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Development of procedures for land use assessment at the regional scale

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CHAPTER I - GENERAL INTRODUCTION

1. Land resources and the future we want

The increasing speed of the global development produces more and more serious problems and issues. World community has been trying to combat various negative processes, caused primarily by human activity, promoting sustainability and finding equilibrium between human and nature.

The increasing population, which rate is expected to reach 9 billion by 2050 (UN DESA, 2009), will require involvement of additional material and spatial resources. The world's agricultural production has already grown by 2.5 -3 times over the last 50 years while the cultivated area has grown by 12 % (FAO, 2011). The ability of agriculture to support growing population, policies and practices needed to boost production and strengthen food security have been a concern for years and continue to be high on the global policy agenda (Brown, 1981; Ehrlich *et al.*, 1993; Maxwell, 1996; Scherr, 1999; Eswaran, 2001; Rosegrant and Cline, 2003; von Braun, 2007; Schmidhuber and Tubiello, 2007; Godfray *et al.*, 2010; FAO, 2011; UNEP, 2012). The situation becomes more complicated by the fact that the biggest part of the future population is expected to be urban increasing pressure on agriculture and rural people, as well as resulting in significant land use change processes, which are already noticed worldwide.

The agricultural production increase will most likely come from the intensive use of existing agricultural lands (FAO, 2011). Generally associated with increased use of external inputs, agricultural intensification is now defined as the more efficient use of production inputs, more efficient use of labour, and better farm and land management (Dixon *et al*. 2001; IFAD, 2010). The significance of good land management was recognized at Rio+20 Summit in Brazil in June, 2012, where world leaders stressed the need to aware contribution of sound and appropriate land management to the economic growth, biodiversity, sustainable agriculture and food security (UN, 2012).

To provide sustainable land management, a comprehensive analysis of land performance under different uses should be held, taking into account multiple function of the land, environmental, socio-economic and political conditions, evaluating possible negative and positive consequences at a clearly defined scale, providing improved and sustainable land management (FAO, 2007). Unfortunately, up to date economic growth is being reached at the expense of natural resources, and many terrestrial ecosystems are being seriously degraded because of the land-use decisions failed to recognize noneconomic ecosystem functions and biophysical limits to productivity (Jones, 2012). The consequences of underinvestment, poor management and lack of governance are widely apparent now as various degradation processes of the land resources, which are expected to provide global food security in the future, and growth of poverty rates in rural areas where agricultural activity is the main source of livelihood (IFAD, 2010).

To meet the increasing population demands, additional land resources will be required and these needs will not be met unless we preserve our land and introduce new techniques and practices aimed at the rational and effective use of existing resources minimising negative impact on the environment. To combat land degradation and desertification processes worldwide, numerous projects and programs aimed at the land restoration, conservation and protection, as well as implementation of sustainable land use practices were organized and executed (Annex 1). While the principles and practices of sustainable land management are known and widely recognized, land degradation, desertification and droughts continue to be a major global threat. Therefore, sustainable land management practices are either not being adopted, or have not been as effective as perceived. According to the UNCCD (2012) to achieve "Zero Net Land Degradation by 2030" commitment, support and active investment of all public and private sector actors, of all parts of the supply and value chain related to land use, including local and community stakeholders is required. Following this idea, new generation of research projects and collaborations, apart from the advanced methodology and innovations, is characterized by orientation to and more close collaboration with the local land users and stakeholders.

Therefore, development and introduction of sustainable practices and measures should be done taking into account diversity of agricultural and environmental, as well as social conditions and systems, focusing on the drivers of the global change, which are the population and economic development (UNEP, 2012). Understanding dynamics and related processes of these drivers, connections between them will assist to address their collective impact and find possible solutions, and, therefore, preserve the environmental benefits on which human societies and economies depend.

The present work addresses two closely related and interconnected issues related to the growing population: urbanization and rural poverty – through the land resources problematique.

1.1 Urbanization

Pressure on land resources has increased during the recent years, resulting in the unprecedented land use changes created by a burgeoning population, economic and global markets development. Urbanization has progressed at an extraordinary rate in the recent decades and this growth is projected to continue throughout the century (Figure 1, Figure 2).

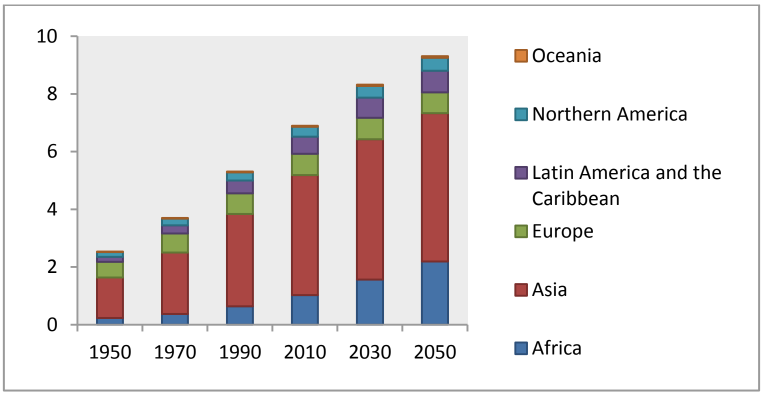

Figure 1 - Urban population (billion) 1950-2050 (UNEP, 2012).

The world will add approximately one new million-plus city every five days until 2050 (Fragkias and Seto, 2012). Significant increase in land requirements for urban uses is expected in the next 40 years: potentially an additional 100–200 million hectares will be taken (Bettencourt *et al.* 2007).

Urban areas consumes mostly agricultural land, but also reduces space of natural and forest areas that provide important services like regulation of the water balance and protection against floods, particularly if soil is highly sealed (Jones, 2012). According to the assessments of the European Environment Agency (2010) performed during the period of 2000-2006 the mean annual land uptake for urban purposes in 36 European countries was 111,788 ha/year. The urban areas in Europe have been increased mainly due to agricultural and, to a lesser extent, forests, and semi-natural and natural areas (Figure 3).

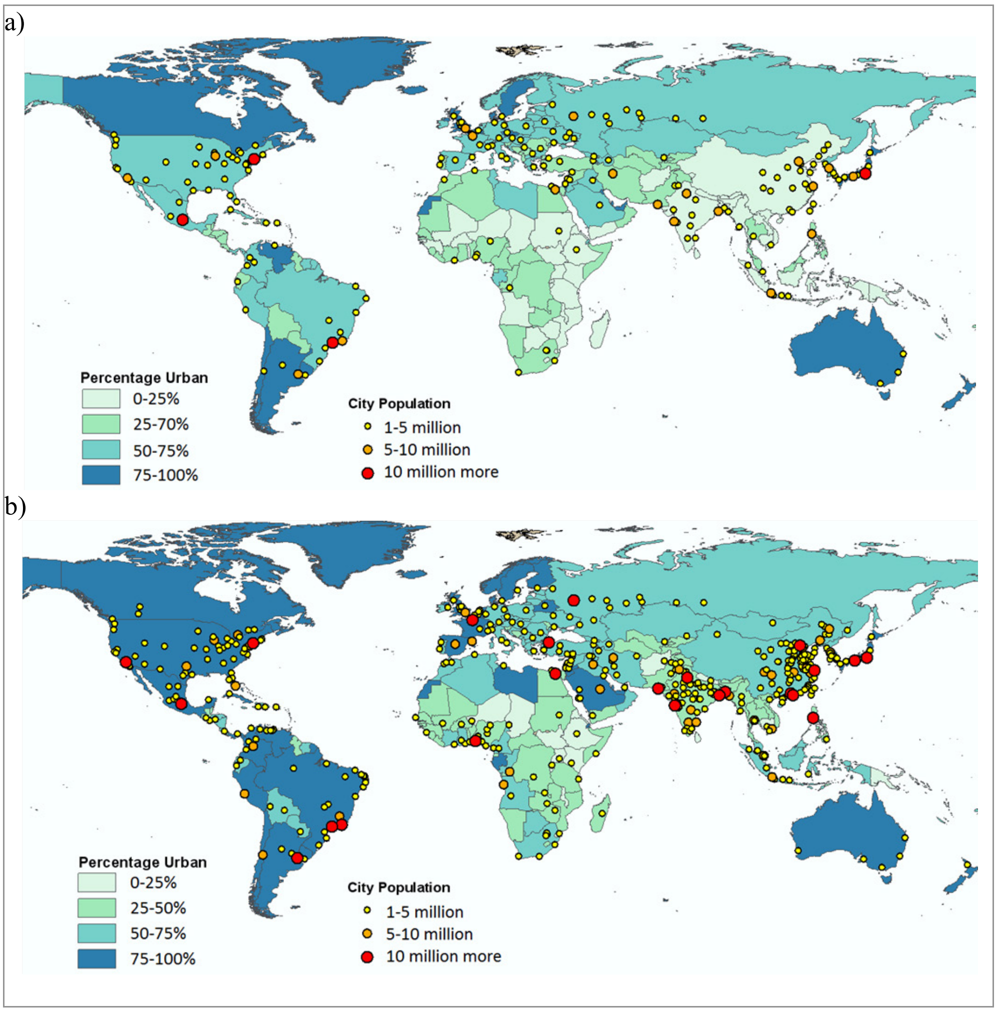

Figure 2 – Percentage of urban population and agglomerations by size class in 1980 (a) and 2011 (b) (UN DESA, 2011)

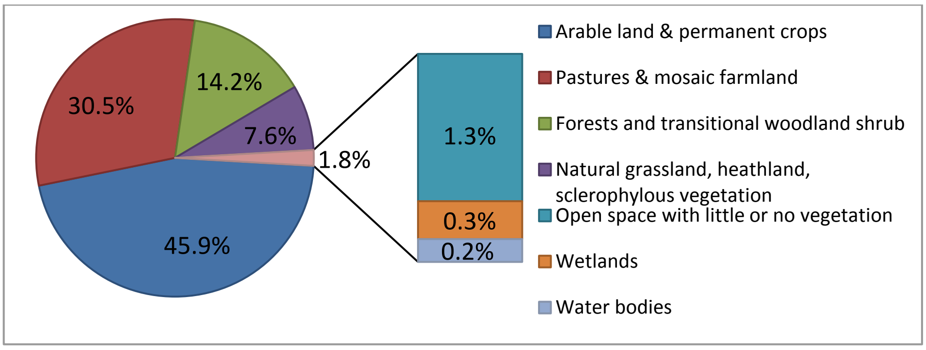

Figure 3 – Relative contribution of land-cover categories to uptake by urban and other artificial land development estimated by the origin of land uptakes as % of total uptake (EEA, 2010).

In average, during this period almost 46 % of the arable land or land under permanent crops was transformed into artificial surfaces. Other spatial sources of urban area development are pastures and mixed farmlands which, on average, made 30.5 % of the total uptake, forests and transitional woodland shrub (14%), natural grassland, heathland and sclerophyllous vegetation (7.6 %), open space with scarce or no vegetation also contributed to urban areas by 1.3 %. Wetlands and water bodies contributed 0.3 % and 0.2 % respectively. Generally, the amount of forests, grasslands and open spaces areas taken by artificial land development were higher than in the previous decade, proving higher loss of natural ecosystems during the period of 2000-2006 (EEA, 2010).

The total land uptake by urban and other artificial development in 36 European countries for the period 2000-2006 amounted to 686 414 hectares, though being almost the same as in the previous decade (1990-2000), land uptake by urban development and transport infrastructure has been slightly faster than in the previous 10 years (EEA, 2010).

The process of transition to urban and infrastructure areas is generally irreversible and results in soil sealing. Converted areas become highly specialised in terms of land use, supporting few functions, being used only as a spatial basis. Understanding land use dynamics under human activity pressure is an important scientific issue, aiding evaluation of the system behaviour under different conditions, assessing importance of different drivers, and thus, predicting future trends and potential changes (Rounsevell *et al.*, 2003).

1.2 Rural poverty

In the future, continued population growth, urbanization and climate change will keep putting pressure on the already scarce resource base. While natural resources are of a great importance for agricultural growth, people still remain the main concern (IFAD, 2010). One of the main problem facing rural areas is the high levels of poverty of the people involved in agricultural production, especially in developing countries, resulting in the unprecedented rural-urban migration (Tacoli *et al.*, 2008). To sustain rural population, improving their livelihood, different strategies aimed at rural development are now being established and implemented by global community (de Janvry and Sadoulet, 2010).

Promotion of the rural economy in a sustainable way has the potential of increasing employment opportunities in the rural areas, reducing regional income disparities and stemming rural-urban migration, as well as reducing the poverty. Moreover, development of the rural areas may contribute to the preservation of the rural landscape, protection of indigenous cultures and traditions (IFAD, 2010). One of the strategies to sustain rural economies is income diversification. In fact, presently rural people are more and more deriving their incomes from non-farm sources along with traditional on-farm activity, since diversified income is often a key aspect in reducing and managing risks of failure (IFAD, 2010).

Such strategies are giving some producers a competitive advantage in today's marketplace. Value can be added to various agriculture products produced and sold to increase profit potential (Burr, 2011). As an effective source of income and employment, particularly in peripheral rural areas, agricultural tourism has been widely promoted, achieving economic and social development and regeneration (Sharpley, 2002). In order to ensure successful implementation of such type of activity and avoid negative consequences, capacity and suitability of land and related resources to support agricultural tourism are to be evaluated.

2. Land evaluation and land evaluation procedures

Sound land governance, supported by proper land use decision making and implementation processes, which takes into account existing governance alongside the social, economic and environmental conditions and their dynamics, is fundamental in achieving sustainable development (Enemark, 2009, Palmer *et al.*, 2009).

To define optimal destination for the land, comprehensive analysis of land performance under different uses should be held, evaluating possible negative and positive consequences at a clearly defined scale. The process of land evaluation should be focused, primarily, on the analysis of land data (soils, climate, vegetation, etc.) and on the identification of the effects and benefits of land uses, providing improved and sustainable management of land (FAO, 2007).

The land suitability for different purposes has long been the subject of evaluation. There exists a wide range of land evaluation systems and methodologies, from the most simple single-factor correlation to the very complicated and complex formulae and models. Land evaluation systems can be generally classified into four main groups: parametric systems, categorical (capability) systems, special purpose systems, and crop-specific assessments (FAO framework) (Verheye, 2008).

Parametric systems (Storie index, the Riquier, Bramao and Cornet System) find their origin in the field trials and fertility tests, especially where a good correlation could be found between crop yield and one or more key factors. Parametric systems like all numerical correlations are simple quantified expressions of soil productivity. Their reliability depends on the choice of the factors determinants, their weighting and the validity of the assumed interactions between the factors. In parametrical approach all factors with a relevant impact on the land use are allocated a numerical value ranging between 1(highest) and 0 (the lowest value). The final index is obtained by either multiplying or adding the individual rating values.

The original Storie Index Rating (SIR) was calculated by multiplying separate ratings for profile morphology (A), surface soil texture (B), slope angle (C), and modifying conditions such as soil depth, drainage, or alkalinity (X). The factor ratings provided were to be taken as guides rather than as absolute values and the ratings were to be changed as soil scientists gained experience with the index (De la Rosa, 2002).

Special-purpose systems are mainly represented by USBR (The US Bureau of Reclamation) land suitability classification for irrigation and FCCS (Fertility Capability classification system). The USBR classification system for irrigated land is carried out in the context of a project plan and with respect to the land uses defined under the project plan, which may be broadly or narrowly defined (FAO, 1985). The system is based on the following principles of prediction, economic correlation, permanent and changeable factors, and arability-irrigability: i) the classification should reflect future conditions as they will exist after the project is implemented; ii) a unique relationship can be established during a classification, between physical conditions of the land such as soils, topography and drainage and an economic measure of the class ranges; iii) the classifier must distinguish between permanent factors, such as soil texture, soil depth, macrorelief, etc., and changeable factors, such as salinity, pH, microrelief, nutrient status, water table levels, etc; iv) land which is physically and economically capable of providing a farmer with an adequate standard of living, should water be available for irrigation, is first classified. Such land is called “arable” which constitute areas that warrant consideration for inclusion in a plan of development. The FCCS is a technical classification of soil according to their fertility limitations (both physical and chemical) with emphasis on topsoil properties but including relevant subsoil parameters as well (Sanches, 1979).

In 1973 the United States Department of Agriculture (USDA) provided specific guidelines for Land Capability Classification (Panhalkar, 2011). Aimed at the support of land management, the land capability procedure evaluates ability of the land to sustain agricultural production without soil degradation or negative effects. According to this framework, land units are classified into three hierarchical levels: classes, subclasses and units (Klingebiel and Montgomery, 1961). The class is assessed by an index from 1 (best) to 8 (worst). The index of class represents a general degree of "goodness" of the soil in the sense of a possible intensity of use. The subclass indicates the main limitations for intensive agricultural use, using one or more letters. The subclasses provided by USDA: *e* - danger of erosion, *w* - excess water, *s* - limitations due to the soil in the root zone as the sole surface, skeleton, constitutional low fertility, salinity, etc., *c* - climatic constraints (temperature or precipitation). The Unit is a division of the subclass that is distinguished from other units of the same subclass for a specific limitation and a different type of management required in order to overcome the limitation.

In 1976 a framework for the land suitability assessment for different uses was developed by FAO. Following this framework, land is classified according to its suitability for specific use, i.e. land characteristics compliance with the requirements of the use (FAO, 1976, FAO, 2007). The final classification is hierarchical and implies first division by order "suitable" (S) or "not suitable" (N), the orders are then divided into classes at different levels of vocation S1 (suitable), S2 (moderately suitable), S3 (marginally suitable) or of vulnerability N1 (currently not suitable), N2 (permanently not suitable).

A land evaluation procedure is intended as a framework where, given a certain evaluation goal, the evaluation criteria and related indicators (calculated from objective and subjective information) are defined to give a ranking of suitability or vulnerability for that land use. While developing land evaluation procedure, first of all, it is necessary to define the aims and the goals of the evaluation, subsequently defining set of evaluation criteria and appropriate indicators and establish also the manner in which the indicators will be calculated and aggregated in order to obtain final evaluation index. An indicator is a numeric value aimed at the representation of some qualitative information. To do this, complex land information is to be normalized and transformed into a definite scale. In evaluation process, indicators support a decision criterion. For each indicator in the procedure it is necessary to define the method of calculation (algorithm) and the critical (extreme) values which will define favourable and unfavourable conditions. The selected indicators should pertain to the aims of evaluation, represent relationships between factors and consequences, respond to the variations of factors, be clear, etc.

Once defined the evaluation model the next step is to recover basic information and its processing. Being of heterogenic nature land information only in some rare cases can be used directly. Usually, before application, it is to be verified and elaborated in some ways: conversion and format transformation, reconstruction (interpolation, spatialization) etc. After model application and obtaining the results, the next step is evaluation of the model outcomes performing validation. If the confidence in model and results is high enough, the cartographic results can be distributed among stakeholders and implemented as land interventions or establishment of regulations on constraints, protection and incentive measures.

3. Objectives and tasks

Multi-criteria land evaluation is an important process required for sustainable resource management. During the process of land evaluation, various factors related to land and corresponding resources need to be addressed. Frequently, development of sound evaluation procedure requires a number of expert and specific knowledge to be involved in the process. For these reasons, already developed automated procedures are particularly valuable, as they allow any user to perform land evaluation for different activities, simply preparing the necessary input data.

Following this idea, the efforts during the Ph.D. program have been dedicated to the development and assessment of the automated land evaluation approaches and tools designed to support decision making process and land management. The thesis, consisted of six chapters, presents approaches aimed at the evaluation of the land resources use. The **first chapter**, focused on the general introduction, outlines the research problems and tasks. The **second chapter** presents an approach to the modelling of land use change processes by use of Cellular Automata techniques integrated with Markov Chain analysis. The approach aimed at the evaluation of agricultural, forest and seminatural land uptake by urban expansion was developed studying the Udine conurbation area, located in Northeast Italy. The **third chapter** describes a fuzzy-based land evaluation model developed to assess land suitability for agricultural tourism development in the Republic of Buryatia, Southeast Siberia, Russia. The area of Lake Baikal becomes more and more attractive for domestic and international tourists, which causes intensification of local authorities' work on promotion of various types of tourism in Buryatia, where particular attention is paid to agricultural tourism, which is expected to bring more sustainability in rural economy, providing rural people livelihood improvement. In order to secure successful realization of the agricultural tourism in Buryatia, as well as prevent negative consequences of the activities performed, it is necessary to evaluate whether given area meets the required environmental and socio-economic conditions. Case study on Dzhidinsky region is discussed.

