drylands. Publishers University of Bern - CDE, Alterra, Wageningen UR and ISRIC - World Soil Information WOCAT-FAO. 250 pp.

Yang D., Kanae S., Oki T., Koike T. 2003. Global potential soil erosion with reference to land use and climate changes. Hydrol. Process 17: 2913–2928.

Wang G., Gertner G., Fang S., Anderson A. 2003. Mapping multiple variables for predicting soil loss by geostatistical methods with TM images and a slope map. Photogrammetric Engineering & Remote Sensing 69, 889-898.

Wischmeier W.H. and Smith D.D. 1978. Predicting rainfall erosion losses: A guide to conservation planning. USDA, Agricu. Handbook 537. Agricultural Research Service, Washington, DC, USA.