Water Quality Impact Assessment of Land Use and Land Cover Changes

A dynamic IT model for territorial integrated management

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***Abstract* – The land use and land cover (LULC) changes have influenced the water quality. Thus, addressing LULC can lead to the understanding of the actual problems and how to avoid future water stress problems. This paper presents a model that integrates land use and land cover changes (LUCC), and their impacts on water quality. The model is tested for the main drinking water reserve for Continental Portugal, the Castelo de Bode Dam located in the Zêzere watershed. This work integrates the specifications of SmartOpenData Project (SmOD), and is strictly related to the work developed in the eEnvPlus, and TerAGUA projects. It considers INSPIRE Directive specifications, and those related to linked open data integration. The results obtained so far address the most relevant LULC changes in Portugal, but can easily be applied to study the problem in other countries, allowing the creation of guidelines for spatial planning integrating the concerns of the Water Framework Directive.**

Keywords - LULC, LUCC; Water; Spatial Planning, SmartOpenData, INSPIRE.

I. Introduction

The land use and land cover (LULC) of the territory is constantly changing, mainly due the anthropogenic actions, but also due to natural causes. Many of these changes have a negative impact on water quality, a fact cited by some authors that show that there is a cause and effect relation between some land use/cover changes (LUCC) and the decrease in water quality [1]-[4]. The human related LUCC, namely deforestation, urbanization, urban sprawl or less adequate agricultural practices where large amounts of chemicals are applied (from industrial or domestic origin) is therefore a key factor to build well balanced land use planning initiates. Many land use practices result in an increase of contaminants that are easily transported to watercourses, contribute to the degradation of important water reserves namely those for public supply, and inducing relevant water stress [6]-[10].

Being so it is important to have an integrated watershed land use planning and management system, integrating the water legal framework with the land use planning legal framework with updated knowledge on LUCC changes and ongoing management of natural resources: water, energy production, environmental protection integrated with socioeconomic development strategies.

The interconnection between these areas is essential to understand the intensity of land use changes upstream of a drinking water reserve, in order to understand the impact of land use changes in water stress [11]. Therefore, it is essential to integrate LULC knowledge, e.g., intensive agriculture, industry location, urbanization and urban sprawl, with existing water treatment plants, the monitoring of human activities and their water management requirements. The gradual decrease in natural water quality, namely for drinking water reserves, leads to increasing pressures on water management efficiency in order to reduce migration or leaching of certain contaminants in surface and ground waters downstream. The increasing risk for public health is also relevant.

Water quality preservation is consequently a main concern for governments and for the communities as a whole. Assuring water quality for different purposes, and namely providing drinking water supply in the short and long terms, is essential to preserve the future of every Nation and is a basis for economic development [7].

Less effective approaches to management imply the need for large investments, which lead to increasing operational and maintenance costs, usually charged, directly or indirectly, to the final consumers. Thus, it is necessary to establish measures linking economic development models to efficient local, regional, national and international water management, establishing priorities to the most relevant water reserves, in line with an efficient and sustainable management of resources and management of the territory.

The provision of environmental and geographic information (linked data), in a semi-structured, shared web based platform, will be an asset for the efficiency and sustainability management models of these resources. This will allow the scientific community to monitor and further study the phenomena in order to build solutions that lead to avoid or reduce negative impacts on water quality and to assure that effective results will increase [5]-[12]-[13]. This information will be important for licensing small and medium-sized enterprises that require this natural resource, for citizens as for public institutions, so that everyone linked to the implementation of the development model can be involved [7]-[8].