Prediction capability and reliability of land evaluation procedures, the validation of which in a classical empirical way is almost impossible, are the issues of the next **forth chapter**, where an approach based on spatial sensitivity analysis is presented. The **fifth chapter** introduces land evaluation tools and, particularly, a raster GIS *SemGrid* (Danuso and Sandra, 2006), where all procedures were implemented and evaluated and the weather generator *Climak 3*. The last **sixth chapter** contains general conclusions and consideration on the studies performed, highlighting points and recommendations needed to be taken into account for further elaborations and improvements of the proposed approaches and models. Each chapter is followed by a list of work references used to examine, analyse and develop the thesis issues. The main body chapters are also supported by the annexes.

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Annex 1. Land degradation and sustainable land management projects

Name	Period	Partners	Goals/objectives	Description
Combating land degradation, droughts and desertification				
DESERTLINKS, http://www.kcl.ac.uk/projects/desertlinks/	2001- 2005	11 research groups from universities and institutes in Portugal, Spain, Italy, Greece, the Netherlands and the United Kingdom.	Contribution to the work of the United Nations Convention to Combat Desertification by developing a desertification indicator system for Mediterranean Europe.	Identification of impact indicators relating to perceptions of land function; driving force and pressure indicators relating to decision making; response indicators relating to land management measures taken to combat desertification. Composite indicators are developed combining stakeholder-identified indicators with bio-physical and socio-economic state indicators already developed for Mediterranean Europe. Together they form an environmentally sensitive area identification system, for use at the sub-national scale. In addition, coarse scale modelling of soil erosion, salinization and channel processes provides a regional degradation index at the Mediterranean-wide scale. The indicators of different scale and type are combined into a desertification indicator system for Mediterranean Europe to explore different management options identified by the local stakeholders. Finally, the experience gained in both the testing and validation of index application is formulated into guidelines for the UNCCD on the development and use of indicators to manage desertification.
LADA (LAnd Degradation Assessment), http://www.fao.org/nr/lada/index.php	2006-2010	FAO, UNEP, GEF, international organizations, universities, research centres of Argentina, China, Cuba, Senegal, South Africa and Tunisia.	Creating an informed policy advice on land degradation at global, national and local level through the assessment of land degradation at different spatial and temporal scales and the creation of a baseline at global level for future monitoring.	At a global level, provides a baseline assessment of global trends in land degradation using a range of indicators collected by processing satellite data and existing global databases (Net Primary Productivity (NPP), Rainfall Use Efficiency (RUE), Aridity Index, Rainfall variability, Erosion risk), which are then used to overview the main factors induced by human activity, affecting the development of land degradation in a given area (Land cover, Urban and protected areas, Livestock pressure, Irrigation, Crops, etc). The national assessment is based on nationally available datasets and national expert knowledge, organized on two main legs: a nationally refined version of the Land Use Systems map (LUS); a questionnaire on land degradation. At the local level, set of biophysical and socio-economic indicators, prepared in collaboration with the University of East Anglia and the WOCAT, used to identify not only the actual status and circumstances of land degradation, but also its historical development and the perception of it by the people, in order to allow a better understanding of the phenomenon, and provide pertinent information for the definition of response measures.

DESIRE, http://www.desire-project.eu/index.php	2007-2012	28 research institutes, non-governmental organizations and policy-makers from around the world.	Establishing of promising alternative land use and management conservation strategies in sixteen degradation and desertification hotspots around the world, based on a close collaboration of scientists with local stakeholder groups.	Close participation of scientists with stakeholder groups in desertification hotspots around the world. Identified conservation strategies will be implemented in the field, to monitor and model their effectiveness at various scales. Results will be extrapolated using indicators, maps, and modelling combining socio-economic and environmental aspects. Finally, the results will be translated into a series of practical guidelines for environmental management, which will be disseminated to all relevant stakeholders, in various formats, and in different languages. Local facilitators will be trained to bridge the gap between scientists and non-scientific product users, and training packages will be made.
The CACILM Multicountry Partnership Framework Support Project (CMPF Support Project), http://www.fao.org/nr/land/projects-programmes/cacilm-initiative/en/	2005-2015	Five Central Asian Countries (CAC) Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan.	Combating land degradation and improving rural livelihoods by adopting an integrated approach to land use planning and management, taking into consideration current international efforts towards a harmonization of land data and information management.	CACILM intends to introduce the LADA methodology and indicators and will work with National Institutes and FAO on the design and development of a sustainable land management information system (SLMIS).
Transboundary Agro-ecosystem Management Project for the Kagera River Basin (Kagera TA MP), http://www.fao.org/nr/kagera/en/	2009-2014	FAO, UNEP, Burundi, Rwanda, Uganda, United Republic of Tanzania.	Adopting an integrated ecosystems approach for the management of land resources in the Kagera Basin that will generate local, national and global benefits.	The adoption of improved land use systems and resource management practices by the range of land users will be supported by stakeholders at all levels and by participatory and inter-sectoral approaches through enhanced regional collaboration, information sharing and monitoring; enabling policy, planning and legislative conditions; increased stakeholder capacity and knowledge at all levels for promoting integrated agro-ecosystems management.
LEDDRA (Land and Ecosystem Degradation and Desertification: Assessing the Fit of Responses), http://leddra.aegean.gr/index.htm	2010-2014	Greece, The UK, The Netherlands, Spain, Germany, Italy, Morocco, China	Advancing comprehensive study of the socio-environmental fit of responses to land and ecosystem degradation and desertification (LEDD) in various contexts.	Adopts the ecosystem approach and an integrated methodology with continuous feedbacks between theory, methods and applications. It focuses on response assemblages (combinations of response types and prevailing environmental, socio-economic and institutional conditions that contribute to or detract from sustainable land management and societal welfare), the associated costs and benefits to diverse stakeholders, barriers to and opportunities for adoption, and knowledge transfer processes.

The REDD-PAC project, http://www.redd-pac.org/index.php	2011-2015	Brazil and the member countries of the Central African Forests Commission (the Congo Basin) further six countries (China, Ecuador, Peru, the Philippines, Uganda and Vietnam).	Identify policies that are economically efficient and socially fair and can safeguard and enhance ecosystem values and help meet the goals of the Convention on Biological Diversity.	A refined global land-use model (GLOBIOM) will be used in scenario analysis of land-use changes under different REDD+ policies, with a focus on Brazil and the member countries of the Central African Forests Commission (COMIFAC) in the Congo Basin. The complementary expertise of the partner organizations will be leveraged to provide a spatially-explicit and multi-criteria assessment of different REDD+ policy options, from an economic, environmental and biodiversity point of view. GLOBIOM projects land use change by spatially modelling supply and demand for competing agricultural, bioenergy and forest commodities. Furthermore, the project will act as a global forum for sharing and improving global data on forests and deforestation drivers, developing reference methodologies and best practices for national REDD+ modelling, as well as more general land-use planning.
Implementing sustainable land management				
KASSA (Knowledge Assessment and Sharing on Sustainable Agriculture), http://kassa.cirad.fr/	2004-2006	France, Denmark, Germany, Norway, The UK, Estonia, Czech Republic, Ukraine, Spain, Morocco, Italy, Greece, India, Vietnam, Brazil, Bolivia, Argentina.	Building up a comprehensive knowledge base on sustainable agricultural practices, approaches and systems in support of European stakeholders: farmers and professionals, researchers and policy makers at local, national, European and global level.	Focused on conservational agriculture the project was implemented simultaneously through four regional platforms: Asia, Europe, Latin America and the Mediterranean, allowing comparison of conservation agriculture practices and experiences across agroecosystems within a large diversity of climates, soils, farming and cropping systems, and socio-economic conditions. KASSA was built on 3 successive tasks each followed by a validation meeting: 1) Comprehensive inventory, assessment and critical analysis of existing knowledge on sustainable agriculture; 2) Learning from local/regional past and ongoing experience; 3) Refining findings. Before the results final delivery, they were critically analysed and assessed by an external panel of experts.
SENSOR - Sustainability Impact Assessment: Tools for Environmental, Social and Economic Effects of Multifunctional Land Use in European Regions, http://www.sensor-ip.org/	2004-2009	Leibniz-Centre for Agricultural Landscape and Land Use Research, Germany, and 35 research institutes throughout Europe, China, Brazil, Argentina and Uruguay.	To develop ex-ante Sustainability Impact Assessment Tools (SIAT) to support decision making on policies related to multifunctional land use in EU regions to enable the economic valuation of social and environmental goods and services; to address region-specific problems, risks and thresholds of sustainability.	The project is based on three key assessment streams: European-wide, indicator-based driving force and impact analysis of land use policy scenarios; region specific problem, risk and threshold assessment making use of spatial reference systems, land use functions and participatory processes; case study based, exemplary sensitive area studies in mountains, islands, coastal zones, post-industrial areas using detailed information on specific sustainability issues, and engaging with stakeholders at the local level. For each policy area, the outputs of the tool were validated with local stakeholders, and a methodology for future stakeholder engagement was developed for use alongside the tool.

FORESCENE Development of a Forecasting Framework and Scenarios to Support the EU Sustainable Development Strategy, http://www.forescene.net/	2005-2008	EU 27.	Develop a framework for creating sustainability scenarios, which integrate different environmental topics such as water, soil, resource use etc. The project will focus on backcasting, to identify different scenarios leading to achievement of future targets.	Description of the chosen by the European commission environmental problems; review of policy objectives and indicators; definition of the cross-cutting driving forces; development of core elements of integrated sustainability scenarios (goal definition); definition of measures and processes to be considered for change (pre-backcasting); addressing quantitative and qualitative parameters for measurement (parametrization); development of a Business-As-Usual (BAU) scenario framework and example projections (forecasting); development of alternative scenarios (incl. backcasting); check the options for modelling, and work out conclusions.
SOILSERVICE (Conflicting demands of land use, soil biodiversity and the sustainable delivery of ecosystem goods and services in Europe), http://www4.lu.se/o.o.i.s/26761	2008-2012	Sweden, The Netherlands, Czech Republic, Finland, Germany, Greece, The UK, Denmark.	Develop methods to value soil ecosystem services during different pressure of land use and changes in soil biodiversity.	Combines interdisciplinary empirical studies and soil biodiversity surveys to construct soil food web models and determine effects of changing soil biodiversity on stability and resilience of carbon, nitrogen and phosphorus cycling, as well as assessing consequences for outbreaks of pests or invasive species. The project links ecological and economic models to develop a system for valuing soil biodiversity in relation to ecosystem services.
Sustainable land management project for Senegal, http://www.worldbank.org/projects/P108144/sustainable-land-management-project?lang=en	2009-2012	World bank, Senegal.	Contribute to the reduction of land degradation and the improvement of ecosystem functions and services in the target areas by adopting sustainable land management practices through the provision of support to the recipient's research and agricultural and rural consultation system and to producer organizations.	There are four components to the project, the first component being support to the agricultural research system, which seeks to increase the capacity of the National Agricultural Research System to generate and disseminate sustainable land management targeted research and knowledge. The second component strengthens agricultural advisory services aimed at supporting the extension of the agricultural advisory system and consolidation of a pluralistic network of service providers. The third component supports producer organizations aimed at strengthening the capacity of producer organizations to access technical and economic services, and to participate in policy formulation. Finally, the fourth component is aimed at the support of sectoral coordination aimed at strengthening the capacity of sectoral ministries (e.g. agriculture and livestock) in policy formulation, planning, coordination, and monitoring and evaluation.

RURAGRI ERA-NET (Facing sustainability: New relationships between rural areas and agriculture in Europe), https://www.ruragri-era.net/	2009-2013	France, Germany, Latvia, The Netherlands, Ireland, Slovenia, Cyprus, Sweden, Lithuania, Israel, Turkey, Denmark, Austria, Hungary, Switzerland, Spain, Poland, The UK, Belgium, Italy.	The reorientation of agriculture towards improved ecological practices, the economic viability of rural areas and their contribution to sustainable development.	RURAGRI is an ERA-NET supported by the European Commission under FP 7. The objective of the ERA-NET scheme is to step up the cooperation and coordination of research activities carried out at national or regional level in the Member States and Associated States. To improve coordination of research in the field of agriculture, rural development and sustainable development, the ERA-Net members will: map existing research programs in these scientific fields and characterise their main features and identify key differences; elaborate a common research agenda and identify potential synergies between consortium partner countries to improve their research capacity; implement joint activities for selected research programs; establish appropriate governance and financial mechanisms which would enhance the initiation and implementation of a common research programme.
CIRCUSE (Circular Flow Land Use Management), http://www.circuse.eu/	2010-2013	Poland, Germany, Austria, Slovakia, Italy, Czech Republic.	Designed to overcome problems of spatial and urban development seen in the transformation of Central European cities and regions by the loss of a number of historical industries, military conversion, inner-urban segregation, migration and demographic change, and to create climate beneficial land use structures and contribute to "developing polycentric settlements structures and territorial cooperation".	Climate friendly land use concepts will be developed and implemented in coherence with new instruments and pilot actions. The project targets will be reached by a strategic approach to urban and peri-urban development based on the principle of Circular Land Use Management. The concept represents an integrative policy and governance approach which presupposes a changed land use philosophy with regard to land utilization (strategy pages). Integrated development strategies and investments will be achieved by providing a viable framework, action plans and pilot projects on land use management as precondition for private investments (pilot projects). The interregional land use data base should support local decision makers on land use options and monitor the impacts on the polycentric development. The spatial concept and instruments will support the urban centre structure and enhance the quality of environment by the creation of open space on former brownfields.
VOLANTE (Visions Of LANd use Transitions in Europe), http://www.volante-project.eu/	2010-2015	14 research groups from universities and institutes in The Netherlands, The UK, Finland, Austria, Germany, France, Greece, Romania, Belgium, Denmark and Italy.	Provision of an interdisciplinary scientific basis to inform European land use and natural resource management policies and decision-making.	Research is structured in modules, centred on the research foci: improving understanding of the processes underpinning land use change, the refinement of assessment tools, and the development of policy relevant visions that help in the identification of sustainable development pathways. Coordination module covers both project management and the scientific coordination between the other modules.

SOLINSA (Support of Learning and Innovation Networks for Sustainable Agriculture), http://www.solinsa.net/	2011-2014	Switzerland, Italy, Germany, The UK, The Netherlands, Hungary, Latvia, France.	Identification of the effective and efficient approaches for the support of successful LINSA (Learning and Innovation Networks for Sustainable Agriculture) as drivers of transition towards Agricultural Innovation Systems for sustainable agriculture and rural development.	Project partners will collaborate with practitioners involved in LINSAs in a series of workshops and consultations throughout the SOLINSA project. Project partners and a group of expert advisors will together reflect on the processes involved in the study of LINSAs to adapt and refine the collaborative learning and research methods. SOLINSA will be characterised by policymakers, practitioners and researchers sharing their experiences and views in a platform that encourages ongoing reflection on the learning processes.
Other				
iSOIL (Interactions between Soil Related Sciences – Linking Geophysics, Soil Science and Digital Soil Mapping), http://www.isoil.info/	2008-2011	Germany, Belgium, The Netherlands, Bulgaria, Czech Republic, The UK, Switzerland, Italy, Austria.	Validate and evaluate necessary concepts and strategies for the transfer of measured physical parameter distribution into maps.	iSOIL develops new strategies and innovative methods for generating high resolution and accurate soil property maps, thereby reducing costs compared to traditional soil mapping. This is being achieved through the Integration of three major components: high resolution, non-destructive geophysical and spectroscopic methods; concepts of Digital Soil Mapping (DSM) and pedometrics; optimized soil sampling with respect to profound soil scientific and (geo) statistical strategies.
HELM (Harmonised European Land Monitoring), http://www.fp7helm.eu/ms/fp7helm//fp7helm_home/	2011-2013	ETC-SIA, EFI, Austria, Czech Republic, Finland, Hungary, Israel, Luxemburg, Norway, Portugal, Spain, Belgium, France, Bulgaria, Iceland, Italy, The Netherlands, Romania, The UK and Switzerland.	Making European land monitoring more productive by increasing the alignment of national and sub-national land monitoring endeavours and by enabling their integration to a coherent European data system.	HELM is a network of authorities concerned with land monitoring across Europe. It will initiate a move to increase the maturity of European land monitoring along five sequential steps: 1) communication between stakeholders involved in national land monitoring programmes or activities, 2) shared visions and planning for the future, 3) joint activities by taking on tasks collectively, 4) alignment of national systems involving the mutual adaptation of data interpretation methods and of the timing of data gathering, and 5) lasting integration and combining data across all administrative levels.

CHAPTER II – AN INTEGRATED CELLULAR AUTOMATA – MARKOV CHAIN APPROACH TO REPRESENT LAND USE/COVER CHANGE

1. Introduction

Land use/cover change is a complex dynamic process driven by a system of different factors and forces. Often this process leads to the environmental, landscape, as well as economic damages and thus requires assessment of the land use evolution to foresee future trends.

Prediction of land use trend is not an easy issue: many stochastic and deterministic approaches such as Markov chain model *MC*, Cellular automata *CA*, spatially explicit simulation models, agent-based models, etc. have been applied to simulate land use change processes (Boumans *et al.*, 2001; Gellrich *et al.*, 2007; Matthews *et al.*, 2007; Mitsova *et al.*, 2011). Complexity of the phenomena to model, data availability, type of output, results expected and level of their reliability vary significantly, and all these factors have to be considered before choosing the model and the approach.

One of the approaches used in spatial and temporal dynamic modelling of the land use change is *MC* analysis. *MC* represents the probabilistic change, over the time, of the state of system elements (grid cells); this change can be parameterized by estimating the transition probability matrix among the discrete states observed (Balzter, 2000). Having a set of n possible states s_i, for $i=1,\ldots,n$, each element starts in one of these states and moves, at each step, to the next one with probability defined by the transition matrix. The *MC* transition matrix gives indications about the direction and magnitude of future changes (Fan *et al.*, 2008), being particularly useful when changes in the landscape are difficult to describe due to the lack of *in situ* statistical data (Zhang *et al.*, 2011) or when changes and processes in the landscape are interpreted with difficulty (Falahatkar *et al.*, 2010). Although the probabilities may be accurate on a *per category* basis, this approach is not able to represent by itself the spatial relationships among the possible transitions and cannot express the socio-economic background of a simulated urban area (Araya and Cabral, 2010; Zhang 2011).

In order to improve the representation ability of the *MC* approach it has been integrated with *CA* techniques (Luijten, 2003; Ye and Bai, 2008; Kamusoko *et al.*, 2009;

Guan *et al.*, 2011). *CA* have shown to be particularly suited for the analysis of land use change in urban and periurban areas (Norte Pinto *et al.*, 2010; Mitsova *et al.*, 2011), for their capability of simulating a wide range of geographic phenomena due to their inherent spatiality and for their ability to simulate complex patterns of the land use, which frequently can be found in urban fringe areas. An additional advantage is that they can operate in combination with other planning models, geographical information systems or digital image processing systems, to support decision making in a planning context (Ozah *et al.*, 2010).

CA is a dynamic system composed by a set of cells which can assume one of *n* discrete states at a time. The state of a cell depends on its previous state and on the states of cells in its neighbourhood, i.e. cells change their states as a function of their current states and the states of adjacent cells, according to given transition rules, which can be qualitative, quantitative or both. A set of transition rules, which specifies the behaviour of cells in time, is the main component as well the main challenge while setting up a *CA* model. There is a number of possible rules that can determine cells behaviour, and it is difficult enough to define those, which would describe land use change dynamic in a best way, providing reliable results.

Apart from the local transition rules, the *CA* models can be globally controlled by spatial and quantitative constraints (Zhang *et al.*, 2011), where the latter consists in the application of additional parameters frequently determined in advance by another model. Among the most used exogenous models in combination with *CA* there are linear regression (He *et al.*, 2008), system dynamics models (Han *et al.*, 2009) and *MC* analysis (Falahatkar *et al.*, 2010, Zhang *et al.*, 2011).

