SPATIAL AND ORGANIZATIONAL DYNAMICS

DISCUSSION PAPERS

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SPATIAL AND ORGANIZATIONAL DYNAMICS

Landscape and Land Use Management

Texts by:
Agnieszka Walczinska
Carlos Alberto Bragança dos Santos
Eric de Noronha Vaz
Thomas Panagopoulos
Vera Ferreira

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cieo@ualg.pt
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Marlene Fernandes

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Helder Rodrigues
Hugo Pinto

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AUTHORS PRESENTATION

Agnieszka Walczinska (walczynska_agnieszka@o2.pl)

Holds a Masters in Geodesy and Cartography from the University of Science and Technology in Poland, Cracow. Having worked as a trainee for the European Comissions Joint Research Centre at the Institute for Environment and Sustainability, Mrs. Walczinska's interests are strongly linked to remote sensing, geographic information systems. She is currently submitting a PhD proposal at the Heidelberg University, Institute of Geography.

Carlos Alberto Bragança dos Santos (cbraganca@ualg.pt)

PhD in Land Management and Environmental Strategies by the University of Seville, Assistant Professor in the High Engineering Institute at University of Algarve. Lectures Spatial Planning, Urban Planning, Environmental Planning, Water Resources Management master course. Researcher on spatial planning, landscape architecture and water management. Member of the New Water Culture Foundation, an Iberian organization promoting a new water management paradigm. Member of the team in charge of preparing the first regional spatial plan of Algarve.

Eric de Noronha Vaz (emvaz@ualg.pt)

Group Leader and Senior Scientist for the Chair of GIScience at the Heidelberg University in Heidelberg, Germany, and Assistant Professor at the University of the Algarve, Portugal. Furthermore, he holds the position as responsible for advanced training at the research centre CIEO at the University of the Algarve and has the academic appointment of visiting researcher at the Free University of Amsterdam. With a PhD in Geographic Information Systems and Science, Prof. Dr. Vaz has over 30 scientific publications in the field of urban sprawl and growth, environmental and regional impact, advanced spatial modeling and geo-information science. His interest is closely related to using spatial information and geographic information science to create a more sustainable future. This vision is shared by his research group at Heidelberg, GIScience for Sustainability, which he directs.

Thomas Panagopoulos (tpanago@ualg.pt)

He graduated in Forestry at the Aristotle University of Thessaloniki, Greece, MSc. in Renewable Natural Resources, and PhD in Forestry and Natural Environment. His main research fields are landscape reclamation and sustainable development. He has been Department Head and Landscape Architecture Master Degree Director at the University of Algarve, Portugal. He is the vice-president of the Research Centre for Spatial and Organizational Dynamics (CIEO). He is at the editorial board of various national and international scientific journals and at the executive board of UNISCAPE (European Network of Universities for the implementation of the European Landscape Convention).

Vera Ferreira (vera.ferreira.85@gmail.com)

She was born in Évora, on the 25th of August, 1985. She did her Bachelors and her Masters degree in Environmental Engineering at the University of Algarve. From April 2010 to April 2011, she worked as a research assistant at the University of Algarve, at the Research Centre for Spatial and Organizational Dynamics (CIEO), of which she is a member. Nowadays, she is a PhD student of Sciences of the Sea, Earth and Environment, branch of Sciences and Technologies of the Environment, specialization of Environment Management, under the research topic of "Predicting risk of soil erosion at the Alqueva dam watershed". She published 2 articles in specialized journals, 5 abstracts in conference proceedings and collaborated with 3 researchers in co-authorship of scientific studies.

A SOCIOECOLOGICAL APPROACH TO TERRITORIAL SYSTEMS IN MEDITERRANEAN ENVIRONMENTS

ABORDAGEM SOCIOECOLÓGICA DE SISTEMAS TERRITORIAIS EM AMBIENTES MEDITERRÂNICOS

Carlos Bragança dos Santos

ABSTRACT

Through a *socioecological* approach we intend to apply to territorial systems a similar interpretation to those currently used in ecosystem's management. Therefore, we will try to consider a territorial unit as a human ecosystem, being an interaction of natural and social dynamics. The persistence of general problems in spatial planning, particularly in the Algarve region, prompted the search for a more integrated approach, which relies on understanding the structural elements and subsystems tailored, in this case, to the specific characteristics of Mediterranean spatial contexts, where water assumes a preponderant role. Thus, the *water-system* and his structuring effect will be the reference that outlines the main prospects for the territory. There will be a theoretical exploration trying to articulate ecological concepts extended to social systems, setting up an evaluation matrix for territorial systems, which constitutes one of the tools in a proposed methodological model for assessing such systems and subsystems. The appliance of the proposed model, or its combination with other alike –'self-organizing holarchic open systems', 'resilience analysis' or 'vulnerability assessment'–, can design alternative views in regional spatial planning and frame lines of research over several areas with an evident territorial incidence.

Keywords: Socioecological Approach; Resilience; Water Management; Spatial Planning.

RESUMO

Através da abordagem *socioecológica* pretendemos aplicar aos sistemas territoriais uma interpretação mais utilizada na gestão de ecossistemas. Tentaremos, pois, analisar uma unidade territorial como ecossistema humano, resultante da interacção de dinâmicas naturais e sociais. A persistência de problemas gerais de ordenamento do território, em particular na região do Algarve, induziu a procura de uma abordagem mais *integrada*, baseada, portanto, na compreensão dos elementos e subsistemas estruturantes, adaptada às características específicas do contexto espacial de tipo mediterrânico, no qual a água assume um papel preponderante. Assim, será com referência no 'sistema água' e no seu efeito estruturante no território que se esboçam as principais perspectivas de evolução do território, segundo um enfoque *socioecológico*. Haverá uma exploração teórica para articular conceitos de ecologia extensíveis aos sistemas sociais, configurando uma matriz de avaliação de sistemas territoriais, que constituirá uma das ferramentas metodológicas de um modelo geral de interpretação e avaliação de sistemas e subsistemas territoriais. A exploração do modelo proposto, ou a sua conjugação com outros similares –'análise de sistemas auto-organizados', 'análise de resiliência' ou 'avaliação de vulnerabilidade'–, poderá projectar visões alternativas de ordenamento à escala regional e enquadrar linhas de investigação sobre vários aspectos sectoriais com incidência territorial.

Palavras-chave: Abordagem Socioecológica; Resiliência; Gestão da água; Ordenamento do Território.

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1. INTRODUCTION

In this case, the search for a socioecological approach emerges from a concern about the results achieved by the conventional practices on territorial interpretation and spatial planning based on a 'offer expansion'. Moreover, it comes from an accrued experience on preparing and monitoring regional and local spatial plans in the Portuguese region of Algarve, in the 1990's and early 2000.

The Algarve is the main touristic region in Portugal and was the first to have a regional spatial plan –PROT– legally approved in March 1991. This has been followed by an approval process for Council Master Plans –PDM– until 1996, which should be framed by the guidelines of PROT. More than twenty years passed, most of the key problems identified still persist or worsened, in particular for environmental impacts.

The causes for this inefficiency are rooted in a prevailing strategy of 'offer expansion', usually followed by an environmental rhetoric, which finds a parallel in water management policies, particularly in the Iberian Peninsula. Once at the level of water management a paradigm shift is witnessing, expressed in the new water culture, which is reflected in the Water Framework Directive, and because water is widely cited as a key structural element on the territory, we inspire in this paradigm shift to extend it on spatial planning.

Thereby, we define a path that begins by stating the territory as a human-ecosystem –like rivers are, above all, ecosystems or socioecological systems–, where water, being close relating with the territory, can clearly be an indicator to evaluate a territorial unit. We then use the example of the Algarve to illustrate a possible application of the concepts we develop to any territorial unit with Mediterranean characteristics.

In this regard we explore a number of ecological concepts that can be extended to social systems, among which resilience stands out as a central attribute. This exploration allows us to generate a matrix combining several attributes, which can be applied to a preliminary evaluation of a territorial system or any of its structuring subsystems. Then we need to integrate the matrix into a more general methodology for assessing territorial systems with mediterranean characteristics; so we resort to other tools –prospect analysis, scenarios–, and methodologies that have been developed to understand socioecological systems: self-organizing holarchic open systems analysis', 'resilience analysis', 'vulnerability assessment'. Thus we come to the construction of a methodological proposal which allows the application of our theoretical matrix and uptake some features of other tools and methodologies. This methodological approach is generated having the backdrop his application to evaluate the *water-system* of Algarve, whose evolution has an obvious repercussion on space planning. Despite the proposal is based on some specific conditions of the Algarve's territory, such can easily be adapted to other structural subsystems or territorial units with similar characteristics.

The evolution of the planning system, even though coming to register some positive developments towards the incorporation of environmental concerns, yet do not seems to have reached a maturity for a practical application according to the current methods used in ecosystems management. This does not prevent us from proposing a development of models based on assumptions that involve a paradigm shift facing current practices, in the sense of projecting alternative visions for regional planning and provide a framework on research in different areas with an evident territorial incidence.

2. THE SPATIAL FRAMEWORK

We start by locating the spatial context that we will refer to, a particular regional unit with his specific problems of increasing vulnerability which can be generalized to several territorial systems with mediterranean characteristics, at different scales. This leads to previously expose a few conceptual lines to interpret the territory as a socioecological system.

2.1 Approach context

In the preparation process of PROT Algarve we kept the idea that the spatial planning practices were being based on a perspective of resolving immediate problems, and/or merely attempting to predict the evolution of some running aspects of human occupation, usually the most dynamic, such as the functioning of urban systems, transports, energy, tourism, etc. From an environmental perspective it is somewhat worrying that this keynote planning usually called 'offer expansion' –to provide natural resources and space for all activities required by the dynamic social agents, in a way that the public administration will make it possible 'for free'.

Although, at least in rhetoric, the carrying capacity of the territory while finite alive system is referred, the prevailing idea seems to be that this capability can most often be increased while technology is available. The fact is that after two decades of applying a Land Management Plan in the Algarve the signs of increased vulnerability in its territorial system can easily be detected, especially if we come from an environmental perspective: strong impact of many urban projects and infrastructures, degradation of wetlands and water quality, soil degradation, increased risk of fire, etc.

These two factors: 'offer expansion' and environmental rhetoric can easily be putted in parallel with the current style of water management, particularly in the Iberian Peninsula. Also in the preparation of the PROT Algarve was quite equated the issue of protecting water resources, with particular focus on groundwater. This justifies the idea of an approach to the territorial system of the Algarve from its *water-system*. For achieving this purpose we highlight the need of an integrated focus on territory interpretation strongly linking natural and social aspects in a same system.

2.2 The needs of an integrated focus

To interpret complex systems, like the natural and social ones, an integrated focus is generally recognized as the most appropriate. It basically means to understand the overall functioning of a complex system. Then it is central to focus the analysis on its structural elements or subsystems and the relationships between them. This way one can more easily reach a system model, rather than a detailed understanding of each component.

On the question if *water-system*[1] can be considered as a structural subsystem in a territory, there is little doubt. Indeed water is an essential structuring element in territory, not just for obvious physical and natural arguments but also for social, economic and cultural reasons.

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1 By using the term *water-system* we try to reach the entirety of the phenomena in which water intervenes as well as its functions –natural and useful. In this system three subsystems can be considered: resource, use and management. The first has the structure of the natural hydrological part, and the functions are the natural ones, joined with those induced by utilisation –useful functions– with four categories: biological, ecological, technical and symbolic. The system of utilisation has, beyond those functions, a physical and technical structure –works and actions that define the field of circulation of flows and exchanges of energy–, as well as an economical structure. The management system refers to the coordination of activity more related to the usage of water, encompassing the series of elements of exploitation-use-restitution and the respective interactions (Erhard-Cassegrain et Margat, 1983).

While a natural element, water compartmentalized space into watersheds, produces various geomorfological processes, influences the distribution of vegetation and soil cover, etc. But it is as recourse that water mostly assumes the role of a driving force in a territory (Box Amoros, 1995). In fact, as stated Del Moral (1994), water penetrates all the pores of the territory because, in addition to the relationships established around is specific use, which is present in all human activities, an interaction is produced , more or less direct or indirect, with all land uses and all interventions on the physical environment. Thus we have a structural subsystem with an enormous variety of interactions with other factors or territorial subsystems. Since this subsystem incorporates the physical, natural and social components, and at the same time the interaction between those components acquires a special relevance he can be representative of the territorial system.

Then there are reasons enough to place the water problems in the context of territorial and environmental concerns, yet considering that many of these problems are merely symptoms of management fails in the human interaction with the life support systems. Such failures occur in result of intense pressures –population growth, urbanization, economic development (Falkenmark, 2001).

2.3 The meaning of a socioecological approach to a territorial system

These failures arise too often in consequence of sectored approaches which are counterproductive and inappropriate regarding the fast changes that are being produced –social, economic, territorial and environmental, including climate change–, once such approaches omits too many interactions (Folke *et al.*, 2002). The set of interactions pointed here has acquired different names, according to several authors: socio-natural, socio-ecological, socio-cultural, social-ecological.

Thus beyond the intense theoretical debate on this issue, we adopt the term socioecological in the sense indicated by Kinzig *et al.* (2000): "… to mean integrated systems –consisting of human institutions and behaviors, non-human ecological systems, and biogeophysical templates– that can't easily or legitimately be parsed into component parts. There is no perfect phrase to describe this concept –'human ecological' systems seems to imply humans are not ecological creatures, for instance– and various other proposed phrases suffer from the same limitation. For want of a better substitute, we have chosen socioecological.". We consider that the use of this term reflects the idea of trying to manage our interaction with physical and natural systems instead of managing ecosystems. In fact even though the social part can take the leading role we face a dynamic co-evolution, for good or for evil, between humanity and nature, as advocated by many authors (Norgaard, 1994; Berkes and Folke, 1998; Raskin *et al.*, 2002).

Indeed our interest is not only about the past evolution of socioecological systems at different scales –its trajectory– but, in a particular way, on the prospects for their future evolution: the possible paths for that co-evolution will always be the core of spatial planning. These paths shall be modeled in territorial units on an appropriate scale to allow the intervention of different actors. Otherwise there is a risk of losing specificity in policy formulation and definition of real actions. In fact, knowing that 40 percent of arable land in the world has strong or very strongly degraded soils is a reason for concern but is unlikely to be useful for an administrator of a territory. Differently, knowing that a particular valley in Colombia has degradated soils can lead to a corrective action (MillenniumEcosystem Assessment, 2000). In a socioecological approach those units correspond to human ecosystems somewhat localized or regional human ecosystems (Walker *et al.*, 2002).

Adopting the notion of human ecosystem for a territorial unit, the subject is to examine those interactions that include both specific human activities and decisions on land use, implying changes in land cover, production, consumption, disposal of various elements in space. Such interactions, locally understood, may provide mediation between the human and ecological elements in a human ecosystem, which in turn is included in a larger one with the inherent hierarchical connections (Redman *et al.*, 2000).

3. TERRITORY-WATER RELATIONSHIPS IN A MEDITERREAN ENVIRONMENT

Two meanings can be considered when one says that an element structures space: the element leads to an objective physical organization of space and/or induces opportunities and constraints. The physical organization will be visible and somewhat objective but, with regard to the opportunities and constraints, issues must be putted in a different way. This will be a key to understand to what extent the *water-system* can be an element for territorial assessment, considering objective aspects and social sensitivity. Moreover there will be particularly borne in mind the specificities of the geographical scope of Mediterranean spaces.

3.1 Water as an indicator for assessing territorial systems

About the opportunities and constraints, one of the problems is knowing how far they arrive and imply a kind of determinism, in the case of water a determinism of water (Béthemont, 1995). Two positions may usually be faced here: on the one hand those who look after precise relations between the biophysical environment factors and the human action –considering first factors determinants– and, on the other hand, those proponents of unlimited capabilities of human action and the absence of limits on initiatives of man on nature. The practical effects of these positions can range from the defense of great hydraulic works (id.), to ensure supplies in the regions 'with deficit', in order to don't lock the ' expectations of growth and territorial development ' (Box Amoros, 1995), until the defense of sustainable development strategies.

Between these two positions there is, of course and at different times, a range of options that influence the physical organization of each existing space. These options depend on the sensitivities that are being fashioned over time. Then an evaluation of water structural capacities becomes more complex in the light of possible changes in perception of a water body: wet zones were considered, over time, as specific habitats, unhealthy places, spaces of agricultural suitability and hydrological regulators with great biological value (Béthemont, 1995).

Despite there is a convergence regarding the fundamental water structuring effect in a territory, especially when water is viewed as a resource. Albeit for a same space water management can lead to such distinct spatial typologies. For evaluating a given territorial typology, or an integrated set of typologies and their conditions of dynamic equilibrium (Battigelli, 1995), some objective aspects must be take in account. Such aspects are not necessarily measurable but must serve as reference to interpret the lines of evolution in a specific territory. His perception depends on the comprehension of the multiple water functions and, on the other hand, of the thermodynamic implications of the cyclical character of water –implying the need to establish relations of interdependence between territorial units in different scales. In addition, a whole set of social values and sensitivities must be close related.

3.2 The cyclical character of water and the specificities of mediterrean environments

In physical terms, it is acknowledged a close relationship between the territorial features and the water cycle. Some reciprocal influences may be underwritten –influences of water in land uses and influences of land use on the hydrological cycle–, although the difficulty to establish a separation between both aspects due to the large overlap of functions. As pointed by Del Moral (1994) water flows throughout the whole territory –in surface or underground– establishing many relationships around his specific use. Once present in all human activities water produces a direct or indirect interaction with all land uses and with all the interventions on the physical environment. On the other hand, in its terrestrial phase, water binds together different users and makes them interdependent. Thus the use made by all users tailors the allocation of flow rates, the quality, or the dynamics of the natural flows and/or storages.

Obviously water is present in all human activities –vital, productive and cultural– and has an important influence in the forms of social and economic organization."Water is not only essential for the biological survival, as is a necessary condition for development and support of the economy and social structure which makes possible the society. Water is not just a commodity; it is a central imperative of survival, support, continuity and life of communities... "(Utton, 1985: 992; cited in Aguilera Klink, 1996: 438).

However, the level reached by the problems derived from the intensive use of water leads to very special concerns about the thermodynamic implications of impacts on the hydrological cycle. Understanding the cyclical nature is therefore essential to relate the qualitative aspects with human activities. Naredo (1997) clearly points that the human intervention on the cycle trying to address localized losses – treatment, desalination, pumping– is always guided by more costs that potential gains, taking into account the energy investment.

A particular attention must be placed in southern Europe where the quality issues are more worrying, once here the natural quality of the water is quite lower than the wet Europe. Yet in coastal areas the quality problems are those that contribute the most to the 'shortage' of the resource (id.). Consequently, the limiting factor usually associated with the quantity is displaced to quality.

Nevertheless the most common practices of water management dresses the provision in quantity and tend to despise the natural limiting factors, since it prevails the vision that everything can have a technical solution in face of the 'modern' demands for hydraulic adjustment. The traditional usages –based on adaptive skills to face limiting natural factors– are usually refuted and labeled as negative images and antiquated solutions. This is a process based on increasing the entropy, where the point is the maximization of extractions to mitigate the temporal and spatial irregularities in quantity, trying to supply the best possible some exogenous and growing demands (id.). Therefore, such policies generate an expectation of constant abundance leading to increased degradation of water quality and quantity.

3.3 Paradigms and social values

All the transformations that took place in the South of the Iberian Peninsula in the last hundred years could not be satisfactorily explained without a reflection on the hydraulic policies that have been followed. The economic growths in recent past decades, the urban system, or even the landscapes have an explanation based on the ambitions and the success of these policies. Thus there is little doubt that the transformation of these regions is the result of over a hundred years of regularization in rivers and groundwater exploitation. Like in other Mediterranean regions, the determinant role of these policies in transforming the territory, gave body to the 'hydraulic paradigm'. According to Del Moral (2000), this paradigm is well identified in other parts of the world by an abundant bibliography and its central axiom was formulated in the late 19th century as "… the need to provide enough water for all social agents willing to use it for production development, particularly for irrigation." (Del Moral, 2000: 15).

Thus water has been a decisive factor for territorial and socio-economic transformation having the government supported the costs of hydraulic infrastructures. Obviously this focus on the constant growth of infrastructures does not meet the functions and roles of freshwater ecosystems, or their patrimonial values. Moreover, the strategies for an efficient use of the resource cannot be successful with a policy of cheap water. But the ' old ' hydraulic paradigm persists unless a whole evolution in the theoretical field. In international literature numerous dichotomies are pointed: offer flexibility against demand management (OECD, 1989); hydraulic culture against hydrological culture (Newson, 1992), period of water development versus water management period (Dzurik, 1996); traditional planning against integrated planning of resource (Beecher, 1998); resource exploitation time versus concentration-time change (Thompson, 1999). All these expressions are used in areas as diverse as the United Kingdom, South Africa, Israel and United States (Pedregal, 2002). The resistance of the hydraulic paradigm –besides the strong conceptual, economic and environmental crisis– is supported by a values system about the relations between nature and society. Such values system has to do with the symbolic universe of water in the Mediterranean environments, where the hostility of the hydraulic context in torrential flows becomes a rich and beautiful environment thanks to human intervention –the 'kitchen gardens' as ideal image, idyllic (Del Moral, 2000).

Thus the emergence of a new water paradigm in a context of increasing environmental awareness (Pedregal, 2002) presents a lot of difficulties in many mediterranean territorial contexts. Here the 'pre-modern' societies show a great social acceptance to the modern strategies, based on the 'offer flexibility' of resources. A lot of negative reactions to the late-modern 'strategies'[2] –based in demand management and disclosed, for example, by the Water Framework Directive– take place. Nevertheless new values that are likely to nurture some alternatives in the context of a neo-traditional[3] knowledge can also be recognized in the same spatial context. Actually new cultural and social values, as the affective value of the territory or the landscape (Mairal, 1999), are having more relevance. This happens when local communities must deal with negative impacts of hydraulic works and, in such cases, strong negative reactions against 'modern' dominant strategies are produced.

A consolidation process of alternative concepts is taken place, facing those who have given support to the management of natural resources until recent times. This process is likely to have some reflexes on the formal power structures –the water framework directive is an example of incorporating these concepts. On the other hand, being sure that this process might be some setbacks, we should consider the possibility of the emergence of local reactions able to create a more positive atmosphere to implement new practices.

3.4 The example of Algarve: paradoxes and emergent issues

As in other areas with mediterranean characteristics, human settlement and land use in the region of Algarve always revealed a close relationship with the natural availability of water. Water has always been a factor influencing territorial features – agroecosystems, landscape, social organization, culture. Traditional *adaptive* systems have always been consistent with the irregular annual and inter annual precipitation, once they were little consumers of water and, to that extent, didn't a relevant influence on local hydrological system. Thus in

[2] In the reaction to modernism it is usual to refer post modernity as an opposite idea. The main reasons of such reaction are around the priority given to the *function* over the *art*. In architecture, one of the first theoretical manifestations of post modern ideas came from Venturi (1992), in terms of planning and intervention on space. He admits the existence of complexities and unpredictable contradictions that must be integrated in such processes. However postmodernism is often identified with attitudes of passive adaptation and he is understood as a way of keeping the *status quo* stating complicity with the formal power (Fernández, 1986). Other times he also acquires a fuzzy interpretation. We then prefer to use a more consensual term: 'late modernity'. In fact, given nowadays tendencies on this matter, some authors refer to a late modernity (Beck, 1992), placing it as a perspective near, but not completely identified with, the theses of the postindustrial society, information society, post/neofordist and post modernity (Allmendinger, 2001 cited in Del Moral *et al.*, 2003).

[3] We refer to a type of knowledge based on well adapted practices to the dynamics of natural elements and ecosystems, even if a historical continuity cannot be reclaimed (Berkes and Folke, 1998).

the mid-20th century there was 'enough water' but, at the same time, a poor production agrarian system.

From there two almost parallel phenomena happened: a) expectations of agriculture modernization framed by a set of agrarian development plans for the South of Portugal, based on a large increase of irrigation schemes; such plans had a high incidence in the Alentejo but its influence was also extended to the land transformation in the Algarve; and b) the 'tourism shock' started in the 1960 culminating in the great constructive impulse of the second half of the 1990, which caused the largest territorial transformation of coastline and has clearly highlighted the need to plan and manage the territory[4].

On this parallelism we must underwrite the response to the relatively rigorous drought period occurred in 1979-80-81. Actually there was a serious warning about water availability to meet the tourism demand on the coastal zone. The issues of quantity and quality were clearly placed for drinking potable water, waste treatment issues, recycling, etc. Then an inventory of available resources was made, particularly for the underground waters, enouncing the principles for its protection. However after the shock of this drought a new impetus on the expansion of water availability has arrived and new prospects were about implementing the hydraulic infrastructures provided for in the years 1950 adding an increase of more than three times the irrigated area originally planned.

The negative impacts resulting from the quality degradation of bathing water, due to the lack of sewage treatment, led to quickly implement all these hydraulic works. A particular attention was give to the coastal areas, in order to clean the negative image of tourism that had been created (Ramos *et al.*, 1988). The feeling of abundance of water and infrastructures –made possible by EU funds after 1986– must be take in account in the expectations of the increased urbanization in all the coastal area. Besides, the decision to draw up a spatial plan for the Algarve was taken on those dates.

As for the measures of spatial planning, in the Algarve as in many other regions, two main issues can be pointed: a) to achieve a better distribution and consolidation of social equipments and infrastructures allowing to improve the conditions of resources exploitation in the coastal area, and repair some obvious situations of conflicting activities, through a program of structural measures; b) to correct or mitigate existing disturbances on land use to prevent future situations which might endanger the identity of the regional territory, essentially based on non-structural measures.

Therefore planning has emerged here as a need or requirement to control land use once the intensity of human pressure at a time when obvious degradations were taking place. The responses that were found somehow reflect the 'land-use control paradox' (Burby and French, 1981) mentioned by some authors in the context of water management and his direct implication on the physical natural system: in flood control, it was found that, on the one hand, the choice of corrective measures induces an increment of the occupation of flood areas and, on the other hand, the non-structural measures that were also considered to be necessary, end up having a very low efficiency once this occupation has already reached a very high intensity, (Saraiva, 1995).

It is a fact that the increase of road infrastructures and/or basic sewage treatment, to correct situations of unsanitary or 'social equity' eventually have the effect of an increase in spread housing and urbanization induced by the demands for residential tourism. The phenomenon of spread housing has been identified in the PROT Algarve as one of the main land use conflicts, having quite negative effects on the tourism image itself, and has been generally prohibited for this reason. The effectiveness of such regulatory

[4] The decision of preparing a regional spatial plan for the Algarve had to do with the negative image of hard touristic occupation in the coastal zone. The lack of basic infrastructures like sewage, transports, road articulation, well organized green spaces, etc. was quite evident. Though many decision makes had in mind that a spatial plan should mainly try to resolve urban planning questions. Then it should be almost exclusively applied on the coastal zone, once for many social actors it was a potentially urbanized territory. The final decision about preparing the PROT for the entire region would be more according European recommendations like those of the European Regional/Spatial Planning Charter.

compliance turned out to be very low, given the prior establishment of a set of conditions on the ground that enhanced the development of the phenomenon.