The SmartOpenData Project has created a Linked Open Data Infrastructure and available data resources for biodiversity and environment protection, in relevant areas (Protected Areas and National Parks) for some European countries. This project is focused on how Linked Open Data can be applied to spatial data resource management, to public open data portals and to initiatives like GEOSS Data-CORE, Copernicus (formerly known as GMES), INSPIRE and voluntary data (OpenStreetMap, GEO Wiki, etc.), and how it can impact on the economic and sustainability progress in European Environment research and Biodiversity Protection. This will be achieved by making existing “INSPIRE based” relevant spatial data sets, services and appropriate metadata available through a new Linked Data structure. In addition, the infrastructure will provide automatic search engines that will search additional available geospatial resources (OGC and RDF structures) across the web. A RDF (Resource Description Framework) structure is used to describe the relation between two objects The point is that by re-using existing identifiers available in the Linked Open Data cloud, SmartOpenData immediately will have access to a lot of other data sources and these will be available through SPARQL queries [9]-[11].

Understanding and maintaining watershed related knowledge is a very high data consuming issue. Namely maintaining LULC updated along with many other socioeconomic relevant data repositories requires substantial financial support.

This issue could be partially addressed by similar open data approaches like the one described above or in a more structured way like the one included in [7], involving communities, enterprises and governments in a shared effort for data maintenance with a clear purpose of monitoring drinking water quality and to achieve sustainable development.

The areas with reservoirs considered strategic for the public water supply, should be integrated into the so-called "Smart Regions" crossing over protection areas like “Nature 2000 network” and requiring specific management rules, integrated in a participative web based platform, business oriented, but built upon an extranet approach so that interested citizens and public authorities can help consolidating effective LUCC changes that lead to effective drinking water preservation and supply in a cost-benefit effective way.

The proposed evaluation model for LUCC and their impacts on water quality should also contribute to the creation of sustainable measures, especially measures that lead to the smallest human pressure in forest soils, agriculture (reduction of agrochemical application), forest fires risk, and artificial unbalanced transformations, in the vicinity of the reservoirs namely near water catchments for public supply.

The relevant framework implemented so far by the researchers in this field, is in line with the concerns of the Inspire Governance Group, and can be used in future territorial planning actions namely identifying combined areas and locations that increasingly contribute to water degradation. Establishing relations of water preservation, land use identification and land use intensity allowance, is therefore essential for drinking water preservation in line with land use planning, in a cost effective way to achieve effective economic growth.

The shared information management, web based approach will furthermore increase the knowledge made available for good governance putting in line different development perspectives, from local and regional views to the national planning intents and investment; all this must be supported by an effective way of redistributing development benefits and preservation costs, taking here, as example, the well balanced watershed management, supports by a well-balanced land use planning model integrating cadaster concerns.

In Section II, we present the methodology to LUCC determinations and the relations with variations of water quality parameters. Section III presents the preliminary results and discussion of LUCC in Continental Portugal, and the relations between LUCC and water quality degradation in Castelo de Bode Dam. Section IV presents the final considerations.

II. METHODOLOGY

In Portugal, substantial work is being developed in order to build solid co-operative Web-GIS based systems to address land use and water management in an effective and equitable way. The most relevant work relates to the TerAGUA co-operative approach and is being explored in the context of the SmartOpenData Project. It contemplates the development of a prototype model that includes the evaluation of land use and land cover changes and their influenced the water quality of Zêzere watershed catchment (sub-basin of Tagus River). The datasets used in this project contemplate essentially open data (CORINE Land Cover - CLC, geomorphologic and environmental data), integrated and put in line with all relevant official data. The shared open analysis model will quantify the LUCC, its spatial distribution within the Portuguese continental area, and allow on the fly comparisons with environmental, namely water related, data. The results will be integrated in INSPIRE infrastructure, under clear descriptions and to be addressed through unique identifiers, including the INSPIRE themes, code lists, application schemas, discovery services, integrated with the RDF application (Fig. 1).