Combination of *CA* and *MC* analysis allows both temporal and spatial dynamics to be managed on the basis of the transition probabilities matrix and of the defined *CA* rules (Kamusoko *et al.*, 2009). Joint with GIS capabilities, *CA-MC* models have become a powerful tool for simulation and evaluation of land use change dynamics. For this reason some GIS software have been integrated with *MC* and *CA* functionalities. In *ArcGIS 9.0* (Esri, NY), a *CA* algorithm has been introduced to simulate urban growth process (Alkheder and Shan, 2005). Ozah *et al*. (2010) have recently introduced a script with *CA* transition rules in *ILWIS 3.4* (Integrated Land and Water Information System, an open source digital image processing and GIS package, ITC, Enschede), for the purpose of simulating rural land use dynamics. The module *CA_Markov* of *Idrisi* GIS (Clark Labs, Worcester) is one of the most widely used in land use simulation (Paegelow and Olmedo, 2005; Houet and Houbert-Moy, 2006; Sun *et al.*, 2007; Araya and Cabral, 2010; Zhang *et al.*, 2011).

Recently, a *CA* module has been implemented in *SemGrid*, a freeware raster GIS, developed at the Department of Agricultural and Environmental sciences of University of Udine, Italy (Danuso and Sandra, 2006). Further development and integration with *MC* approach have resulted in a *SemGrid* command `camc`, which allowed development of the *CAMC* approach presented in this work. The model is spatially explicit and simulates land use change on a grid cell basis, considering both stochastic aspects and spatial relationships (e.g. proximity to roads, urban centres, etc.). It should be kept in mind that the *CAMC* was not intended to be a model as such, but rather an approach or a framework through which required indicators can be implemented in order to represent complex processes of the land use system. Current *CAMC* indicators were employed with a view to demonstrate the approach workflow and functioning. The *CAMC* approach has been developed and then evaluated by simulating artificial, agricultural, and forest and semi-natural area dynamic in the Udine conurbation area, Friuli Venezia Giulia, North-East Italy, on the basis of land use maps of the years 1950 and 2000.

2. CAMC methodology

The *CAMC* model refers to a concept of transition suitability (*TS*), i.e. the future state of a cell depends on its propensity to transition, which is defined by: a) current cell state, b) states of the adjacent cells, c) other conditions and factors related to the cell neighbourhood, such as closeness to roads and urban centres, etc. and 4) rules governing the evolution of the territory. The simulation procedure (Figure 1) is consisted of the following steps:

1) calculation of the suitability maps (LUS_j) for each state;
2) definition of the stability coefficient, *Kstab* (which will be used to calculate instability coefficient *Kinst*) for each state;
3) *CAMC* simulation;
4) model evaluation and parameters adjustment.

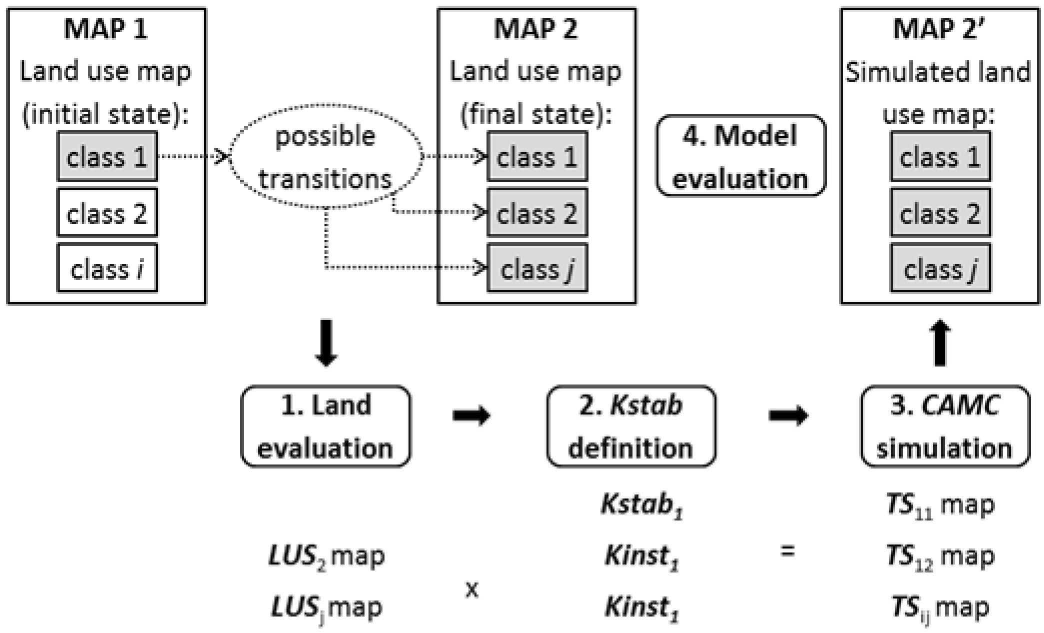


Figure 1 – The *CAMC* procedure for simulating land use change processes.

Before going into details, it is necessary to clarify the difference between *Kstab* and *Kinst*. The coefficients are used to represent the intrinsic stability or instability of each state and vary between 0 and 1. The higher the value of *Kstab*, the more steady the state: when it reaches 1, i.e. *Kstab=1*, there will not be any transition to other states in the next step, map cell remains in its initial conditions, nonetheless its suitability for other potential land uses . The values of *Kstab* are defined by user and stabilized iteratively during the *CAMC* simulation, achieving maximum correspondence between the simulated and the original land use maps. The coefficient of the state instability, *Kinst*, is derived from the corresponding coefficient of stability *Kstab*, as in Equation (1), and used when transition to other state different from the initial one is performed.

$$Kinst = 1 - Kstab \qquad (1)$$

So, the implemented *CAMC* approach is based on a driving force/resistance paradigm: forces are the cell suitability for other states that tend to shift the cell to another state; resistances, instead, preserving the current state, are the stability coefficients, specific for each state. Which state will succeed depends on the combination between the strength of the driving forces, determined by the transition suitability (*TS*) and the resistance to change, represented by *Kstab* values.

Given a grid layer, the cells of which can have *n* possible states (land use types) s_i for $i = 1,\ldots,n$, at each evolution step some states can disappear, being consumed by others, or conversely, emerge, resulting in a layer with *k* states s_j for $j = 1,\ldots,k$. In order to represent this evolution, for each transition from state s_i to state s_j, maps TS_{ij} indicating cells suitability for each possible transition are obtained, on the basis of the land suitability for certain state s_j (LUS_j) and transition resistance of the state s_i, represented by coefficient of stability $Kstab_i$ and instability coefficient $Kinst_i$:

$$TS_{ij} = Kstab_i \qquad \text{for } j=i \qquad (2)$$

$$TS_{ij} = Kinst_i \cdot LUS_j \qquad \text{for } j \neq I \qquad (3)$$

TS_{ij} map of cells suitability for transition from state *i* to state *j*;
$Kstab_i$ stability coefficient of state *i* from which transition is performed (s_i);
$Kinst_i$ instability coefficient of state *i* from which transition is performed (s_i);
LUS_j suitability map for state to which transition is performed (s_j).

The TS_{ij} maps are then used to calculate transition probabilities according to which the transitions by the first order *MC* is performed. Thus, for each cell of a grid a Markov transition matrix is created, the parameters of which are determined by the transition rules, set up by *LUS* maps, obtained through multi-criteria evaluation, and coefficients of stability/instability.

Hence, as a first step, for each land use type maps of land use suitability LUS_j are to be prepared. These maps, being a weighted average of different indicators, calculated on the basis of specific evaluation criteria for each land use type, indicate cells suitability for a particular land use. The values of the LUS_j maps are imposed to vary from 0 to 1, with 0 for not suitable, and 1 for highly suitable area. The evaluation criteria are defined by the user, depending on the evaluation aims and amount of available land information.

Once the LUS_j maps are obtained, they are multiplied by the instability coefficient *Kinst*. While the LUS_j maps just indicate areas suitable for certain use, the *Kinst* parameter represents the volume of transition or stability/instability of the territorial system, the tendency of each state to remain in its condition. The land use suitability maps LUS_j and stability coefficients *Kstab* (the *Kinst* values are calculated automatically) are to be declared in the *CAMC* script file (Annex 1), which will be used subsequently during the simulation.

The *CAMC* simulation is performed running the *SemGrid* command `camc` (Annex 2), developed to simulate system evolution by the first order *MC* on a grid cell basis according to the transition probabilities (TP_{ij}) derived from the TS_{ij} maps. Having *k* possible transitions for each of *n* current land use type s_i, the transition probabilities are internally calculated by dividing each TS_{ij} related to *k* transition by the sum of *k* TS_{ij} as in Equation (4):

$$TP_{ij} = \frac{TS_{ij}}{\sum_{j=1}^{k} TS_{.j}} \quad (4)$$

TP_{ij} transition probabilities

TS_{ij} transition suitability

The command works on a grid layer (*EvoLayer*, land use map in this case), the cells of which can possess one of *n* possible states/classes presented in the system (there is the possibility to handle more than one layer at the same time). Each *EvoLayer* is characterized by observed initial (*iObs*) and final (*fObs*) states. The simulation is performed in one or several steps, defined by user. Working with several *EvoLayers* there is an opportunity to assign different evolution speeds to them: while some *EvoLayers* are changed once, other *EvoLayers* go through several simulation runs having faster evolution. The command allows the application of *CA* and *MC* techniques both in integrated and separated ways: to obtain a pure *MC* simulation it is sufficient to declare *Kstab* and *Kinst* coefficients with values equal to the *MC* transition probabilities (without *LUS*); otherwise, to perform pure *CA* simulation, it is necessary to declare only *LUS* layers, calculated according to criteria representing deterministic *CA* rules.

To define stability coefficients, several *CAMC* simulations using different *Kstab* values are to be run, assessing each time the model performance. The simulated map is compared with the original one by estimating *Kappa* statistics. The *Kappa* coefficient is composed by two factors of similarity between categorical maps in terms of quantity (*Khisto*) and location (*Kloc*). The “quantity” refers to the total presence, as a fraction of all cells, of a category over the whole map while the “location” means spatial allocation of this quantity over the map (Pontius 2000, Hagen 2002). Since the maps generated by the *CAMC* procedure are probabilistic due to the stochastic nature of the *MC* method, each modification of the *Kstab* parameters was followed by generation of 30 maps, providing more reliable estimation of the similarity coefficients and allowing average values of the similarity coefficients to be obtained. For the graphical representation of the model performance, a sample of the generated maps is compared with the original map using *Per_category* method, which performs a cell-by-cell comparison with respect to a selected category (state) and gives information about the occurrence of this category in the maps confronted.

3. Case study

3.1 Study area

The *CAMC* approach has been evaluated through its application to the Udine conurbation area (327 km^2). Raster land use maps of 30 m cell size for the years 1950 and 2000 were used (Figure 2). In the maps, land use is represented with level 1 of the Moland (Moland 2002) classification scheme, derived from the Corine Land Cover. In order to simplify computational efforts and operations, the maps were reclassified, deriving maps containing 3 classes: Artificial surfaces, Agricultural areas, and Forests and seminatural areas (Table 1).

Table 1 – Land use types reclassification.

Moland code	Description	New code	Description
1.1	Urban areas	1	Artificial surfaces (Urb)
1.2 (without 1.2.2.1;1.2.2.2; 1.2.2.3)	Industrial, commercial and infrastructure areas		
1.3; 1.4	Other artificially modified areas		
2.1	Arable	2	Agricultural (Agr)
2.2	Permanent crops		
2.3	Grasslands		
2.4	Other agricultural areas		
3.1	Forested areas	3	Forest and seminatural (Nat)
3.2	Bushes		
3.3	Open areas with scarce vegetation		

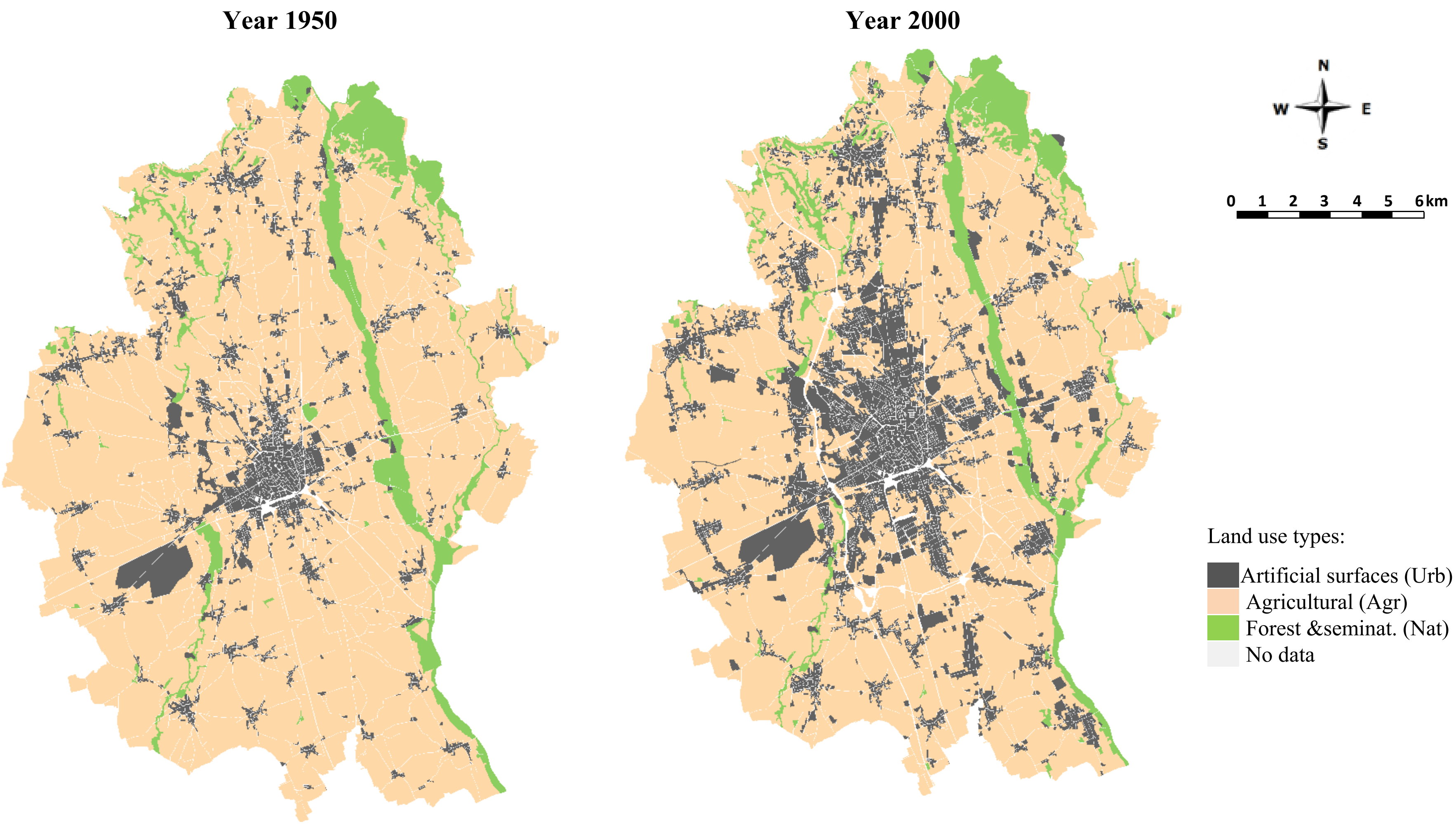


Figure 2 – Land use maps of Udine conurbation area.

Land use dynamics in the study area between 1950 and 2000, presented in Table 2, show that in the course of 50 years there has been a significant urbanisation process. The share of artificial surfaces has increased twice from 9.4 to 21.0 %, while agricultural areas have been lost for about 11 % due to urbanization.

Table 2 – Share of land use types (%) in the Udine conurbation area in the years 1950 and 2000

Land use type	1950	2000
Urb	9.4	21.0
Agr	82.1	71.0
Nat	8.5	8.0

3.2 CAMC: land suitability evaluation

Cells change their state (land use type) according to suitability for transition, formed by the suitability for another state and the tendency of the state to transformation. Even if the suitability of a cell is high enough for another land use, its future state depends on the general tendency to land use change. To evaluate whether the area under consideration is suitable for a certain use, a set of evaluation criteria and related indicators has been defined (Table 3). The *LUS* map for each land use type was calculated as a weighted sum of the *X* related indicators. The weights were assigned by expert judgement according to the indicator relative importance (FAO 2007, Wang 2013). As mentioned before, the values of LUS_j vary from 0 to 1, where 0 indicates areas not suitable and 1 entirely suitable for a particular land use type.

Thus, to define area potential for artificial surfaces, indicators such as the closeness to the roads, closeness to dense urban centres (agglomerations) and the presence of artificial surface cells in the neighbourhood circle, formed by eight adjacent cells was considered (Houet and Houbert-Moy 2006, Norte Pinto *et al.* 2010, Guan 2011). As for agricultural, forest and seminatural areas the indicators of distance from as well as the presence of cells of the same class in the neighbourhood was taken into account. Thus, two any cells both located at the same distance from, for example, agricultural land can have different suitability scores, because of their neighbourhood. One can be surrounded by 2 agricultural cells, while another by 5 agricultural cells, which means that the latter is more likely to become agricultural in the next step. The indicators were calculated by using membership functions and land information derived from the land use map of 1950.

Table 3 – Calculation of the LUS_j maps for each land use type on the base of related indicators.

LUS_j	Land use type	Indicators
$LUS_j = \sum I_x \cdot w_x$, $x = 1,\ldots, X$.	Urb	- proximity to Urb land (Id_u) - proximity to Urb centres ($Ipes_u$) - Urb support (Inb_u) - proximity to roads (Id_r)
	Agr	- proximity to Agr land (Id_a) - Agr support (Inb_a)
	Nat	- proximity to Nat land (Id_n) - Nat support (Inb_n)

Hence, the LUS_j maps were obtained as a weighted mean of the indicators of distance from cells of the same class ($Idis_j$), presence of cells of the same class (Inb_j), distance from other land uses (i.e. urban centres, agglomerations, $Ipes_{urb}$, distance from roads, Id_r).

3.3 CAMC: stability coefficients definition

The stability coefficient *Kstab* set for each type of land use is utilised to modify values of the land use suitability maps, providing higher or lower probability for particular type of transition. Preliminary analysis of the study area, performed by calculating the *MC* transition probability matrix, has shown that there can be following transitions (Table 4): artificial surfaces tend to remain constant; part of agricultural cells (14%) transformed into artificial cells and 1% became natural, while the most part still did not change the state; perturbation of forest and seminatural areas is caused by the expansion of artificial areas and need for additional agricultural areas. The values of probabilities to remain in the same state (diagonal) were used as preliminary information to determine *Kstab* affecting on *TS*.

Table 4 – Land use type's transition from 1950 to 2000 in the Udine conurbation area (*MC* transition probabilities).

1950 \ 2000	Urb	Agr	Nat
Urb	0.99	0.00	0.01
Agr	0.14	0.85	0.01
Nat	0.05	0.12	0.83

3.4 CAMC: land use change simulation

The initial state map (land use map of the year 1950), the LUS_j maps and the stability coefficients, obtained for each land use type, were used as the input for the *CAMC* model. The simulation of the land use change process was performed by executing the *SemGrid* command `camc`, modelling dynamically the future state of the cells, depending upon their current state and the forces affecting them. The command has the following syntax:

```
camc iobs(LU50) fsim(LU00sim) script(script1)
```

where `iobs`, declaring the layer with the observed initial states, refers to the 1950 land use map (*LU50*); `fsim` declares the layer to be generated with the *CAMC* – here the land use map simulated for 2000 (*LU00sim)*; `script` declares the name of the script containing the *CAMC* model.