There is a real dichotomy between, on the one hand, planning and management practices designed as a set of corrective measures –strengthening of infrastructure and equipment– and, on the other hand, a resistance to non-structural measures –essentially normative. This makes difficult to legitimate planning strategies supported on long-term visions.

Then it will be natural to reinforce the need to assess the effects of the current water management and spatial planning, trying to explore alternatives within and outside the conventional framework, particularly in local contexts. In other words, a search for problems solution will tend to increasingly integrate various scientific approaches and even multiple types of knowledge, once the present planning system internalizes the social contradictions and difficulties in response to unpredictable and progressively changing territorial realities. Unless existing institutional arrangements turn around the dominant values –mostly in perspectives of modernization processes–, making more difficult the emergency or assertion of new values, it is urgent to move towards an increasing flexibility and, to some extent, conditionality to allow real negotiations between the social actors.

Thus, in the case of the Algarve, given the relatively small scale of hydraulic transformation, it is logical to put the hypothesis of a 'social climate' likely to react to hard hydraulic transformations and to build emerging management styles for natural resources and land uses. The implementation of some of the current trends that imply transfer of decision-making power of national States to regional or local levels and, on the one hand, to supranational structures (Del Moral *et al.*, 2003), can even promote some kind of 'neo-tradicional' values –similar to the community value of water– which may allow changes in the current territorial models.

4. THEORETICAL REFERENCES

Starting from the need for less usual references to interpret territorial systems, and the emergence of different values for their transformation, we expose the theoretical bases for alternative assessments of a territory and/or its structural subsystems. To management a territory as a human ecosystem, taking into account the central attributes that are the basis of the general functioning of ecosystems is a key issue for building such alternatives.

4.1 Adaptive management and holistic vision

Many social scientists express usefulness in following ways of ecological thinking, recognizing the ecology –for a long time committed to the interpretation of complex and multiscale systems (Gibson *et al.*, 1998) –as a central discipline to analyze the human dimensions of global change. In turn, there are scientists in areas such as biology and ecology that come emphasizing the role of social, to put in evidence the always incomplete nature of the systems knowledge and the inevitable nature of 'surprise effects'. This congregation has necessarily some reflexes in alternative management policies.

In fact the growing perception of the likelihood of the occurrence of crises makes that, contrasting to conventional styles of natural resource management and planning, the so-called adaptive management take the lead. This strategy is based on a combination of ecological and social factors, necessarily including the contributions of the social and environmental sciences. A process of constant learning is clearly assumed, including a social and institutional learning path, given that the organizations and institutions, such as individuals, are able to 'learn' (Lee, 1993). Then it's about an iterative process, based on feedback and learning, called co-evolution (Norgaard, 1994) with a dual sense of feedback between management policies and the state of resources. This way, by contrast to the trends of institutional rigidity, the adaptive management drives to transparency, information, participation and, at the same time, emphasizes the value of the process and reduce the importance of urgent outcomes.

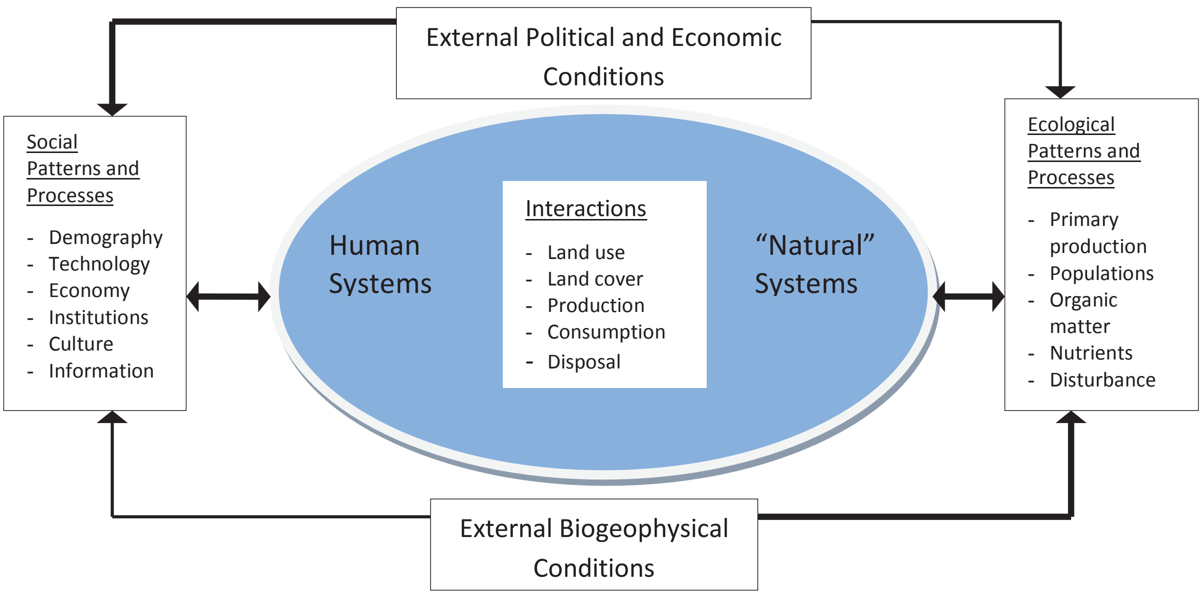
One of the key issues will be the perception of the management scale. For our case we consider that the Algarve belongs to a broader geographical scope with relatively homogeneous characteristics bio-climatic and socio-economic aspects – the Western Mediterranean. In turn, the human ecosystem we refer to includes several subsystems and, among them, water subsystem is particularly important, once it plays a multiplicity of roles. Therefore the adoption of an ecosystem approach is an essential prerequisite to interpret the problems and development prospects of the territory, on the need for paradigm shift by a society responsible for its resources (Bergkamp, 1999).

This approach is somewhat reflected in the trends of water management, and particularly evident in the new water culture –NWC (Martinez, 1997). The holistic vision suggested in NWC adds the world of human feelings – beauty, evocation capacity of metaphysical values, play needs– (Antoranz y Martínez, 2002), seeming quite suitable not only to interpret the water but the whole territorial system. Moreover this vision leads to recognize the importance of information and socio-cultural control on human ecosystems.

4.2 Socio-cultural regulation of human ecosystems

Indeed the development of the now classic concept of human ecosystem incorporates the basic qualities from ecological sciences combined with territorial concerns, and leads to a greater emphasis on the information role. Therefore the concept is quite suitable for the analysis of interactions and variables, as graphically shown in figure 1.

Figure 1. Conceptual framework for investigating the integrated human ecosystem

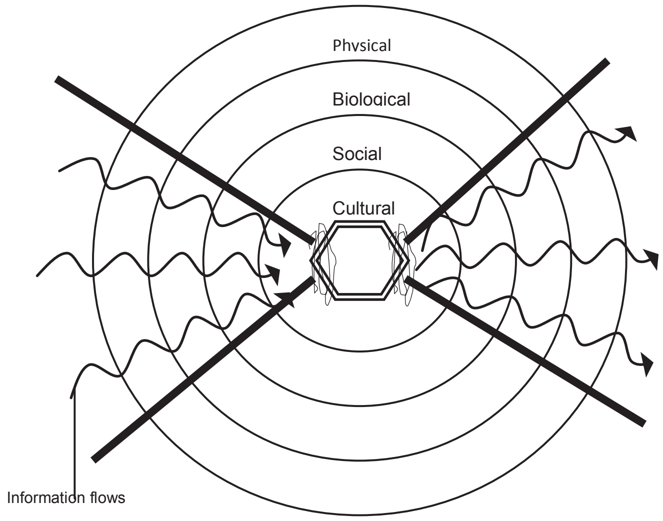


Interactions are defined as the specific activities that mediate between the human and ecological elements of the broader human ecosystem, including activities involved with land use decisions –land cover and land-cover changes, production, consumption and disposal. The next step is to develop a perspective on what motivates these activities, using *drivers.* For conceptual convenience those drivers are divided into two categories: 1) ecological patterns and processes and 2) social patterns and processes.

Source: Adaptation from Redman *et al.*, 2000: 3

In his evolution this concept integrates, more recently, the significance of indirect causalities through complex interconnected interactions and flows, confirming the role of information in ecosystems. In the presentation of the 'multiple environments' concept, advanced by Stepp *et al.* (2003) –figure 2, in which the human ecosystem is considered as a 'place' or *locus*, within a set of environments that, in turn, always displays inbound and outbound environments–, it is clear that the role of information reinforces the importance of a socio-cultural regulation which may even be extended to individual actions.

Figure 2. A partial concept of multiple environments



"An aggregated consumer symbol representing a human population or individual as a transformer of matter/energy/information lies in the middle (after Odum 1983). The wavy lines represent information flows from the multiple environments that pass through an epistemological filter/field/editor/screen for any given individual or population. This represents the co-occurring and often overlapping processes of human cognition, which are shaped by environmental affordances, belief systems, and the types of information that are available. Matter and energy flows are not represented in this depiction but are, of course, present in all human ecosystems." (Stepp *et al.*, 2003: 2).

This also leads us to value an action-research positioning, in which the researcher considers itself as an integral part of the social actors set that influence the management of natural resources and the decisions about the territorial transformations. In fact, we built a model doing some interpretations of reality, aware that "there is no single reality, but rather multiple realities, and what is represented depends on one's position in the field of negotiation" (Dempster, 1998: 14).

Moreover, in the debate about environmental issues where typically facts are uncertain, values in dispute, stakes high, and decisions somewhat urgent (Funtowicz and Ravets, 1998), quality tends to be the principle that orients decision-making, and quality depends on the open dialogue among all those affected. Nevertheless, we need to follow some conservation objectives, having in mind the robustness of our human ecosystem.

4.3 The notion of territorial robustness

When we refer to conservation objectives in a socioecological system we have in mind that its functional dynamics maintains *integrity* when stressed by adverse environmental conditions capable to provoke great disturbances. It means to preserve all its components as well as the functional relationships among the components. But it also means to recognise a human perspective, the ability of an ecosystem to continue to provide the services that humans expect. Integrity reflects then the capability of those systems to support services of value to humans (De Leo and Levin, 1997). This notion applies independently of the degree of intervention to which an ecosystem is submitted. Differently from reflecting the 'health' of a natural system, we see it is as a tool for management (id.).

In fact, we live in a context of complexity, implying an evolution from strategies of nature's control to management strategies, based on adaptation and adjustment. So, the introduction and articulation of several concepts to enrich and fit a better understanding of environmental issues (Funtowicz and Ravets, 1998) acquires more importance. Starting from this point we attempt to make converge in integrity the various concepts and attributes to construct a grid where we place what we designate as "robustness area". The grid is based on the comprehension of natural systems and of reactions that these can have when submitted to exploitation in a greater or lesser extent.

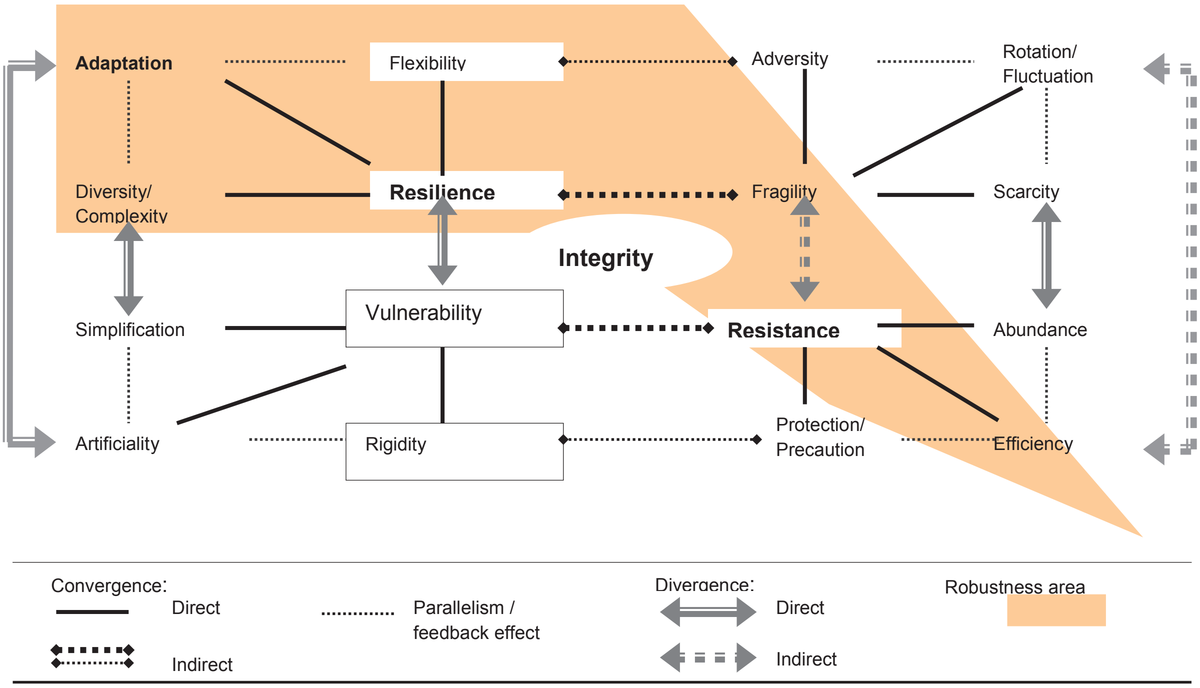
As concepts stem from our informal understanding of the ideas of stability, sustainability, and resilience (Ludwig *et al.*, 1997), we start by presenting these ideas as a first frame to reinforce the objective of integrity. Stability will be, informally, the tendency that a system presents to return to a position of equilibrium when disturbed (id.). It refers to the desirable configuration of a system (Walker *et al.*, 2002). From there we can get pretty close to integrity, entailing the maintenance of multiple states of equilibrium. At the same time, "sustainability involves maintaining the functionality of a system when it is perturbed, or maintaining the elements needed to renew or reorganise if a large perturbation radically alters structure and function" (Walker *et al.*, 2002). Because the ability to do this is termed *resilience*, we take this concept as central in our articulation network, once our point of interest is the evaluation of social-ecological systems in a mediterranean environment, where great variations in natural conditions regularly have an effect on the way of life of its inhabitants. A resilient system will be that which tends to maintain its integrity, recovering from great disturbances (Holling, 1973).

Nevertheless we think that it will be necessary to consider –given the modifications that have been introduced in natural systems– that the stability is guaranteed by an increased productive capacity that confers them resistance. That's why we utilise resistance complementarily to resilience, in the sense used by several ecologists, as the degree in which each system maintains immutable when we alter its components (Pimm, 1999). We later articulate other attributes whose relation is more or less consensual, establishing a network of correlations that are complementary, contrary, and of feedback effects. In the interpretation of the attributes with complementary functions the concern is to find a platform for stimulating the reflections about the correction of situations of imbalance in territorial systems, and above all, about how to avoid the 'disintegration' of these systems. We have as such an articulation of various attributes interpretable as much in physical aspects as in socio-economic aspects, which we schematise in the matrix in figure 3.

The horizontal reading of the upper part of the matrix can be applied to the interpretation of a natural adverse environment, but in which human intervention does not largely modify it's functioning.

The great capacity of *adaptation*, the *diversity* and *complexity* are conditions that allows a territorial system for a great *resilience* once he presents the faculty of recovering from situations of natural scarcity without losing the main traces of its identity. This lost would hardly occur if there were greater external disturbances in situations of extreme scarcity, the reason that justifies the *fragility* of such systems. Therefore, for keeping resilience, *flexibility* is the main principle of human intervention.

Figure 3. Robustness Matrix



The horizontal reading of the inferior part of the matrix can allow the interpretation of a group of influences tending to increase the *resistance*, entailing a human action based on the use of conventional technologies. The input of *energy* and *materials*, external to the system, entails a *simplification* and *artificiality* that will have relative *abundance* as a reflex, the greater the efficiency in the transformation of the input. The *rigidity* ends up as a characteristic of management, being able to be attenuated by efficiency in the utilisation of resources and conservation of natural aspects/values, according to the principles of *protection* or *precaution.*

The 'robustness area' is encountered in the conjugation of the two readings, implying as conditions:

- To emphasise the adaptation to sustain the quality and the identity of the territorial system;
- To assure the global diversity and complexity, recognising the fragility and, in part, the adversity but avoiding situations of intense scarcity;
- *To recognise the resistance as a complementary property of resilience*, stemming from the input of materials and energy and consequent simplification and artificiality circumscribed, which allows to some relative abundance and requires efficiency;
- To emphasise flexibility as a principle of natural resources management allowing partial activities guided by the principles of protection and precaution.

4.4 Interpretation of a Mediterranean water system

The theoretical matrix of robustness could serve as a way to interpret various territorial systems or subsystems in a mediterranean environment –ecological systems, transport systems, urban systems. To interpret the *water system*, that have a 'special' territorial significance, we will try to identify in its diverse territorial manifestations –structural effect, functions carried out and interactions with other systems, management options– the different attributes that highlight the resilience or, in the opposite sense, increase the vulnerability. This way we can discuss the affectations of territorial robustness and/or the possibilities of its reinforcement.

Figure 4. Robustness and vulnerability of a water system in a mediterranean environment

Image of robust water system: resilience and resistance in the systems of resource, of utilisation and of management	
Resilience as a dominate characteristic	**Resistance as a complementary property**
The *resilience* of the system will be guaranteed: By *diversity/complexity* of the system of resource and of the system of utilisation: · Domination of natural flows over modified parties; · Utilisation tending to be closer to natural flows; · Different origins for different utilisation; · Variety and differentiation of distribution circuits, to accomplish different objectives; By the conditions of *adaptation* of the system of resource and of the system of utilisation: · Adjustment of needs to the real resource disponib.; · Guarantee of vital needs and rationality on great “consumption”; · Supply based on resources in the same watershed; · Treatment of sewage with regeneration of flows and new utilisation; By *flexibility* of the system of management: · Participation of the users on the decisions about production, control of quality, distribution; · Capacity to change strategy -new knowledge, risks; By recognising the *fragility* of the system of resource: · Identification of the conditions of natural adversity; · To foresee the scarcity situations.	The locals of *resistance* will be characterised: By *efficiency* in the system of resource and in the system of utilisation: · Resource capture with less investment on energy; · Minimisation of losses; · Recuperation of quality –recycling; By a relative *abundance* in the system of resource and in the system of utilisation: · A more intense use of natural flows and storage in the most rainy years, managing aquifers and superficial water together; · Careful exploitation of strategic storage on critical periods; · Productivity and benefits of water – agriculture, recreation, transport; By applying of the *protection/precaution principle* to the system of utilisation: · Normative of protection of the quality of the resource and of the sewage treatment; · To avoid situations of potential risk.
Increase of vulnerability in a water system: simplification, inputs and rigidity in the subsystems	
A system will increase his *vulnerability* in result of: Structural s*implification* of the system of resource and *artificiality* of the system of utilization: · Big works for resource capture and storage, in a growing rhythm, following a spiral of a growing demand; · Constant increasing density of channel network for supply and run-off all over the territory; Great *inputs of materials and energy*: · Hard and sophisticated systems of pumping –inverse osmosis, big depth extraction, etc.; · Transportation at big distances; · Hard and sophisticated systems of treatment on resource capture and on sewage; *Rigidity* in the management system: · Rigorous rules with a week acceptation by the users; · Centralised management system in a bureaucratic or technocratic style.	

To configure the *water system* we consider the systemic approach proposed by Erhard-Cassegrain et Margat (1983), emphasising the functions of water, the structural aspects of subsystems that can be identified and even various interactions that occur among them. Therefore, we can put the various attributes of the matrix in relation to subsystems of resource, utilisation, and management as shown in figure 4.

If we develop a reflection on the forecasts for the ‘algarvian’ *water system* –figure 5–, relating some factors with the attributes of the matrix, we can easily demonstrate that:

- The actual trends will deteriorate robustness for lack of *adaptation*, lack of *recognition of natural fragility* and due to an increase of *input of materials and energy.*
- Robustness can actually be enhanced by applying the principles of *efficiency*, of *protection / precaution*, and by diminishing the *input of materials and energy.*

- The tendencies towards new infrastructures, stimulating a spiral of growth in demands of water resources, interfere negatively with the attributes of *resilience* and reinforce those of *vulnerability*.

The alternatives that are still hardly to achieve, such as the adoption of adaptive technologies and management ways based on "endogenous potentialities", will be those that can have a most positive contribute to strengthen the attributes of *resilience-resistance* and that mostly may diminish the importance of the attributes of *vulnerability*.

Figure 5. Forecast for the water 'consumption' in Algarve (2000-2020) and characteristics of the hydrological system

Population				**Irrigation**			
Resident		Visitors		Public		Private	
Year 2000	Year 2020	Year 2000	Year 2020	Year 2006	Year 2020	Year 2006	Year 2020
400.000	-	973.000	1.542.000	8.400 ha	12.800 ha	>19.470 ha	~28.000ha
Urban cons. (hm3): losses reduction 50% in 2020				Needs (hm3): normal year, expansionist hypothesis			
22	36 a 38,5	46	87,5	41,8	62,9	108,1	131,2
Per capita l/day: cities with 5.000 a >50.000 inhab.				Needs (hm3): critical year, expansionist hypothesis			
200-250	240-280	250	280	42,2	69,6	120,1	145,7
Total consumption in 2020, critical year (38,5+87,5+69,6+145,7) - **341,3 hm3**							

Source: adapted from MAOT, 2001

Characteristics of the hydrological system

Normal annual precipitation (Ribeiras do Algarve)	620 mm, <500 mm 1 in every 5 years*
Precipitation in dry semester (April-September)	<20% of a normal year*
Potential evapotranspiration	1.240 mm**
Total water resources availability (level of guarantee 95%)	**370 mm***
Net capacity of the existing dams	~ 266 hm3***

Sources: * Henriques (1985), ** MAOT (2001[a]), *** INAG

5. METHODOLOGICAL TOOLS

Despite can provide a reference to evaluate territorial systems and its subsystems, in particular the most structuring ones, the conceptual matrix has not be generated as an autonomous instrument, rather integrating a more elaborated methodology. Although each subsystem has its modes of interpretation –as in the case of *water system* we have tried to apply above, joining the systemic approach of Erhard-Cassegrain et Margat (1983)– we need to apply other tools that allow us to formalize a global scheme to deliver an assessment synthesis model that sets up our methodological proposal.

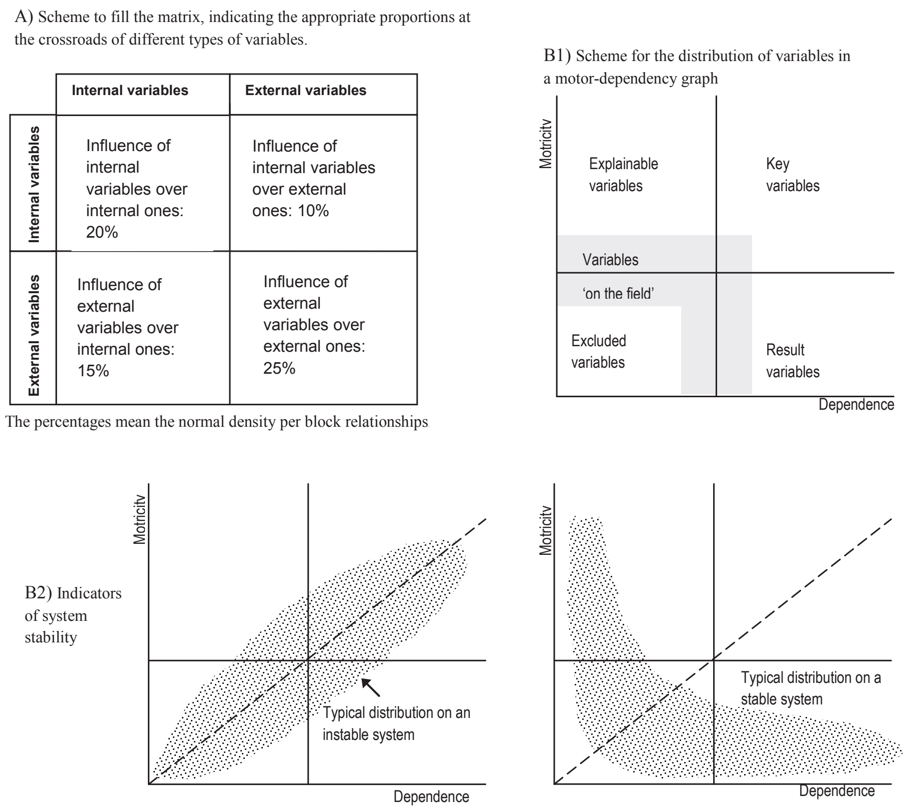
Firstly we need a tool that allows us to detect the existing problems in each subsystem and its future trajectory, involving various actors. The method of 'structural analysis' is one that allows us to formulate diagnosis and territorial repercussions of several subsystems through an identification of its variables, their hierarchy and dynamic, according to the sensibilities of those involved in such subsystems. After that, a particular importance must be placed for the prospects for future development of the territorial system, once the goal is to assess systems under a spatial planning perspective. In this sense, the development of scenarios and visions of the future is another key piece that is far from being a consensual technique. Finally, we recognize that the above methodological tools, including the *water-system* modeling, can hardly be articulated. Then to give body to a concrete model, we will pay particular attention to some models known on assessing socioecological systems. We will expose the basic qualities of the three models in which we base our methodological approach: Self-Organizing Holarchic Open System –SOHO– analysis, resilience analysis and vulnerability assessment.

5.1 Structural analysis

Basically, "… the structural analysis offers the possibility to describe a system with the aid of a matrix that relates all the constitutive elements of the system. The method allows the study of such relationships and makes the essential variables appear." (Godet, 1993: 102)[5]. Despite requiring a great dedication by participants we believe that, given the current difficulties of participation, it will be possible to obtain practical results in a simplified way, particularly in the identification and hierarchy of variables. The various key players can be progressively involved in the entire process of management.

To apply this tool to the regional *water-system* we need to identify the problems of management, as well as their causes and effects, and to systematize the system variables with major territorial influence. One of the initial conditions is the separation between internal and external variables, being internal those which depend of the system dynamic –in the case of water aspects related to the natural hydrological structure, the use or management– and external those that depend on external dynamics of the analyzed system –largely economic and social aspects in higher scales.

Figure 6 – A) Guides for filling a matrix of structural analysis; B) Typology and significance of variables distribution



Source: Godet, 1990

[5] The structural analysis techniques are being applied in social sciences since the decade of 1990. Although his application is more frequent in business management or economic systems analysis there are also some applications on spatial planning on regional scales (Gabiña, 1998), territorial studies on a local scale (Guerra, 1999) and on watershed planning (Vàsquez y Conceição, 1999). The methodology is based on the active participation of a group of influent actors in a real system, for preparing scenarios about the evolution of that system and orient current decision making through visions of future.