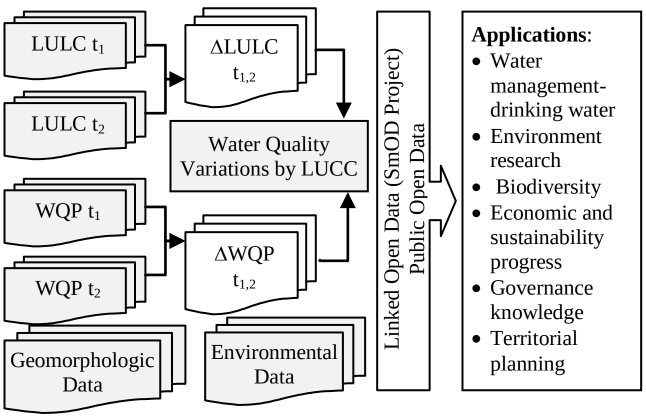

Figure 1. Model of Linked Open Data of the Portuguese Pilot (SmOD Project) and the possible aplications (WQP - Water Quality Parametrs; LULC – Land User and Land Cover; t – time).

The expected results will be used as a complement in planning actions, in particular to identify uses and locations that contribute the most to the degradation of water quality (depending on the LULC and also of LUCC that cause high negative impacts). This identification of LUCC with greater impact on surface water will be crucial to water quality preservation within the study area (economic cost reduction in line with efficient management of water treatment), but also to estimate the impact of intensively artificialized territory near water catchments, and will be used as the basis for a sustainable water and land planning in the EU.

III. Preliminary Results and Discussion

A. LUCC in Continental Portugal

In Continental Portugal the larger areas of LULC are the heterogeneous agricultural areas and forests (Table 1). According to this data, in the last two decades, forest areas have declined due to the transition to scrub and/or herbaceous vegetation, hence an increase in the area of this last type of LULC. The reduction of this type of LULC has direct implications on water quality, namely in the increase of sediments dragged to the water courses due the erosion along with the increase of chemical elements dragged or leached from exposed soils without any type of protection to storm water [2].

The registered loss of arable land may be explained to some extent by the disinvestment in agriculture and to the lack of structural support to small and medium-sized farmers, owners of small fragmented land, the most common within the Portuguese context, inducing abandonment of these lands. These soils, due to the advance of natural vegetation, began to be occupied by scrub and/or herbaceous vegetation associations, land cover that is strictly related to increasing risk of forest fire.

The area of artificial surfaces also increased, taking agricultural and forest soils. Land artificialized or built area can be highly correlated with the amount of sediment that goes into watercourses, with several aggravating factors as, for example, the amount of surface runoff waters due to soil sealing, but also the speed of runoff, causing sometimes flooding and increasing sediments transport. Increasing urban sprawl along the margins of water bodies, delivers wastewater (sewage) drainage without any domestic treatment directly to these reservoirs leading to water quality deterioration within these reservoirs.

TABLE I. LULC of Continental Portugal in Different moments. Area (%) obtained by CORINE Land Cover Data.

LULC	Year			
	1990	*2000*	*2006*	*2012*
Arable land	15,1	14,3	13,9	12,7
Artificial, non-agricultural vegetated areas	0,1	0,1	0,1	0,2
Forests	27,7	26,7	22,6	22,6
Heterogeneous agricultural areas	26,6	26,3	26,0	26,3
Industrial, commercial and transport units	0,2	0,4	0,5	0,6
Inland waters	0,5	0,6	0,8	0,9
Inland wetlands	0,0	0,0	0,0	0,0
Marine waters	0,6	0,6	0,6	0,6
Maritime wetlands	0,3	0,3	0,3	0,3
Mine, dump and construction sites	0,1	0,2	0,2	0,2
Open spaces with little or no vegetation	2,0	1,9	1,9	1,5
Pastures	0,6	0,5	0,5	0,7
Permanent crops	6,5	6,6	6,6	7,1
Scrub and/or herbaceous vegetation associations	18,2	19,2	23,2	23,6
Urban fabric	1,5	2,4	2,5	2,7

B. LUCC and Water Quality Degradation in Castelo de Bode Dam

Assessing main LUCC in Continental Portugal, lead us to better understand these LULC impact on water quality.

Castelo de Bode Dam reservoir is the most relevant drinking water public supply within the Portuguese context. It is located in the Tagus River Watershed. For this work the drainage area considered is the area that includes the water catchment drainage upstream of the Zêzere river watershed (an area of 396434 ha). Within this area it has been a statistical based model, and established a correspondence between the LUCC and the variation of water quality parameters (WQP), considering the four years that covers the LUCC. The most important LULC of this drainage area in the 1990s were forests, however, this type of LULC decreased since then and the scrub and/or herbaceous vegetation associations became predominant in 2012 (Table 2).