4. Results and discussion

4.1 CAMC: land suitability evaluation

The results of the evaluation procedure for the land use suitability (*LUS*) are presented in Figure 3. The calculated suitability maps show, from grey to green, an increasing level of suitability for agricultural, artificial and forest and seminatural areas. These maps together with the stability/instability coefficients are used to calculate the transition probabilities and simulate land use transition.

4.2 CAMC: stability coefficients definition

The coefficients used in this study were initially defined using the diagonal values of the *MC* transition probability matrix and then, adjusted iteratively running several simulations, each time generating 30 maps. The stability coefficients *Kstab* provided the best results, achieving highest values of *Kappa* statistics, are reported in Table 5.

Table 5 – Stability and instability coefficients for land use types.

Land use type	Stability coefficient *Kstab*	Instability coefficient *Kinst*
Urb	0.99	0.01
Agr	0	1
Nat	0.71	0.29

Values declared in Table 5 show the stability of the land use classes considered. It is possible to observe that the artificial area class has been the most resistant class, as well as forest and seminatural areas, while agricultural areas appeared to be a very weak and vulnerable class. In fact, the main source for the artificial surface development in Udine is agricultural area (Peccol and Movia 2012).

4.3 CAMC: land use change simulation

An example of map generated by *CAMC* simulation, applying those stability coefficients, provided highest *Kappa* values, is presented in Figure 4. The simulation step was equal to 1, which refers to 50 years. The cells distribution within land use classes in the original map and a sample of the generated maps is reported in Table 6.

Table 6 – Cell distribution among land use types in the original land use map of the year 2000 and a map sample generated for the same year.

Land use type	Original	Generated
Urb	74873	74769
Agr	253201	252953
Nat	28631	28983
Total	356705	356705

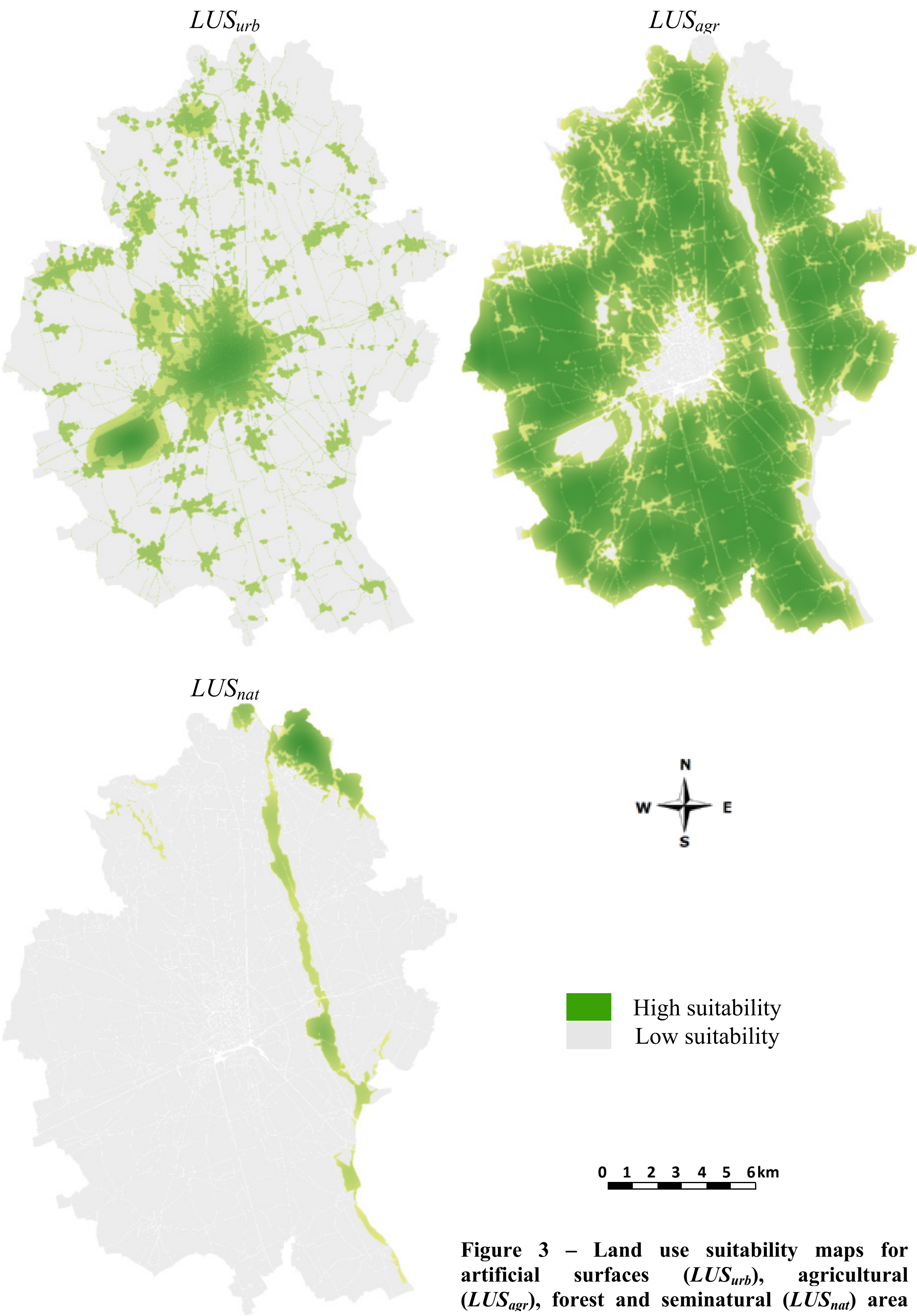


Figure 3 – Land use suitability maps for artificial surfaces (*LUS_{urb}*), agricultural (*LUS_{agr}*), forest and seminatural (*LUS_{nat}*) area for the Udine conurbation area.

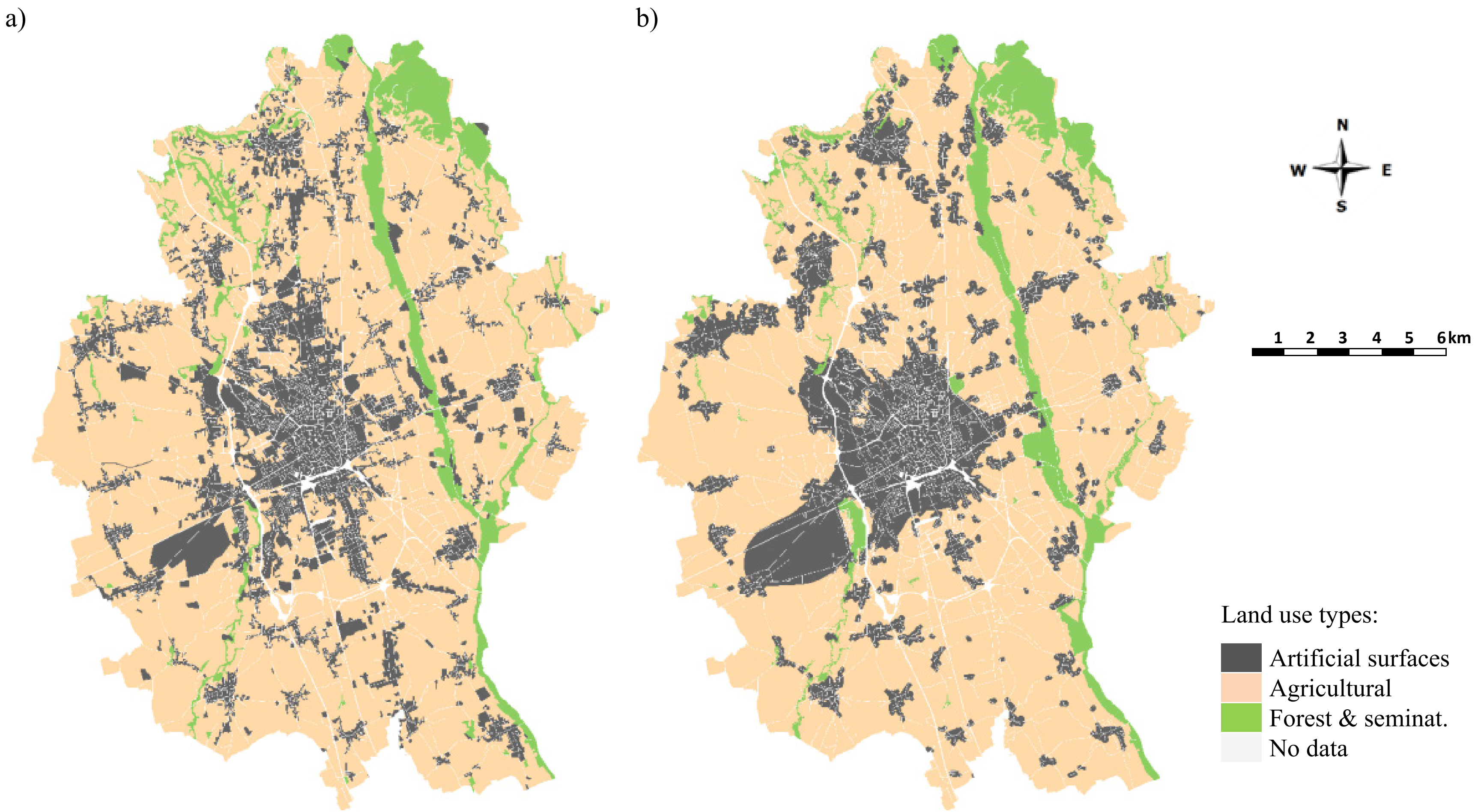


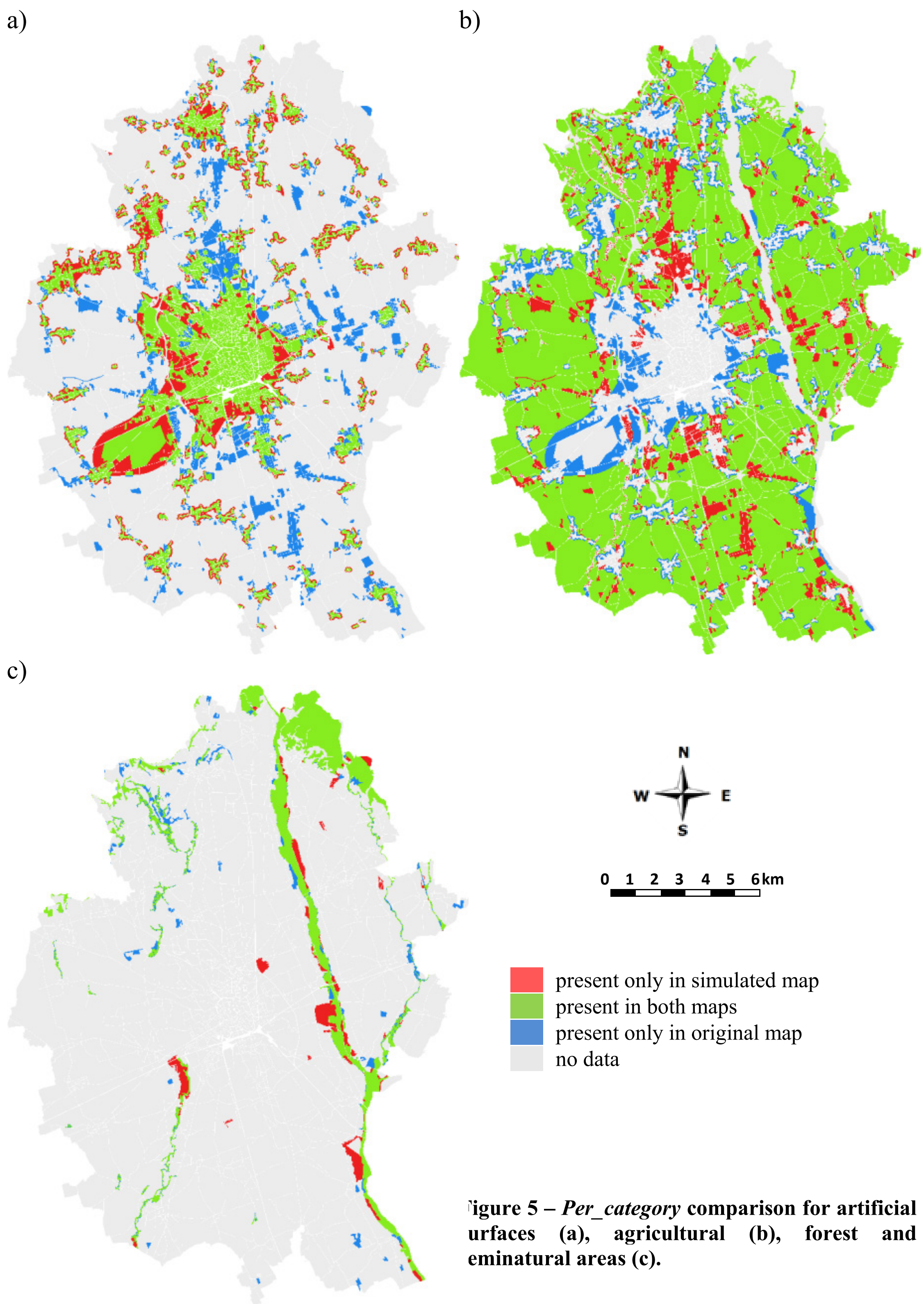
Figure 4 – Original (a) and simulated (b) land use maps of the Udine conurbation area for the year 2000.

The results of the *Kappa* statistics (Table 7) show that the generated and original maps are quite similar both by cells location, giving mean *Kloc* equal to 0.85, 0.67 and 0.97 for artificial, agricultural and forest and seminatural areas respectively, and quantity with mean *Khisto* reaching 0.99 for artificial, agricultural and forest and seminatural areas. The mean general *Kappa* values obtained from *Kloc* and *Khisto* are equal to 0.85 for artificial, 0.67 for agriculture, 0.97 for forest and seminatural areas, thus proving enough good performance of the model.

Table 7 – Mean Kappa statistics obtained from 30 generated maps for the year 2000 and their standard deviations.

Land use	$\overline{Kloc}$	σ	$\overline{Khisto}$	σ	$\overline{Kappa}$	σ
Urb	0.85	$5.41 \cdot 10^{-5}$	0.99	$4.25 \cdot 10^{-5}$	0.85	$3.67 \cdot 10^{-5}$
Agr	0.67	$3.95 \cdot 10^{-4}$	0.99	$2.25 \cdot 10^{-4}$	0.67	$2.55 \cdot 10^{-4}$
Nat	0.97	$2.04 \cdot 10^{-4}$	0.99	$1.12 \cdot 10^{-4}$	0.97	$1.06 \cdot 10^{-4}$

The results of the *Per_category* comparison are presented in Figure 5. Areas in green indicate the cells of the considered category which are present in both maps. Those cells present only in simulated map and not in the real one (positive false prediction) are indicated in red colour, while blue indicates cells existed in reality (in the original map), but not generated by model (negative false prediction).



igure 5 – *Per_category* comparison for artificial urfaces (a), agricultural (b), forest and eminatural areas (c).

5. Conclusions

The results of *CAMC* application allow the approach developed to be considered reliable enough for the selected study area. Of course, the indicators employed in this study are not enough to fully represent the complex land use change processes, but it should be kept in mind that the *CAMC* was not intended to be a model as such; it is rather an approach or a framework through which required indicators can be implemented. In order to improve it additional information about forces and constraints, such as land use policies currently in force, land use plans, other socio-economic factors influencing the process of land use change are to be considered. In particular, constraints deriving from planning and environmental policies could be easily implemented in the land evaluation procedure and represented as Boolean land use suitability maps. The use of more detailed maps is also essential for the better performance.

The *CAMC* procedure developed as a set of *SemGrid* scripts, is completely open and free (http://www.dpvta.uniud.it/~Danuso/docs/SemGrid/SemGrid.htm). Indeed it is possible to modify, adjust and implement additional factors and parameters which should be considered for simulating land use change processes. At present, the main lack of the *CAMC* is that, in case the results obtained are not satisfactory enough, its parameters must be adjusted manually according to the indications provided by the maps comparison. Further development will be focused on implementation of an automatic parameter calibration algorithm.

The model run is not too much time-consuming, but the time required to perform a simulation step can vary, depending on model complexity and project size. The procedure, being able to take into account the main driving factors and forces of the system evolution, can be used to evaluate future scenarios and policies on land use, estimate and test factors that lead to land use change/cover transformation. Even discrepancies between simulated and original maps can give useful information and insights about the driving forces for the changes, highlighting non evident phenomena.

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Annex 1 – *CAMC* scripts to represent land use dynamic

The implementation of a *CAMC* model in *SemGrid*, preliminarily, requires the calculation of the land suitability maps (LUS_j) performed by scripts developed using a multi-criteria evaluation model (available upon request). Then, the *CAMC* script performs the: 1) importation of initial land use maps and *LUS* maps; 2) declaration of parameters *Kstab* scalars; 3) definition of transition suitability (*TS*) layers for each land use type.

Then this script is executed by `camc` command that performs 1) normalization of *TS* layers to transition probabilities (*TP*) and 2) application of *TP* to generate the new land use maps. Note that, any name can be adopted for *Kstab* and *Kinst* coefficients while for *TS* names, the prefix **`TS_`** is to be respected.

To represent Udine conurbation area land use dynamics, land evolution process has been considered to involve three land use types: artificial surfaces (U), agricultural (A), forest and seminatural (N). The initial state of the territory is represented in the land use map *LU50* (state on year 1950).

```
'=========== CAMC script - SemGrid 1.5.3 ======================
'- Evolving layer: Lu50
'state U (artificial surfaces)
'state A (agricultural)
'state N (forest and seminatural)
'------- map input ------------------------------------------
import Lu50 as(ArcGis)gen(Lu50)type(int)  'loading of initial state
map
import LUS_U as(ArcGis)gen(LUS_U) type(float)'loading of LUS map
for U
import LUS_A as(ArcGis)gen(LUS_A) type(float)'loading of LUS map
for A
import LUS_N as(ArcGis)gen(LUS_N) type(float)'loading of LUS map
for N
'------- Parameters ------------------------------------------
scalar Kstab_U=0.99           ' U stability coefficient
scalar Kstab_A=0              ' A stability coefficient
scalar Kstab_N=0.71           ' N stability coefficient
scalar Kinst_U=1-Kstab_U      ' U instability coefficient
scalar Kinst_A=1-Kstab_A      ' A instability coefficient
scalar Kinst_N=1-Kstab_N      ' N instability coefficient
'------- Transition suitabilities -------------------------------
fgen TS_U_U=Kstab_U         replace    ' Transition U to U
fgen TS_U_A=Kinst_U*LUS_A   replace    ' Transition U to A
fgen TS_U_N=Kinst_U*LUS_N   replace    ' etc.
fgen TS_A_A=Kstab_A         replace
fgen TS_A_U=Kinst_A*LUS_U   replace
fgen TS_A_N=Kinst_A*LUS_N   replace
fgen TS_N_N=Kstab_N         replace
```

```
fgen TS_N_U=Kinst_N*LUS_U  replace
fgen TS_N_A=Kinst_N*LUS_A  replace
   ' ==============================================================
' SemGrid 1.5.2 script

'================ LUS maps calculation ===============
'%1% - the year of initial observation
 import Idist_u_%1% as(arcgis) gen(Idist_u)
 import Idist_r_%1% as(arcgis) gen(Idist_r)
 import Idist_a_%1% as(arcgis) gen(Idist_a)
 import Idist_n_%1% as(arcgis) gen(Idist_n)
 import Ipes_u_%1%  as(arcgis) gen(Ipes_u)
 gen int nb_u=ng8count(1,15) 'N of U cells in the neighb.
 gen Inb_u=mtrapez(nb_u,0,8,8,8)
 gen int nb_a=ng8count(1,2)  'N of A cells in the neighb.
 gen Inb_a=mtrapez(nb_a,0,8,8,8)
 gen int nb_n=ng8count(1,3)  'N of N cells in the neighb.
 gen Inb_n=mtrapez(nb_n,0,8,8,8)
 gen suit_U=Idist_u*0.2+Ipes_u*0.4+Inb_u*0.35+Idist_r*0.05
 gen suit_A=Idist_a*0.6+Inb_a*0.4
 gen suit_N=Idist_n*0.6+Inb_n*0.4
 export suit_U as(arcgis) saving(suit_u_%1%.txt) replace
 export suit_A as(arcgis) saving(suit_a_%1%.txt) replace
 export suit_N as(arcgis) saving(suit_n_%1%.txt) replace
```

where:	**import**	command to import a new map
	gen	option declaring the name for the map
	replace	command for recalculating an existing grid layer
	scalar	command for defining and handling scalar numerical variables
	fgen	command to generate new grid layer (fast version)

Annex 2 – `camc` command description

The *CAMC* simulation is performed by running a script, written following the rules of Appendix 1, with the *SemGrid* command `camc`. The full `camc` command syntax is presented below where in square brackets the optional settings are indicated.

camc [**fsim**(*layerlist*)] **iobs**(*layerlist*) [**fobs**(*layerlist*)] [**script**(*script*)] [**speed**(*#list*)] [**nstep**(*#*)] [**plot**] [**list**] [**help**]

fsim declares the names of the evolving layers (*EvoLayer*) to be generated with *CAMC* model. If not declared, the names in `iobs()` with suffix `_f` are adopted;

iobs declares list of layers with the observed initial states of the cells, for each *EvoLayer*:

fobs declares the list of layers with the observed final cells states for each *EvoLayer*. The layers of `fobs` are used to check the validity of the simulation by calculation of the fraction of the transitions agreement between `iobs` and `fobs`;

script declares the script containing the *CAMC* model. If not declared, a template script will be created, with standard names, formed by the layer names found in option `iobs`. If **script** option is declared but not available in the script folder, a template is created using the declared script name;

speed declares number of simulation steps, for each layer of `iobs` list, to be performed within each global time step. The default value is 1, for each layer. For example, the following command: `camc iobs(`*RomanEmp*`,`*PersEmp*`)` `fobs(`*Remp*`,`*Pemp*`) speed(`*2*`,`*1*`)`
means that *RomanEmp* evolves twice faster than *PersEmp*, transition probabilities are applied 2 times for *RomanEmp*, while 1 time for PersEmp;

nstep number of global simulation steps (speed of the slowest layer), default value is 1;

plot requires the map plot during simulation steps. At the end of simulation, each map is saved as bitmap, with the same name of the layers in `iobs()`;

list displays the *CAMC* scripts in use;

help gives the command help.