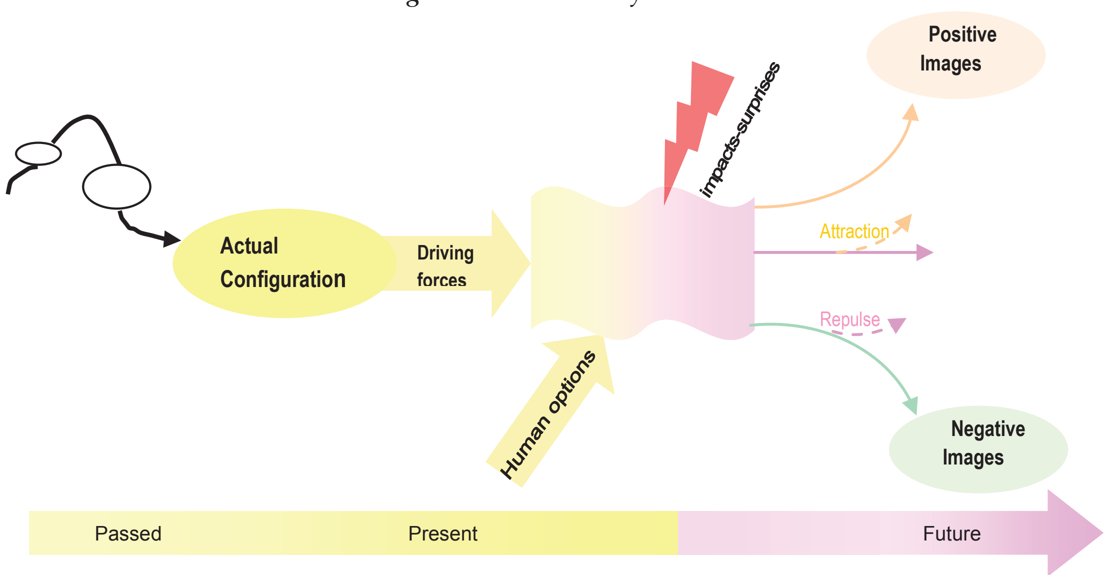
The most delicate task is to cross more or less exhaustively all variables with each other in a table of double entry or structural analysis matrix. Four types of influences are considered that each variable exercises in relation to the other: strong, medium, weak and potential. For each type of influence a numeric value is assigned. Once populated the matrix, it is possible to draw up a chart of motricity-dependence, resulting from the sums of the values assigned to each variable in the horizontal reading –motricity– and vertically –dependence. Five types of variables will be identified, according to the position occupied in the quadrants of a chart –figure 6 A)– which will have different meanings: the variables with a big motricity and little dependence are the explainable variables; b) those which at the same time have a big motricity and are very dependent are the key variables; c) those with little motricity and very dependent are the result variables; d) those with intermediate values on motricity and dependence variables "on the field" and e) those with a little motricity and dependence shall be excluded variables –figure 6 B1). The distribution spectrum of the variables in a chart is an indicator of system stability – Figure 6 B2).

5.2 Scenarios

Although the identification and variables hierarchy relates to a process of scenarios preparation, usually used as strategic planning instruments, we intend to adopt a somewhat different perspective, closest to the use of scenarios in environmental studies, and without the usual visions, better known in the context of the analysis of the war games or business management in civil society, thanks to Kahn and Wiener (1967). Indeed in ecosystems assessment, developed for example by the IPCC, the scenarios describe 'images of the future, or alternate futures', while in a more common sense scenarios are taken as a result of emerging events or a course of predicted actions or events (Alcamo, 2001).

Since on socioecological systems there are driving forces with difficult prediction –non-linear relationships, unknown aspects and surprises– that usually make common forecasts quite impossible, scenarios arise to manage, in a structured way limitations of forecasts, as an alternative option (Peterson *et al.*, 2003).

Figure 7. Scenarios dynamics



Source: Adapted from Raskin, 2002, in Reid *et al.*, 2002: 37

In fact, "Scenarios provide insight into drivers of change, implications of current trajectories, and options for action. Alternative policies can be considered in light of contrasting scenarios and to compare their robustness to possible futures." (Clark *et al.*, 2001: 659). That's why, in our approach, we intent to integrate the scenarios general dynamics, focusing on the actual configuration of the territorial system, trends on human options, surprise effects and unpredictable impacts, positive and negative images, as well as their attraction and repulse, in a scheme similar to figure 7.

Therefore, in our case, scenarios are fed by the main factors or variables identified in the territorial system by participants. These variables can be detected in an explicit way in group discussions, or through the perception revealed by participants when they indicate the problems, their causes and effects. In turn, the verification of the alternatives robustness in terms of policies and actions generated from the scenarios requires a clear identification of kea variables on the territorial system generated from the scenarios requires a clear identification of kea variables of the territorial system, and/or subsystems with a major structural effect.

5.3 Reference Methods

To complete the prospective analysis and the use of scenarios we will essentially focus our attention on two relatively recent methodological models that constitutes a reference on practical applications on various scales. We add the main features of the strategy followed to more general problems whose principles can also be applied on a local or regional scale. The references that we consider useful to build our own model are present in the following methodologies:

Self-Organizing Holarchic Open – SOHO[6] (Kay *et al.*, 1999); resilience analysis (Walker *et al.*, 2002); vulnerability assessment (GIECC, 1997; Clark *et al.*, 2000).

All these methods and strategies have some common characteristics, which emerge from a same theoretical root and a similar approach, as the acceptance of plurality of options instead of searching for a single option, the consideration of social values in decisions rather than the simple consideration of scientific data and scenarios and visions of the future instead of mere forecasts or projections of experts.

5.3.1 *Self-organizing system analysis*

SOHO analysis can be applied to human ecosystems, justifying the integration of human vision and different preferences, from which scenarios and visions about possible and desirable futures can be generated. Each scenario will display different sets of opportunities that require planning and negotiations between the participants in order to bring together these possibilities, aiming to develop a plan or a future path. Throughout this framework a set of human activities are encouraged or discouraged, and the institutional arrangements best suited to new forms of governance can be identified (Kay *et al.*, 1999).

The emphasis on self organization implies an idea of keeping the ecosystems integrity or, more precisely, of keeping the integrity of the self-organization processes (Schneider and Kay, 1994).

[6] As stated by Dempster (1998: 37), "self-organized systems are emergent systems generated by the interaction of global and local influences." The global influences are typically field-like in nature –gravity or magnetism, for example– and may be long-range and invisible. Local influences show blockages or constraints that act as an impediment for the components, and typically occur on a meso to micro scale. Rivers are ideal examples of the emergence of self organization. Gravity –global influence– makes that drops get together and generate flows that are later conditioned by the characteristics of relieve and landscape –local influence –, from soil particles to la geologic composition (id.). Self-organization occurs in all open systems, like ecosystems or human systems. As exposed by Kay *et al.* (1999), self-organized systems have a dynamic dominated by negative and positive feedback processes that act through a set of spatial and temporal scales. In turn they present weak hierarchic structures, several emergent phenomena and quite fast reconfigurations, implying the possibility of the existence of some unpredictable changes. The identification of characteristic unitary elements of systems, that Koesttler (1978) called 'holon', and their way of grouping in the system's composition, justifies the use of the term 'holarchy'. Then, the 'holarchy' is not more than a version of the hierarchy implying a few reciprocal power relations among the levels of organization, instead of the strict preponderance of a power from top to down. The conjunction of all these skills –openness, self-organization, 'holarchy'– justifies the designation proposed by Kay *et al.* (1999) for self-organized open holarchic systems: SOHO.

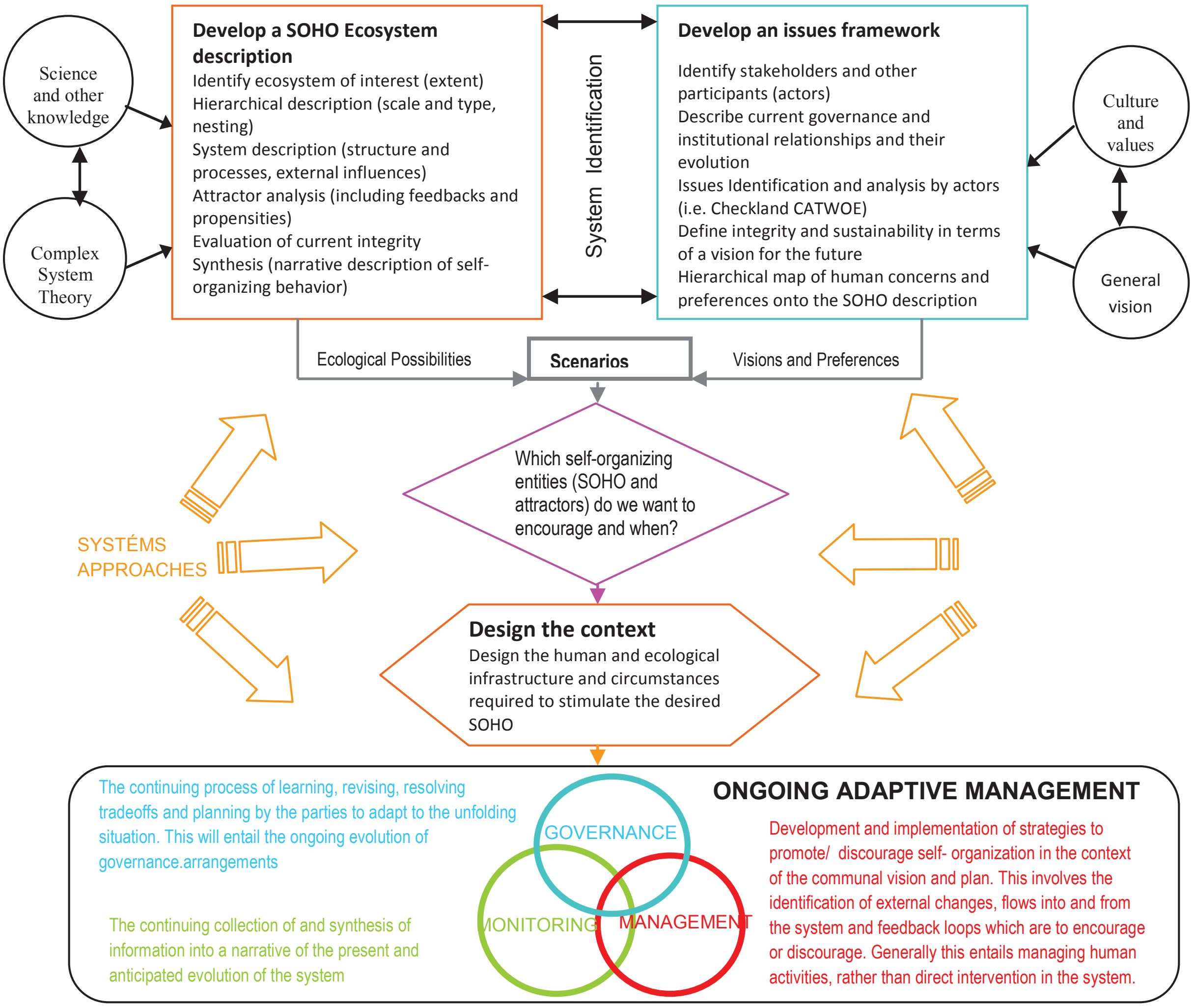
The entire methodology has its support in the theory of complex systems, with all its thermodynamic implications[7], and incorporates, in an explicit way, the principles of post normal science.

> *In the post normal paradigm, a scientist role in decision making shifts from inferring what will happen, that is, making predictions which are the bases of decisions, to providing decision makers and the community with an appreciation, through narrative descriptions, of how the future might unfold.* (Kay *et al.*, 1999: 728).

In Figure 8 we reproduce the layout of a human ecosystem analysis taken as a SOHO that, according to its authors, wants to move towards a sustainable and healthy ecosystem.

This heuristic model, known as ' diamond diagram ', proposed by Kay *et al.* (1999) with the intention of driving the investigations of ecosystems, was in some way assessed and served as reference to some practical applications.

Figure 8. Adaptive management approach on a SOHO



Source: Kay *et al.*, 1999

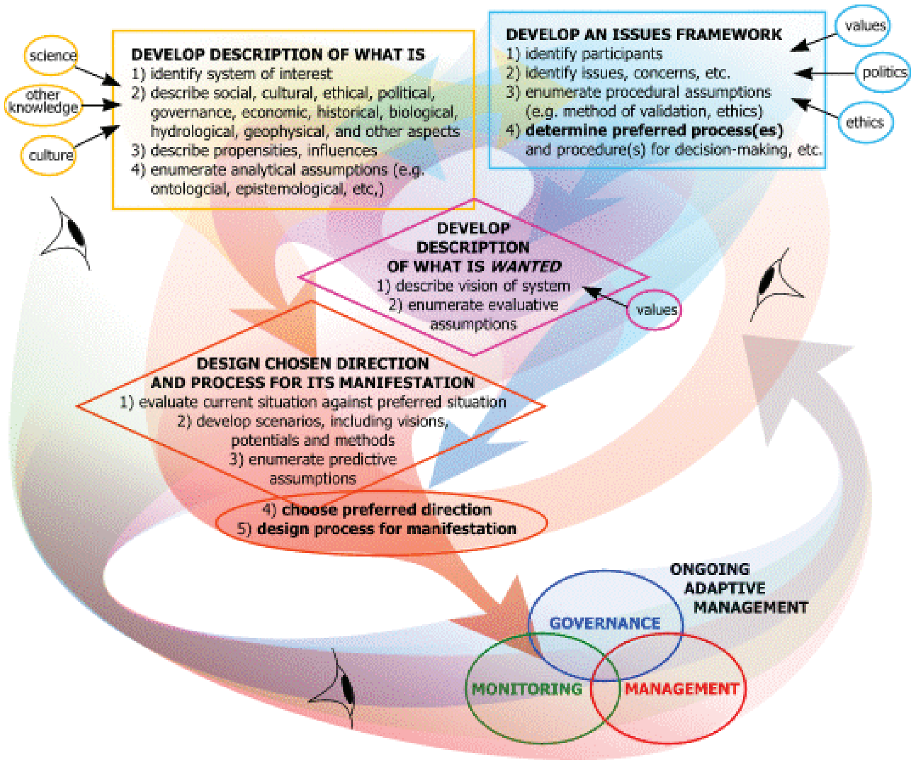
[7] After Kay *et al.* (1999), the key for understanding organization phenomena and coherent and spontaneous behavior on open systems stays on processing and keeping high quality energy flows–'exergy'. On the analysis of Schneider and Kay (1994), when 'exergy' is pumped inside an open system he get far from equilibrium but has a compensation because nature resist to the movements of getting far from equilibrium. However, when high quality energy and materials enters pushes the system beyond a critical distance for keeping the equilibrium, and the open system responds with a spontaneous emergency of a new and reconfigured behavior, using the 'exergy' for building, organize and keep the new structure. This process reduces the capacity that the high quality energy has to keep getting the system far from equilibrium.

Discussion around the initial model has resulted in some adjustments and criticism coming mainly from the discussion group of complex systems and post normal science at the University of Waterloo (Canada). Some new proposals emerged and, among all of them, we have chosen the diagram synthesized by Dempster (2000) –figure 9.

Figure 9. Evolution of SOHO analysis model

Dempster (2000) underlies five concerns on the initial model, which intents to add in the reformulation:

- To clarify the differences between what the system *is* and what he *must* be;
- To assure that the process that defines the 'must' will be the duly considered;
- To assure that the description of the 'eco'system incorporates something more than biophysical aspects;
- To stimulate 'reflexivity';
- To emphasize the 'recursive' nature of investigation process.



Source: Dempster, 2000

In this diagram, cultural values are related with the box of what is, the ethical processes being related with the box of processes and the values being related with the diamond of what is *wanted*. In a similar way some 'eyes' turn into a graphic symbol of our condition as observers embedded in the process.

Another interesting aspect is the need to continually incorporate new information in several steps of the process while an adaptive management is taking place, supposing several feedback loops, graphically expressed by circles and arrows. Finally, there's a concern of extending the model to several types of system by simplifying the references to the complicated language of a systemic approach (Dempster, 2000).

5.3.2 *Resilience analysis*

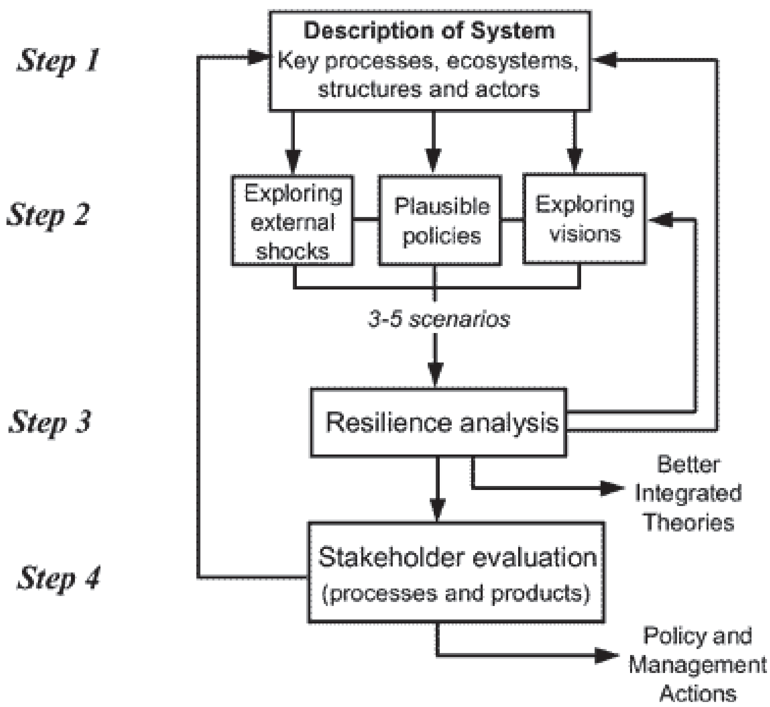
The proposals of Walker *et al.* (2002) intent to be more pragmatic by exposing a methodology of resilience analysis applicable to *social-ecological systems* –SES– on a regional scale. A starting point is the recognition of extreme uncertain and complex conditions on SES, conditioning the major previsions that can take place. "A fundamental difficulty in managing socialecological systems (SESs) for long-term, sustainable outcomes is that their great complexity makes it difficult to forecast the future in any meaningful way. Not only are forecasts uncertain, the usual statistical approaches will likely underestimate the uncertainties. That is, even the uncertainties are uncertain." (Walker *et al.*, 2002: 2).

However, a SESs behavior might not be so unpredictable if he is "…looked at from a larger perspective, ignoring such details as agents and variables, and concentrating on the coarse-grained features of the system." (ibd.). Therefore, the main objective consists on assure to maintain the system capacity to cope with whatever the future brings, without changing in undesirable ways; this means to maintain or reinforce resilience. As mentioned by Gunderson and Holling (2002), the heart of sustainability is based on understanding the loss, creation, and maintenance of resilience through the process of co-discovery –by scientists, policy makers, practitioners, stakeholders, and citizens.

A strong point of this methodology consists on stimulating a creative process for facing the future, by comparing maps with different ways. "The challenge, then, is to understand the biophysical and social components of resilience and bring them to the consideration of voters, interest groups, and politicians. Therefore, we also offer resilience analysis and management as an approach that is better attuned than optimal command-and-control solutions to the conflicting objectives and complexity of a pluralistic modern society." (Walker *et al.*, 2002: 5).

Figure 10 shows the general scheme of a resilience analysis. The information of two first steps is used in the third on for developing more detailed analysis, including quantifications about the identification of the ecosystem resilience. The fourth step consists on an integrated evaluation of management options and politics, involving the direct participation of social actors and scientists (cf. Walker *et al.*, 2002).

Figure 10. Scheme of a resilience analysis



Source: Walker *et al.*, 2002

5.3.3 *Vulnerability assessment*

Vulnerability assessment is an emergent strategy for social and ecological systems focusing on policy-driven assessments of global environmental risks in arenas as different as the ongoing work of the Intergovernmental Panel on Climate Change (IPCC), the World Economic Forum(WEF), and the World Food Programme (WFP) (Clark *et al.*, 2000). As a main reason:

The last several years have witnessed a significant evolution in what society wants to know about global environmental risks such as climate change, ozone depletion, and biodiversity loss. Until recently, most scientific assessments of such risks focused on the anatomy of conceivable environmental changes themselves, while devoting relatively little attention to the ecosystems and societies the changes might endanger. (Clark *et al.*, 2000: 1)

Thus this assessment differs from conventional approaches of environmental impact, which selected a particular environmental stress of concern –climate change, large dams, new fishing technologies, etc.–, seeking to identify its most important consequences for a variety of social or ecosystem properties. In opposition, vulnerability assessment seeks to determine the risk of specific adverse outcomes for a particular group or unit of concern –landless farmers, forest ecosystems, coastal communities …– in the face of a variety of stresses, identifying a range of factors that may reduce response capacity and adaptation to stressors. Vulnerability emerges as a multidimensional concept involving *exposure* – the degree to which a human group or ecosystem comes into contact with particular stresses; *sensitivity* – the degree to which an exposure unit is affected by exposure to any set of stresses; and *resilience* – the ability of the exposure unit to resist or recover from the damage associated with the convergence of multiple stresses. (Clark *et al.*, 2000).

Once vulnerability is an inherently scale-dependent property of systems, one of the main questions will be about how future assessments can determine the scale of exposure units. Yet, useful vulnerability assessments will need to address multiple stresses that interact across a variety scales.

Assessment focuses on a dynamic combination of environmental and social stresses who can reveal adverse outcomes. This way, vulnerability analysis enhances multiple causes for critical outcomes, rather than only the multiple outcomes of a single event, turning in an evaluation of alternative mitigation and adaptation strategies that could help to avoid such dangerous combinations. (id.). In this context, scenarios are the tying pieces of the system story, becoming a central output of the vulnerability assessment rather than a peripheral input.

6. EVALUATION MODEL

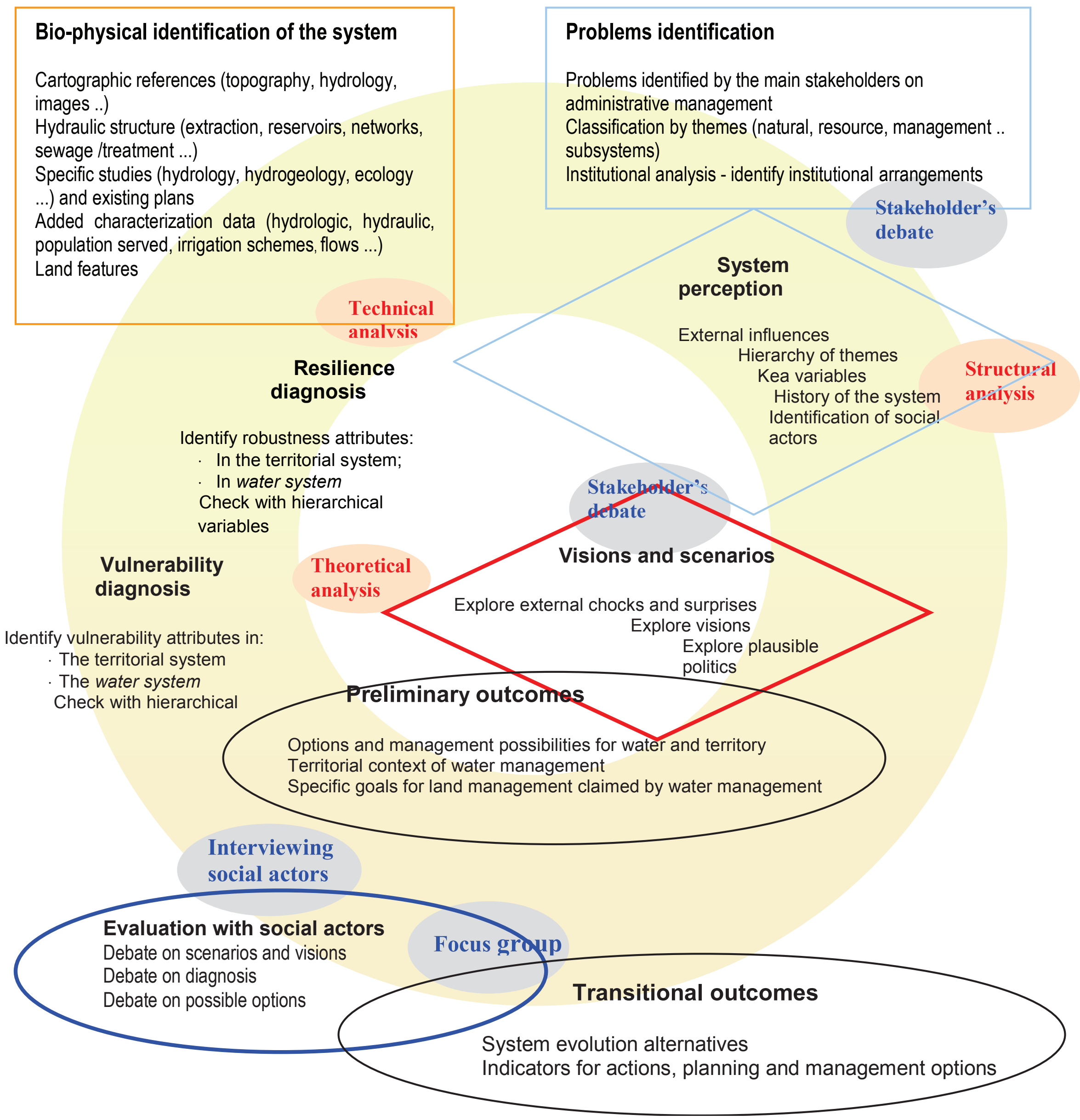
Our proposal for finding a model to assess a territorial system in Mediterranean environments lies on adapting the main features of the reference methods, exposed above. However, we first develop a methodological proposal to evaluate the regional *water system* of Algarve, where an ongoing planning and management process is taking place, expressing an institutional will to change negative states. This implies taking in account some local constraints.

The first one is the lack of an active public participation in planning and management; the most current practice is an elaboration of technical proposals by an expert staff subject to a public consultation. This practice leads normally to an increase of conflicts, once most of social actors are suddenly faced with an amount of complex and unknown issues that imply important decisions involving their interests. The second constraint lays on a lack of continuous monitoring practices by public entities responsible by planning; the consequence is a poor stimulation to institutional learning processes in planning and management. The thirst one is a limited capacity to mobilize social actors and implement social debates, once the conventional decision making is merely based on 'classic' technical-scientific arguments; this complicates to apply prospective methodologies. The fourth consists on a desire to obtain practical results on the short term in several technical domains. In fact, public entities normally want to obtain results by stages and on well defined delays, making systemic approaches difficult. Moreover, this constrains an integrated view of the territory that tries to relate several territorial subsystems.

Attempting to minimize all these constraints, we try to follow a progressive approach for involving the most social actors, beginning by an exposure of technical data made by experts. This will imply an effort of the technical- scientific staff for repeatedly explain the main features when the several actors are incorporated in the debates, overcoming the lack of tradition on mutual learning.

In figure 11 we highlight four main steps.

Figure 11. Model of a methodological proposal for evaluating the water system in Algarve



In a first step we try to characterize the system considering two blocks: in the left side the physical identification of *water system* and, in the right side, the identification of problems, interdependences and institutional arrangements. It supposes a constant feedback between the two blocks, once the problems identification cannot be complete without a comprehension of the system's physical expression, as well as the representation of the water system's structure is influenced by the problems that are being identified.