TABLE II. LULC OF DRAINAGE AREA OF CASTELO DE BODE DAM (ZÊZERE WATERSHED) IN DIFFERENT MOMENTS. AREA (%) OBTAINED BY CORINE LAND COVER DATA.

LULC	**Year**			
	1990	***2000***	***2006***	***2012***
Arable land	4.0	4.0	3.9	4.0
Artificial, non-agricultural vegetated areas	0.01	0.01	0.01	0.01
Forests	41.9	44.0	28.5	31.0
Heterogeneous agricultural areas	15.2	14.9	14.7	13.8
Industrial, commercial and transport units	0.0	0.1	0.2	0.2
Inland waters	1.3	1.3	1.3	1.3
Mine, dump and construction sites	0.1	0.1	0.0	0.1
Open spaces with little or no vegetation	4.7	3.8	2.8	2.4
Pastures	0.1	0.1	0.1	0.3
Permanent crops	1.7	1.7	1.7	2.3
Scrub and/or herbaceous vegetation associations	30.8	29.4	46.0	44.0
Urban fabric	0.4	0.7	0.7	0.7

Analyzing more deeply the available data we can observe an increase in built area during the first decade.

The water quality parameters (WQP) are shown in Table 3.

TABLE III. WATER QUALITY PARAMETERS OF CASTELO DE BODE DAM (ANNUAL AVERAGE).

WQP	**Year**			
	1990	**2000**	**2006**	**2012**
BDO 5 days (mg/l)	1.43	2.44	3.08	3.00
Total Lead (mg/l)	0.027	0.002	0.004	0.003
Total Coliforms (MPN/100ml)	2839.4	320.7	243.5	75.6
Conductivity in laboratory at 20ºC (µS/cm)	59.0	76.6	85.3	70.8
Color (PtCo)	5	6	9	7
Phenols (mg/l)	0.001	0.008	0.012	0.001
Total Nitrogen (mg/l NO_3)	3.45	1.73	1.84	1.27
Total Nitrite (mg/l NO_2)	0.03	0.02	0.01	0.02
pH - Field	7.46	7.06	7.70	7.24

WQP were obtained through data recorded by automatic stations located in Castelo de Bode dam reservoir (Alb. de Castelo Bode - 16H/03; Cabeça Gorda - 16H/06; Constância - 17G/03; Colmeal - 16H/05) and thought laboratorial analysis, data provided by the National System of Hydrological Decade Resources of Portugal.

The correlation coefficients obtained and presented in Table 4, show a high positive correlation between soil artificialization and the variation of BOD5 (Biochemical Oxygen Demand). These results indicate that the more soil artificialized the greater the biochemical oxygen demand in the waters of the Castelo de Bode Dam reservoir.

On the other hand, variations of lead content, total coliforms, total nitrogen and total nitrites in water shows positive correlation with mine, dump and construction sites and open spaces with little or no vegetation, might be explained by the high use of leaded materials in the construction of infrastructures, entrainment of materials resulting from mining extraction and also by the presence of waste dumps.

Water color changes is positively correlated with variation in areas of industrial, commercial and transport units, as with associations of scrub and/or herbaceous vegetation. These LULC types influence the amount of materials dragged by surface runoff leading to reduction of water quality downstream.

Another relevant conclusion concerns the positive correlation between phenols variation and urban fabric industrial, commercial and transport units, or artificial, non-agricultural, vegetated areas.

The positive correlation between arable land and total nitrites might be explained by previous application of chemical fertilizers in these soils and agrochemicals in these cultures.

All this assumptions demonstrate that LUCC influence water quality and consequently water Framework Directive accomplishment could benefit from this data management insight approach.