CHAPTER III – A FUZZY SET MODEL FOR THE ASSESSMENT OF AGRITOURISM LAND SUITABILITY IN BURYATIA

1. Introduction

Aimed at the attraction of people into agricultural areas and provision of rural areas development, agricultural tourism (*AT*) is becoming more and more popular all over the world (Sharpley, 2002; Keith *et al.*, 2003; Malkanthi and Routry, 2011). Within a stagnant agricultural economy conditions, for many farmers the only way to stay on the course is to find alternative sources of income. As a possible solution, in Europe and US, farmers have already implemented "cultivation" of tourists in addition to crops, referred to "agriturismo" in Italy, "sleeping in the straw" in Switzerland, "farmstays" in New Zealand, and "farm holidays" in England (Beus, 2008).

For Russia *AT* is a relatively new type of activity, nonetheless the tourism sector is being developed very intensively recently. Potential of rural areas and small towns for *AT*, both natural and historical-cultural, are little used (Sevan, 2005), and today's issue of converting this potential in the resource that can be used for touristic purposes is widely treated on the local, regional and international levels. The whole thematic module dedicated to the eco-tourism and tourism development in Russian rural areas has been developed within the Tempus project RUDECO (2010-2012) by Buryat State Academy of Agriculture (Imeskenova *et al*., 2012).

One of the most promising areas for tourism development in Russia is Republic of Buryatia, situated in the South-Eastern Siberia (Abramova, 2011). Extensive range of natural and cultural resources allows development of various forms of tourism, such as eco-tourism, camping, sport tourism, beach tourism, health tourism, city sights seeing, cultural and rural tourism (Slepneva and Yampilova, 2010). An increasing interest in Lake Baikal area (Figure 1) included in the list of World Heritage sites by UNESCO (UNESCO, 1996) causes work intensification of the republic government on promotion of tourism in Buryatia.

a) b)

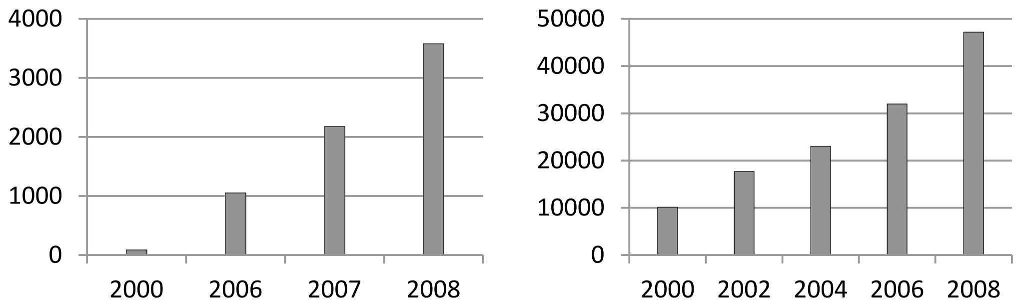

Figure 1 – Revenue of travel agencies, 10^3 € (a) and number of tourists (b) in Buryatia per year (BuryatStat, 2010)

Nowadays great efforts are being dedicated to the development of international and domestic tourism through implementation of the Federal Program of tourism development in the republic, according to which the main activity should be focused on the formation and competitiveness enhancement of the tourism, which would satisfy the requirements of Russian and foreign citizens in high-quality tourism services (Government Decree No. 462, 2010). For the federal program, the main tasks which are to be solved in the nearest future are the creation of favourable economic and legal bases for tourism development, the improvement of the tourist services quality and provision of the tourists' safety and promotion of the Republic of Buryatia on the international and domestic tourist markets. As a result of the program implementation, by 2016 it is expected to achieve the rate of 1085 thousand tourists per year, resulting in rendered services of 7840 million rubles per year (196 million euro/year[1]).

Being an agricultural region, Buryatia, with huge areas of agricultural lands can become one of the leading regions of *AT* development in Russia. The volume of agricultural production during the last years was 11745.6 million rubles (293.64 million €) in 2008; 12086.3 (302.16 million €) in 2009; 15374.4 (384.36 million €) in 2010 in comparison to the 7907.4 (197.69 million €) in 2004 (BuryatStat). In order to provide successful realization of agricultural tourism in Buryatia it is necessary to identify the best area for these purposes by evaluating its suitability, i.e. evaluate whether a given area meets the environmental, socio-economic and legislative conditions, providing the fulfilment of the requirements by resources availability. This will lead to useful information for rural development planning and an optimal use of the resources.

[1] 1 euro = 40.2 rubles on 20/10/2012

Defining site potential for any kind of tourism, different criteria can be used as a reference. Various studies related to this issue, performed evaluation applying different sets of evaluation criteria (sometimes called dimensions or aspects) and related indicators. Zhang *et al*. (2011) to evaluate tourism destination competitiveness in China applied four aspects (criteria): tourism resources endowment, tourism reception capacity, tourism industry strength and tourism support ability (socio-economic and eco-environment conditions), each supported by a set of indicators. Evaluating tourism attractiveness in the region of Moldavia (Romania) through analysis of relationships between tourist resources and infrastructures (potential and existent supply) and the regional economy such factors as presence of cultural and natural resources supported by good infrastructure has been resulted particularly important (Iatu and Bulai, 2011). In some studies the accessibility, education, relevance, recreation, financial, local community, and quality have been considered as key elements for the evaluation of site attraction (Garrod and Fyall, 2000).

Site evaluation for *AT* refers to the estimation of its value in terms of its suitability for tourism development, on the basis of qualitative and quantitative features of the natural and anthropogenic environment. Among the criteria for evaluation of *AT* suitability there are landscape attractiveness, presence of areas of wild nature and wilderness, cultural values (historical buildings, small towns, villages and places, ethnic heritage), favourable conditions for hunting, fishing, skiing, hiking, good accessibility to a broad market of consumers (Peccol and Bonfanti, 2000, Sznajder *et al.*, 2009). Park and Yoon (2011), based on the criteria of accessibility, convenience, accommodations, subsidiary facilities, environment, community planning, etc. have proposed a set of 33 indicators that can be employed to measure sustainable rural tourism development.

Once defined a set of evaluation criteria and related indicators, generally, it is difficult to clearly and completely express the character and significance of criteria defined, thus the use of fuzzy sets theory (Zadeh, 1965) and natural language to evaluate the site quality is more convenient (Chou *et al*., 2008; Rajaram and Das, 2010; Stojanović, 2011; Liu *et al*., 2012; Lu *et al*., 2012; Balezentiene *et al*., 2013). Land evaluation methods based on fuzzy set theory or fuzzy logic, started to appear in the 1980s (McBratney and Odeh, 1997), allowing decision makers to express their ideas freely and adequately.

In fuzzy logic modelling for agricultural land evaluation, the fuzzy inference, based on membership functions and rule aggregation, is constructed with predetermined evaluation criteria, including value ranges for fuzzy linguistic terms, and weights of land variables. However, most existing evaluation criteria systems are built on the basis of expert knowledge; hence, they can be highly subjective and containing uncertainty (Liu *et al*., 2012). The main advantage of fuzzy logic approach with respect to a Boolean approach is the more complete and quantitative use of land information, even if expressed in qualitative or semi-qualitative forms.

Therefore, the aim of the study was to develop a land evaluation procedure, using fuzzy set theory, to identify areas suitable for *AT* in the Republic of Buryatia. A case study carried out for the Dzhidinsky region is presented. The procedure was implemented and applied within the framework of GIS *SemGrid* (Danuso and Sandra, 2006)

2. Materials and methods

2.1 Fuzzy-based land evaluation procedure

The multi-criteria fuzzy-based evaluation is performed according to a set of predefined criteria and related indicators, which reveal whether and how much each homogeneous area, i.e. an area characterized by the same features and conditions, matches the criteria. The land suitability class is determined performing two-phase fuzzy inference. The first inference process is performed to define three indicators, which determine land suitability according to the reachability (*Reach*), amenity (*Amen*) and compatibility (*Comp*). The second inference defines the final suitability for *AT* activity, elaborating the three indicators obtained during the first phase.

Development of fuzzy-based land evaluation procedure consists of two main phases: 1) fuzzy expert system (*FES*) development and 2) *FES* application. The *FES* development is formed by 1) definition of relevant input and output variables, according to the criteria considered, 2) establishment of the input and output fuzzy sets, through definition of linguistic variables, shapes and parameters of the corresponding membership functions; 3) definition of the rules describing the inter-dependencies between the variables and relating input fuzzy sets to output fuzzy sets and 4) definition of the defuzzification method, which converts the fuzzy output into a single value or a single linguistic variable (Reshmidevi *et al*., 2009).

The *FES* application is performed in three main steps: 1) fuzzification, 2) fuzzy rule inference, and 3) defuzzification (Hartati and Sitanggang, 2010; Stoyanovic, 2011; Liu *et al*., 2012). Fuzzification is the process of fuzzy sets calculation using membership function, defined for each linguistic variable (class), determining for all input data (land characteristics, LC) the degree of membership (closeness) to the defined class. The membership values vary from 0 to 1, ranging from non-membership to a complete membership, respectively. The inference process applies the defined rules and relates land characteristics to the suitability classes. Defuzzification of the fuzzy inference output generates a "crisp" evaluation value for each cell.

2.2 FES development

2.2.1 Definition of input and output variables

Seen as an activity which involves agriculture-based operations with offering to the tourist board and lodging, as well as recreation activities (Peccol and Bonfanti, 2000), the potential successfulness of *AT* implementation is evaluated by six land characteristics, presented in Table 1. The reachability indicator defines location convenience in sense of proximity to main roads and proximity to villages. The site amenity indicator evaluates sites attractiveness on the base of proximity to the natural landmarks and water bodies (rivers and lakes). The compatibility represents rationality of *AT* implementation in the given area evaluating topographic (slope steepness) and land use suitability in order to avoid any negative consequences from the activities performed.

Table 1 – Evaluation index, indicators and land characteristics considered for the agritourism suitability evaluation model.

Index	Indicator	Sub-indicator	Land characteristics
AS	*Reach*	Proximity to roads (I_{PR})	Distance from roads (*DistR*)
		Proximity to villages (I_{PV})	Distance from villages (*DistV*)
	Amen	Presence of landmarks (I_{PL})	Distance from landmarks (*DistL*)
		Proximity water bodies (I_{PW})	Distance to water bodies (*DistW*)
	Comp	Suitability for agriculture (I_{AS})	Land slope steepness (*LandS*)
		Land use suitability (I_{US})	Land use type (*LandU*)

During the first inference land characteristics, represented by sub-indicators after their fuzzification, are used to calculate three indicators of *Reach*, *Amen* and *Comp*. The second inference is performed based on the first fuzzy results defining final suitability classes of *AS*.

2.2.2 Definition of the linguistic variables and related membership functions

The first phase of fuzzy process defines specific suitability related to one of the aspects considered (*Reach*, *Amen* and *Comp*) based on the land characteristics expressed as linguistic variables (short, medium, long, etc., Table 2).

Table 2 – Linguistic variables for classify land characteristics

LC	Linguistic variables		
DistR	short	moderate	Long
DistV	short	moderate	Long
DistL	short	moderate	Long
DistW	short	moderate	Long
LandU	suitable	moderately suitable	not suitable
LandS	gentle	moderately steep	Steep

Fuzzification of land characteristic is performed by using trapezoidal and triangular membership functions (Figure 2), which calculate membership of each *LC* to the related linguistic variable, obtaining sub-indicators.

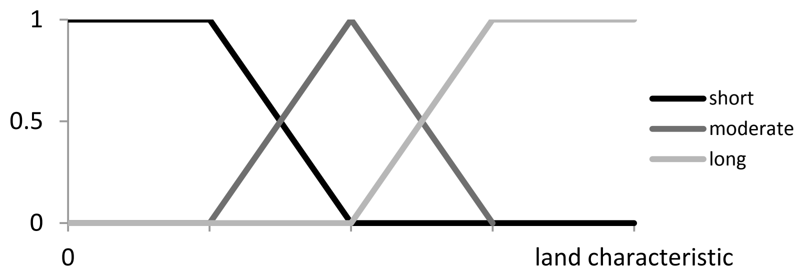

Figure 2 – Set of membership functions for land variables

The output linguistic variables for the indicators *Reach*, *Amen* and *Comp* are presented in Table 3.

Table 3 – Linguistic variables for the evaluation indicators (output set of the first inference stage).

Indicator	Linguistic variables				
Reach	low	moderately low	moderate	moderately high	high
Amen	low	moderately low	moderate	moderately high	high
Comp	low	moderately low	moderate	moderately high	high

Thus, the output fuzzy set for each indicator is represented by 5 membership functions (Figure 3). The suitability range of *Reach* (abscissa axis) varies between 0 and 1, where 0 indicates very low suitability and 1 indicates the highest one. The same for the membership grade (ordinate axis) – 0 is for non-membership and 1 is for complete membership.

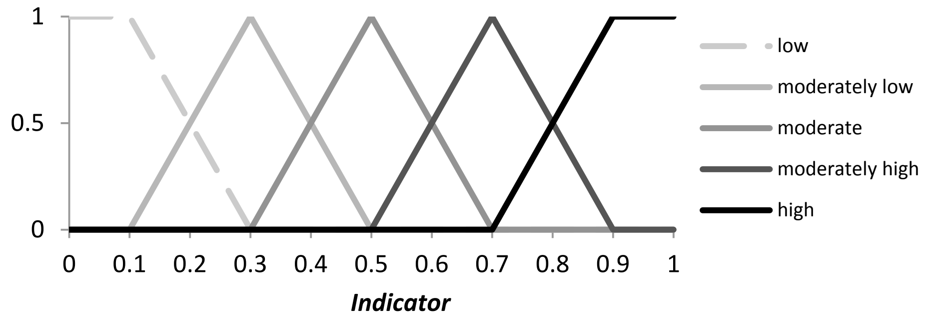

Figure 3 – Output sets defined by the membership functions adopted for evaluating indicators

The second inference process aimed at the definition of the final land suitability class for *AT* activity is performed based on the indicators *Reach*, *Amen* and *Comp*, previously obtained. Combination of these aspects gives the final suitability class. The fuzzification of output variable into seven linguistic variables (Table 4) is presented in the Figure 4.

Table 4 – *AT* suitability classes and related prescriptions

Suitability class	Name	Description
1	Very low	Land is not suitable
2	Low	Land is low suitabile due to low compatibility, negative effects on environment may occur
3	Moderately low	Scarcely suitable land, significant additional expenses are required to improve land and provide better infrastructure (road construction, land reclamation, etc.)
4	Moderate	Land is moderately suitable. Some additional expenses for land and infrastructure improvement can increase the suitability
5	Moderately high	Land is almost suitable. It is enough close to main roads and villages as well as natural landmarks. The compatibility level is moderate or high, additional attention should be paid
6	High	Land is of high compatibility, available resources create favourable environment for *AT* development
7	Very high	Land is highly suitable for *AT*. Environmental, socio-economic conditions will provide successful implementation and development of *AT* activity.

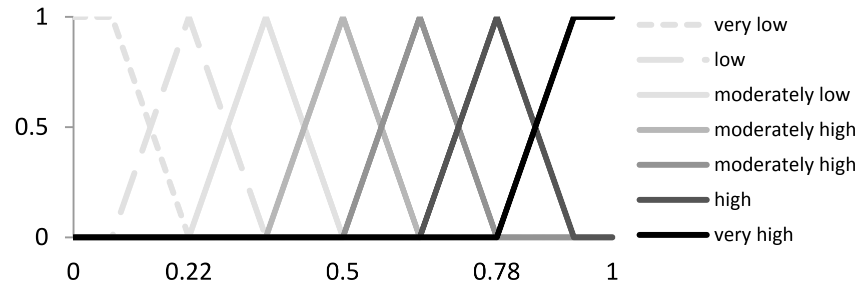

Figure 4 – Set of membership functions for *ASI*.

2.2.3 Definition of fuzzy rules

Using fuzzy set defined for input and output variables, fuzzy rules “IF…THEN” are developed on the base of experts’ knowledge. The minimum–maximum (Min–Max) fuzzy inference method is used to aggregate the rules (Hartati and Sitanggang, 2010, Stojanović, 2011).

2.2.4 Definition of defuzzification method

The final crisp value is obtained from a result function after rules composition. There are different methods to perform this operation (defuzzification) such as the average maximum method, the weighted average maxima method, and the method most commonly used, the centroid method (Siler and Backley, 2005). In this study, the method of centre average is used (Hartati and Sitanggang, 2010), defined as follows:

$$y = \frac{\sum_{k=1}^{M} c_k \cdot \mu_k}{\sum_{k=1}^{M} \mu_k} \qquad (1)$$

where y is output crisp value, c_k is a centre of the k^{th} fuzzy set, μ_k is membership value to this set. The fuzzy inference and defuzzification processes of the II inference are based on the same principles described above for Inference I.

3. Case study

3.1 Study area

The procedure for identification of the areas suitable for *AT* was applied to the area of Dzhidinsky region, one of the major agricultural regions in the republic, situated in the south-western part of Buryatia, South-eastern Siberia, Russia (Figure 5). The total area of the region is 86000 km^2, corresponding to 2.4% of the whole territory of the Republic of Buryatia. The major settlements are Petropavlovka with a population of 7918 people, Dzhida with a population of 5160 people and Nizhny Torey with population of 2146 people. The density of the population is now little over than 4 persons/km^2.

Dzhidinsky region covers the dry steppe area adjacent to the middle and lower parts of the Dzhida River. In the north it is bounded by the Khamar-Daban and Borgoyskiy ridges and in the south by Dzhidinsky ridges. The region, as well as the whole country, is characterized by continental climate with large amplitudes of the oscillations of the annual and daily temperature. The average temperature in January is 36 °C below zero and in July 20 °C above zero. The annual precipitation is about 410-423 mm; the most intensive rainfalls occur during the summer period (Imethenov, 1997; Atlas of Buryatia, 2000).