The second step consists on exposing the perception of system's dynamic, as well as his environment –the territorial system. This will be done by incorporating and working data of the previous phase. This step necessarily involves the subjectivity from who works and manage data; that's why it should involve a strong stakeholder's debate, very difficult in the present circumstances. Conversely, a prospective tool is used to minimize this disadvantage and the graphic expression with a diamond wants exactly mean that an amount of subjectivity is involved.

In the third step all the data of previous phases will be evaluated –and some diagnosis will be made– allowing his use in visions and scenarios development. A diagnosis of *water system's* robustness –and vulnerability– will be made, attempting his interaction with the territorial system, using the robustness matrix. At the same time, the external influences over the *water system* will be analyzed in a more detailed, including the probability of shocks and surprises liable to affect the subject of appraisal systems. Given these influences, some hypothesis will be developed for the kea variables in the *water system*, as result of exploring plausible management policies for the territorial system.

The fourth step promotes an evaluation, by the main social agents, of the *water system* and his probable evolutions inside the territorial framework. For promoting this evaluation it's necessary to make some interviews and use other tools to involve most agents on the debate of diagnosis, visions and scenarios, for finding possible or plausible ways on the evolution of territorial and water systems.

As a final note regarding the graphic expression of the model we highlight the 'recursivity' in the whole process, represented by the ring of information that forms its backdrop; we use shades of yellow to dark pink for the ring in stand of arrows that could complicate the lecture of the all scheme. Of course, all the different phases interact, expressing an exigency of constant adjustments.

7. FINAL REMARKS

In all our research we found some difficulties for interpreting a territorial unit as an ecosystem, or a human ecosystem. In a general way, spatial planning methods are guided by an administrative corpus that looks for short term results. We can say that the evolution of the planning system, even though coming to register some positive developments towards the incorporation of environmental concerns, yet do not seems to have reached a maturity for a practical application according to the current methods used in ecosystems management.

Then, the methodological proposal presented here hardly can have a practical application in the near future, once the dominant paradigm based on the 'offer expansion' still persist and still didn't achieve the phase of 'demand management'.

However, this methodological approach has been generated having the backdrop his application to evaluate the *water-system* of Algarve, whose evolution has an obvious repercussion on space planning. A scenario of practical application is then always present, once our research concerns emerge from a practical experience and intents to extend the practical knowledge. That's why, despite the proposal is based on some specific conditions of the Algarve's territory, such can easily be adapted to other structural subsystems or territorial units with similar characteristics.

The existing gap between theoretical research and immediate practical application does not prevent us from proposing a development of models based on assumptions that involve a paradigm shift facing current practices, in the sense of projecting alternative visions for regional planning and provide a framework on research in different areas with an evident territorial incidence.

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UNCERTAIN FUTURES IN THE DYNAMICS OF TERRITORIAL CHANGES: WHEN WETLANDS MEET EROSION PROCESSES

FUTUROS INCERTOS NAS DINÂMICAS DE MUDANÇAS TERRITORIAIS: QUANDO ZONAS PANTANOSAS SE DEPARAM COM EROSÃO COSTEIRA

Eric de Noronha Vaz
Agnieszka Walczynska

ABSTRACT

Erosion has been a distress on anthropogenic activity since antiquity. The changes in spatial properties in coastal changes in wetland systems have had a constantly mutating morphology, often obliging economic activity to readapt itself to the geomorphological conditions. This has had a profound impact on a common territorial identity based on the land use processes of regions prone to geomorphological change. The case of fisheries in the Algarve for instance, where often local catchments would be a support for economic activity in Mediterranean regions, are a vision of economic and historical activity that has changed, not only due to economic transitions, but also due to availability of resources and natural phenomena such as coastal erosion. Wetland and coastal systems are coined with the existence of over 70% of all human activity, all of these intricate relations of environmental and socio-economic change occur at a spatial level and where economic activity is often present. The manifested physical effect on the geophysical and land changes is evident in the occurring consequences on land cover, but also on land use types and anthropogenic exploration of these areas. A deeper understanding of the changes occurring at territorial level simultaneously on the tendencies on coastal erosion, allow monitoring of most adequate actions in fragile regions. This paper proposes an integrated assessment based on spatial analysis and quantitative spatial methodologies as to allow a methodology of analyzing change, and studying the impacts registered in the valuable stretch of the Ria Formosa in Portugal.

Keywords: Coastal Change; Territorial Dynamics; Spatial Modelling; Coastal Systems; Spatial Analysis.

RESUMO

A erosão tem sido uma angústia sobre a atividade antrópica desde a antiguidade. As mudanças nas propriedades espaciais nos sistemas costeiros pantanosos tiveram uma morfologia em constante mutação, muitas vezes obrigando a atividade económica a se readaptar as condições geomorfológicas. Isto teve um impacto profundo sobre a identidade territorial devido as transições de uso do solo em regiões propensas à mudança de características geomorfológicas. O caso da pesca no Algarve, por exemplo, onde muitas vezes captação local seria um suporte para a atividade económica nas regiões mediterrânicas, são uma visão de atividade económica e histórica que mudou, não só devido a transições económicas, mas também devido à disponibilidade de recursos e fenómenos naturais como a erosão costeira. Sistemas de zonas litorais e costeiras são identificadas com a existência de mais de 70% de toda atividade humana, todas estas intrincadas relações das mudanças ambientais e socioeconómicas ocorrem em um nível espacial e onde a atividade económica esta frequentemente presente. O efeito físico manifesto sobre as mudanças geofísicas e da terra é evidente nas consequências que ocorrem sobre a utilização do solo e tipologias de cobertura vegetal, mas também sobre os tipos de uso e ocupação de solo de exploração antrópica destas áreas. Uma compreensão mais profunda das mudanças que ocorrem a nível territorial, simultaneamente, sobre as tendências de erosão costeira, permitir o monitoramento adequado da maioria das ações em regiões frágeis é de extrema importância. Este trabalho propõe uma avaliação integrada baseada em análise espacial e quantitativa metodologias espaciais para permitir uma metodologia de análise de mudança, e estudar os impactos registrados na valiosa área da Ria Formosa em Portugal.

Palavras-chave: Mudanças Costeiras; Dinâmicas Territoriais; Modelação Espacial; Sistemas Costeiras; Análise Espacial.

JEL Classification: Q01; R14; R52.

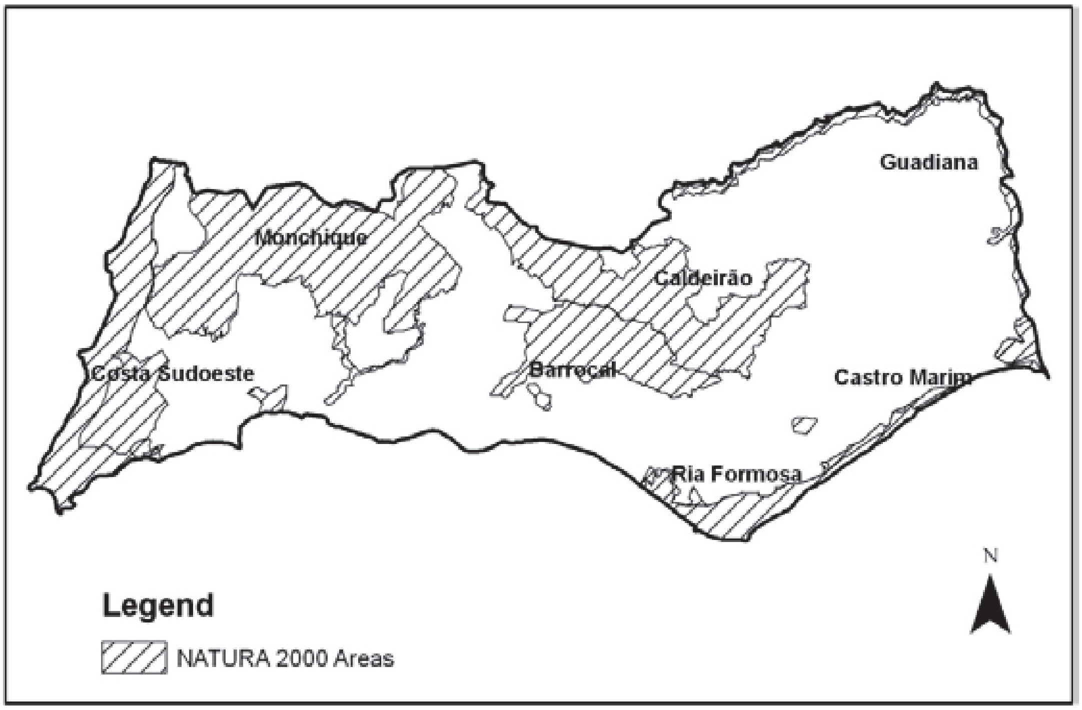
1. INTRODUCTION

In the report "Lessons from the European Commission's Demonstration Programme on Integrated Coastal Zone Management" the difficulty to arrive to a clear definition of coastal zones is evident. One of the main reasons pointed out for such a difficulty in formalizing a descriptive definition of coastal zones is at hand in a context of complex coastal dynamics, integrating social, economic and natural forces but also a question of scaling of spatial phenomena. From a socio-economic perspective, wetlands and coastal areas are the prime location for of most anthropogenic activity, and management of these areas of paramount importance (Costanza et al., 1989). The growing concern of coastal zone management are defined in the World Commission on Environment and Development where a growing concern is claimed by rapid changes throughout the coastal regions in Europe, with a particular concern in southern Europe. Portugal has had a particular synergistic relation with its coast. With one of the largest coastal areas compared to country size in Europe, national legal initiatives have engaged been engaged in planning initiatives of Portuguese coastal areas since 1864 due to commercial routes, but the tradition of exploring human activity with a socio-economic context remounts historically in Portugal already to XV century Discoveries where cartography already played a key importance (Kimble, 1933). The POOC (Planos de Ordenamento da Orla Costeira *trans.*: Territorial Plans of Coastal Zone Organization) decree n. 309/93 of 2nd September and 218/94 of 20th August, consider coastal zones as the buffer area of 500 meters along the shoreline as well as an additional bathymetric line of up to 30 meters. Coastal response has expressed an increasing concern of coastal erosion and climate change in Portugal (Andrade et al., 2007). Regions such as the Algarve, the southernmost region of Portugal, are of particularly vulnerable given the existence of fragile ecosystems and location of the major urban infrastructures (Vaz et al., 2011a). Coastal erosion is leading to loss of these fragile ecosystems and is an increasing threat to economic activities as well as natural and historical landscapes (Vaz et al. 2011b). Followed by an increasing destruction of habitats, loss of biodiversity and, changing in the existing equilibrium in ecological regions, an aggravation of the availability of hydric resources, affects quality and quantity of water. A direct impact of these sinks becomes associated to the quality of the landscape, which has an adverse effect on landscape dependent activities, such as tourism. Followed by negative externalities such as unemployment, social instability, loss of landscape value, the consequence is a rupture in the economic but also ecologic cycle. In the Algarve, a region of strong touristic dependence, this would have dramatic consequences on the economic activity, which has been one of the leading economic drivers at national level, but also within a regional dimension.

2. STUDY AREA

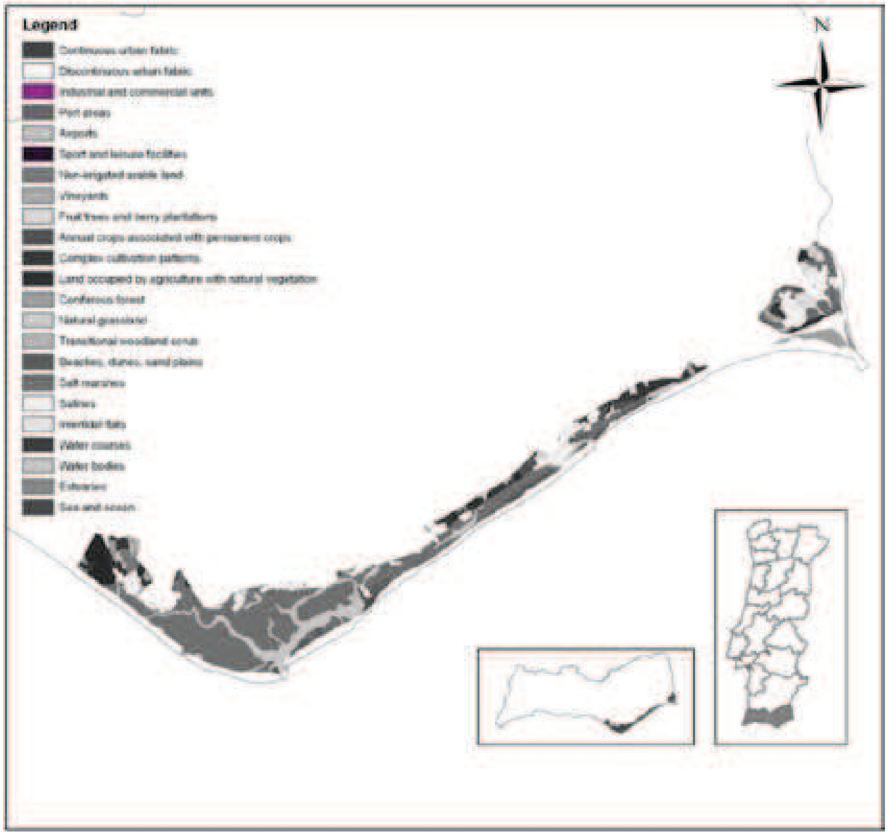
The Algarve region is the most southern region of Portugal and its district capital Faro, is located at 37°0'52"N 7°56'7"W. With an average elevation of 11 m, the Algarve has had a long tradition of using its coastal area as main provider for the regional economy. The Algarve has been one of the most important fishery industries of Portugal since the XIX century. Since the sixties the Algarve has been transformed to one of the most important regions of Portugal for tourism, and its coastal area is located in recurrent connections to dune strands forming several islands and unique wetland ecosystems such as the Ria Formosa. These peculiar characteristics have created a large dependency on the Algarve to its coastal areas relating agricultural wetland system (in particular for salt production) and. The Algarve takes its name from the Moorish name "*Al-gharb*" (*transl.* The Beacon), showing the geographical importance of the region for the southern and Eastern civilizations during the Middle Age. As described by Strabo the Geographer, during the Roman Empire, the Algarve served as one of the most important trading routes. The production of *Garum,* one of the most common spices throughout the Roman Empire, was common in the region of the Algarve and exported in cisterns throughout the Roman Empire through land and sea. This salty fish sauce was a mixture of fermented fish with spices and quite common in many of Roman dishes. In the late eighteen hundreds, the Algarve became one of the most important fish industries throughout Europe. The traditions of the production of *Garum*, facilitated the historical tradition of canned sardines and fish industry throughout the Algarve, which became a major driver of economic prosperity until the nineteenth century. While this historical agro-food sector diminished largely over the last sixty years. The Algarve became one of the most appealing Tourism destinations of Europe. The aesthetical value of the unique littoral ecological landscape and the existent moderate climate, facilitated the development of a mass tourism industry, which nowadays is the main economic driver of the Algarve. This justifies the close relation that the Algarve has to its coastal regions which at present and in future, are of utmost importance for continued economic prosperity. To maintain biodiversity and to contribute for sustainable development, most of the ecological regions are part of the NATURA 2000 initiative, addressing seriously threatened habitats throughout Europe in 1992. In this context, total of 38.6% (193000.5 ha) of the inland territory are part of this network, and are characterized by unique ecological richness. This corresponds to 14 sites with particular ecological, biological and geographical characteristics, defining unique habitats in the region. The following sites are currently part of the NATURA network (with their special conservation numbers): *Costa Sudoeste* (PTCON0012), *Leixão da Gaivota* (PTZPE0016), *Arade / Odelouca* (PTCON0052), *Ria de Alvor* (PTCON0058), *Ria Formosa – Castro Marim* (PTCON0013), *Ribeira de Quarteira* (PTCON00038), *Ria Formosa* (PTZPE0017), *Sapais de Castro Marim* (PTZPE0018), *Monchique* (PTCON00037), *Cerro da Cabeça* (PTCON0050), *Barrocal* (PTCON0049), *Caldeirão* (PTCON0057), *Guadiana* (PTCON0036), *Vale do Guadiana* (PTZPE0047). It is only natural, that the main setlling location in the Algarve due to socioeconomic growth, are located in the coastal perimeter. Excessive pressure brought from urban sprawl related to continued eutrophication (Newton et al., 2008) is leading to permanent loss of the sixteen sites part of the NATURA 2000 Network in the Algarve (Figure 1). Of these sixteen sites, six are particularly vulnerable to coastal erosion, as they are located within wetland ecosystems. These regions are also a prone to additional pressure, brought forth from urban sprawl and population growth.

Figure 1. The Algarve and its natural geomorphological divisions



The combination of climate change, land use change, coastal erosion in the Algarve, as such, is an eminent problem putting at risk the continued economic development at regional level by the impacts on tourism industry, as well as leading to a destruction of ecosystems, archaeological landscapes, beach areas and in future urban areas. This problem is moreover allied by the adversities on the natural drainage system of the region sheds out to the coast, given the close proximity the mountain range to the north. The natural lagoons formed along the coastline are a place for many edaphic species and are a strong hope for ecotourism activity in the region. Increasing urban pressure is leading to the destruction of these natural environments, while natural factors such as cliff retreat are leading to a further strain (Dias and Neal, 1992). This is jeopardizing some of the protected ecosystems part of the NATURA network. As such, a constant monitoring of coastal erosion in the Algarve must been present at spatial level, in an attempt to better understand the dynamics of spatio-temporal change and create stronger and more effective legislation on the decision making process for sustainable regional development. Developed in the eighties, the CORINE Land Cover (CLC) project was used for land use information. The spatial information of this database is strongly linked to the availability of multi-temporality. This multi-temporal scope is only possible due to the different existing dates of production of land use maps for CLC. As such we used for an initial assessment CORINE Land Cover 1990 (CLC90) and compared for land use change purposes with the land use / cover types for CORINE Land Cover 2000 (CLC2000). The comparison between CLC90 and CLC2000 originated an assessment based on the smalled unit mapped at 25 ha, of land use change. Both data were combined in order to benefit from the main advantage of GIS as tools to analyze, maintain and manipulate spatial data (Longley et al., 2005) leading to an accurate interpretation of spatial land use change and transitions for the Ria Formosa (Figure 2).

Figure 2. Location of the Ria Formosa reserve and land use in 1990

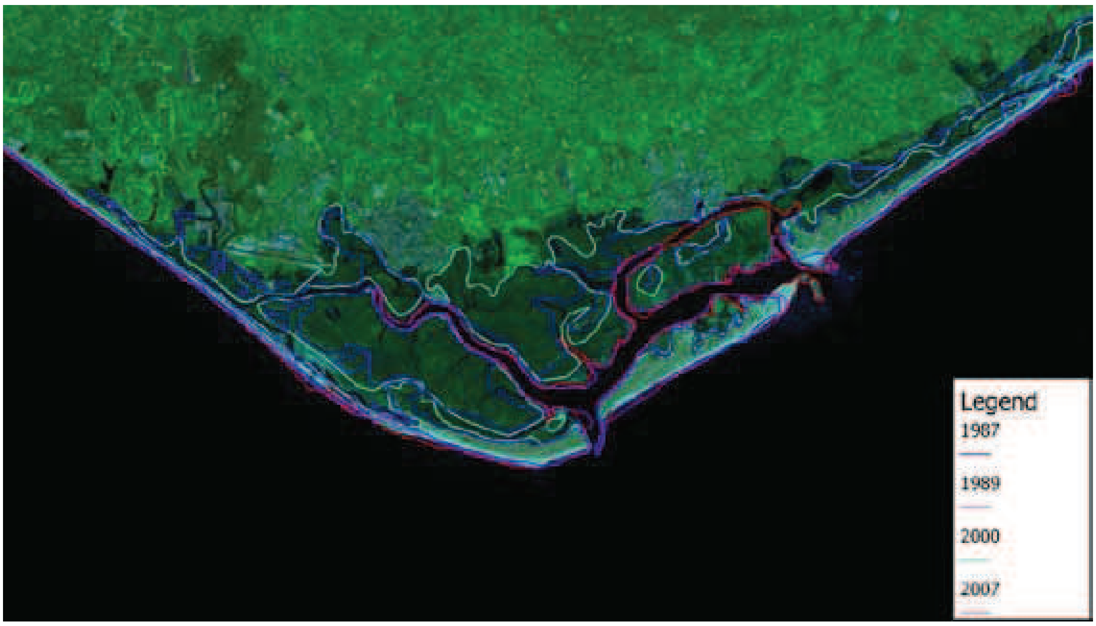


At the 1:100,000 scale (EEA, 2008), three levels can be separated for CLC. At the more general level, we may assess artificial surfaces, agricultural areas, forests and semi-natural areas, wetlands and water bodies. Sub-sequent disaggregation of these classes leads to 44 available classes, which adopt the common CORINE nomenclature (Caetano et al., 2008). Currently in its third edition, the CLC is updated on a 10 year interval. The reason for such a delayed updated is strongly linked to the resources and the complex task of gathering and filtering available information, as well as integrating the different European key-players in the projects development. A ten years interval is certainly a large timeframe to scope certain activities related to micro-spatial simulation, as incurring change might not be assessed within such a large gap of time. However, for analysis that embody coastal recession and climate change phenomena and especially at a regional level, it presents itself as an excellent tool for quantitative land use analysis, decision making processes and geovisualization of land change properties. Regional interpretations of urban sprawl in Europe, as well as assessments on land-cover loss and structural changes in agricultural land use classes have been widely assessed. For the three existing CORINE Land Cover levels a total of global exactitude was tested for Level 1 at 97.59%, Level 2 90,12% and Level 3 at 82.8.

4. METHODOLOGY

Several methods have been developed for the coastline detection using satellite imagery. The simplest one is based only on one of the infrared band. The reflectance in the infrared band, where water is nearly equal to zero and the reflectance of absolute majority of land coverage is greater than water (Chand and Acharya, 2010) shares important results on the coastal recession patterns. For such purposes histogram tresholding (HT) method is used. Due to tiny reflectance of water and high reflectance of vegetation the histogram displays two peaks, exhibiting a strong contrast between land and water (Figure 5). The transition zone is the effect of mixed pixels and moisture regimes between land and water that's why it is quite difficult to find a proper threshold value (Kamthonkiat, et al., 2010). To reduce influence of the threshold value choice and to improve extraction of the coast line, the second condition is introduced: the ratio b2/b5 is greater than one for water and less than one for land in large areas of coastal zone (Alesheikh et al., 2007). This methodology (Figure 3) was applied for the Ria Formosa given the spatial and distilled remote sensed characteristics which guarantee optimal circumstances on a multi-temporal basis for such assessment. Shore lines from the year 1987, 1989, 2000, and 2007 have been detected and extracted using two open source software. This allowed to conclude several important features through geovisualization that within a quantitative interpretation allowed to define that: (i) there is a strong coastal recession propensity for the entire Ria Formosa stretch, this patterns is also present in the entire coastal region of the Algarve, (ii) the most dense recession pattern emerges eastward towards the river Guadiana, expanding itself with the administrative division of Spain, (iii) the greatest changes are present between 1987-2000, having in account the inter-zonal and tidal aspects of the studied period of 1987 to 2007.

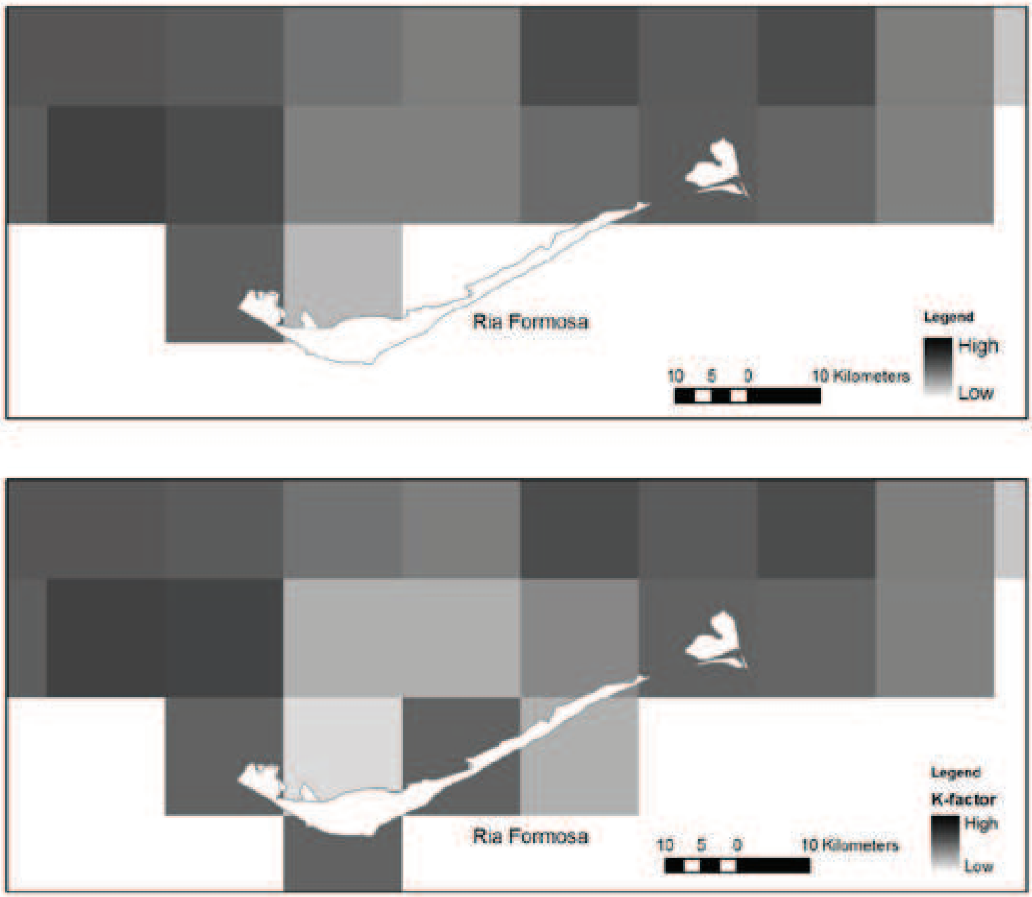
Figure 3. Methodology of extracting coastlines from images (Alesheikh *et al.*, 2007)



The interaction of water and land, given the shallow water properties had to be considered effectively in the several imported dates, as to

The downloaded K-Factor data based on LUCAS point data extrapolated by Panagos and others for the European Union (2011), served as base information to integrate erosion information within the GIS. The coarse resolution of the dataset for Europe with a 10km pixel size, needed some additional inference for completion of the total information for Ria Formosa. The creation of a vector grid for spatial extrapolation of pattern characteristics at the regional level (Vaz et al., 2011c) allowed covering the area of the Ria Formosa with missing values existent due to the 10km pixel size (Figure 4). In this sense, the total grid was extended by maximum likelihood estimation for the area encompassing the total ground surface of the Ria Formosa.