C. *Interative Model and Results Dessimination*

These data models and presented results are being integrated into a WebGIS databases in order to take advantage of Information and Communication Tools (ICT) to assure government action integration and public participation can be effective. Currently the data harmonization (according to the INSPIRE Directive) is being

TABLE IV. CORRELATION COEFFICIENTS FOR THE WQP IN WATER OF CASTELO DE BODE DAM RESERVOIR AND AREAS OF LULC OF DRAINAGE AREA.

LULC	**WQP**								
	BDO 5 days (mg/l)	***Total Lead (mg/l)***	***Total Coliforms (MPN/100ml)***	***Conductivity in Laboratory at 20ºC (µS/cm)***	***Color (PtCo)***	***Phenols (mg/l)***	***Total Nitrogen (mg/l NO_3)***	***Total Nitrite (mg/l NO_2)***	***pH - Field***
Arable land	-0.62	0.62	0.60	-0.95	-0.85	-0.99	0.43	0.93	-0.35
Artificial, non-agricultural vegetated areas	0.93	-1.00	-1.00	0.84	0.73	0.54	-0.97	-0.88	-0.22
Forests	-0.77	0.42	0.52	-0.53	-0.80	-0.28	0.50	0.46	-0.59
Heterogeneous agricultural areas	-0.73	0.60	0.67	-0.21	-0.35	0.23	0.78	0.23	0.20
Industrial, commercial and transport units	1.00	-0.92	-0.95	0.82	0.85	0.49	-0.93	-0.83	0.05
Inland waters	0.98	-0.97	-0.99	0.87	0.83	0.56	-0.95	-0.88	-0.05
Mine, dump and construction sites	-0.93	0.80	0.83	-0.94	-0.98	-0.74	0.74	0.91	-0.35
Open spaces with little or no vegetation	-0.96	0.80	0.86	-0.64	-0.75	-0.25	0.89	0.63	-0.07
Pastures	0.60	-0.51	-0.57	0.06	0.18	-0.39	-0.71	-0.08	-0.32
Permanent crops	0.51	-0.37	-0.45	-0.07	0.10	-0.50	-0.60	0.05	-0.25
Scrub and/or herbaceous vegetation associations	0.80	-0.46	-0.56	0.54	0.81	0.27	-0.55	-0.48	0.55
Urban fabric	0.95	-0.99	-1.00	0.83	0.75	0.51	-0.98	-0.86	-0.19

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done in order to its dissemination using relevant WebGIS platforms (e.g., SmartOpenData, DGT WebSIG - SNIG and IGEO, eEnvPlus, TerAGUA).

These results show the relations between LUCC and water quality changes. The platform being developed can be used as a knowledge base for all decision makers researchers and interested agents involved in water management and territorial planning and survey. The interactivity between producers and users of these data (including the stakeholders) in Web platforms will enable the improvement of information production efficiency, and will lead to increased knowledge in an integrated and harmonized way.

IV. Final Considerations

The results presented in this article show LULC is tightly related to water quality. In fact, LUCC within a watershed, namely those related to anthropogenic activities explain to a large extent the impacts on the quality. This can be verified in the Castelo de Bode Dam reservoir between 1990 and 2012.

In this sense, classifying LULC in terms of their impact in water quality degradation, integrating all assumptions in a WebGIS collaborative portal has high relevance to achieve efficiency in water and land use management domains.

The developed work points to the relevance of sharing knowledge and integrating data in a structured way, that users can address and combine to evaluate land use planning alternatives and their impact on water quality. Data providers can also receive inputs from one another and from relevant users, namely governmental entities with clear attributions in these fields, allowing them to be effective in data collection and integration.

The increase in area of certain types of LULC has an effect on water quality and contributes to the increase on the concentration of pollutants drained or dragged to the main water reservoirs. This study is a highly demanding task that needs a knowledge base complete and up to date. It is essential to extend this approach to other regions so that water management efficiency will increase and the effectiveness of public investments can lead to water stress decline supported in the long term by land use planning efficiency.

All these concerns have to be in line with data collection policy, existing data integration, and well balanced management tools development.

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