Figure 5 – Study area: Dzhidinsky region, Republic of Buryatia, Russia

Agriculture is one of the main economic sectors in the region, as well as generally, in the republic. The main specializations of the farms are crop production (mainly cereals), dairy and meat cattle breeding. The data on agricultural production in the region, provided by BuryatStat (2011), are given in Table 5.

From Table 5, it is possible to state that the agricultural sector is characterized by stable dynamic behaviour, though, by some terms, the production is being slightly decreased. Another indicator representing stability of agricultural activity in the region is the amount of agricultural area and it's dynamic over the years (Table 6). The data provided by BuryatStat (2009) show that from 2003 to 2004 the area of lands involved in agricultural production decreased by almost 32 thousands hectares, remaining constant during the following years around 292000 hectares. The beauty of natural landscapes, presence of different water, geological, botanical and historical monuments and natural reserves (Tagleisky, Borgoisky) enhances the attractiveness of the area for tourism (Figure 6; Atlas of Buryatia, 2000).

Table 5 –Gross agricultural production in Dzhidinsky region as compared to the total production of Buryatia

	2008	2009	2010
Grain production, 10^3 t			
Republic of Buryatia	100.8	79.3	72.4
Dzhidinskyi region	25.8	24.7	10.8
Share (%)	25.6	31.1	14.9
Potato production, 10^3 t			
Republic of Buryatia	160.0	167.8	164.7
Dzhidinskyi region	10.2	7.9	7.8
Share (%)	6.4	4.7	4.7
Vegetable production, 10^3 t			
Republic of Buryatia	46.3	46.6	46.5
Dzhidinsky region	2.8	2.8	3.1
Share (%)	6	6	6.6
Meat and poultry production, 10^3 t			
Rep. of Buryatia	47.3	49.9	49.9
Dzhidinsky region	5.2	5.9	5.6
Share (%)	11	11.8	11.2
Poultry production in eggs, millions			
Rep. of Buryatia	64.9	63.8	64.9
Dzhidinsky region	3.5	2.8	2.4
Share (%)	5.4	4.4	3.7
Dairy production, 10^3 t			
Republic of Buryatia	247.3	238.6	229.5
Dzhidinsky region	24.1	24.4	21.8
Share (%)	9.7	10.2	9.5

Table 6 – Area of agricultural lands in Dzhidinsky region in the period 2003-2007 (ha).

	2003	2004	2005	2006	2007
Hayfields	20944	19314	19314	19314	19314
Pastures	199857	177038	177038	177040	177040
Abandoned	6518	6476	6476	6476	6476
Arable lands	96908	89106	89106	89106	89106
Total	**324227**	**291934**	**291934**	**291936**	**291936**

The land information of the study area, required for evaluation of suitability for *AT* activity, was derived from the maps of land use, elevation and data about natural landmarks presence, provided by the Baikal Institute for Nature Management. The study was performed using a raster approach employing maps with cell size of 40 m, resulting in a grid of about 10 million cells. The statistics of land characteristics used to evaluate *AT* suitability are presented in Table 7 and Table 8.

Figure 6 – Landscapes of Dzhidinsky region.

Table 7 – Statistics of continuous land variables used in the evaluation model, obtained from the 5581000 cell map of the study area of Dzhidinsky region.

Land information	units	mean	max	Standard deviation
Dist. from roads, *DistR*	m	15393	63711	15116
Dist. from villages, *DistV*	m	14138	62378	13299
Dist. from landmarks, *DistL*	m	21297	62879	12879
Dist. from water res., *DistW*	m	2285	14093	1996
Slope steepness, *LandS*	%	9.4	66.5	7.0

Table 8 – Land use types considered in the evaluation model.

Type of land use	Code	Area (ha)	Share (%)
Arable	1	140237	16
Grasslands	2	24262	3
Pastures	3	240773	27
Forest and seminatural	4	461423	51
Other	5	26264	3
Total	**-**	**892962**	**100**

3.2 FES application

3.2.1 Fuzzification

Fuzzification of land characteristic (Figure 7), obtained calculating membership of land characteristic to each related linguistic variable, is performed using trapezoidal and triangular membership functions and parameter ranges as defined in Table 9.

Table 9 – Parameter ranges associated to linguistic variables to transform land characteristics into input fuzzy sets.

		Linguistic variables		
LC	Unit	*Short/gentle/suitable*	*moderate*	*Long/steep/not suitable*
DistR	m	0-3000	1500-5000	3000- >5000
DistV	m	0-3000	1500-5000	3000- >5000
DistL	m	0-3000	1500-5000	3000- >4500
DistW	m	0-3000	1500-5000	3000- >4500
LandS	%	0-10	5-15	10-15
LandU	-	1	2, 3, 4	5

3.2.1 Fuzzy inference

Based on the input and output fuzzy sets obtained the fuzzy rules were defined using MIN-MAX method (Annex 1).

3.2.2 Defuzzification

The process of defuzzification was performed using previously defined centres of the output subsets and formulae of centre calculation for trapezoidal and triangular figures (Annex 2).

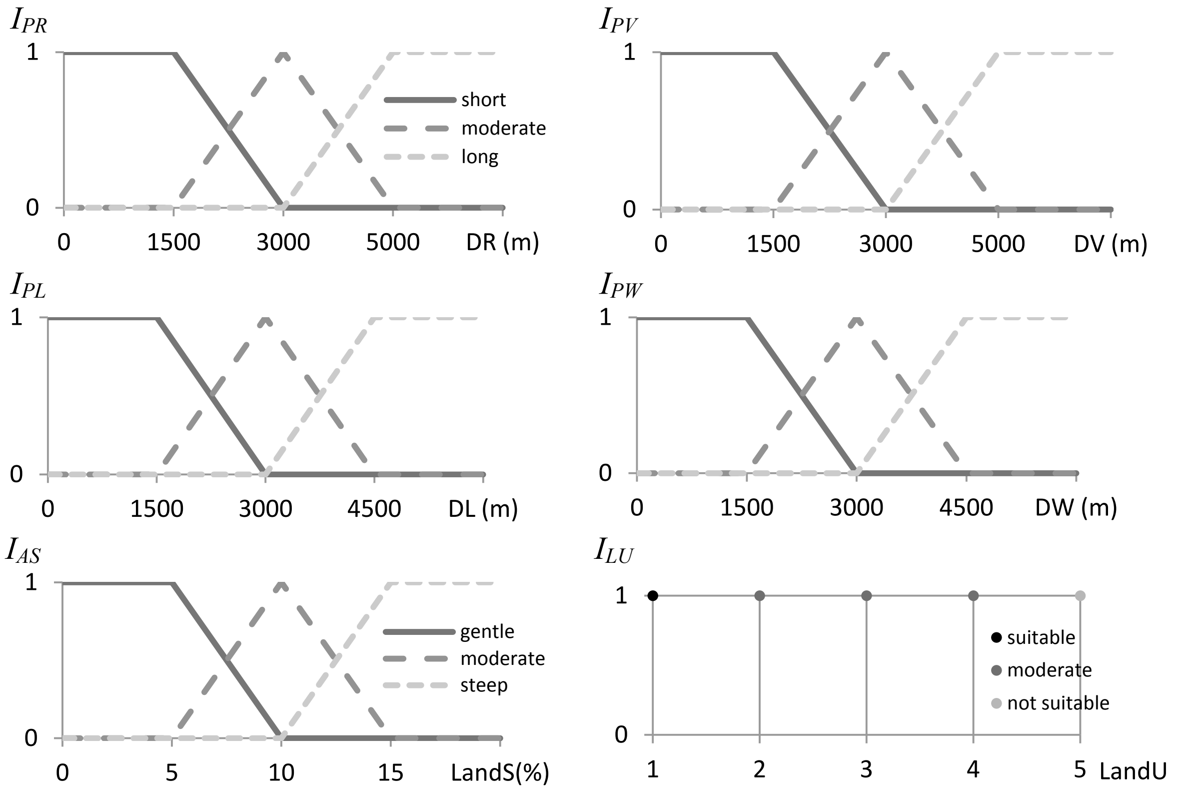

Figure 7 – Fuzzification of land variables: set of membership function for linguistic variables and their parameters.

4. Results and discussions

The results of *FES* application are presented below in Figure 8, 9. The results of *FES I*, i.e. maps of land suitability, indicating the most suitable areas in terms of site reachability, amenity and compatibility, are presented in Figure 8. The indicators *Reach*, *Amen* and *Comp* were obtained from the sub-indicators, which in their turn were calculated using related land characteristics as distances from roads and villages for *Reach*, distances from natural landmarks and rivers for *Amen*, and slope steepness and land use type for *Comp*. Each map is characterized by five classes of suitability.

Table 10 – Area distribution within the suitability classes for *Reach*, *Amen* and *Comp* indicators.

Suitability class	*Reach*, ha	%	*Amen*, ha	%	*Comp*, ha	%
1	303518	34.0	569687	63.8	441983	49.5
2	174431	19.5	273369	30.6	68891	7.7
3	280634	31.43	44939	5.0	188680	21.1
4	134302	15.04	5115	0.6	183781	20.6
5	225	0.03	-		9775	1.1
Total	**893110**	**100**	**893110**	**100**	**893110**	**100**

The overall map of land suitability for *AT* activity resulted from *FES II* procedure is shown in Figure 9. The map indicates general suitability of the region area for agricultural tourism development, considering *Reach*, *Amen* and *Comp* indicators derived from *FES I*. The map contains seven classes of suitability, where the most favourable ones are coloured in dark green and the most unfavourable are in red. The total area for each suitability class is presented in Table 11. In general, the areas suitable for *AT* activity development in Dzhidinsky region are concentrated in the south-eastern part of the region, which is conditioned by presence of agricultural areas in that zone, gentle slopes, as well as closeness to the roads, settlements and natural landmarks.

Table 11 – Area distribution within the *AT* suitability classification.

AT suitability class	Area, ha	%
1	174303	19.5
2	285279	31.9
3	187540	21.0
4	181042	20.3
5	60286	6.8
6	4660	0.5
7	-	-
Total	**893110**	**100**

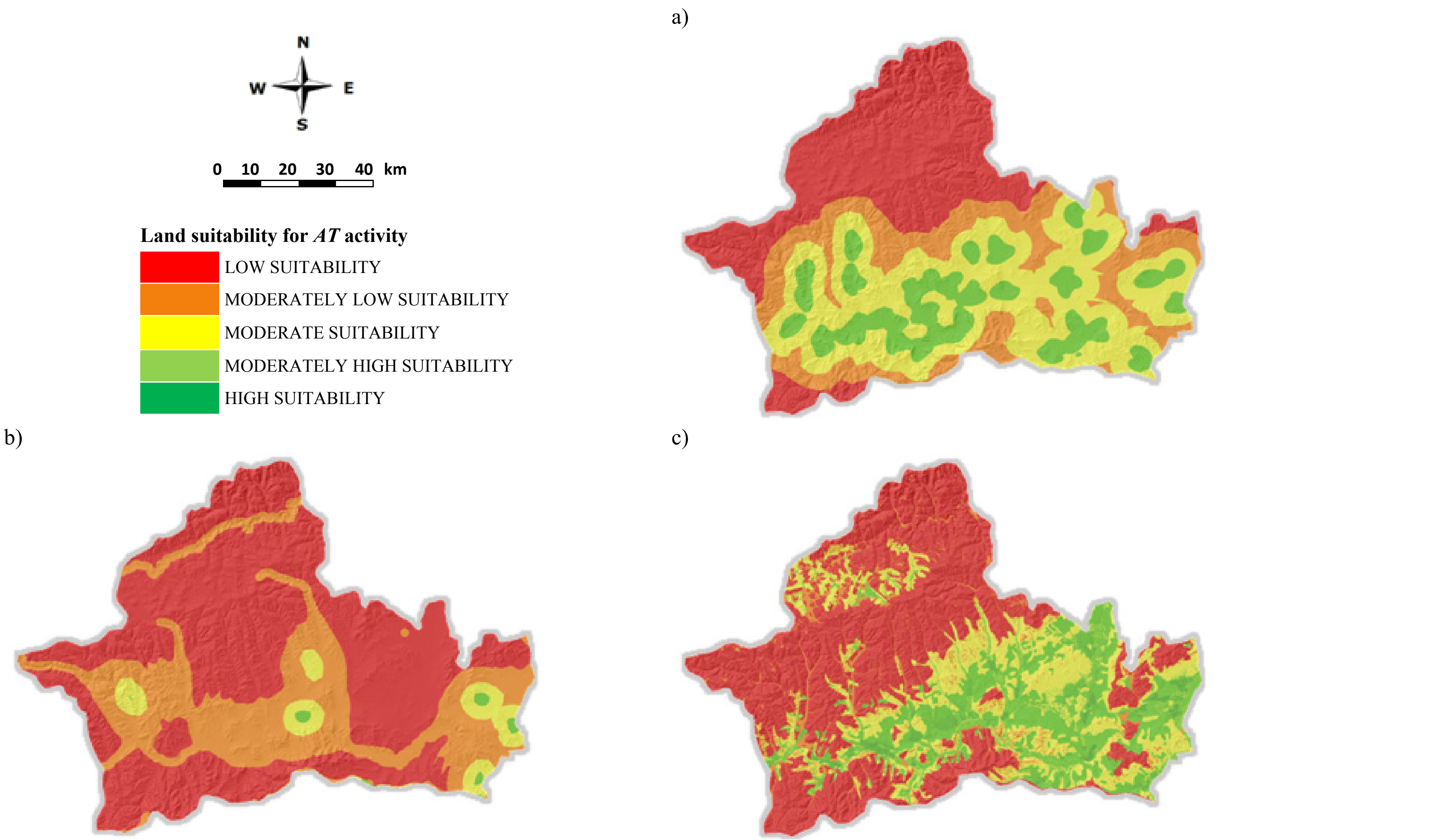

Figure 8 – Maps of land suitability indicators for: a – *Reac*; b – *Amen*; c – *Comp*.

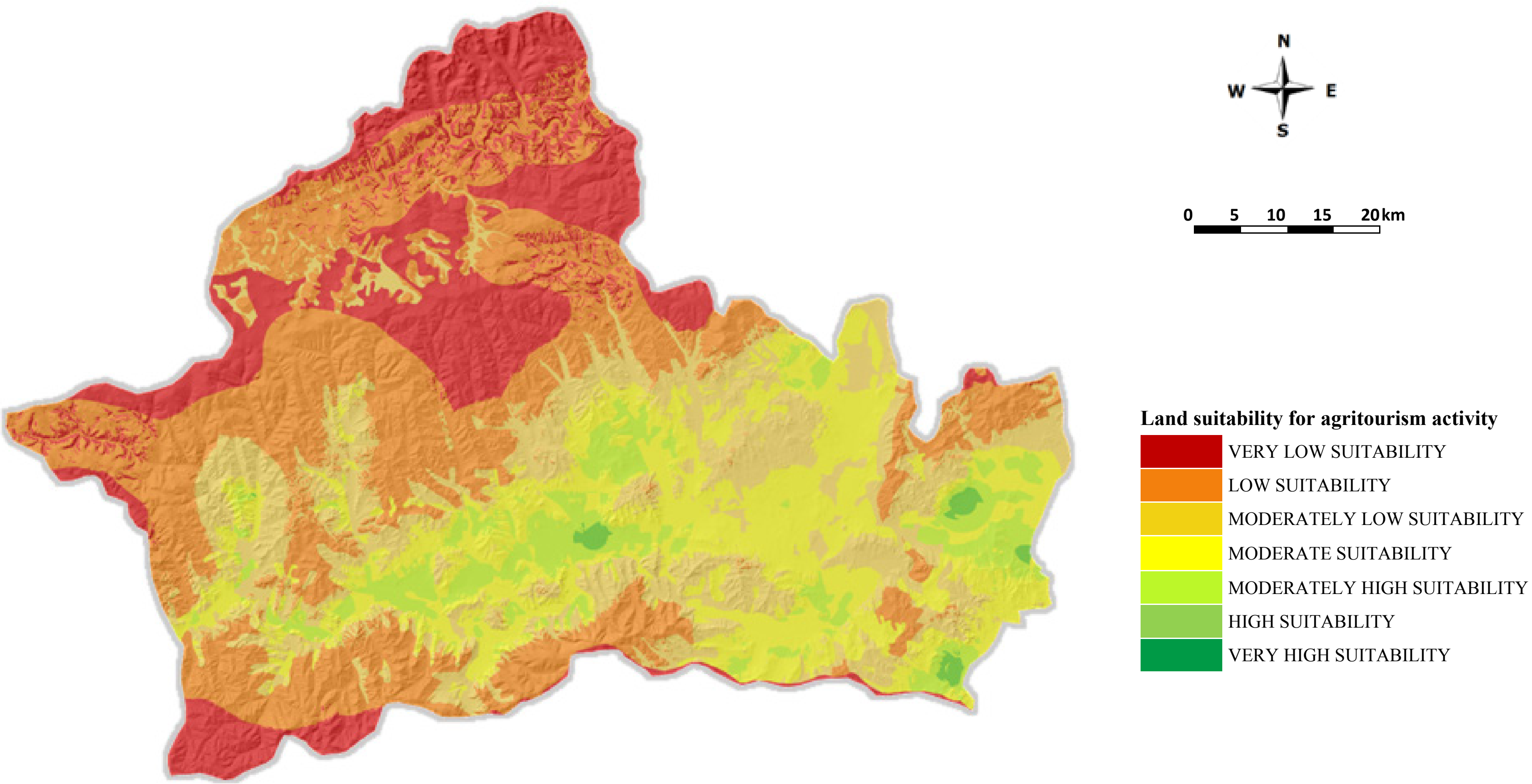

Figure 9 – Map of land suitability for agritourism activity in Dzhidinsky region, Buryatia.

5. Conclusions

The on-going intensive works on promotion of the tourism activity in the republic is to be based on the comprehensive assessment of the resources and services related to the multiple functions of the land. In this case, multi-criteria decision support systems have been considered particularly helpful and effective. The presented evaluation procedure is aimed at the identification of land suitability for *AT* activity in the Republic of Buryatia, using fuzzy logic techniques. Developed within the *SemGrid* framework, the procedure is implemented by a set of scripts, which can be easily modified and adapted to other areas, possibly introducing additional indicators and information not considered in the present study. The current work is a case study presenting results of the procedure applied to the area of Dzhidinsky region of Buryatia.

The obtained map of suitability identifies the areas with the highest potential for *AT* development in terms of site location, amenity and compatibility with environment (land use compatibility, relief). According to the results obtained, the most suitable areas are concentrated in the south-eastern part of the region, which is conditioned by the presence of agricultural areas in that zone, gentle slopes, as well as closeness to the roads, settlements and natural landmarks. However, the biggest part of the region is still occupied by the areas inappropriate for this kind of activity. More than half of the total area belongs to the classes below the middle one. This can be justified, primarily, by the low infrastructure development conditioned by small population, and vast areas of the forest areas considered unsuitable during the evaluation.

The results of the procedure application will provide decision making process with valuable information about the prospects of *AT* implementation. For instance, some lands can meet criteria related to reachability and amenity, but mismatch the final one of the compatibility. This means that this type of land is to be avoided; otherwise the land owner must be warned that implementation and development of the *AT* on this land will require significant costs associated with land reclamation and restoration. It would be preferable that for *AT* activity the lands of classes higher than the moderate one are considered, thus avoiding additional expenses and providing its successful implementation. However, regardless of the suitability class, significant attention is to be paid primarily to the environment, in order to avoid its degradation and pollution.

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Annex 1 – Fuzzy inference rules

Fuzzy inference I rules developed to evaluate suitability levels for site reachability (*Reach*), amenity (*Amen*) and compatibility (*Comp*). *DistR* and *DistV* are land characteristics related to the distance from roads and distance from villages respectively. *DistL* and *DistW* are the distances from landmarks and water bodies, while *LandS* and *LandU* define land slope steepness and land use type.