Figure 4. Extrapolated K-Factor weight for the Ria Formosa

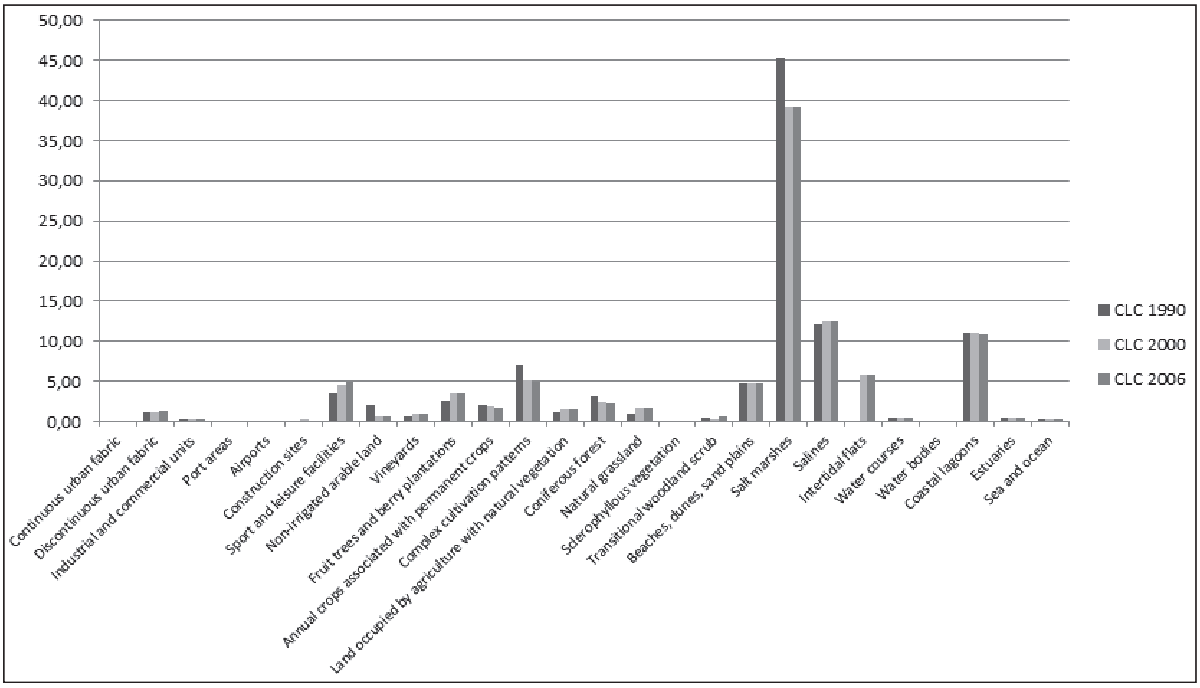


5. DISCUSSION

The combination of the integrated patterns formed in land use transitions with regional coastal dynamics was only possible by combination in a GIS. The possibilities were then related with the geovisualization properties of existing land use change dynamics, but also with the prospection of erosion and coastal regression purposes. By means of a Markov transition matrix frequencies of changes in each cell were assessed between the period of CLC90 and CLC06 . The used Markov transition matrix randomized the possibilities of land change for any cell, with addition to the cost surface calculated through the exerting coastal recession and erosion pressures mentioned in the previous section. The combinations of this information allowed for an exact extraction of most endangered land use types within the Ria Formosa including a spatio-temporal interpretation of land use dynamics prone to both types of erosion. Regarding the study area, most significant changes were present between CORINE Land Cover 1990 and CORINE Land Cover 2000. The significant changes are related to a strong decrease of salt marshes and among complex cultivation patterns. While in CLC 90 salt marshes corresponded to 45.31% of the total Ria Formosa area, only 39.23% were found in the subsequent land covers. A significant and steady increase was registered in artificial land (CORINE Nomenclature class 1), showing the direct impact of human behavior on the Ria Formosa ecosystem. Counting with an initial 5.20% of urban patterns a growth was registered of up to 6.74% for CLC 2000, and of 7.16%. These changes (Figure 10) are mainly related to the increase of discontinuous urban fabric and creation of sport and leisure facilities. Within the sport and leisure facilities, the ecological landscape of the

Ria Formosa, has been of increasing interest for private stakeholders for the creation of Golf courses. While the complex dynamics of spatial land use change in the Ria Formosa is evident, the complex patterns seem to be strongly linked to human activity and changes in the geomorphology of the water and wetland systems.

Figure 5. Changes in CLC 1990, CLC 2000 and CLC 2006 in land use in the Ria Formosa area



6. CONCLUSIONS

The existing pressure on the coastal fringe due to coastal recession and the erosion potential of the Algarve as a whole, but in particular at along the eastern part of the region and affecting locally the Ria Formosa area, suggests a continued loss of salt marshes, and increasing salinity on the natural forest cover types. Within a context of climate change, and adding on the IPCC perception that coastal recession is in larger part a result of human impact, it is possible to claim a continued decrease on natural land cover on the area, predominantly located within the regions of high erosion measured. The slight changes in urban fabric, allied to the increase in leisure facilities, suggest an increasing concern on the already vulnerable stretch of the Ria Formosa. From one side, the erosion potential with loss of anthropogenic activity is maximized, from the other, the fragility of the recessive coastal fringe is leading to a double caused eutrophication for the region. The integration of changes in dunes and sand areas located also in the area of prone for higher coastal recession, suggest that in the next decades a higher probability exists of irreversible changes in the nature of vegetation and balance of these lagoon system. The usage of GIS and advanced spatial analysis tools combined with remote sensing and land use information, have allowed for a crucial analysis of one of the most vital natural reserves of the Algarve. For decision making and policy planning, the lesson learned is one of the importance of using spatial information for monitoring fragile ecosystems and stretches, but also on using spatial information and remote sensing techniques to measure with existing European data the dimension of change dynamics and impacts on our environment for better regional decision making in fragile coast stretches.

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THE ROLE OF SOIL PROPERTIES VARIABILITY TO RECLAMATION SUCCESS ON THE LIGNITE STRIP-MINED LAND IN NORTHERN GREECE

O PAPEL DA VARIABILIDADE DAS PROPRIEDADES DO SOLO NO SUCESSO DE RECUPERAÇÃO DAS MINAS DE LIGNITE DO NORTE DA GRÉCIA

Thomas Panagopoulos

ABSTRACT

The present paper present some of the adverse ecological parameters studied for the assessment of reclamation of the lignite spoil heaps of Ptolemaida in North Greece. Natural revegetation was the first step before reclamation began and it was studied. Natural vegetation of lignite spoil heaps was heterogeneous and 7 plant communities were identified, described and mapped. Soil samples geographically positioned indicated that the spoil heaps were heterogeneous and with many unfavourable physicochemical properties. Soil properties were related to natural vegetation and were indicators in assessment of reclamation potentiality of the site. Surface soil temperatures reached 62ºC during summer and temperature difference observed between the lightest and darkest spoil materials was 12ºC. Between a bare soil and a soil covered by natural vegetation, the soil temperature difference was nearly 20ºC. In order to understand the variation of soil properties, graphical interpretation was done with the use of geostatistics in a geographic information system. Cross validation was used to compare the prediction performances of the geostatistical interpolation algorithms. Site quality was estimated from soil properties and natural vegetation composition. The prediction maps resulting from the interpolation techniques help to determine which areas had optimal conditions for forest species development and landscape reclamation success.

Keywords: Geostatistics; Landscape Reclamation; Soil Temperature; Lignite Mine.

RESUMO

O presente trabalho apresenta alguns dos parâmetros estudados para a recuperação dos taludes de desperdício nas minas de lignite de Ptolemaida no Norte da Grecia. A re-vegetação natural foi a primeira etapa antes do inicio da recuperação. A vegetação natural nos taludes de desperdício das minas era heterogénea e 7 comunidades phytosociológicas foram identificadas. Amostras de solo georreferenciadas demonstraram a heterogeneidade do local e com propriedades fisico-químicas desfavoráveis. As propriedades do solo foram relacionadas à vegetação natural e ambos poderiam ser indicadores na avaliação do potencial da recuperação. As temperaturas de superfície do solo alcançaram 62ºC e com diferenças de 12ºC observadas entre os materiais os mais claros e os mais escuros, que alcançava diferenças de 20ºC em sítios sem cobertura vegetal. A fim compreender a variação de propriedades do solo foram usadas técnicas de geoestatistica em sistema de informação geográfica. A qualidade local da zona em estudo foi estimada pelas propriedades do solo e da composição natural da vegetação. Os mapas da predição que resultaram das técnicas de interpolação geoestatistica ajudaram determinar que áreas precisem melhoramentos locais e que áreas tiveram condições óptimas para o desenvolvimento da floresta e o sucesso da recuperação da paisagem.

Palavras-chave: Geoestatistica; Recuperação da Paisagem; Temperatura do Solo; Mina de Lignite.

JEL Classification: Q01; Q15; Q24.

1. INTRODUCTION

In Greece, lignite is the most important energy resource for the electric power production, but mining continues without planning for subsequent rehabilitation, and the Greek landscape is changing significantly through lignite surface mining. Following the appropriate program in all stages of mining the area can return to the society even improved and ready for uses as agriculture, forestry, recreation, sports, industrial areas and others (Wang *et al*., 2001).

Although, every reclamation trial has to fight with peculiar problems caused by the adverse ecological conditions that are present. Species selection appropriate for the climate and soil, irrigation, fertilisation and additional soil were suggested for many reclaimed lignite mines (DePruit *et al*., 1982; Hart *et al*., 1999). Several researchers have studied the use of natural revegetation and forest establishment on the spoils some years before those areas to be rehabilitated to agricultural lands (Alexander, 1989; Wade, 1989). Seeding of the spoils to minimize erosion suggested from some authors (Rosiere *et al*., 1989), but was not supported from others because is not allowing or is delaying the establishment of more profitable species (Chambers *et al*., 1987; Andersen *et al*., 1992).

The establishment of natural vegetation and reforestation help to cover and stabilise the soil, to start biological activity, soil genesis and generally impose the physical and chemical properties of the spoils soil, thus agriculture can be re-established to these areas 20-30 years after reclamation. (Warman, 1988; Gonzalez *et al*., 1991)

Soil characteristics with similar vegetation associations were shown to be reasonable autochthonous indicators of soil degradation and rehabilitation (Paniagua *et al*., 1999). Bioindicator-based studies have the potential to make a major contribution to optimise different reclamation systems and to influence policies governing landscape management and transformation (Iverson & Wali, 1982; Pakeman *et al*., 1997; Paoletti, 1999).

Prior to the mining of heavy minerals, the vegetation diversity has to be investigated to serve as a benchmark for the future rehabilitation of the area (De Villiers *et al*., 1999). Topsoil replacement improved the physical and chemical properties of the soil and water retention in some extreme microenvironments, decrease the high surface soil temperatures and helped in fast and diverse establishment of natural vegetation and microorganisms (Day & Ludeke, 1990).

Soil temperature is another indicator of the ecological status of an area and an important soil property. The soil temperature changes are affecting soil properties, soil genesis and plant growth. High soil temperatures increase water evaporation in the upper soil layers and decrease water availability to plants. The thermal soil properties depend on the type of soil, soil roughness, air porosity, moisture, soil colour, specific weigh of the soil, wind velocity, clouds, topography, air temperature, relative humidity, chemical properties, soil structure and vegetation cover (Geiger, 1973). Snow and organic matter also reduce fluctuations in soil temperature. A dark-coloured soil and a light-coloured sand may absorb, respectively, about 80 and 30% of incoming solar radiation (Foth, 1984).

When reclamation or restoration starts is important to provide specific scientific biological information and incorporate it in a geographical information system to support decision making during the design of the reclamation or conservation plan (Panagopoulos & Hatzistathis, 1995). In order to understand the variation of soil properties a graphical interpretation of those could be obtained through geostatistical techniques. Geostatistics provide inexpensive maps of a given area and decrease uncertainty (Chilès & Delfiner, 1999).

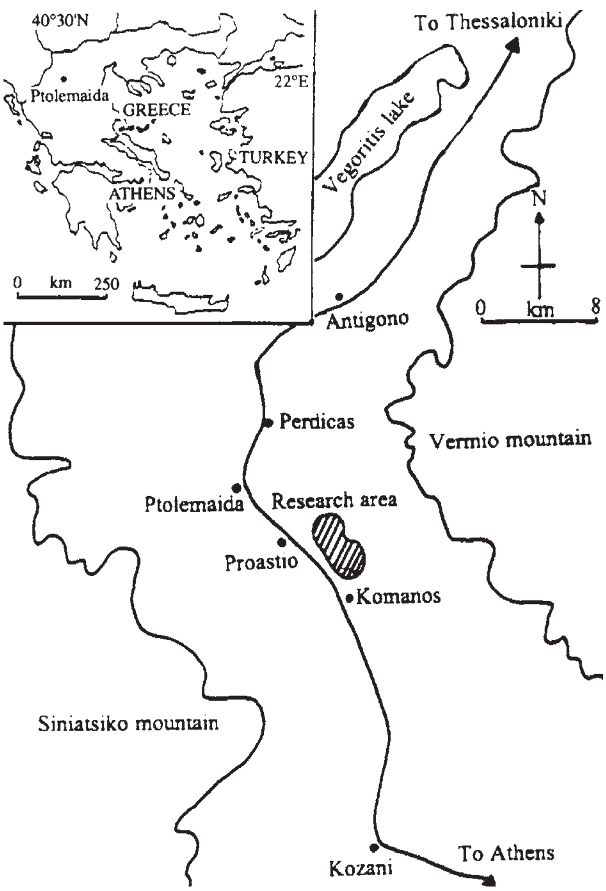
This study examines the geographical variability of relationships between natural vegetation and some soil properties of the lignite spoils of Ptolemaida and their influence on landscape reclamation success.

2. MATERIALS AND METHODS

2. 1 Description of the study area

Before mining began, the area was an almost plain valley with surrounding mountains that rise to an altitude of 1500 meters. The lignite mines studied are located in Northwest Greece near the city of Ptolemaida, in a valley with 667.5 meters mean altitude, at latitude 40^{o} 30' North and longitude 22^{o} East of Greenwich (figure 1). The valley is rich in lignite, with six active lignite mines in the area. Fourteen electricity-generating plants produce more than 70% of Greece's electric power. Until recently, of the 12,500 affected by mining only 400ha were rehabilitated and by the year 2025, it is estimated that the area affected by mining will be 20,000ha.

Figure 1. Location of the study area



The climate of the area is continental Mediterranean with very hot and dry summers and mild winters. Average annual precipitation is 551.26mm (Ptolemaida meteorological station, 35 years of record) with a maximum monthly average in November (68mm) and a minimum in August (27mm). Average annual air-temperature is 12.3^oC with coldest month January (1.8^oC) and warmer July (22.5^oC). The absolute maximum air temperature during the research period was 41^oC and the absolute minimum air temperature was -21^oC. The dry period, relatively shorter than other regions of Greece, starts at the end of June and finishes at September.

The lignite of Ptolemaida is a soft brown to black coal with a low fuel value of 10-16Kj/g and sulphur content generally below 0.6%. The geological period of the lignite layers is the Pleistocene and the thickness of the lignite layers varies between 12 and 32 meters. The spoils are generally consisted of the materials that arise after the extraction of lignite. The transportation and deposition of the spoil materials were not programmed or planned.

The overburden of the lignite layers were mixed together with bad quality lignite and lignite gasification ashes (fly ash) and surface soil. The new soils that arise from this mixture were heterogeneous, unstable and unconsolidated, with a high pH and low compaction. The overburden that covers the lignite layers in the valley consisted of marls (forms of soft limestone characterized by high quantities of $CaCO_3$, alkaline and rich in bases), sediments, red-soils, alluvial, peat mould, earthy lignite, fossils, and others. The pH of the fly ash varies between 9 and 12. Soil analyses showed that the new soils are poor in nutrients and with some toxic elements.

Unplanned placement of the spoil materials provoke the instability of the new soils and the high risk of erosion. Topsoil in most of the cases buried in high depths and lost, self-igniting fires when unburned lignite is exposed close to the surface of the spoils, soil on the surface with unidentified properties, mineral toxicity and problems on vegetation survival in areas of high fly ash presence.

The vegetation of the Ptolemaida valley corresponds to the sub Mediterranean vegetation zone of *Quercetalia pubescentis* (Athanasiadis, 1986). The main forest species planted in the area were *Pinus nigra, Robinia pseudoacacia, Cupressus arizonica* and farmers grew wheat, corn, sugarbeet and livestock forage. Species composition on the spoils depend on the age of the spoil with Chenopodiacae species to dominate on newly established spoils and Compositae species on older spoils. Leguminous species are common on younger and herbaceous species on older spoils.

2. 2 Phytosociological study

For the phytosociological study were established 48 geographically positioned sampling areas of 1 m^2, on a lignite spoil where soil preparation for reclamation activities terminated 3 years before. For every sampling area the Braun-Blanquet method was used and soil type, percentage of soil cover by plants and plant vitality were also estimated. Species identification was done using Flora Europea of Tutin *et al*. (1964-1980). Phytosociological units were separated with criteria based on species physiognomy, ecology, flora and evolution (Athanasiadis, 1986). The method based on ecology and flora was assisting better on the target of the study, which was the ecological description of the separated communities that will arise from the plant-table process.

The method used by the present study was not based neither on the characteristic or differential species of the Zurich-Montpellier school, neither on the dominant species, but on the combination of the indicator groups that were appearing in the phytosociological units. In the same group were included all the species with the same or similar ecological behaviour. The ecological description of the separated plant communities was done with the help of the ecological properties of the indicator groups. Cluster analysis was used to identify groups in raw data and helped to find structure in it and to separate it in classes (Longman *et al*., 1995).

2. 3 Soil study

The high spatial variability of spoils soil properties was estimated with 16 geographically positioned soil samples. The samples were collected every 7 meters on 2 cross lines passing from the 4 corners of the experimental field. Many soil and water parameters that could explain the cause of spatial variability in revegetation success were analysed. Thus, it was identified the soil colour, type of soil (lignite, peat, topsoil, fly ash, marl or mixture of the above) and percentage of vegetation cover.

Soil samples were packed in polyethylene bags, transferred to the laboratory, weighted and dried. The fine earth fraction was analysed for the following: texture by sieve and pipette method, particle density, specific weight, available water content by pressure membrane extraction of saturated soil at 0.33 and 15 bar, total porosity, air porosity, organic matter, pH, electrical conductivity in 1:1 slurry of soil and distilled water, calcium carbonate ($CaCO_3$), available phosphorus, total nitrogen, and exchangeable calcium, magnesium and potassium by ammonium acetate extraction at pH 9.

Soil temperature during summer is a very important factor limiting reclamation success in the lignite mines of Ptolemaida, due to the black colour of lignite, which is the main element in the surface in most spoil area. For the estimation of the soil temperature were placed mercury thermometers at 0.5, 2.5, 11 and 17 cm depth, in three different soil colours: red (5R 4/7), light grey (10Y 7/1) and black (10YR 3/1). The red coloured area was a zone covered with surface soil; the grey was on areas represented by marl or fly ash and the black by lignite. Air temperature was measured under shadow, 50cm above the soil. The influence of shadow on soil surface temperatures at the black coloured area was examined separately.

Temperature readings were made at 15 minute intervals and average hourly values were recorded for each location. Air and soil temperatures were measured for a 20 day period during July.

2. 4 Statistical Analysis

Statistical analysis of the data included computation of the sample mean, variance and coefficient of variation for maximum and minimum soil temperatures measured at each depth and compared with the soil surface temperatures of a black coloured soil under shadow of natural vegetation and trees.

Two-way analysis of variance was used to determine significant differences ($P<0.05$) in maximum and minimum soil temperatures between shaded and unshaded areas. Comparisons of all means were examined with Fisher's protected LSD's and with Duncan's test. Regression analysis were used to identify significant correlations between soil temperatures in shaded and unshaded areas and between soil type and colour with natural vegetation species.

All data was entered into a field-scale geographic information system, and interlayer data analytical tools were utilized to quantify spatially dependent relationships (Kitanidis, 1997). A semi-variogram was produced for each soil property and several parameters that a semi-variogram can provide were analysed. Cross validation indicators and additional model parameters (nugget, sill and range) helped to choose the most appropriate model of the prediction maps for each soil property (Issaks & Srivastava, 1989).

Geostatistics could help to quantify the magnitude of spatial variability of selected properties, as well as model the spatial structure of the variability. This kind of information could be used in a modelling framework to increase the accuracy of model estimates by dissecting the landscape into distinct units which can be modelled separately (Issaks & Srivastava, 1989).

The Kriging interpolator that was used to create prediction maps of soil properties, assumes that the distance or direction between sample points reflects spatial correlation that can be used to explain variation in the surface (Armstrong, 1998).

3. RESULTS AND DISCUSSION

3. 1 Phytosociological research

Phytosociological units were determined with the help of the indicator plant groups. After the plant-table process, 7 indicator plant groups were separated in the table of species sampling. The result of the combination of the indicator groups published from Panagopoulos *et al*. (2001) and the ecological description of the 6 plant groups was done bibliographically and after an "on site" research (Ellenberg *et al*., 1992).

Group A: Includes average drought species that appear in infertile, clay soils, with relatively high salinity, pH 8 and in relatively worm environments. The characteristic species of this group were: *Melilotus officinalis, Medicago lupulina, Cichorium endivia, Medicago coronata,* and *Dasypyrum villosum.*

Group B: Includes species of average humid areas, indicators of fertile soil with normal moisture and pH 7-8. The characteristic species of this group were: *Bilderdykia convolvulus, Carduus sp., Centaurea cf. depressa* and *Rumex crispus.*

Group C: Drought species, with large ecological adaptation, developing in medium fertile soil with pH 8 and warm environments. The characteristic species of this group were: *Tragopogon dubius* and *Reseda lutea.*

Group D: Species of average drought, with large ecological adaptation, growing in warm environments and average fertile soil with pH 7-8. The characteristic species of this group were: *Sonchus arvensis, Crepis foetida, Lappula squarrosa, Elymus repens* and *Crepis pulchra.*

Group E: The characteristic species of this group (*Calamagrostis epigejos*) can be seen in humid and cool environments, in soil of average fertility and pH 7-8.

Group F: Drought resistant species, growing in warm environments and soils with poor fertility and pH 9. The characteristic species of this group was: *Vaccaria pyramidata.*

Group G: Drought resistant species, expanding in warm environments with fertile soils and pH 7-8. The characteristic species of this group were: *Crepis pulchra, Avena barbata* and *Linaria genistifolia.*

In the following description of the phytosociological units the indicator plant group with a strong presence was represented with capital letter and when presence in the table was minor was recorded with small letter between parentheses.

Phytosociological unit E_1. Indicator plant group (d): This unit appeared in areas affected from topsoil that exists in a depth of more than 30cm and covered with lignite spoils. Soil was fertile and pH varied between 7.5-8. The forest species planted at the specific area had fast growth. Dead trees noted in that area were caused from the high soil surface temperatures. Natural vegetation was covering the soil between 40 and 50% and its shadow assisted in the survival of the new established forest species. Dominant species of this unit were *Bromus tectorum*, *Tussilago farfara* and *Carduus thoermeri*. Indicator value for this community had only the species *Bromus sterilis, Crepis foetida* and *Lappula squarrosa* of group D. This plant community was characterized by the absence of any other indicator groups.

Phytosociological unit E_2. Indicator plant groups A(c): This unit could be seen in areas affected from topsoil. That soil had clay loam texture, pH 8-8.5 and high content of Na^+ (0.5-0.6meq/lit). The forest species planted in that area had low growth and survival. The soil was compacted and waterlogged. Hydraulic conductivity and air porosity were lower than in the other soil types of the spoil. Soil cover by natural vegetation was less than

50%. Dominant species of this unit were *Tussilago farfara, Bromus tectorum*, and *Artemisia vulgaris*. Indicator value for this community had *Melilotus officinalis* of group A that usually appears in compacted, clay and salty soils as noted by Ellenberg *et al*. (1992) and *Tragopogon dubius* and *Reseda lutea* of group C.

Phytosociological unit E_3. Indicator plant groups (a)B: This unit appeared in areas affected from topsoil mixed with marl, lignite and fly ash. Soil was loamy with pH between 7 and 8. The forest species planted in the area had good growth and survival. Dominant species of this unit were *Tussilago farfara, Centaurea solstitialis* and *Rumex crispus.* Indicator value for this plant community had the species *Cichorium endivia*, *Centaurea cf. depressa,* and *Carduus* sp.. This plant community was the intermediate stage between E_2 and E_4 and *Cichorium endivia* was increasing its presence by time. The main characteristic of this plant community was its relationship with group A species.

Phytosociological unit E_4. Indicator plant groups (a)Cd: The soil of the area where the community was developing had well mixed all of the spoil materials with higher content of fly ash and marl. Texture was sandy loamy and pH was varying between 7 and 8. Dominant species of this unit were *Tussilago farfara, Bromus tectorum* and *Carduus thoermeri,* but indicator value had the species *Cichorium endivia, Tragopogon dubius* and *Crepis foetida*.

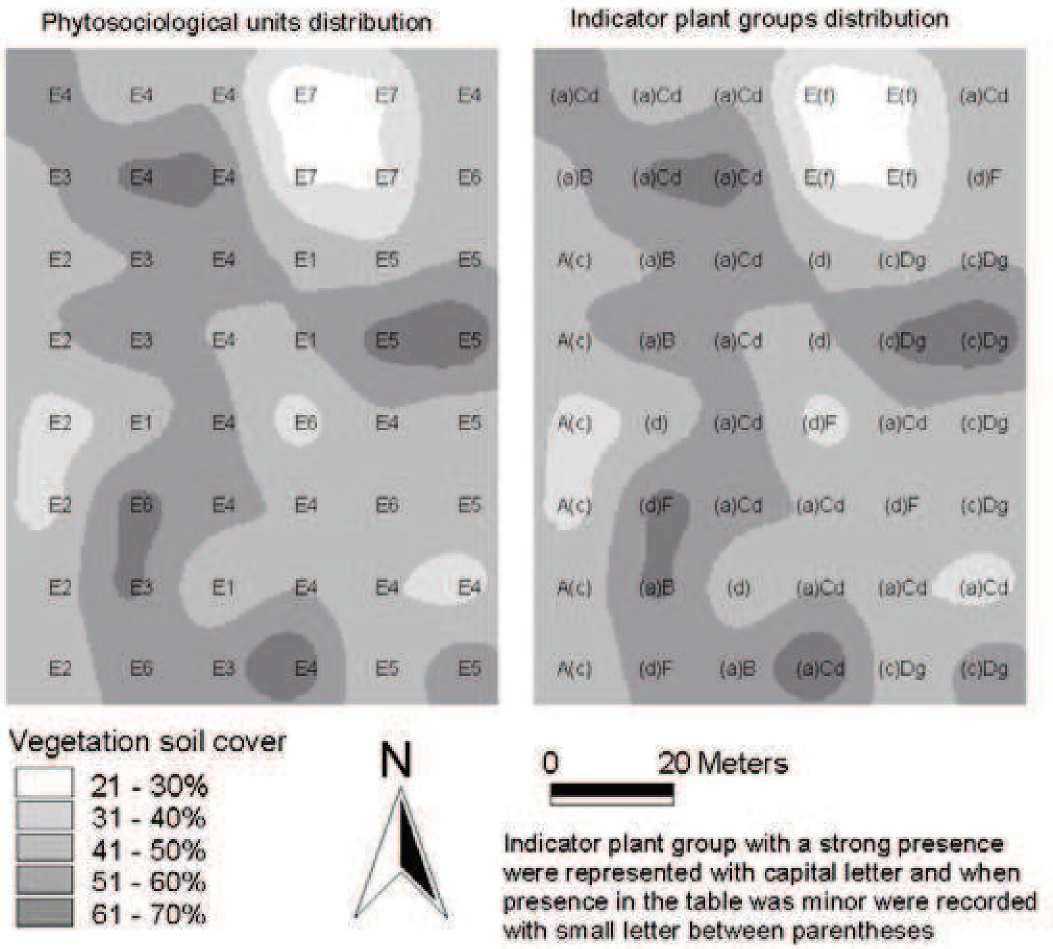
Phytosociological unit E_5. Indicator plant groups (c)Dg: This community was developing on soil that was a mixture of all spoils materials. Texture was loamy and pH was varying between 7 and 8. The forest species planted in that area had good growth and survival. Dominant species of this unit were *Tussilago farfara, Bromus tectorum* and *Lactuca serriola.*

Phytosociological unit E_6. Indicator plant group (d)F: This community appeared in soil similar to E_5 unit but in spots were fly ash content was high and, as consequence, pH was higher than 9. The forest species planted in that area had low growth but high survival. Seedling growth was low due to high competition from natural vegetation, but survival rate was high due to shadowing effect of almost total soil cover that kept low surface soil temperatures during summer. Dominant species of this plant community were *Bromus squarrosus* and *Bromus tectorum,* but indicator value had the species *Crepis foetida, Lappula squarrosa* and *Vaccaria pyramidata*. Ellenberg *et al*. (1992) cited that those species are indicator of calcareous, dry and infertile soils with pH 9.

Phytosociological unit E_7. Indicator plant group E(f): This unit appeared in areas of marl soil with loamy clay texture. Soil surface temperatures were lower than in the other sites of the spoil because soil colour was white. The forest species planted in that area had low growth but high survival. Dominant species of this community were *Tussilago farfara, Lappula squarrosa* and *Bromus tectorum.* Indicator value had the species *Calamagrostis epigejos* that is increasing its presence with time and *Vaccaria pyramidata*, which appears in spots around the area of *Calamagrostis epigejos*. Natural vegetation cover was less than 20%, but the forest species planted in that area had higher rate of survival for the reason that the lighter soil colour had moderate surface soil temperatures.

Geostatistics were used to quantify and visualise vegetation cover in areas that were not measured. Figure 2 illustrates the indicator plant groups and phytosociological units distribution in the experimental area and the vegetation soil cover after a Kriging (spherical) interpolation with lagged distance 10m and after taking in consideration all samples. Additionally, it was possible to examine the influence of phytosociological units and the indicator plant groups distribution on the soil cover. In the same figure it can be seen that plant groups E, F and A appear generally on areas with poor soil cover, while the plant groups B, C and D develop on areas with better soil cover.

Figure 2. Vegetation soil cover and phytosociological units distribution on the research spoil area



3. 2 Soil physical properties

The physical properties of a soil govern its suitability for any further use of it. The bearing capacity, drainage, erodibility, moisture storage capacity, plasticity, ease of penetration by roots, aeration and availability of nutrients are related to the physical conditions of the soil. From the dataset of soil physical properties was analysed the distribution of data to get a better understanding of trends, directional influences and obvious errors. In most of the cases the data was not normally distributed presenting large spread and no symmetry. For hydraulic conductivity (Ks), and porosity that existed doubts about soil sampling and laboratory analyses it was decided to find the previous position of the samples in the field and repeat analysis of extreme values.

Kriging was chosen as the most appropriate technique because of the very low values of the mean cross-validation error of almost all production parameters studied and because kriging was offering the possibility of flexibility in assumptions required for the data to continue the study.

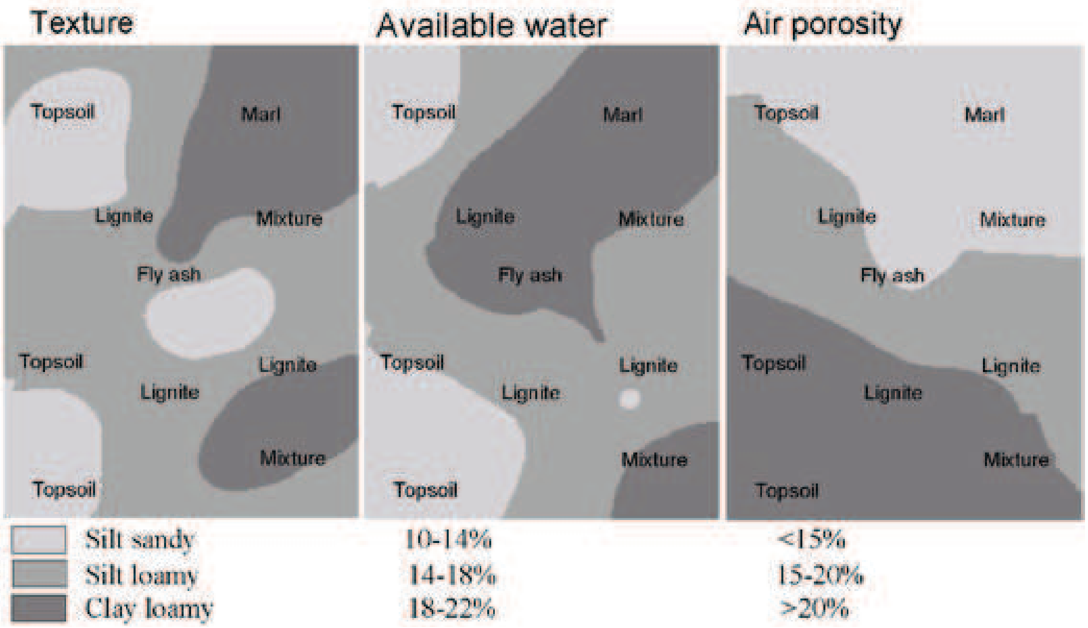
From the several parameters that the semi-variogram provided, the very high nugget effect indicated a big variance at short distance as it is mentioned also from Armstrong (1998). Lower nugget and sill and larger range were the semi-variogram indicators that helped to choose the most appropriate model of semi-variogram for the creation of the prediction map for soil properties.

Cross-validation was used to estimate which of the semi-variogram models could give the most accurate predictions of the unknown values of the field. The closer to 0 was the mean cross-validation error and the closer to 1 was the root-mean-square standardized error signified that the prediction values were closer to measured values (Wackernagel, 1995). When models presented similar values for mean cross-validation error and root-mean-square standardized error it was taken in consideration the lowest values of root-mean-square error and average standard error.

Exponential semivariograms were the most frequent for most factors studied. Particle size composition of the soils on the spoil heaps were varied primarily because of the composition of the soil mixtures on which soil forms. Generally, they were characterized as medium-textured silt sandy, silt loamy or clay loamy (figure 3).

Many authors have been studied the soil heterogeneity for forest and spoil soils (Schafer, 1979; Vauclin *et al*., 1982; Grigal *et al*., 1991; Boruvka & Kozák, 2001; Fitzjohn et al., 2002) with purpose to study the minimum area that can be treated uniformly during the vegetation establishment. Spatial heterogeneity, which is expected in such lands, has a pattern rather than being random, so surface sampling must be planned to accommodate this pattern (Eastment *et al*., 1989). The USA standard soil sample distance is 69 meters, while Hardy *et al*. (1991) propose 140 meters as the most appropriate distance between samples. In the present study, ranges of variogram models were between 70 and 80 meters.

Figure 3. Distribution of spoil type materials assessed at the surface and some soil physical properties after kriging interpolation



Colour is the most obvious and easily determined soil property and usually is one of the first properties to be noted in a field description. Distribution of spoil type materials are assessed at the surface mainly from soil colour changes. Generally, the colour of the spoils in Ptolemaida was light grey to dark black, depending on water content, calcium carbonate, the percentage of unburned lignite and ash mixed with overburden and the presence of organic matter.

The significance of soil colour is its use as an indirect measure of other important soil characteristics and also in making many important inferences regarding soil genesis and land use (Kaleberta, 1978). In the spoils of Ptolemaida, dark coloured sites contain more lignite and some of them well accumulated humus; grey sites more fly ash and light grey sites a mixture of marls, sand, limestone and ash. Topsoil usually used in the lignite mines to mix with the other materials has generally red or brownish red colour.

Samples with high lignite content keep larger quantities of water available to plants. Topsoil had lower keeping water capacity because it had less organic matter and different texture and structure. In contrary, soil samples with more lignite had capillary water that was reaching 50.42%. However, the high amount of hygroscopic water decreased to 21.60% the available to the plants water.

Bulk density and particle density were measured to calculate total porosity and air porosity. Particle density was varying between 2.41 and 2.62 g cm^{-3}, depending on the presence or not of the organic matter. Bulk density was varying between 0.77 and 1.43 g cm^{-3}, depending on soil compaction, texture, structure and organic matter in soil.

Total porosity was higher than 45% in all samples, although air porosity of the heavy textured area was low with minimum value in high fly ash content area (8.9%). Physical properties should be improved with amelioration means before any other reclamation action in areas with air porosity lower than 20% (Papamichos, 1985). Clay and loamy soils are particularly susceptible to poor aeration when wet, because most of the pore space is water filled and the spaces or avenues for gas diffusion become discontinuous (Barth & Martin, 1984).

Because of the lignite, ashes and humus at the surface, the loamy textured spoils keep much of their water as hygroscopic and capillary water, and they have low gravitational water (between 40 and 60%). With increasing fineness of texture, there is a tendency for diffusion rates to decrease in relation to the increasing amount of water through which the gases must pass (Armson, 1977).

In saturated soil most of the pore space is filled with capillary or hygroscopic water so aeration may be insufficient, especially during long precipitation periods. Foth (1984) says that as the water content of the soil increases, the diffusion path of oxygen to the root surfaces increases in length, causing a decrease in available oxygen for root respiration.

The spoils of Ptolemaida are structureless and fine textured, containing large quantities of ash and lignite so, that problems of aeration may explain why some hydrophilic species (such as *Salix alba* and *Rubus tomentosus*) have invaded the spoils naturally. However, in dry years, soil moisture deficits during summer may be a more important determinant of tree survival and growth than short-term winter water logging as it is mentioned also in a study of Moffat & Roberts (1989).

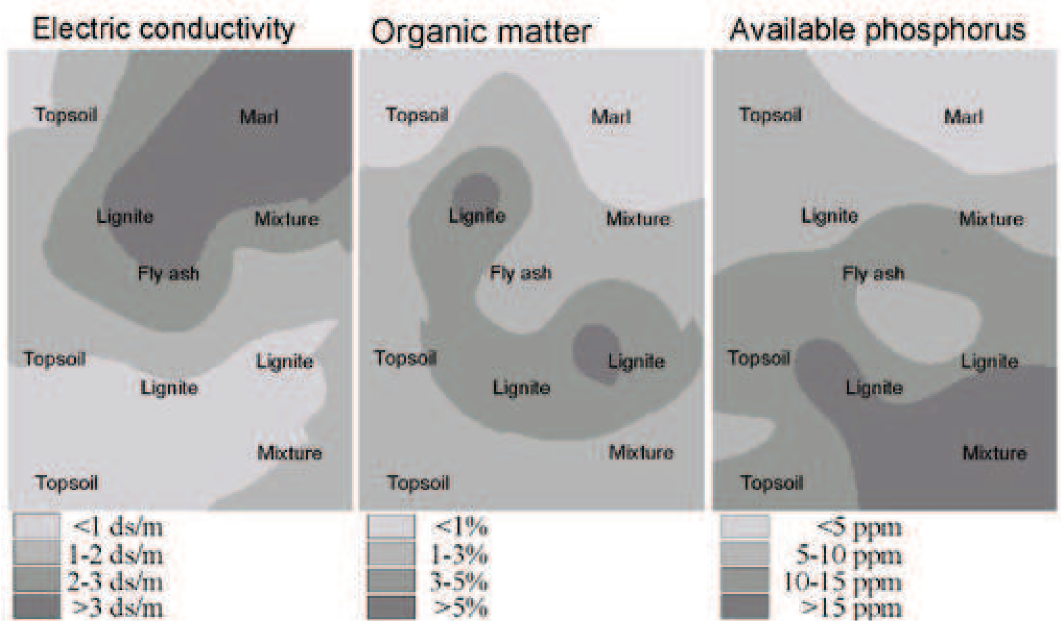
3. 3 Soil chemical properties

To estimate the soil chemical properties were measured pH, carbon, organic matter, $CaCO_3$, available nitrogen, available phosphorus, electric conductivity and the exchangeable cations of calcium, magnesium, potassium and sodium.

Usually the lignite mines are characterized by their low pH and the absence of calcium (Bussler, 1984). Although, in the lignite spoils of Ptolemaida, all soil samples had high pH, with an average of 8.08. $CaCO_3$ content was high in most samples, with higher values reaching 96.8%.

Soil electric conductivity was low in most of samples except on spots with high fly ash content and marl where it was found to have high electric conductivity (3.85 and 7.68 ds m^{-1} respectively). Soluble Na content was also very high on the same areas (9.95 and 15.65 cmolc kg^{-1}), indicating high salinity, resulting in poor plant growth. In the first map of figure 4 it can be seen the estimation map provided from geostatistical interpolation of electric conductivity. At that map was detected those high electric conductivity spots in the Northwest of the study area and it was suggested to use locally salt tolerant forest species and to wash the soil of the area for at least 2 consequent years.

Figure 4. Distribution of soil type materials as assessed from soil colour at the surface and some soil chemical properties after kriging interpolation



Carbon, organic matter and nitrogen were varying through the study area. Samples with high lignite content were rich in organic matter and nitrogen, while some topsoil samples were poor. Nitrogen is a limiting factor in tree growth. The average percentage of organically bound nitrogen in spoils was 0.18%, below the minimum satisfactory amount suggested by Papamichos (1985). The generally high percentage of organic matter was due to the presence of peat mould and unburned lignite in the spoils, which usually keep large amounts of carbon, but in a form not available to plants.

The amounts of organic matter and available nitrogen were directly related. The C:N ratio is an important factor influencing both the rate of decomposition and nutrient cycling, with low ratios favouring more rapid decomposition (Vimmerstedt *et al.*, 1989). C:N ratios were higher than 20:1 in all samples indicating slow decomposition and limited availability of nitrogen.

Available phosphorus varied between sites and was generally low (4.23-19.78ppm) in all samples. Most forest species need at least 15ppm to grow well (Papamichos, 1985). Areas with less than 15ppm phosphorus where located on the map that made from geostatistical interpolation of soil properties (figure 4) and compared with the map coming from bioindicator natural revegetation species (figure 2). It was found that species of phytosociological groups A and F appeared in areas with less available phosphorus. It was suggested to use sewage sludge as soil amendment of the areas that the above phytosociological groups were expanding. Fertilizer instead of sewage sludge as soil amendment was suggested to be avoided because those areas had low organic matter, clay loamy texture most physical properties needed improvement.

Exchangeable Ca was high on all sites, 32.71 cmolc kg^{-1} average indicating a possible deficiency in boron and potassium. Potassium in the spoils of Ptolemaida was low, 0.71 cmolc kg^{-1} average. Exchangeable Mg that must range from 20-33% of the exchangeable Ca (Papamichos, 1985) was less than 10% in the lignite spoils indicating Mg deficiency.

3. 4 Soil temperature and moisture

A very important parameter limiting tree growth and survival of forest species planted on the lignite spoils of Ptolemaida is the high surface soil temperature during the hot summer days. This is due to the black colour of lignite leftovers mixed with overburden on the surface and the luck of shadow provided by revegetation.

Soil temperature during the two years of experiment was varying between 35°C on the surface when the weather was cloudy and 62°C during hot days. The highest values of soil temperature were measured at 0.5cm depth on a black coloured bare soil. The air temperature in all four areas were the soil temperatures were measured showed no significant differences between areas at any time of the day.

The average soil temperature at 0.5cm depth, at all mentioned times were statistically significant different (by Duncan's multiple range test at P<0.05), with the higher differences during the hot midday hours. The average soil temperature at 3:00 p.m. in the black coloured soil was 55°C (table 1), while the red coloured soil had 47.05°C soil temperature and the white marl soil 42.94°C. Deely & Borden (1969) found that the average temperature difference observed between the darkest and lightest spoil materials was approximately 15°C.

Table 1. Average soil-temperature at surface of a lignite spoil heap at different times of the day

Colour - Time	11:00 a.m.	1:00 p.m.	3:00 p.m.	5:00 p.m.
Black (10YR 3/1)	40.41^{a*}	49.65^{a}	55.00^{a}	48.29^{a}
Light grey (10Y 7/1)	35.05^{b}	39.76^{c}	42.94^{c}	39.94^{c}
Brownish red (5R 4/7)	36.29^{b}	43.76^{b}	47.05^{b}	43.64^{b}
Black with vegetation cover	32.70^{c}	36.35^{d}	35.41^{d}	35.11^{d}

* Values in the same column followed by different letters are significantly different by Duncan's multiple range test (P<0.05)

In natural environments, soil temperature can reach 65-75°C while in mines soil temperatures could reach 80°C when the air temperature was 45°C as stated by Lenichan & Fletcher (1976). Salisbury and Ross (1985) found that most plants die when exposed at temperatures between 44 and 50°C, although exist some resistant species that can survive at high temperatures. Young seedlings are more sensitive to high temperatures, in which the tissue start to die when the soil surface temperature is more than 52°C (Helgerson, 1990). Pinus and red-fir seedlings cannot survive more than 5 minutes in soil temperatures more than 54-55°C (Levit, 1980).

The lowest soil surface temperature during summer was measured at a black lignite soil under the shadow of the natural vegetation. Specifically, surface soil temperature under shadow at 3:00 p.m. was 19.49°C lower than the temperature of the same area at bare soil. The influence of shadow on soil surface temperatures was also large during all day measurements and differences were varying between 12 and 13°C. Under the protection of a four year old Robinia forest stand the difference of the temperature between bare and covered soil was reaching 24°C.

Moulopoulos (1947) mentioned that the soil temperature difference between a bare and a covered grassland was approaching 30°C. Geiger (1973) stated that plants absorb 38-84% of the sun radiation and with their respiration they regulate the temperature in the layer close to the soil. This has as result the soil surface temperature in areas covered with herbaceous vegetation to be 30% lower than bare soil and 40% lower when the soil is covered with forest.

Lee (1978) noticed that forest coverage decreases the air temperature during the hot summer days in comparison with the bare interspace areas and is keeping the temperature higher for longer period after sunset. In the lignite mines of Ptolemaida the highest temperature under vegetation cover was noted at 1:00 p.m., while in bare soil the highest temperatures were measured at 3:00 p.m.

Soil temperature of bare soil fall rapidly at afternoon times while under vegetation cover there was noticed a gradual decrease confirming the previous author. Between red and grey coloured soil there were significant differences at all hours except at 11:00 a.m. (table 1). At 11cm depth, there were significant differences between the darker area and all others. At 11 and 17cm depth the soil temperature continued to increase in all soil colours till late in the afternoon.

At 2.5cm depth, at 11 a.m. and 1:00 p.m., there were not significant differences between the white, red and black-shaded soil. At 3:00 p.m. there were differences at soil temperatures among all areas with the highest temperatures in the black soil followed by the red, the white coloured and soil under shadow (figure 5). At 5:00 p.m. there were no significant difference between the lignite and the red topsoil, because lignite decreased its temperature faster even though was warmed during midday more than the topsoil.

In figure 6 it can be seen the graphical interpretation of the soil temperature after kriging interpolation at various depths during the hottest time of the day. From those prediction maps it was resulting that dominant spoil material at the surface was influencing soil temperature. However, seedling survival on the black coloured soil was high and natural vegetation cover was higher in areas where the dominant material was topsoil or a mixture of lignite with topsoil and lower at spots with marl, fly ash or lignite.

Figure 5. Average air and soil temperature of a lignite spoil heap, at 3:00 p.m., in 3 areas with different soil types (lignite, topsoil and marl)

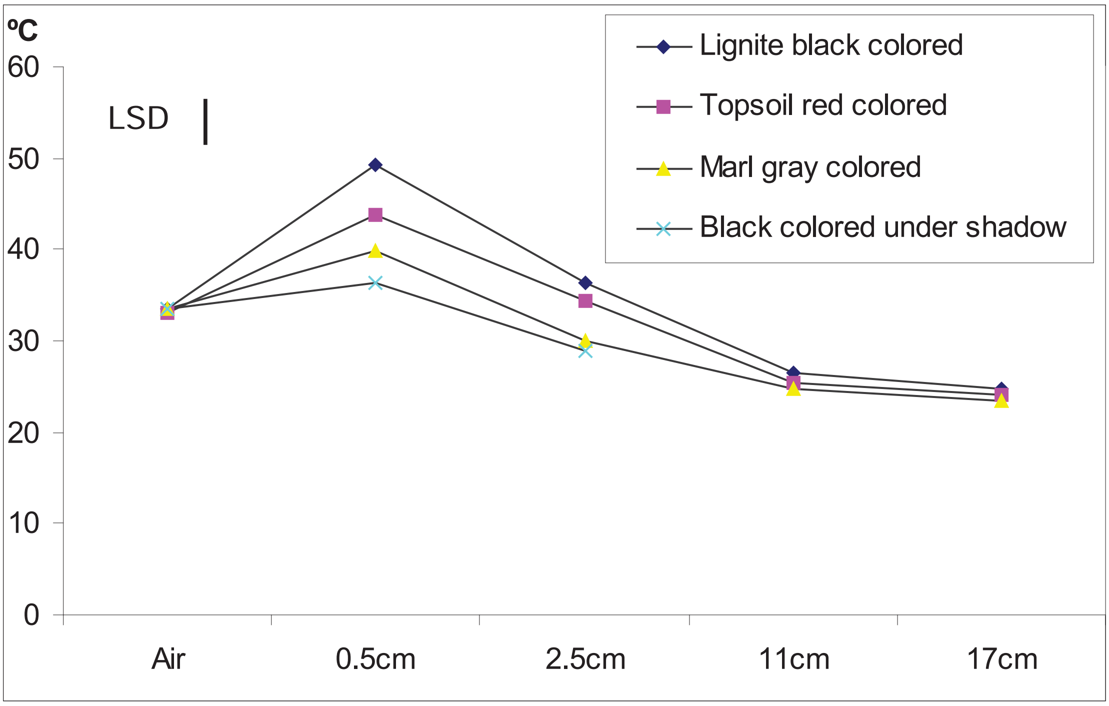
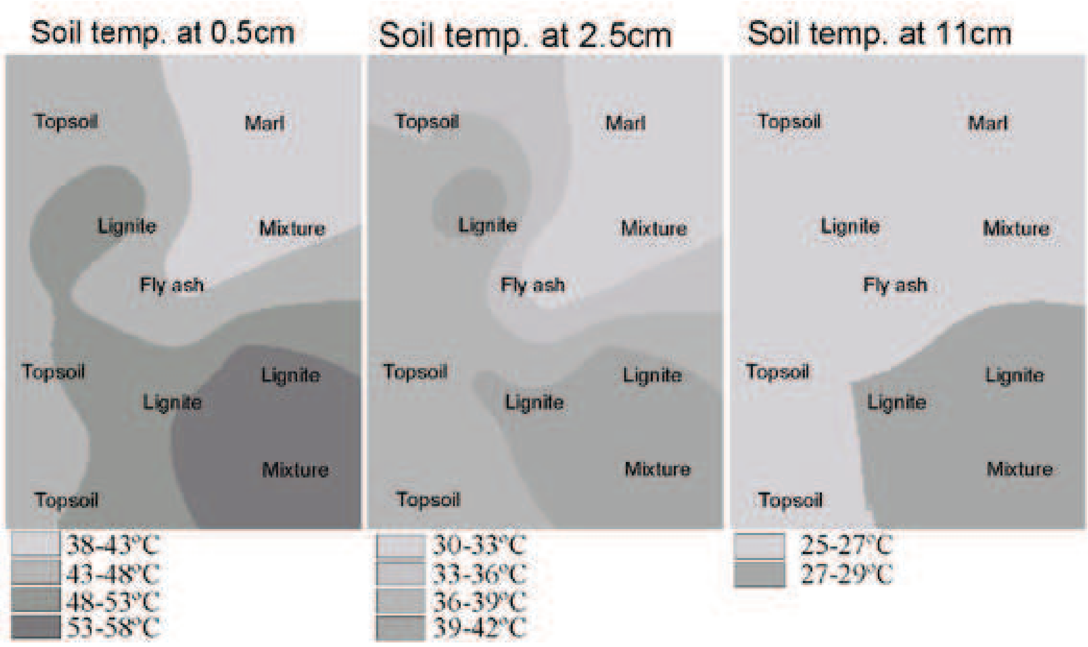


Figure 6. Distribution of soil type materials as assessed from soil colour at the surface and soil temperature after kriging interpolation



Surface soil temperature under shadow was 19.49°C lower than temperature at bare soil of the same area at the same time and type of spoil. Those 19.49°C difference was weighted depending on the percentage of vegetation cover and was subtracted from the prediction map of soil temperature at 0.5cm. The resulting prediction map was showing that highest temperatures occur on small spots with dominant materials lignite or fly ash. On those areas was suggested to take additional measures during afforestation to decrease heat damage and increase afforestation success.

Helgerson (1990) noted that when one or two year old seedlings are planted on a field already covered with vegetation heat damage is minimized. Richardson *et al*. (1987) mentioned that natural vegetation cover increases the success of forest species establishment. Thus, seedling survival will be minimum if their establishment were done on an early reclaimed bare spoil.

At the experimental area of Ptolemaida was suggested to start afforestation only when occur a relatively good soil cover with natural vegetation and never on black coloured bare spoil. Papamichos (1985) mentioned that 54°C is the temperature that the living plant tissues are dying and the best way to protect young seedlings from high soil temperatures was to plant them densely to be self shaded and to place light coloured materials at the base of the plants.

Soil moisture during summer at 30cm depth was 23% for the black coloured soil, 16% for the red and 17% for the white. Soil moisture was measured at a depth critical for the survival of tree seedlings and as the available to the plants water was lower than the hygroscopic water, was concluded that there was not available water for the plants during summer. These results depend mainly from soil physical properties and less from the soil ability to absorb or to reflect the sun radiation, for the reason that at 30cm depth, soil temperature was the same at all soil types.

4. CONCLUSIONS

The soil and natural vegetation of the lignite spoil heaps were spatially heterogeneous. The reclamation of environment at the lignite spoil heaps of Ptolemaida was composite and difficult due to adverse ecological conditions. Natural revegetation could be the first step before reclamation began.