IF	THEN		Code
DistR is short AND *DistV* is short *DistR* is short AND *DistV* is moderate *DistR* is moderate AND *DistV* is short	Reach	High	5
DistR is moderate AND *DistV* is moderate		Moderately high	4
DistR is long AND *DistV* is short		Moderate	3
DistR is long AND *DistV* is moderate		Moderately low	2
DistR is short AND *DistV* is long *DistR* is moderate AND *DistV* is long *DistR* is long AND *DistV* is long		Low	1
DistL is short AND *DistW* is short	Amen	High	5
DistL is short AND *DistW* is moderate *DistL* is moderate AND *DistW* is short		Moderately high	4
DistL is moderate AND *DistW* is moderate		Moderate	3
DistL is short AND *DistW* is long *DistL* is long AND *DistW* is short		Moderately low	2
DistL is moderate AND *DistW* is long *DistL* is long AND *DistW* is moderate *DistL* is long AND *DistW* is long		Low	1
LandS is gentle AND *LandU* is suitable	Comp	High	5
LandS is gentle AND *LandU* is moderate *LandS* is moderate AND *LandU* is suitable		Moderately high	4
LandS is moderate AND *LandU* is moderate		Moderate	3
LandS is gentle AND *LandU* is not suitable *LandS* is steep AND *LandU* is suitable		Moderately low	2
LandS is moderate AND *LandU* is not suitable *LandS* is steep AND *LandU* is moderate *LandS* is steep AND *LandU* is not suitable		Low	1

Fuzzy inference II rules are defined to determine final suitability class for *AT* development. The numbers in columns represent the suitability levels related to *Reach*, *Amen* and *Comp*, obtained previously by inference I: 1 – low, 2 – moderately low, 3 – moderate, 4 – moderately high and 5 – high. The combination of these levels gives the final suitability class. The MIN-MAX method is applied to aggregate the rules. For example, the first rule presented below should be read as follows: "IF *Reach* is moderately low (2) and *Amen* is moderately low (2) and *Comp* is low (1), THEN suitability for *AT* (*AS)* is "very low" and so on.

IF			**THEN**
Reach	*Amen*	*Comp*	*AS*
2	2	1	Very low
2	3	1	
2	4	1	
2	5	1	
3	2	1	
3	3	1	
3	4	1	
3	5	1	
4	2	1	
4	3	1	
4	4	1	
4	5	1	
5	4	1	
5	5	1	
2	2	2	Low
2	2	3	
2	2	4	
2	3	2	
2	4	2	
2	5	2	
3	2	2	
3	3	2	
3	4	2	
3	5	2	
4	2	2	
4	3	2	
4	4	2	
4	5	2	
5	4	2	
2	2	5	Moderately low
2	3	3	
2	3	4	
2	3	5	

IF			**THEN**
Reach	*Amen*	*Comp*	*AS*
2	4	3	Moderately low
2	5	3	
3	2	4	
3	2	5	
3	3	3	
3	4	3	
2	4	4	Moderate
2	4	5	
2	5	4	
2	5	5	
3	3	4	
3	3	5	
3	4	4	
3	5	3	
4	3	3	
4	4	3	
4	5	3	
3	4	5	Moderately High
3	5	4	
3	5	5	
4	3	4	
4	4	4	
5	4	3	
5	5	3	
4	3	5	
4	4	5	High
4	5	4	
5	4	4	
4	5	5	Very high
5	4	5	
5	5	4	
5	5	5	

Annex 2 – Scripts of fuzzy based land evaluation procedure to identify area suitable for AT development.

```
'SemGrid script (04-12-2012)
' FUZZY BASED LAND EVALUATION PROCEDURE
'===== dentification of areas suitable for agritourism =====
'1) Calculation of land evaluation indicators
 '----------------- location suitability -------------------
02_3_Indicator_DR.cmf "script to calculate fuzzy set for DistR"
02_2_Indicator_DV.cmf "script to calculate fuzzy set for DistV"
 '--------------- landscape attractiveness -----------------
02_4_Indicator_DSA.cmf "script to calculate fuzzy set for DistL"
02_5_Indicator_DWR.cmf "script to calculate fuzzy set for DistW"
 '------------------- compatibility -----------------------
02_1_Indicator_LU.cmf "script to calculate fuzzy set for landL"
02_7_Indicator_Sl.cmf "script to calculate fuzzy set for landS"

'2) Definition of the areas suitable for the activity
FUZZY_I.cmf "fuzzy inference procedure I"
FUZZY_II.cmf "fuzzy inference procedure II"
```

```
'============= Script to calculate fuzzy set for DistR ==========
'Linguistic variables:
'A – "SHORT"
'B – "MODERATE"
'C – "LONG"
'parameters for membership functions:
 scalar A1=0
 scalar A2=0
 scalar A3=1500
 scalar A4=3000
 scalar B1=1500
 scalar B2=3000
 scalar B3=3000
 scalar B4=4500
'Membership of DistR to variable "SHORT"
 import f_distroads.txt as(arcgis) gen(distroads) type(float) replace
 fgen mDR_A=mtrapez(distroads,A1,A2,A3,A4)
 export mDR_A as(arcgis) saving(mDR_A.txt)
 drop all
'Membership of DistR to variable "MODERATE"
 import f_distroads.txt as(arcgis) gen(distroads) type(float) replace
 fgen mDR_B=mtrapez(distroads,B1,B2,B3,B4)
 export mDR_B as(arcgis) saving(mDR_B.txt)
 drop all
```

```
'Membership of DistR to variable "LONG"
 import mDR_A.txt as(arcgis) gen(mDR_A) type(float) replace
 import mDR_B.txt as(arcgis) gen(mDR_B) type(float) replace
 fgen mDR_C=1-mDR_A-mDR_B
 export mDR_C as(arcgis) saving(mDR_C.txt)
 drop all
```

```
'===================== FUZZY INFERENCE I ====================
'Linguistic variables for Reach:"high", "moderately high",
'"moderate", "moderately low", "low"
'----------------------- REACHABILITY ----------------------
'1.high: DR_A & DV_A | DR_A & DV_B | DR_B & DV_A
 fuzzy_min mDR_A mDV_A Re_High1          "application of MIN
operator"
 fuzzy_min mDR_A mDV_B Re_High2
 fuzzy_min mDR_B mDV_A Re_High3
 fuzzy_max Re_High1 Re_High2 Re_High_butta "application of MAX
operator"
 fuzzy_max Re_High_butta Re_High3 Re_High
 erase Re_High1.txt
 erase Re_High2.txt
 erase Re_High3.txt
 erase Re_High_butta.txt
 '2.moderately high: DR_B & DV_B
 fuzzy_min mDR_B mDV_B Re_mHigh
 '3.moderate: DR_C & DV_A
 fuzzy_min mDR_C mDV_A Re_Mod
 '4.moderately_low: DR_C & DV_B
 fuzzy_min mDR_C mDV_B Re_mLow
 '5.low: DR_A & DV_C | DR_B & DV_C | DR_C & DV_C
 fuzzy_min mDR_A mDV_C Re_Low1
 fuzzy_min mDR_B mDV_C Re_Low2
 fuzzy_min mDR_C mDV_C Re_Low3
 fuzzy_max Re_Low1 Re_Low2 Re_Low_butta
 fuzzy_max Re_Low_butta Re_Low3 Re_Low
 erase Re_Low1.txt
 erase Re_Low2.txt
 erase Re_Low3.txt
 erase Re_Low_butta.txt
'-------------------AMENITY----------------------------
'1.high: DSA_A & DWR_A
 fuzzy_min mDSA_A mDWR_A Am_High
'2.moderately high: DSA_A & DWR_B | DSA_B & DWR_A
 fuzzy_min mDSA_A mDWR_B Am_mHigh1
 fuzzy_min mDSA_B mDWR_A Am_mHigh2
 fuzzy_max Am_mHigh1 Am_mHigh2 Am_mHigh
 erase Am_mHigh1.txt
```

```
erase Am_mHigh2.txt
'3.moderate: DSA_B & DWR_B
fuzzy_min mDSA_B mDWR_B Am_Med
'4.moderately low: DSA_A & DWR_C | DSA_C & DWR_A
fuzzy_min mDSA_A mDWR_C Am_mLow1
fuzzy_min mDSA_C mDWR_A Am_mLow2
fuzzy_max Am_mLow1 Am_mLow2 Am_mLow
erase Am_mLow1.txt
erase Am_mLow2.txt
'5.low: DSA_B & DWR_C | DSA_C & DWR_B | DSA_C & DWR_C
fuzzy_min mDSA_B mDWR_C Am_Low1
fuzzy_min mDSA_C mDWR_B Am_Low2
fuzzy_min mDSA_C mDWR_C Am_Low3
fuzzy_max Am_Low1 Am_Low2 Am_Low_butta
fuzzy_max Am_Low_butta Am_Low3 Am_Low
erase Am_Low1.txt
erase Am_Low2.txt
erase Am_Low3.txt
erase Am_Low_butta.txt
'------------------Compatibility-------------------------
'1.high: LU_A & SL_A
fuzzy_min mLU_A mSL_A Co_High
'2.moderately high: LU_A & SL_B | LU_B & SL_A
fuzzy_min mLU_A mSL_B Co_mHigh1
fuzzy_min mLU_B mSL_A Co_mHigh2
fuzzy_max Co_mHigh1 Co_mHigh2 Co_mHigh
erase Co_mHigh1.txt
erase Co_mHigh2.txt
'3.moderate: LU_B & SL_B
fuzzy_min mLU_B mSL_B Co_Med
'4.moderately low: LU_A & SL_C | LU_C & SL_A
fuzzy_min mLU_A mSL_C Co_mLow1
fuzzy_min mLU_C mSL_A Co_mLow2
fuzzy_max Co_mLow1 Co_mLow2 Co_mLow
erase Co_mLow1.txt
erase Co_mLow2.txt
'5.low: LU_B & SL_C | LU_C & SL_B | LU_C & LU_C
fuzzy_min mLU_B mSL_C Co_Low1 'MIN operator
fuzzy_min mLU_C mSL_B Co_Low2
fuzzy_min mLU_C mSL_C Co_Low3
fuzzy_max Co_Low1 Co_Low2 Co_Low_butta
fuzzy_max Co_Low_butta Co_Low3 Co_Low
erase Co_Low1.txt
erase Co_Low2.txt
erase Co_Low3.txt
erase Co_Low_butta.txt
drop all
scalar drop
```

```
'================== DEFUZZIFICATION I =====================
'Definition of the centres for output fuzzy sub-sets
 scalar a=0.1
 scalar b=0.3
 scalar x1=a*0.5
 scalar x2=(a+a+b)/3
 scalar S1=a*1
 scalar S2=0.5*(b-a)
 scalar C1=(S1*x1+S2*x2)/S1+S2
 scalar C2=0.3
 scalar C3=0.5
 scalar C4=0.7
 scalar a=0.1
 scalar b=0.3
 scalar x1=0.9+a*0.5
 scalar x2=(0.7+0.9+0.9)/3
 scalar S1=a*1
 scalar S2=0.5*0.2*1
 scalar C5=(S1*x1+S2*x2)/(S1+S2)
 defuzzification Re_High Re_mHigh Re_Med Re_mLow Re_Low ReS
 defuzzification Am_High Am_mHigh Am_Med Am_mLow Am_Low AmS
 defuzzification Co_High Co_mHigh Co_Med Co_mLow Co_Low CoS
```

```
'================ FUZZY INFERENCE II =================
'1 - class "HIGH"
'2 - class "MHigh"
'3 - class "MED"
'4 - class "mLOW"
'5 - class "LOW"
'================== FUZZY RULES ======================
' reachability (Re) 1 2 3 4 5
' amenity (Am) 1 2 3 4 5
' compatibility (Co) 1 2 3 4 5
'vHIGH: 455, 545, 554, 555
 fuzzy_minII Re_mhigh Am_high  Co_high LSA_vhigh1
 fuzzy_minII Re_high  Am_mhigh Co_high LSA_vhigh2
 fuzzy_minII Re_high  Am_high  Co_mhigh LSA_vhigh3
 fuzzy_minII Re_high  Am_high  Co_high LSA_vhigh4
 fuzzy_max LSA_vhigh1 LSA_vhigh2 buffer
 fuzzy_max buffer     LSA_vhigh3 buffer2
 fuzzy_max buffer2    LSA_vhigh4 LSA_vhigh
'HIGH: 445|454|544
 fuzzy_minII Re_mhigh Am_mhigh Co_high LSA_high1
 fuzzy_minII Re_mhigh Am_high  Co_mhigh LSA_high2
 fuzzy_minII Re_high  Am_mhigh Co_mhigh LSA_high3
 fuzzy_max LSA_high1 LSA_high2 buffer
 fuzzy_max buffer    LSA_high3 LSA_high
'mHIGH: 345|354|355|434|444|543|553|435
 fuzzy_minII Re_med Am_mhigh Co_high LSA_mhigh1
 fuzzy_minII Re_med Am_high Co_mhigh LSA_mhigh2
 fuzzy_minII Re_med Am_high Co_high LSA_mhigh3
 fuzzy_minII Re_mhigh Am_med Co_mhigh LSA_mhigh4
 fuzzy_minII Re_mhigh Am_mhigh Co_mhigh LSA_mhigh5
 fuzzy_minII Re_high Am_mhigh Co_med LSA_mhigh6
 fuzzy_minII Re_high Am_high Co_med LSA_mhigh7
 fuzzy_minII Re_mhigh Am_med Co_high LSA_mhigh8
 fuzzy_max LSA_mhigh1 LSA_mhigh2 buffer
 fuzzy_max buffer LSA_mhigh3 buffer2
 fuzzy_max buffer2 LSA_mhigh4 buffer3
 fuzzy_max buffer3 LSA_mhigh5 buffer4
 fuzzy_max buffer4 LSA_mhigh6 buffer5
 fuzzy_max buffer5 LSA_mhigh7 buffer6
 fuzzy_max buffer6 LSA_mhigh8 LSA_mhigh
'MED: 244|245|254|255|334|335|344|353|433|443|453
 fuzzy_minII Re_mlow Am_mhigh Co_mhigh LSA_med1
 fuzzy_minII Re_mlow Am_mhigh Co_high LSA_med2
 fuzzy_minII Re_mlow Am_high Co_mhigh LSA_med3
 fuzzy_minII Re_mlow Am_high Co_high LSA_med4
 fuzzy_minII Re_med Am_med Co_mhigh LSA_med5
 fuzzy_minII Re_med Am_med Co_high LSA_med6
 fuzzy_minII Re_med Am_mhigh Co_mhigh LSA_med7
 fuzzy_minII Re_med Am_high Co_med LSA_med8
 fuzzy_minII Re_mhigh Am_med Co_med LSA_med9
 fuzzy_minII Re_mhigh Am_mhigh Co_med LSA_med10
 fuzzy_minII Re_mhigh Am_high Co_med LSA_med11
 fuzzy_max LSA_med1 LSA_med2 buffer
 fuzzy_max buffer LSA_med3 buffer2
 fuzzy_max buffer2 LSA_med4 buffer3
 fuzzy_max buffer3 LSA_med5 buffer4
 fuzzy_max buffer4 LSA_med6 buffer5
 fuzzy_max buffer5 LSA_med7 buffer6
 fuzzy_max buffer6 LSA_med8 buffer7
 fuzzy_max buffer7 LSA_med9 buffer8
 fuzzy_max buffer8 LSA_med10 buffer9
 fuzzy_max buffer9 LSA_med11 LSA_med
```

```
'mLOW: 225|233|234|235|243|253|324|325|333|343
 fuzzy_minII Re_mlow Am_mlow Co_high LSA_mlow1
 fuzzy_minII Re_mlow Am_med Co_med LSA_mlow2
 fuzzy_minII Re_mlow Am_med Co_mhigh LSA_mlow3
 fuzzy_minII Re_mlow Am_med Co_high LSA_mlow4
 fuzzy_minII Re_mlow Am_mhigh Co_med LSA_mlow5
 fuzzy_minII Re_mlow Am_high Co_med LSA_mlow6
 fuzzy_minII Re_med Am_mlow Co_mhigh LSA_mlow7
 fuzzy_minII Re_med Am_mlow Co_high LSA_mlow8
 fuzzy_minII Re_med Am_med Co_med LSA_mlow9
 fuzzy_minII Re_med Am_mhigh Co_med LSA_mlow10
 fuzzy_max LSA_mlow1 LSA_mlow2 buffer
 fuzzy_max buffer LSA_mlow3 buffer2
 fuzzy_max buffer2 LSA_mlow4 buffer3
 fuzzy_max buffer3 LSA_mlow5 buffer4
 fuzzy_max buffer4 LSA_mlow6 buffer5
 fuzzy_max buffer5 LSA_mlow7 buffer6
 fuzzy_max buffer6 LSA_mlow8 buffer7
 fuzzy_max buffer7 LSA_mlow9 buffer8
 fuzzy_max buffer8 LSA_mlow10 buffer9
'LOW:222|223|224|232|242|252|322|332|342|352|422|432|442|452
|542|552
 fuzzy_minII Re_mlow Am_mlow Co_mlow LSA_low1
 fuzzy_minII Re_mlow Am_mlow Co_med LSA_low2
 fuzzy_minII Re_mlow Am_mlow Co_mhigh LSA_low3
 fuzzy_minII Re_mlow Am_med Co_mlow LSA_low4
 fuzzy_minII Re_mlow Am_mhigh Co_mlow LSA_low5
 fuzzy_minII Re_mlow Am_high Co_mlow LSA_low6
 fuzzy_minII Re_med Am_mlow Co_mlow LSA_low7
 fuzzy_minII Re_med Am_med Co_mlow LSA_low8
 fuzzy_minII Re_med Am_mhigh Co_mlow LSA_low9
 fuzzy_minII Re_med Am_high Co_mlow LSA_low10
 fuzzy_minII Re_mhigh Am_mlow Co_mlow LSA_low11
 fuzzy_minII Re_mhigh Am_med Co_mlow LSA_low12
 fuzzy_minII Re_mhigh Am_mhigh Co_mlow LSA_low13
 fuzzy_minII Re_mhigh Am_high Co_mlow LSA_low14
 fuzzy_minII Re_high Am_mhigh Co_mlow LSA_low15
 fuzzy_minII Re_high Am_high Co_mlow LSA_low16
 fuzzy_max LSA_low1 LSA_low2 buffer
 fuzzy_max buffer LSA_low3 buffer2
 fuzzy_max buffer2 LSA_low4 buffer3
 fuzzy_max buffer3 LSA_low5 buffer4
 fuzzy_max buffer4 LSA_low6 buffer5
 fuzzy_max buffer5 LSA_low7 buffer6
 fuzzy_max buffer6 LSA_low8 buffer7
 fuzzy_max buffer7 LSA_low9 buffer8
 fuzzy_max buffer8 LSA_low10 buffer9
 fuzzy_max buffer9 LSA_low11 buffer10
 fuzzy_max buffer10 LSA_low12 buffer11
 fuzzy_max buffer11 LSA_low13 buffer12
 fuzzy_max buffer12 LSA_low14 buffer13
 fuzzy_max buffer13 LSA_low15 buffer14
 fuzzy_max buffer14 LSA_low16 LSA_low
'vLOW:
220|230|240|250|320|330|340|350|240|430|440|450|540|550
 fuzzy_minII Re_mlow Am_mlow Co_low LSA_vlow1
 fuzzy_minII Re_mlow Am_med Co_low LSA_vlow2
 fuzzy_minII Re_mlow Am_mhigh Co_low LSA_vlow3
 fuzzy_minII Re_mlow Am_high Co_low LSA_vlow4
 fuzzy_minII Re_med Am_mlow Co_low LSA_vlow5
 fuzzy_minII Re_med Am_med Co_low LSA_vlow6
 fuzzy_minII Re_med Am_mhigh Co_low LSA_vlow7
 fuzzy_minII Re_med Am_high Co_low LSA_vlow8
 fuzzy_minII Re_mlow Am_mhigh Co_low LSA_vlow9
 fuzzy_minII Re_mhigh Am_med Co_low LSA_vlow10
 fuzzy_minII Re_mhigh Am_mhigh Co_low LSA_vlow11
```

```
fuzzy_minII Re_mhigh Am_high Co_low LSA_vlow12
fuzzy_minII Re_high Am_mhigh Co_low LSA_vlow13
fuzzy_minII Re_high Am_high Co_low LSA_vlow14
fuzzy_max LSA_vlow1 LSA_vlow2 buffer
fuzzy_max buffer LSA_vlow3 buffer2
fuzzy_max buffer2 LSA_vlow4 buffer3
fuzzy_max buffer3 LSA_vlow5 buffer4
fuzzy_max buffer4 LSA_vlow6 buffer5
fuzzy_max buffer5 LSA_vlow7 buffer6
fuzzy_max buffer6 LSA_vlow8 buffer7
fuzzy_max buffer7 LSA_vlow9 buffer8
fuzzy_max buffer8 LSA_vlow10 buffer9
fuzzy_max buffer9 LSA_vlow11 buffer10
fuzzy_max buffer10 LSA_vlow12 buffer11
fuzzy_max buffer11 LSA_vlow13 buffer12
fuzzy_max buffer12 LSA_vlow14 lsa_vlow
```

```
'================= DEFUZZIFICATION II ==================
 scalar a=0.07
 scalar b=0.14
 scalar x1=a*0.5
 scalar x2=(a+a+b)/3
 scalar S1=a*1
 scalar S2=0.5*(b-a)
 scalar C1=(S1*x1+S2*x2)/S1+S2
 scalar C2=0.22
 scalar C3=0.36
 scalar C4=0.5
 scalar C5=0.64
 scalar C6=0.78 scalar a=0.075
 scalar b=0.15
 scalar x1=0.925+a*0.5
 scalar x2=(0.85+0.925+0.925)/3
 scalar S1=a*1
 scalar S2=0.5*(b-a)*1
 scalar C7=(S1*x1+S2*x2)/(S1+S2)

 defuzzification2 LSA_vHigh LSA_High LSA_mHigh LSA_Med LSA_mLow LSA_Low LSA_vLow
ASM
```

where	**import**	command to import a new map
	gen	option declaring the name for the map
	replace	command for recalculating an existing grid layer
	scalar	command for defining and handling scalar numerical variables
	fgen	command to generate new grid layer (fast version, with some limitation)

CHAPTER IV – PARAMETER SENSITIVITY ANALYSIS FOR THE VALIDATION OF LAND EVALUATION PROCEDURES

1. Introduction

1.1 Land evaluation procedures

Land evaluation is an important process required for sustainable resource management. It supports land use planning and land degradation control, and it is aimed at defining the optimal destinations for the territory. During the land evaluation process, resources and services related to the multiple functions of the land need to be addressed. A variety of analytical procedures can be implemented for the spatial representation of different land uses for better-informed planning decisions. The process is often based on the principle of "best available information", but it is not generally known how good this information is. This can result in two undesirable situations: the first one is decision making without information support, determining, as a consequence, sub-optimal decisions; the second is interpretation of the evaluation results without consciousness, thus determining casual governance of the land. Land evaluation procedure is intended as a framework where, given a certain evaluation goal, evaluation criteria and indicators (calculated from objective and subjective information, e.g. expert judgement) are defined to give a ranking of suitability or vulnerability for particular type of land use.