Phytosociological research showed that drought resistant species of group A were limited in areas where clay topsoil was spread on the spoil. The average drought group B was decreasing as percentage of soil cover and soil fertility were decreasing. The groups C, G and D emerged in areas with high lignite content, with the first two to develop at infertile areas and the last in more fertile soils. Indicator group E appeared in a part of the spoil where marl was dominant at the surface and surface soil temperature was lower due to lighter soil colour. Group F appeared in small spots where fly ash was the dominant material (fly ash pH was higher than 9).

Soil properties were related to natural vegetation succession and both could be indicators in assessment of reclamation potentiality on the site. Geostatistics minimized the sampling cost with the estimation of a minimum sampling distance. Geostatistics proved to be useful tools for spoil soils where spatial distribution of soil properties and natural vegetation composition is determined more by human activity than by natural evolution.

Geostatistics helped to map with relative precision site quality. A geographic information system with the support of geostatistics could facilitate solutions locally on some specific soil quality problems. Soil amendments, irrigation, addition of light coloured materials on the surface or species selection could be decided for specific locations of the heterogeneous spoils. The construction of a geographic information system that links the information from prediction maps of soil properties and natural vegetation composition with database information of the reclamation species needs, could be a useful decision support tool on reclamation of surface mine areas.

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PREDICTING SOIL EROSION RISK AT THE ALQUEVA DAM WATERSHED

AVALIAÇÃO DO RISCO DE EROSÃO DO SOLO NOS MONTADOS DA BARRAGEM DO ALQUEVA

Vera Ferreira
Thomas Panagopoulos

ABSTRACT

Soil erosion is serious economic and environmental concern. Assessing soil erosion risk in the Alqueva dam watershed is urgently needed to conserve soil and water resources and prevent the accelerated dam siltation, taking into account the possible land-use changes, due to tourism development, intensification of irrigated farming and biomass production, as well as climate change. A comprehensive methodology that integrates Revised Universal Soil Loss Equation (RUSLE) model and Geographic Information Systems (GIS) with geostatistical techniques was adopted to study different land-use and management scenarios. The main objective of this study stage is to determine the soil erosion vulnerability of an agro-silvo pastoral system. The resultant soil erosion map shows an average of 14.1 t/ha/year, with serious erosion risk (higher than 50 t/ha/year) in 4.3% of area. The highest values are associated mainly to high slopes and low vegetation. The final prediction maps for soil erosion and for each factor considered, can be used as a solid base to create a Decision Support System so as to provide specific procedures for decision-makers, promoting for sustainability of the ecosystems, reducing the risk of erosion and consequently increase lifetime of dam, under various land use and management scenarios.

Keywords: Soil Erosion; Land-use; Geostatistic; RUSLE; Geographic Information System.

RESUMO

A erosão do solo é um problema ambiental e económico. Avaliar o risco de erosão nos montados da barragem do Alqueva é urgente para proteger o solo e prevenir o rápido assoreamento da barragem, tendo em conta futuras alterações do uso do solo, devido ao desenvolvimento turístico, agricultura de regadio e produção de biomassa, assim como possíveis alterações climáticas. Esta investigação envolve o uso da RUSLE (Revised Universal Soil Loss Equation), em combinação com Sistemas de Informação Geogáfica e geostatistica, para estudar diferentes cenários de uso e gestão do solo. Nesta primeira fase do estudo o principal objectivo foi modelar a vulnerabilidade da erosão do solo num sistema agro-silvo pastoral. O mapa de erosão resultante mostra uma média anual de 14.1 ton/ha/ano, com risco sério de erosão (maior que 50 ton/ha/ano) em 4.3% da área. Os valores mais elevados de erosão estão associados principalmente a elevados declives e baixas percentagens de vegetação. Os mapas de erosão do solo e a contribuição de cada factor, tendo em conta diferentes cenários, podem ser usados como base para criação de um Sistema de Suporte à Decisão, promovendo um planeamento sustentável do uso do solo na região, reduzindo o risco de erosão e consequentemente aumentar o tempo de vida útil da barragem.

Palavras-chave: Erosão do Solo; Uso do Solo; Geostatistica; RUSLE; Sistemas de Informação Geográfica.

JEL Classification: Q01; Q15; Q24.

1. INTRODUCTION

Soil erosion is a complex land degradation process, in many parts of the world, which leads to decline in soil quality and productivity, because resulting in a decrease in effective root depth, nutrient and water imbalance in the root zone, reduction in infiltration and increase in runoff (Yang *et al.*, 2003; Lal, 2001). This sediment yield can result in the acceleration of natural sedimentation in rivers and reservoirs reducing their storage capacity as well as life span (Pandey *et al.*, 2007). Consequently, soil erosion is a serious environmental and economic problem and it is sensitive mainly to land-use, through deforestation, agricultural intensification and improper practices, and due to climatic change (Zhang *et al.*, 2009; Yang *et al.*, 2003; Nearing *et al.*, 2004).

Land-use change in Europe over the past century has been largely driven by the technology development and in future the land-use depends of social, political and economic development (Bakker *et al.*, 2008). The relationship between land-use and soil erosion has attracted the interest of a wide variety of researchers (Kosmas *et al.*, 1997; Wang *et al.*, 2003; Long *et al.*, 2006; Cantón *et al.*, 2011). These investigations found that these changes in land-use greatly affected runoff and soil erosion. Mediterranean environment may be particularly vulnerable because of specific poor soil characteristics, low vegetation cover and contrasted climate, with extensive dry periods followed by heavy erosive rains falling on steep slopes characterized by fragile soils (Grimm *et al.*, 2002). According to the CORINE program, mediterranean countries, such as Portugal and Spain, face the greatest risks of erosion (Desir and Marín, 2007). In Portugal, areas at high risk of erosion cover almost one third of the country (Grimm *et al.*, 2002).

Management of reservoirs is of major importance regarding the water supply in Portugal. The Alqueva reservoir constitutes the largest artificial lake in Europe, however the capacity cannot be maintained due to a yearly deposition of sediment resulting in a silting up. Alqueva surrounding region now has new challenges as traditional land-uses and human activities are changing and new risks are arising. The possible land-use changes in this region will be due to tourism development, intensification of irrigated farming and biomass production.

Therefore, the objective of this research is to use a soil loss prediction model (in that case RUSLE) in combination with Geographic Information Systems (GIS) and geostatistical techniques to model the potential soil erosion risk in this region under different land-use-scenarios. In this fist study stage, erosion risk maps were produced on smaller sub-watersheds of Alqueva, an agro-silvo pastoral system, to consider the vulnerability of this lans-use. These results are essential to increase the knowledge about local conditions, to create a solid base for a Decision Support System (DSS), to provide site specific measures to site specific methods and measures for decision-makers. These methods and measures could decrease the risk of soil erosion, helping spend less money, increasing the dam's life span, promoting for sustainability of the ecosystems.

2. LITERATURE REVIEW

2.1 Soil Erosion Models

Research on erosion issues and the essential basics of erosion processes have been studied over the past few years. But research is still continuing and progressively focuses on these fundamentals as well as its modeling. Parallel to the detailed modeling of physical processes, many efforts are undertaken to develop universally appropriate erosion models to predict the soil loss and sediment delivery. Models available in the literature for sediment yield estimation can be grouped in following categories: physically-oriented models and empirical models (Bhattarai and Dutta, 2008; Fu *et al.*, 2010) and conceptual models (Merrit *et al.*, 2003; De Vente and Poesen, 2005; Mulligan, 2004; Volk *et al.*, 2010).These models differ in terms of complexity, processes considered, and the data required. However, according to Volk *et al.* (2010) in general there is no "best" model for all applications, because depend on the intended use and the characteristics of the catchment considered".

Physically based models characterize the essential mechanisms controlling the erosion process, in a high level of detail, through the solution of the fundamentals physical equations, namely equation of mass conservation (Bhattarai and Dutta, 2008; Merrit *et al.,* 2003). Examples for physically-based models include the Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS, Beasley *et al.*, 1982), the European Soil Erosion Model (EUROSEM, Morgan *et al.*, 1999) and Water Erosion Prediction Project (WEPP, Nearing *et al.*, 2000). Although these have several disadvantages, because they include large computational demands, almost always requires calibration against observed data of more parameters, this creates additionally uncertainty and lack of identifiably (Merrit *et al.*, 2010; Fu *et al.*, 2010; Bhattarai and Dutta, 2007).

Conceptual models only considered by some authors, pay some attention to the physics process and represent a catchment as a series of internal storages, including a general and aggregated description of catchment processes, though without including the specific details of process interactions (Merrit *et al.*, 2003; Mulligan, 2004). Agricultural Non-Point Source model (AGNPS, Young, 1989) and Soil and Water Assessment Tool (SWAT; Arnold *et al.*, 1998) are some of the examples of conceptual models, according to De Vente and Poesen (2005) and Volk *et al.* (2010).

Empirical models are generally the simplest of all three model types, and are based on analyses of observations data using stochastic techniques (Merritt *et al.*, 2003; Volk *et al.*, 2010). Empirical models are frequently used for the estimation of surface erosion and sediment yield from catchment areas (Bhattarai and Dutta, 2008), are useful for annual loads and for identifying erosion "hot spots" (Fu *et al.*, 2010). Among the commonly used empirical erosion models include the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.*, 1997). Empirical models are often censured for employing unrealistic assumptions about the physics of the catchment system, for not considered temporal variation of rainfall, runoff and erosion processes, for ignoring the heterogeneity characteristics of the system (Merit *et al.*, 2003) and because are limited to conditions for which they have been developed (Aksoy and Kavas, 2005), hindered the application in different scale (Fu *et al.*, 2010). However, these models are frequently used in preference to more complex models as they can be implemented in situations with limited data and parameters inputs, and are particular useful as a first step in identifying sources of sediment generation (Merrit *et al.*, 2003).

2.1.1 RUSLE

The Universal Soil Loss Equation, an empirical model, is one of the most widely used models for estimating annual soil loss (USLE, Wischemeier and Smith, 1978). The USLE was originally applied to the prediction of soil losses from agriculture in the USA in order to preserve soil resources, but has been extended for use in numerous countries. The USLE has been modified in the last few decades and its modifications include the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.*, 1997). RUSLE was developed to take advantage of knowledge and data obtained initially and to be applied in different crops and management systems not present in the original experiments used to develop the model (Kinnell, 2010). USLE and its modifications are defined as:

$$A = R\ K\ L\ S\ C\ P \quad \textbf{(1)}$$

where A= potential erosion (computed annual average soil loss in t ha^{-1} $year^{-1}$), R= rainfall and runoff factor, K= soil erodibility factor, LS= slope length and gradient factor, C= vegetation cover factor and P= vegetation control practice factor.

Although developed for application to small hill slopes, the RUSLE and its derivatives have been incorporated into many catchment scale erosion and sediment transport modeling applications. The typical output from the USLE is an annual estimate of soil erosion from hill slopes (Merit *et al.,* 2003). It is simple and easy to use, because of the simplicity of structure, less input data requirements and the availability of parameter values, compared with most other models. However it lacks insights on the soil erosion process and mechanism (Bhattarai, 2007, Volk *et al.*, 2010, Merrit, *et al.*, 2003). One of the main criticisms of USLE (Universal Soil Loss Equation) (Wischmeier and Smith, 1978; Renard *et al.*, 1997) based models is that they fail to consider the interdependence of soil erosion factors.

2.2 Geographic Information Systems (GIS)

GIS is an integrated suite of computer-based technology and methodology, is a powerful set of tools for collecting, storing, retrieving, transforming, analyzing and presenting spatial data from the real world for a particular set of purposes (Burrough and McDonnell, 2000). In essence, GIS are spatial databases of digital maps which accumulate information on various characteristics and their locations (Davis, 2001).

GIS have been used in various environmental applications, for representing and simulating different scenarios (Lang, 2003). A GIS provides an important spatial/analytical function performing the time-consuming georeferencing and spatial overlays to develop the model input data at various spatial scales (Sharma *et al.*, 1996). The ability to represent elevation in terms of topographic surfaces is central to geomorphological analyses and thus to the importance of representing topography using Digital Elevation Maps (Schmidt *et al.* 2000).

Due to the spatial variation in rainfall and field heterogeneity, soil erosion is spatially varied, and erosion models often require moderate to high amounts of spatial data like topography, soil properties and land use, which can be effectively handled through GIS (Bhattarai and Dutta, 2007; Mulligan, 2004). The GIS can be used for the discretization of the watershed into small grid cells, to determine the factor values for predicting erosion (Bhattarai and Dutta, 2007).

The combination use of GIS and erosion models, such as RUSLE, has been vastly adopted in many studies and showed to be an effective approach for estimating the magnitude and spatial distribution of erosion (Millward, 1999; Shi *et al.*, 2004; Fu *et al.*, 2006;; Bhattarai and Dutta, 2007; Terranova *et al.*, 2009, Kouli *et al.*, 2009). GIS have emerged as a powerful tool useful for effective decision-making (Renschler and Harbor 2002).

2.3 Geostatistics

Spatial variability is a well-known phenomenon of soil systems and this variation in soil has been recognized for many years (Burrough, 1993). Spatial variability means that soil variables are correlated as a function of distance, i.e. the sample values are not independent of each other and one sample value gives some information about its neighbouring data point (Wackernagel, 1995).

Geostatistics is a branch of applied statistics that focusses on the characterization of spatial dependence structure of the underlying random field (Wackernagel, 1995; Webster and Oliver, 2001; Atkinson and Lloyd, 2010). Geostatistics (Goovaerts, 1997; Webster and Oliver, 2001) has been extensively used for quantifying the spatial pattern of environmental variables. It has been used in combination with GIS, to identify the risk of erosion areas, to account local uncertainly (Diodato and Ceccarelli, 2004). This approach allows various measurements and soil properties at a specific location to be combined into a single integrative indicator of soil erosion.

2.3.1 Semi-Variogram

Regionalized variables are distributed in space and time, and are usually known only at number finite experimental points. The methods of geostatistics use the stochastical theory of spatial correlation (Burrough, 2001) for incorporating the spatial coordinates of soil observations in data processing, allowing for modeling of spatial patterns, predicting at unsampled locations, and assessing the uncertainty attached to these predictions (Gooverts, 1999).

Semi-Variogram is the main tool in the geostatistic, which express the spatial dependence among samples (Chilés and Delfiner, 1999). The semivariogram is a plot between the distances of ordered data and their value of semivariance (Isaaks and Srivastava 1989). This plot explains the spatial relation between the samples, and is given by the following Equation 2 (Clark, 1979):

$$\tilde{a}(h) = \frac{1}{2} N_{(h)} \sum \left[Z_i - Z_{i+h} \right]^2 \tag{2}$$

The most related samples have lower values of semi-variance (**γ (h)**), where **N(h)** is the number of samples that can be grouped using vector **h**; **Zi** represents the value of the sample; **Zi+h** is the value of another sample located at a distance ||**h**|| from the initial sample **Zi**.

For a quantitative description of these features, it is useful to fit standard models to the semivariance functions. Typical standard semivariograms include linear, spherical, and exponential models (Wackernagel, 1995). The model fitted provided two important parameters which are the Nugget and Sill. Those parameters help to determine if the samples are spatially correlated or not. If the ratio between Nugget and Sill is low (<0.25) then the samples are spatially correlated, if the ratio is high (>0.75) then the samples have a very low spatial correlation (Cambardella *et al.*, 1994).

2.3.2 Ordinary Kriging (OK)

Geostatistics provide great flexibility for interpolation, providing ways to interpolate to areas or volumes larger than support, methods for interpolating binary data, and methods for incorporation soft information about trends or stratification. All these methods of interpolation yield smoothly varying surfaces accompanied by an estimation variance surface. Combining soft information and conditional simulation is useful for computing data for raster-based environment models (Burrough and McDonnell, 2000).

In general, kriging is one of the most widely used interpolation geostatistical methods that assumes that variables close in space tend to be more similar than those further away, minimizing the error variance with unbiased estimates (Gooverts, 1999).

Kriging tries to have a mean residual error equal to zero with the lowest possible value of the standard-deviation of the error, at the same time that estimates the weighted linear combinations ($\mathbf{w_i}$) of the available data ($\mathbf{z(x_1)}$) for the interpolation result ($\mathbf{z(x_0)}$) as it is shown in Equation 3 (Wackernagel 1995).

$$z(x_0) = \sum_{i=1}^{n} w_i \, . \, z(x_i) \qquad \wedge \qquad \sum_{i=1}^{n} w_i = 1 \tag{3}$$

The linear weight necessary for the interpolation is obtained by the ordinary kriging Equation 4 (Wackernagel 1995).

$$\begin{array}{ccccc} C & . & w & = & D \\ \begin{bmatrix} C_{11} & \cdots & C_{1n} & 1 \\ \vdots & \ddots & \vdots & \cdots \\ C_{n1} & \cdots & C_{nn} & 1 \\ 1 & \cdots & 1 & 0 \end{bmatrix} & . & \begin{bmatrix} w_1 \\ \vdots \\ w_n \\ \mu \end{bmatrix} & = & \begin{bmatrix} C_{10} \\ \vdots \\ C_{n0} \\ 1 \end{bmatrix} \\ (n+1)*(n+1) & & (n+1)*1 & & (n+1)*1 \end{array} \tag{4}$$

In the above equation the matrix **C** contains the co-variances from all samples surrounding the sample to be interpolated. The matrix **w** contains the weights as well as a parameter called Lagrange Parameter. The matrix **D** contains the co-variance from the sample to be determined and the surrounding ones. The final objective of the ordinary kriging interpolation is to determine the matrix **w.**

2.3.3 Inverse Distance Weighted

In some cases that ordinary kriging could not be used due to low spatial correlation of the samples and a nugget effect Semi-Variogram the Inverse Distance Weight method is used. The samples had a very weak spatially correlation (nugget/sill > 0.75) and the nugget model was the best fitting model, the Inverse Distance Weighted was used instead (Eq. 5). This interpolation method is very simple and considers the importance of the samples to be used in the interpolation to be inversely proportional to the Euclidean distance (Isaaks and Srivastava 1989).

$$z(x_0) = \frac{\sum_{i=1}^{n} \frac{1}{d_i^p} . z(x_1)}{\sum_{i=1}^{n} \frac{1}{d_i^p}} \tag{5}$$

In this equation, $z(\mathbf{x_o})$ is the interpolated point, $\mathbf{z(x_i)}$ is a known value, $\mathbf{d_i}$ is the distance from the know value to the interpolated value. The importance of the weight is mainly dictated by the value of **p**. According to Isaaks and Srivastava (1989), when **p** tends to infinite then a bigger weight is given to the nearest sample, and if **p** tends to 0 then the different weights become similar and the final interpolated value will be the simple average of the closest points.

3. STUDY AREA

3.1 Alqueva Dam

The Alqueva reservoir is located on the river Guadiana in Alentejo, a semiarid region in the south of Portugal (8º30’ W, 38º30’ N) (Figure 1). It covers an area of 250 km^2 (from which 35 km^2 are in Spain) and the total capacity of the reservoir is 4150 hm^3. The lake total shoreline is approximately 1100 km, it extends for 83 km and is considered one of the biggest in Europe (Lindim *et al.*, 2011). The complex project was constructed during 1998-2002 (Figure 2), and the main objective was to create a strategic water reserve, for supply water to the populations, irrigation for farms in the surrounding area (about 110000 ha), produce hydroelectric power, as well as a large reservoir where several tourist projects are also being built. Alqueva dam has direct influence in the regions surrounding it (namely 18 counties).

This region of Alentejo, Southern Portugal, is characterized by a highly heterogeneous and complex landscape structure. A typical landscape is named “Montado”, is an agro-forestry system in which agricultural and forest activities complement each other (Borges *et al.* 2010), comprising an open formation of cork oak (*Quercus. suber*) and holm oak (*Quercus ilex*) in varying densities, combined with a rotation of crops/fallow/pastures (Figure 2). In some montado areas, oaks are mixed with olive trees. In this region, during the 20st century, the intensification of agriculture lead for numerous environmental impacts and namely increased soil erosion. In the past few years increased the abandonment of agricultural activities in Alentejo, however Bakker *et al.* (2008) believes there are already, a problem associated with soil erosion in some sites, because exist an environmental imbalance. Thus, it is necessary to decide on to sustainability of the montados, important for protection and restoration of soils.

The climate is Mediterranean, with very hot and dry summers and mild winters. 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 ranges between 450 and 550 mm (Sanches and Pedro, 2007).

Figure 1. Location of the Alqueva Dam

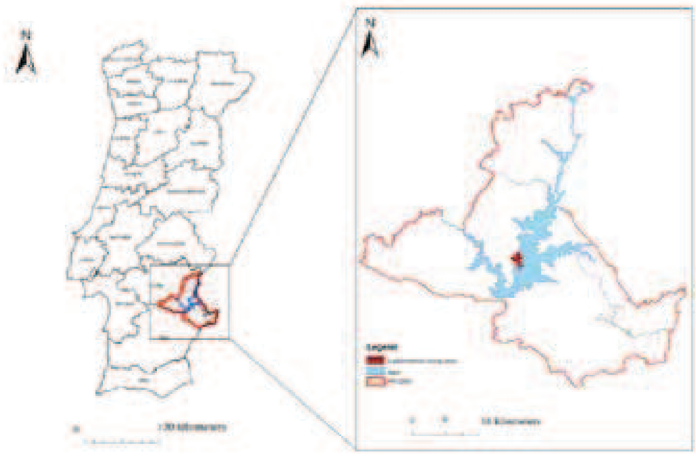


Figure 2. Alqueva Dam Project

3.2 Experimental study area

An experimental research site (Figure 3) was primarily chosen to study the potential risk of the soil erosion and to help making the first conclusions for the total area. The study area lies in Herdade do Roncão (Roncao D'el Rey) beside the dam, near the Regengos de Monsaraz city. A tourism project will be implemented in this site (included in "Parque do Alqueva" project). It has about 739 ha and the future land-uses are: a marina, a hotel and several golf areas. Currently, the typical local landscape is the "Montado" (Figure 4). As we can see in the Figure 5 the project is being employed.

Figure 3. Experimental study area

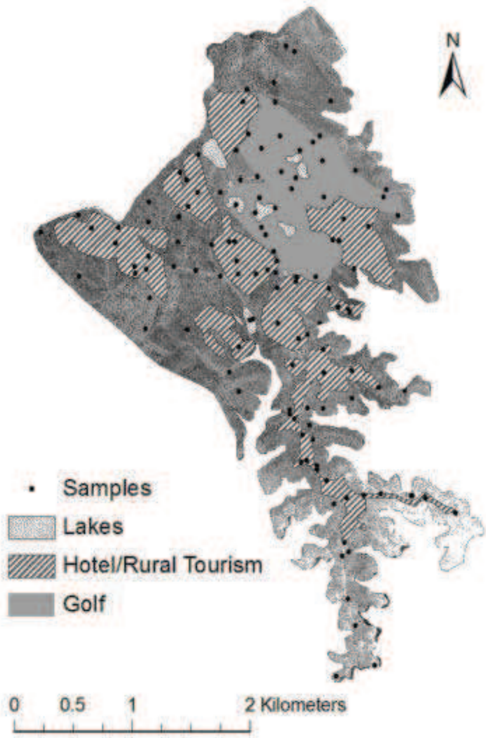


Figure 4. Montado type landscape

Figure 5. Implementation of golf areas

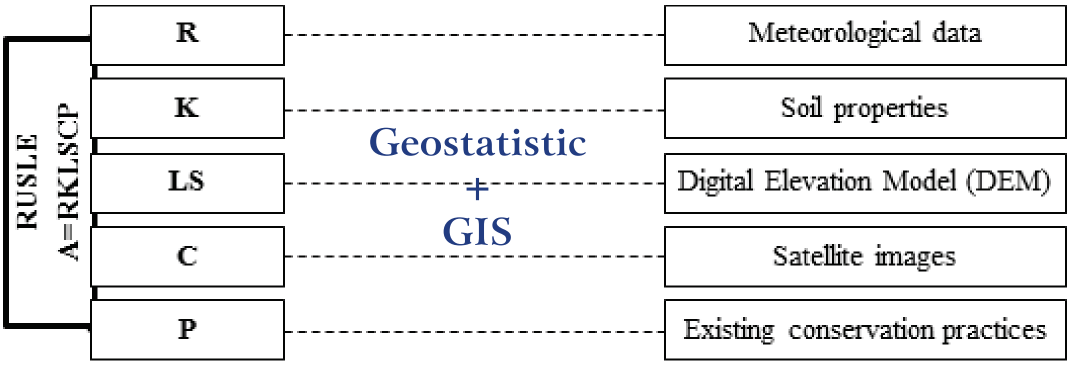
4. METHODOLOGY

This study was an initial phase of soil erosion risk assessment in this region. RUSLE was used to predict the average annual soil loss.

4.1 RUSLE data collecting and processing

The value of RUSLE factors are computed on the methods described by Renard *et al.,* 1997. Soil data, land use inventory, digital elevation data, and climate data are used as resource data sets to generate RUSLE factor values (outlined in Figure 6).

Figure 6. RUSLE factors and data collected



4.1.1 Rainfall-runoff Erosivity Factor (R)

The rainfall-runoff erosivity factor is generally known as one of the most important indicators of the erosive potential of raindrops impact (Goovaerts, 1999b). According to Renard *et al.* (1997), the rainfall-runoff factor is determined through the sum of erosive storm values EI30 occurring during a mean year, which result for the product of total storm energy (E) times the maximum 30 minute intensity (I30), where E is in MJ/ha and I30 is in mm/h. Coutinho *et al.* (1994) obtained an exponential relationship between rainfall and erosivity index. The equation was defined as:

$$EI30=0,33P-52,9 \qquad \textbf{(6)}$$

where P is precipitation. In the study we used this relation with precipitation data from 137 meteorological stations, between 1990 and 2011, to estimate erosivity. The R-factor is usually calculated according to the values measured over 20 years to accommodate apparent cyclical rainfall patterns. Annual erosivity was computed for these stations, as the sum of monthly erosivities. An erosivity map for south of Portugal was created with geostatistical techniques (ordinary kriging).

4.1.2 Soil Erodibility Factor (K)

Soil erodibility factor (K) represents the susceptibility of a soil to erode and the amount and rate of runoff, as measured under the standard unit plot condition. The unit plot condition is a continuously cultivated fallow plot, 72.6 ft (22.1 m) long with a slope of 9% (Renard *et al.*, 1997). The soil erodibility factor is a quantitative value experimentally determined. The K values is estimated using information about soil properties, such as soil texture, content of organic matter, soil structure and permeability (Renard *et al.*, 1997). An algebraic approximation (Wischmeier and Smith, 1978) of the nomograph was used to estimate soil erodibility factor (K):

$$K = [2.1 \times 10 - 4(12 - OM)\ M1.14 + 3.25(S - 2) + 2.5(P - 3)]/100 \qquad \textbf{(7)}$$

where OM is organic matter, S is soil structure, and P is permeability class. M is the product of the primary particle size fractions (% Silt) × (%Silt + %Sand), where % Silt is percent modified silt (0.002-0.1 mm) and % Sand is percent modified sand (0.1-2 mm). K is expressed with U.S. units and division with the factor 7.59 will yield K values expressed in SI units of t. ha. h.ha-1 MJ-1mm-1.

To evaluate this factor, a total of eighty-two (82) soil samples of about 1 kg and with 0 to 20 cm depth were collected (Figure 7). The sample localizations, in field, were determined using a Global Positioning System (GPS). In laboratory the individual samples were dried, weighed and carefully sieved through a 2 mm screen and later analysed their properties. Soil texture was analysed using standard hydrometer procedure. Organic matter was estimated after it goes to muffle during 24 hours at 375ªC. To estimate the permeability the field-saturated hydraulic conductivity was measured in field using an infiltrometer (Figure 8). Permeability class and soil structure class was defined in accordance with Renard et al. (1997). Computed K factor values for each soil sample unit were added into GIS environment and a continuous surface representing the spatial distribution was created using geostatistics.

Figure 7. Field works

Figure 8. Turf-Tec Infiltrometer used to measure permeability

4.1.3 Slope Length and slope steepness factors (LS)

Slope Length (L) is defined as the horizontal distance from the origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or runoff becomes concentrated in a defined channel. The slope steepness (S) factors show the influence of slope gradient on erosion (Wischemier and Smith, 1978). Ever since the first applications of USLE, estimating the slope length factor has given rise to many calculation difficulties. Direct measurements of slope and slope length were initially proposed to evaluate these factors (Renard *et al.*, 1997). However this method is only suitable for small plots and parcels, because intensive field measurements are obviously not feasible on a regional scale. In watershed scale, the use of a Digital Elevation Model (DEM) in GIS, for data input is a better approach (Nekhay *et al.*, 2009).

In this study, to estimate this factor we created a Digital Elevation Model (DEM) in ArcGIS software (ESRI, 2008) by digitizing contour lines from topographic maps. GIS analyses allow users to generate slope steepness (S) and slope length (L) raster covers by a number of different methods. In that case, the combined LS factor was computed for the watershed by means of ArcGIS spatial analyst extension using DEM, following the equation (4), as proposed by Moore and Burch (1986).

$$LS=(\text{flow accumullation.} \times \text{cell size}/22.13)^{p} (\sin \alpha/0.0896)^{q} \quad \textbf{(8)}$$

where p and q are empirical exponents (p = 0.4 and q = 1.3) (Moore and Wilson, 1992), flow accumulation signifies the accumulated upslope contributing area for a given cell, cell size is the size of DEM grid cell (for this study is 14.98) and α is the slope degree value.

4.1.4 Vegetation Cover and Management Factor (C)

C Factor reflects the effect of cropping and management practices on soil erosion rates, considering that vegetation reduces the erosive impact of precipitation. This factor ranges between 0 and 1, and is 1 for bare soil (Renard *et al.*, 1997). The C factor has a close linkage to land use types. According to the Land Cover Corine 2006 (Caetano *et al.*, 2008) there are three types of soil cover in the study area: 77% of agro-forestry areas, 20% of broad-leaved forest and 3% of wetlands. Vegetation cover can be estimated using vegetation indices derived from satellite images. The most widely used remote-sensing derived indicator of vegetation growth is the Normalized Difference Vegetation Index (NDVI), that ranges from -1 to 1(Van der Knijff *et al.*, 2002; Kouli *et al.*, 2009). In this study Landsat TM data was used and the NDVI was therefore computed utilizing band 3 (red) and band 4 (near-infrared) as follows:

$$NDVI= (Band4 - Band3)/(Band4-Band3) \quad \textbf{(9)}$$

Satellite images with a spatial resolution of 30 m were used from February of 2007. To estimate C factor, the most common procedure using NDVI involves the use of regression equation model derived from the correlation analysis between the C factor values measured in the field and a satellite-derived NDVI (Van der Knijff *et al.*, 2002; De Asis and Omasa, 2007; Karaburum *et al.*, 2010). Landsat TM images were processed using the IDRISI software (Eastman, 2006) and the following formula was used to generate a C factor surface from NDVI values (Van der Knijff *et al.*, 2002):

$$C= e^{(-\alpha(NDVI/(\beta-NDVI))} \quad \textbf{(10)}$$

where α and β are unitless parameters that determine the shape of the curve relating to NDVI and the C factor. Van der Knijff *et al.* (2002) found that this scaling approach gave better results than assuming a linear relationship and the values of 2 and 1 were selected for the parameters α and β, respectively. The C factor map was produced with ArcGIS software.

4.1.5 Vegetation Control Practice Factor (P)

The P factor is an expression of the effects of specific conservation practices in soil loss, such as contouring, stripcropping, terracing, and subsurface drainage. These practices affect erosion by modifying the flow pattern, grade, or direction of surface runoff and by reducing the amount and rate of runoff (Renard *et al.*, 1997). In this case P factor was assigned the value of 1 (no support practice factor), because the support practices in this area are mainly nonexistent (before the implementation of the tourism project) and the objective of this first study was to analyze the erosion risk according to the actual conditions.

4.2 Statistical and spatial analysis

All spatial data were processed within a GIS (ArcvGIS 9.3). A dataset of soil factors was created with their geo-referenced position in the field. Different digital maps of RUSLE factors are created and integrated in algebra map to understand the variation of the erosion.

Graphical interpretation of each factor is performed. To obtain some factors, namely erosivity (R) and erodibility (K) it was necessary use geostatistical techniques. The techniques were used for each soil property considered in the nomograph K Factor, and helped to obtain spatial distribution. The interpolation method used for raster creation was Ordinary Kriging (OK) which is a common method for data interpolation, which gives the most accurate results after validation (See section 2.3.2).

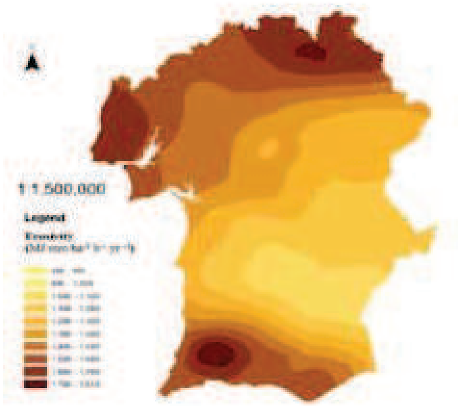
The first step for making use of ordinary kriging method was to investigate the presence of spatial structure among available data in order to get a better understanding of trends, directional influences and obvious errors. Before the creation of the maps, semi-variograms were produced for each property. Transformation and trend removal was performed when necessary.

Cross-validation was used to compare the prediction performances of the semi-variograms, and the best fitted, *i.e.* the one that gives the most accurate predictions, was chosen. From the cross-validation of the models the mean error (ME), root-mean-square (RMSE), average standard error (ASE) and root-mean-square standardised error (RMSSE) were used. The closer the ME was to zero, and the closer the RMSE was to 1, signified that the prediction values were close to measured values (Wackernagel, 1995). Where models presented similar values for ME and RMSE, the lowest values of root-mean-square error and average standard error were taken into consideration. After cross-validation, all maps of properties were reclassified, weighted and overlaid to obtain final prediction map.

5. RESULTS AND DISCUSSION

The first step was to generate a map of rainfall erosivity in the South Portugal. R-factor values were calculated from over 20 years of rainfall intensity data from all the meteorological stations of this region. The prediction map of the rainfall erosivity was created using ordinary kriging (Figure 9).

Figure 9. Map of rainfall erosivity of the Algarve region, southern Portugal, EI30 (MJ mm-^{1}ha^{-1}h-^{1} yr)



Erosivity values were found to range in the South Portugal region between 477-3603 MJ mm ha^{-1} h^{-1} yr $^{-1}$, for a mean annual rainfall of 515.3 mm. The mean value of the R factor in the experimental area (Herdade do Roncão) was found to be 1156 MJ mm ha^{-1} h^{-1} yr $^{-1}$.

Soil erodibility (K) was analysed according to laboratory results. Descriptive statistics of soil proprieties are given in Table 1. The statistical results of soil properties reflect mostly sandy loam soils that are formed mainly with sand (62.711%), followed by silt (22.013%) and clay (15.276%) with relativity low average of organic matter and moderate to fast hydraulic conductivity (15.1cm/h). Skewness results indicated that almost all properties were normally distributed (skewness between -1 and 1), whereas silt and especially hydraulic conductivity was not normally distributed (skewness more than +1). Normal distribution is essential in order not to cause large prediction errors, however in this case the possibility of errors is low (see Table 2).

Table 1. Descriptive statistics of soil proprieties and RUSLE-K values

Statistics	Sand (%)	Clay (%)	Silt (%)	Msilt (%)	OM (%)	H.C. (cm/h)	K factor (t ha h ha^{-1}MJ^{-1} mm^{-1})
Mean	62.711	15.276	22.013	35.533	3.631	15.116	0.023
Min	36.470	8.560	5.640	13.710	0.800	1.500	0.003
Max	80.800	27.280	44.980	64.830	7.728	62.400	0.047
Std. Dev.	8.402	3.511	7.764	9.788	1.395	17.552	0.009
Skewness	-0.796	0.623	1.077	0.468	0.630	1.515	0.550
Kurtosis	3.585	3.562	3.638	3.120	3.649	3.941	3.601

Cross-validation was applied and many indicators, shown in Table 2, were studied in order to facilitate the choice of the most appropriate model of semivariogram, for the creation of prediction maps. The cross-validation results of the mean values of the estimation of error (ME) were very low, i.e. close to zero, and the root mean square standardized of error (RMSSE) is close to 1 which shows that the estimation had an acceptable accuracy and the prediction values are close to the measured values. The root mean square (RMSE) and average standardized error (ASE) are low which means good quality of prediction The nugget-to-sill ratio presented in Table 2 indicted weak spatial dependence for almost all soil properties, which reflects high variance at short distances (high heterogeneity). Moderate and high spatial dependence was obtained for clay and hydraulic conductivity, respectively. Cambardella *et al.* (1994) suggested that there is weakly spatially dependent if the ratio was

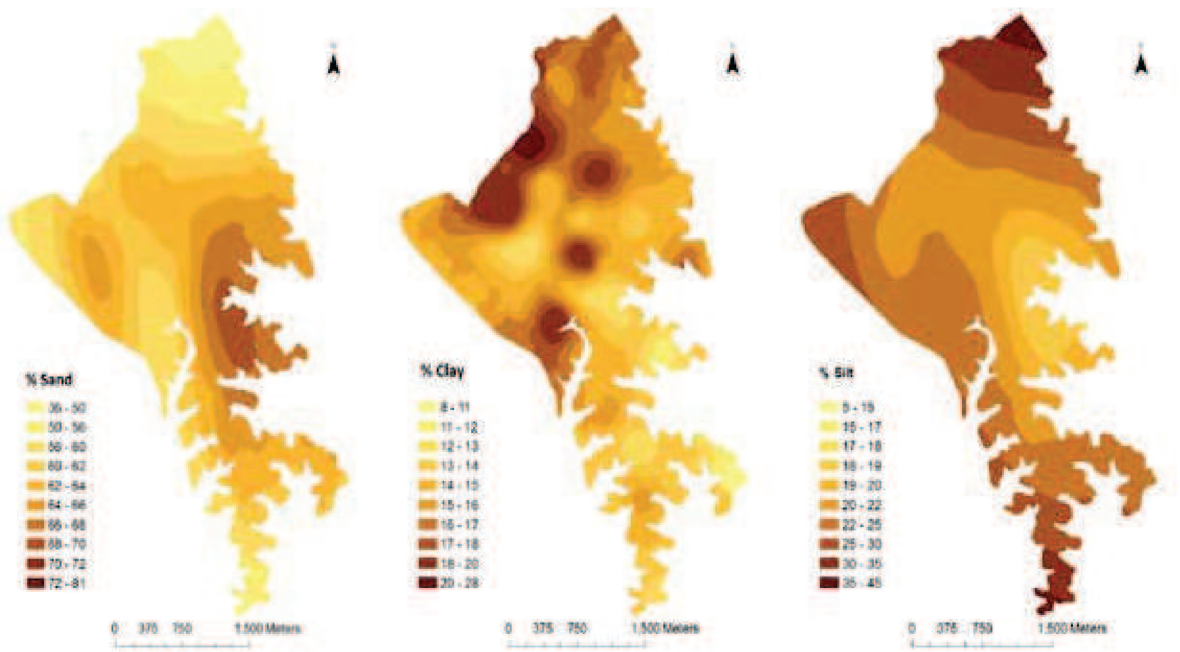
>0.75. According to the same author, weak spatial dependence is controlled by non-intrinsic changes such as inappropriate management. In the other hand, these results could show that, for these properties, the number of samples isn't enough or the distribution isn't the best.

Table 2. Cross-validation results of the fitted semi-variogram models used to create the prediction maps of soil properties and K factor values

Soil property	Sand (%)	Clay (%)	Silt (%)	MSilt (%)	OM (%)	Hydr C. (cm/hr)	K factor
Model	Pentaspherical	Pentaspherical	Exponencial	Exponencial	Exponencial	Exponencial	Exponencial
Nugget	44.567	4.7433	42.606	68.544	0.89201	0	0.00005551
Sill	17.534	8.9499	15.558	50.649	1.1115	10.381	0.000035367
Range	921.785	640.178	3323.6	5104.63	277.8	372.49	5104.63
ME	0.07544	-0.01481	-0.03616	-0.04387	-0.00072	-0.00283	-0.000032
RMSE	8.162	3.352	7.687	9.012	1.384	3.161	0.00799
ASE	7.458	3.358	6.978	9.093	1.402	3.205	0.00812
RMSSE	1.093	0.9883	1.099	0.9949	0.9891	0.9829	0.9893
Nugget/ Sill	2.541747	0.529984	2.738527	1.353314	0.802528	0	1.569542229

Figure 10 shows the soil texture prediction maps in study area.

Figure 10. Soil texture prediction maps



From the maps derived it could be seen some trends. Soils with low sand contents are located mainly in the north and south part. Clay percentages show a high spatial variation, with highest values in some zones in the north and centre. Silt percentage has a strong negative correlation with sand percentage because the areas with higher sand are associated with areas with lower silt contents. Modified silt prediction map (silt and very fine sand) shown in Figure 11 reveal identical trends to silt prediction map.

Soil hydraulic conductivity is a fundamental parameter to understand flow process in soils. Figure 11 shows the geostatistical results. The highest hydraulic conductivity, i.e.

permeability occurs at the central and east part, near dam (more than 4 mm/min), where soils generally have highest values of sand and lowest values of clay.

The prediction map of soil erodibility (K), obtained through nomograph previously presented, is presented also in Figure 11. The K factor values were predicted to vary from 0.0026 to 0.047 t ha h ha^{-1} MJ^{-1} mm^{-1}, with a mean value of 0.023 t ha h ha^{-1} MJ^{-1} mm^{-1}. From the map derived it could be seen that the highest soil erodibility K values are mainly located in the south and north sections, where the highest amount of susceptible particles (silt and very fine sand) are found. Soils with high permeability are more resistant to erodibility, and this was confirmed with the results.

Figure 11. Soil erodibility (K factor) prediction map

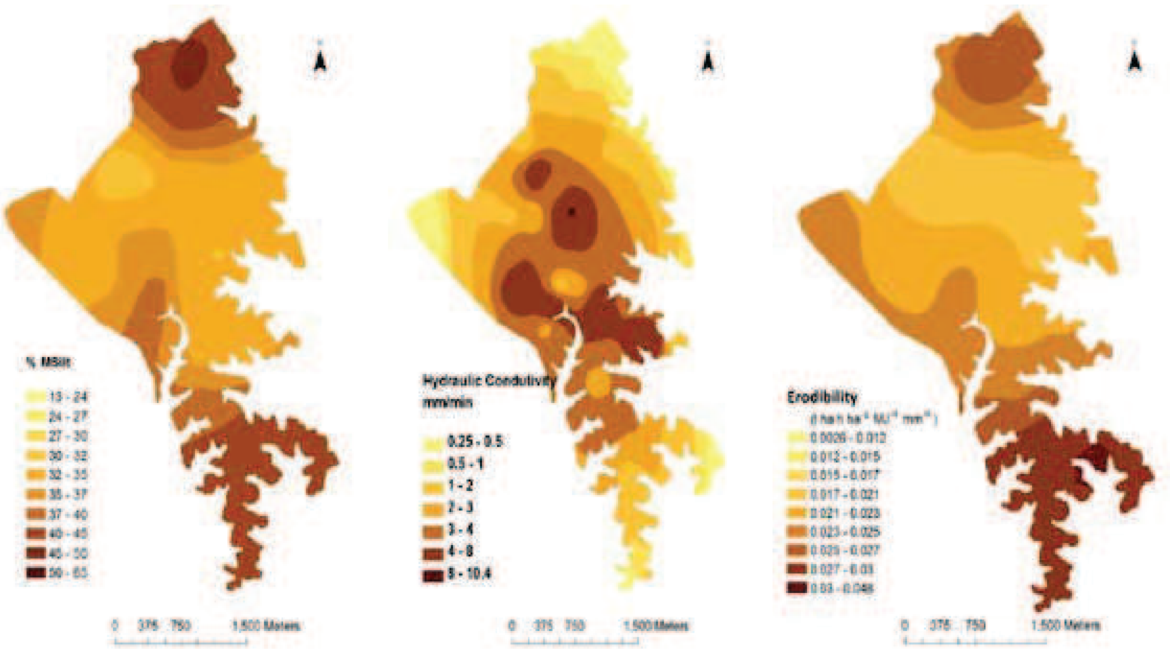
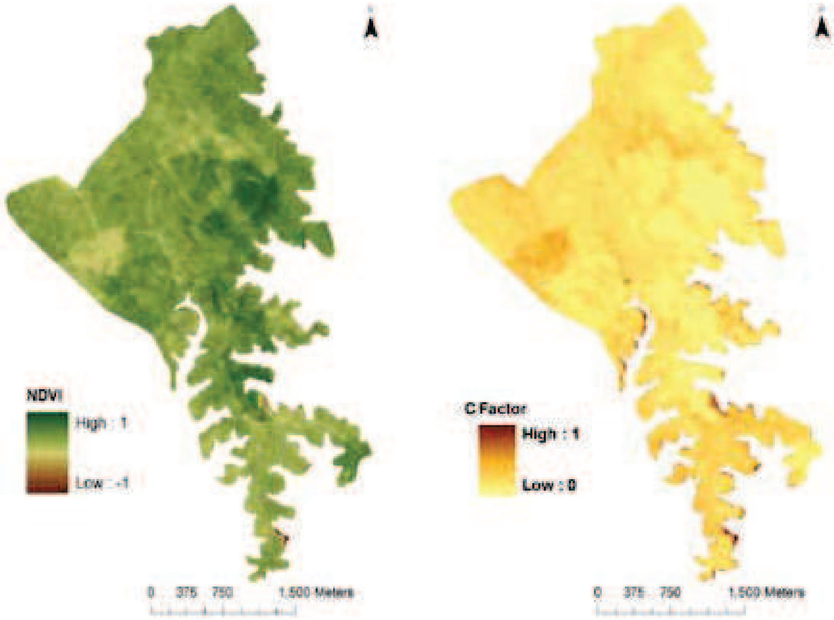


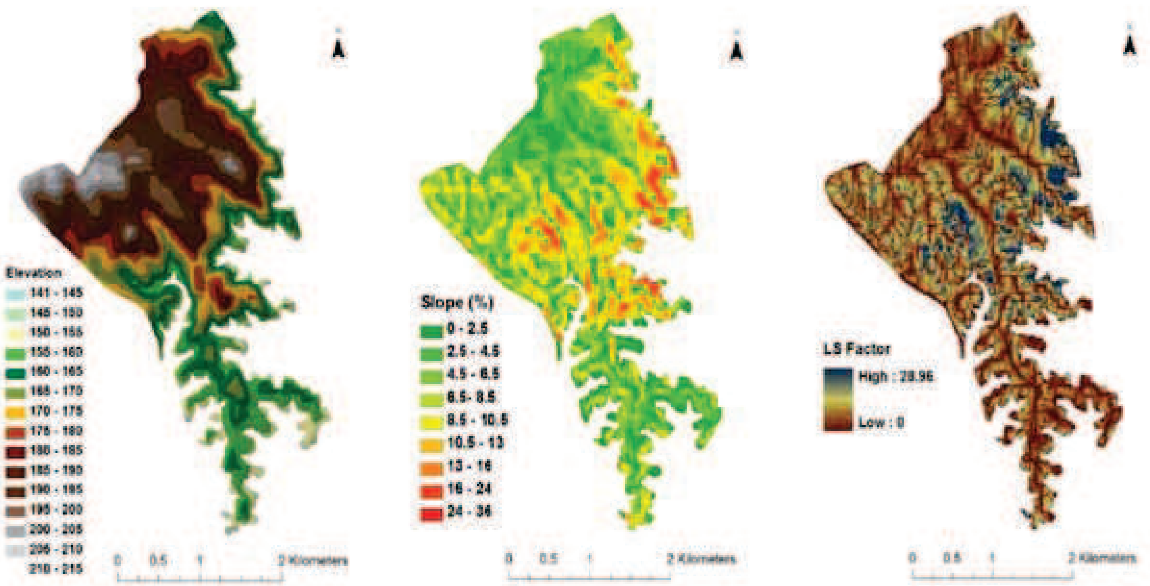
Figure 12 shows the typical NDVI values in this area and the corresponding estimated C factor. NDVI values in this agro-silvo pastoral system, before the implementation of the tourism project, were found to have a maximum of about 0.714 and an average of 0.434. By analysing the maps it can be concluded that C Factor has a negative correlation with NDVI values and that the highest values of NDVI caused the lowest values of C factor, resulting in lowest erosion values.

Figure 12. NDVI and cover management factor maps (C-factor)



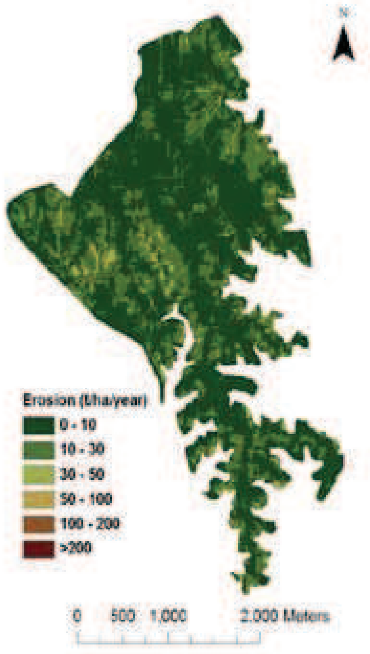
Regarding LS factor, in Figure 13 can be seen the Triangulated Irregular Network (TIN), a map of slopes and LS factor created in ArcGIS 9.3 after the production of a DEM. It was found that the elevation in this area ranges between 145-215 meters. Slope values in this study area vary from 0 to 36% with an average of 5.4%, whereas only 2.5% of total area exceeds a slope of 15%. The highest slopes result in an increased overland flow, rilling and concentrated flow depth. LS factor in the study area, which depends on slopes and flow accumulation, varies from 0 to 28.96, with mean and standard deviation of 1.62 and 1.81, respectively. The results demonstrate that LS factor has a clear correlation with slope, because areas with highest slope values have the highest LS factor values. The highest values of LS occur in the centre of the area, in the southwest part and the east side close to the dam.

Figure 13. Triangular irregular network (TIN) map, slope percentages map and LS map



The RUSLE factors were integrated within the raster calculator option of the ArcGIS spatial analyst to obtain and quantify soil erosion rates using RUSLE equation. The spatial distribution of soil erosion is shown in Figure 14. The annual soil loss in this agro-silvo pastoral system was estimated to have a mean 14.1 t/ha/year. The terrain with serious erosion risk (higher than 50t/ha) cover about 4.3% of area. In this map, it can be seen that these high soil-erosion risk values lie mostly in the southwest part of the experimental area. Comparing with previously results, this area has the highest slope values and lowest vegetation cover (highest values of C Factor). In addition, soils in this zone have moderate soil erodibility. These results demonstrated that the soil erosion is highly dependent on the local terrain, soil properties and land-use. The estimated values are according to the predicted values for the entire Guadiana River Watershed (INAG, 2000), that were found to vary from 0 to more than 25 t/ha and values greater than 50 t/ha occur exceptionally.

Figure 14. Map of soil erosion risk



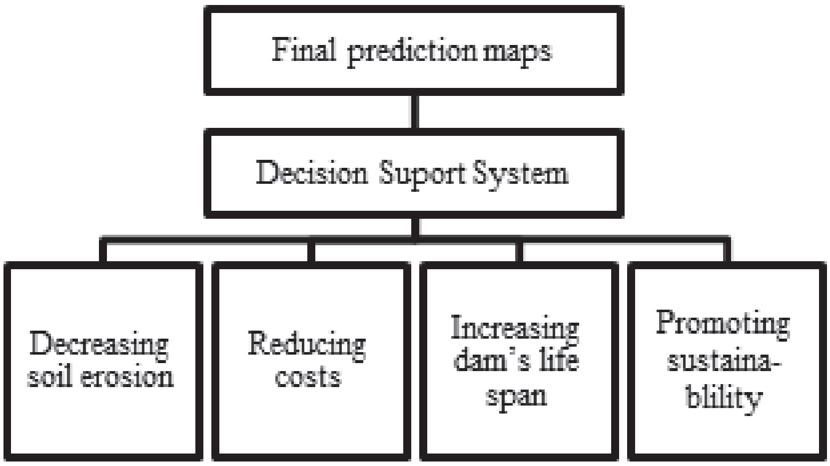
6. CONCLUSION

Modelling soil erosion is complicated because soil loss varies spatially and temporally depending on many factors and their interactions. The study proves that soil erosion model in combination with GIS is an efficient tool for determining the spatial distribution of sediment yield under a variety of simulation scenarios. The RUSLE is a good method to estimate soil erosion risk for different scenarios because it is simple, fast and economic to use. This study demonstrates that geostatistic techniques are advantageous to estimate soil erosion and their factors at unsampled locations, based on the sampled data, showing the confidence level for samples. Remote Sensing also reveals to be very useful to analyze land-use the total area of watershed.

The evaluation of soil erosion risk vulnerability is essential for sustainable land-use planning and comprehensive local and regional development. Those maps can be important to plan the future land-use alternatives and to apply specific soil conservation practices at the identified high-risk areas. Some land-use changes in vegetation management of those areas could be positive, because some soils are degraded since they were subjected to intensive agriculture in the past, some without any conservation practice. However it is important to be aware of that these future uses without adequate soil management and conservation solutions can also result in negative impacts.

In the future research we intend to analyze different land-use scenarios, which will be implemented in the region. The prediction maps produced can be used as a solid base to create a Decision Support System (DSS) so as to provide site specific methods and mitigation measures for decision-makers (Figure 15). These methods and measures could decrease the risk of soil erosion, reducing costs, increasing the dam's life span and promoting sustainability of these ecosystems. In the other hand, one DSS could increase the quality and justification of decisions.

Figure 15. Chart illustrating the potential service of a new modelling approach based on the RUSLE model



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AUTORES
Agnieszka Walczinska
Carlos Alberto Bragança dos Santos
Eric de Noronha Vaz
Thomas Panagopoulos
Vera Ferreira

UAlg
UNIVERSIDADE DO ALGARVE

CIEO
Centro de Investigação sobre o Espaço e as Organizações

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