The procedure, in its more general form, may be represented as a calculation performed on georeferenced data, that put together objective land information with subjective information from the decision making level (weight of importance for the different indicators, value functions; Malczewski, 1999; Ananda and Herath, 2003). Value functions, in other contexts also called *membership functions*, are considered as tools for objective information (measurements) transformation into a utility value for the evaluation goal. This is accomplished by a function, parameterized based on expert judgement, which defines a utility value of the measurement. Thus, all input information for the procedure can be classified into four groups: 1) georeferenced land data; 2) parameters for the value functions selected to calculate indicators; 3) weight of importance for the indicators; 4) threshold values for the classification of the final evaluation index.

1.2 Model validation and sensitivity analysis

Evaluation models can be qualitative, mainly based on expert judgement, or quantitative, based on simulation models (Beek *et al.*, 1997). In this work we deal with qualitative models, here called "procedures", while the term "simulation model" refers to the quantitative, process based models. Confidence in models outputs can be increased by testing model structure, behaviour, and implications, and by applying other approaches to analyse its accuracy and representativeness, thus obtaining the information about its correspondence to the system represented (Forrester and Senge, 1980). If there is a good match between model prediction and independent (reference) data, then the model is considered to be empirically valid. Validation should measure the performance of a model in order to enable the scientist to know the level of trust that one should put into the model; it should also give essential information to improve the model (Kok *et al.*, 2001). A major issue in modelling is the large number of parameters and input data; thereby, it is important to define how sensitive the model is to their variations. However, if the model shows to be sensitive to parameters, it is necessary to accurately adjust their values (Gupta *et al.*, 1999). Sensitivity analysis allows defining where calibration and modelling efforts are to be concentrated, i.e., where the model is most sensitive. For models' sensitivity analysis there is a number of different methods ranging from measures of importance to sensitivity indices or from regression and correlation methods to variance-based methods (Chen *et al*., 2010). Sensitivity analysis is able to provide assistance in model building and to find out the more sensitive parameters. This can contribute to the model simplification, since - if there are factors and parameters insensitive to any value within the range - they can be eliminated, so reducing the computational efforts (Saltelli *et al.*, 2000). Unfortunately, in land evaluation procedures, it is almost impossible to perform empirical validation based on measurements; thus, sensitivity analysis can be a useful tool for testing the model.

1.3 Sensitivity analysis of land evaluation procedures

Uncertainty in land evaluation results can derive from input maps, subjective parameters, weights and thresholds, and the indicators' aggregation method. The selection of value functions and their parameters is the responsibility of the land analyst, while the weights selection pertains to the decision maker. Since the selection of parameters of value functions is subjectively given by the analyst, it can be strongly questioned by stakeholders. So, in this case, sensitivity analysis can demonstrate the reliability of the procedure that has been implemented. Nowadays land evaluation procedures have become more complex, the number of parameters to be estimated has increased, and thus it is important to estimate the effects that these parameters have on the model response and how these influences vary with the model complexity (Bastidas *et al*., 2006). In order to avoid subjectivity in presence of uncertainty, it is important to perform sensitivity analysis (*SA*), which characterizes the effect of individual variables and input parameters on the procedure outputs. For land evaluation and optimal allocation of land uses, the method of multi-criteria analysis (MCA), integrated with GIS, has been found particularly efficient, but the use of *SA* for the evaluation of procedures based on MCA is not common: *SA* has been often used to estimate the influence of the inputs (parameters, forcing variables) on simulation models without a spatial dimension. In procedures using spatial data, the *SA* can be applied to analyse the contribution of each input parameter on the output map. It evaluates the effect of the input data on the final map, which also depends on many factors such as the type of value function and its shape, the weights of the indicators and the uncertainty associated to each map (Napolitano and Fabri, 1996). Many complex techniques for *SA* have been recently developed in the field of simulation modelling (Saltelli *et al.*, 2000; Saltelli *et al.*, 2004); more specifically, sensitivity of spatial models to uncertainty in input maps (Lilburne and Tarantola, 2009) and to the weight of importance (Chen *et al.*, 2010; Rocha *et al.*, 2010) has been already treated. Not so common is the analysis of sensitivity of spatial models to the parameters of value functions obtained by expert judgement.

In this study, the efforts are focused on evaluating the sensitivity of the parameters of the value functions. The aims were to propose a method for the validation of land evaluation procedures based on spatial sensitivity analysis by considering the influence of the parameter values on the resulting land evaluation map, and to develop computer procedures for an easy application of the methods. The sensitivity of land evaluation procedures due to the uncertainty of input maps, accurately treated by other authors, is not considered here, as well as from weights and from the classification thresholds. In this study the sensitivity analysis method has been applied to an evaluation procedure developed to identify areas suitable for agritourism in a Northeast Italy region (Peccol and Bonfanti, 2000). For the purposes of the present study, the original model has been simplified to test the applicability of SA procedures.

2. Materials and methods

2.1 Land evaluation procedure

The evaluation procedure was originally developed by Peccol and Bonfanti (2000) and was aimed at identifying areas suitable for agritourism in a marginal mountain area (165 km^2) of the Friuli Venezia Giulia region, Northeast Italy. In this context, agritourism involves agriculture-based operations or activities aimed at offering tourists board and lodging plus, sometimes, recreation and sport activities. The economy of the study area is mainly based on agriculture and forestry and, to a lesser extent, on tourism. The size of the grid map was about 3 Mcells of 10x10 m. The evaluation procedure was developed by applying a multicriteria analysis through the following steps: 1) definition of a set of evaluation criteria; 2) collection and preprocessing of data; 3) standardization of the data and calculation of the value function in order to create indicators; 4) assignment of weights to each indicator, according to their importance for the analysis. The suitability evaluation was performed considering those criteria, which may influence agritourism settlement and its attractiveness. The weights (W) assigned to the indicators were defined with the support of a panel of experts by using the Analytical Hierarchy Process (AHP; Saaty, 1988). The evaluation index (VA) was calculated as:

$$VA = I_{DS} \cdot W_{DS} + I_{DVA} \cdot W_{DVA} + I_{DVS} \cdot W_{DVS} + I_{DV} \cdot W_{DV} + I_{Q} \cdot W_{Q} +$$
$$+ I_{P} \cdot W_{P} + I_{PC} \cdot W_{PC} + I_{MD} \cdot W_{MD} + I_{AA} \cdot W_{AA} + I_{US} \cdot W_{US}$$

Where the indicators are:

I_{DS} opportunities for trekking
I_{DVA} site amenity
I_{DVS} historical interest
I_{DV} reachability by car
I_{Q} site suitability for agriculture considering altitude
I_{P} site suitability for settlements considering slope
I_{PC} existence of traditional rural buildings
I_{MD} quality of social life (index of social well-being)
I_{AA} economically advantaged zones (presence of special land designations such as quality labels, DOC and DOCG wine areas, etc.)
I_{US} compatibility of land use with agritourism settlements

The original evaluation procedure was performed by using the decision support module of Idrisi GIS. In order to perform sensitivity analysis, the evaluation procedure has been re-implemented in *SemGrid* (Danuso and Sandra, 2006), a raster GIS developed at the Department of Agricultural and Environmental Sciences of the University of Udine, Italy. The land evaluation procedure is based on ten indicators each corresponded to a proper criterion. The normalization of continuous data (altitude, slope, distance from roads, etc.) has been performed by using membership functions (trapezoidal and j-shaped) from the fuzzy logic (figure 1). The qualitative data (presence of alpine huts, indicator of population wellness, land use, special land designations) have been normalized by assigning new values between 0 and 1, according to the scores from the original study (Peccol and Bonfanti, 2000). So, the information data have been standardized within a scale between 0 and 1, where 1 indicates the most favourable condition and 0 indicates the most unfavourable.

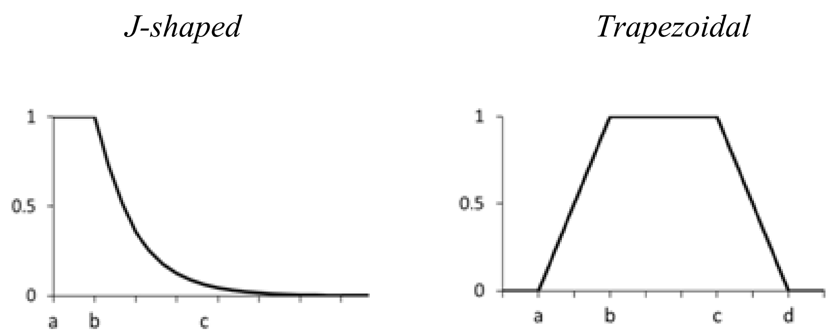


Figure 1 – Membership (value) functions used to calculate indicators from continuous data: a, b, c and d are the parameters of membership functions to represent expert knowledge

2.2 Parameter sensitivity analysis

The evaluation procedure of land suitability for agritourism has been validated through sensitivity analysis. Fourteen parameters of six evaluation indicators defining the value functions shapes (table 1) have been analysed.

Table 1 – Evaluation criteria, indicators and their parameters. `mJoff` and `mTrapez` are membership functions implemented in the *SemGrid* scripting language syntax.

Criterion	Land information	Calculation of the indicator
Trekking opportunities	Distance from footpaths (*Sentdistn*, m)	$I_{DS} = mJoff(Sentdistn, 0, a_{DS}, b_{DS})$ a_{DS} = 50 m b_{DS} = 200 m
Site amenity	Distance from natural features (*Natdistn*, m)	$I_{DVA} = mJoff(Natdistn, 0, a_{DVA}, b_{DVA})$ a_{DVA}= 50 m b_{DVA}= 200 m
Historical interest	Distance from cultural sites (*Vstdistn*, m)	$I_{DVS} = mJoff(Vstdistn, 0, a_{DVS}, b_{DVS})$ a_{DVS}= 50 m b_{DVS}= 200 m
Reachability by car	Distance from roads (*Roaddistn*, m)	$I_{DV} = mJoff(Roaddistn, 0, a_{DV}, b_{DV})$ a_{DV}= 50 m b_{DV}= 300 m
Site environmen. suitability	Elevation (*Altitude*, m)	$I_{Q} = mTrapez(Altitude, 0,0, c_{Q}, d_{Q})$ c_{Q}= 650 m d_{Q}= 1820 m
Site suitability for settlements	Slope (*Slope*, %)	$I_{P} = mJoff(Slope, 0, a_{P}, b_{P})$ a_{P}= 5 % b_{P}= 188 %

The most common way for applying sensitivity analysis is to vary input factors One-At-a-Time (OAT method or mono-dimensional local sensitivity analysis). This method consists in changing one parameter at a time, while all the others are fixed to their central, or baseline, value (Chen *et al*., 2010) and it is applicable for continuous maps. Another approach relies on the concept of "*insensitivity range*" for the parameters. This is particularly useful when the final evaluation map is discrete. The range of insensitivity for a parameter is the range of values that do not generate a significant variation in the final classification of the cells, with respect to the standard value (Wainwright and Mulligan, 2004). For a correct estimation of the parameters' sensitivity, the impact of the indicator weights has been eliminated by assuming them as equal (W_I = 0.1, for ten indicators). The proposed method analyses the changes in each map cell value caused by the parameters change. For each parameter, two sensitivity measures have been obtained (figure 1): the sensitivity coefficient (*SC*) and the insensitivity range (*RI*). To calculate the sensitivity coefficient of parameters (P), an increment of 5% has been applied (Beck and Arnold, 1977). The sensitivity coefficient maps have been obtained calculating, for each cell, the ratio between the relative variation of VA and the parameter relative variation:

$$SC = \frac{\frac{\Delta VA}{VA}}{\frac{\Delta P}{P}} = \frac{\frac{VA - VA'}{VA}}{\frac{P - P'}{P}}$$

where:

- VA continuous index of the standard parameter value
- VA' continuous index for parameter P increased by 5% (P')
- P standard value of the parameter
- P' parameter value increased by 5 %

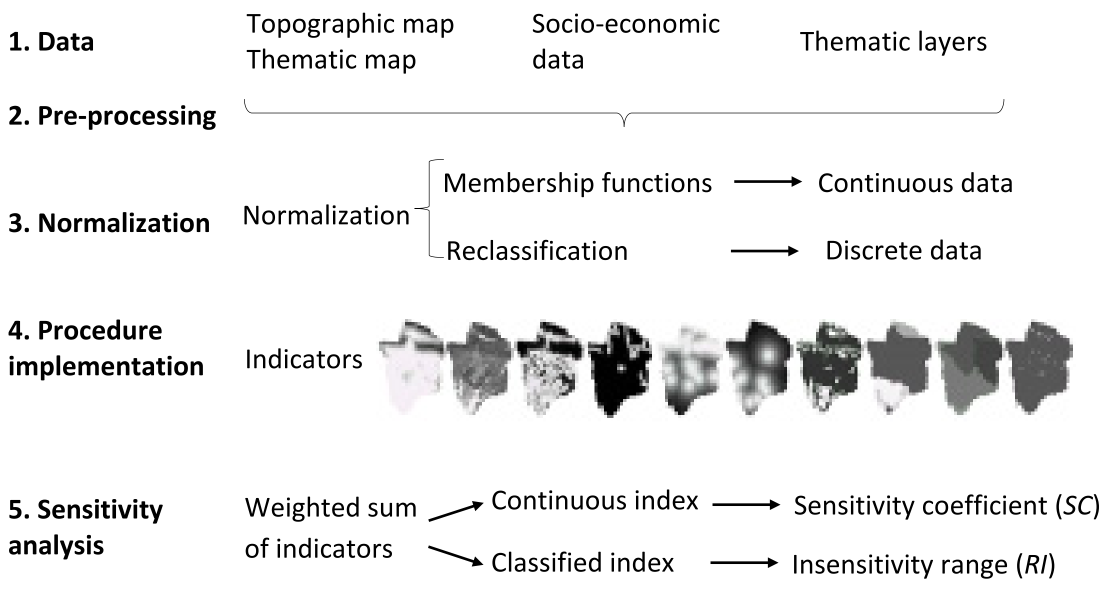


Figure 1 – Procedures of land evaluation and sensitivity analysis.

The range of insensitivity has been considered as the range of parameter values within which the difference between maps doesn't exceed 5%. In order to define the RI, each parameter has been varied by ± 2%, 5%, 8%, 11%, 15%, 30%, 40%, 50 % of its initial (baseline) value. New land evaluation maps of the suitability index have been generated using modified parameters and classified in 5 classes of suitability (low, moderately-low, moderate, moderately-high and high suitability) using equally spaced thresholds. Each new classified map has been compared with the reference map by creating contingency tables, also known as "confusion matrices". On the base of contingency table, many similarity statistics can be derived (Pontius and Schneider, 2001; Hagen, 2002; Pontius *et al.*, 2007). In this study the degree of correspondence (*CD*), calculated as sum of the diagonal values, has been used. If the maps are identical, *CD* is equal to one; otherwise *CD* decreases till to zero. Thus each parameter value, which causes changes in the final map, gives a certain degree of correspondence. On the basis of the *CD* values and of the corresponding parameters, it is possible to create curves which represent the influence of the parameters on the resulting maps. In the case study presented, the *SC* map calculation requires one run of the procedure for the baseline map and one for each parameter to be processed. For the *RI* identification, the procedure has been run 225 times in order to consider parameter variation. To run the complete procedure, several hours could be required, depending on the map size. A good solution is to implement evaluation procedures and the sensitivity analyses by using scripts of commands. Scripts allow several advantages with respect to the interactive data processing: a maximum level of flexibility, the possibility to save time by adapting or repeating the procedures for other cases, the possibility to improve the procedure and the possibility to check the sequences of the calculations and for the debugging.

3. Results

In figure 3, the sensitivity coefficient (*SC*) maps are presented. Areas of medium ($0.4<SC<0.6$]) sensitivity are coloured in yellow, areas of medium low sensitivity ($0.2<SC<0.4$) in green, while black represents areas not sensitive ($SC<0.2$) to the changes of parameter value. The areas of the highest sensitivity are in red ($SC>0.8$). It is to be noted that the different parameters show different sensitivity and that it varies depending on the location on the map. For example, the parameters of I_{DS} show higher degree of sensitivity near the footpaths. The same occurs with the parameters of the reachability indicator I_{DV} with respect to the roads. Instead, sensitivity of altitude and slope indicators (I_Q and I_P) follows the terrain of the area. In general, parameters show medium and low degrees of sensitivity, which might indicate a correct behaviour of the procedure. Highest levels of sensitivity can be found for the a_{DV} and b_P parameters of indicators which define the suitability according to the possibility for walking and slope respectively. The sensitivity curves in table 2 show the influence of each parameter on the final maps and define the range of parameter insensitivity (*RI*), i.e. an interval of the parameter values within which there is a good level of agreement (95 %) between maps. Results obtained about the parameter sensitivity provide with information for further improvement of the land evaluation procedure.

Thus, high sensitivity of the parameters indicates the need to check whether they are set properly; this can lead to an improvement of the procedure by modifying the parameters or identifying new membership functions. In case of parameter insensitivity, the values applied to the parameters can be treated as constant, as for parameters a_Q, b_Q and c_Q. If the disturbance of these parameters doesn't lead to significant changes of the final map, then they can remain the same in subsequent applications of the procedure.

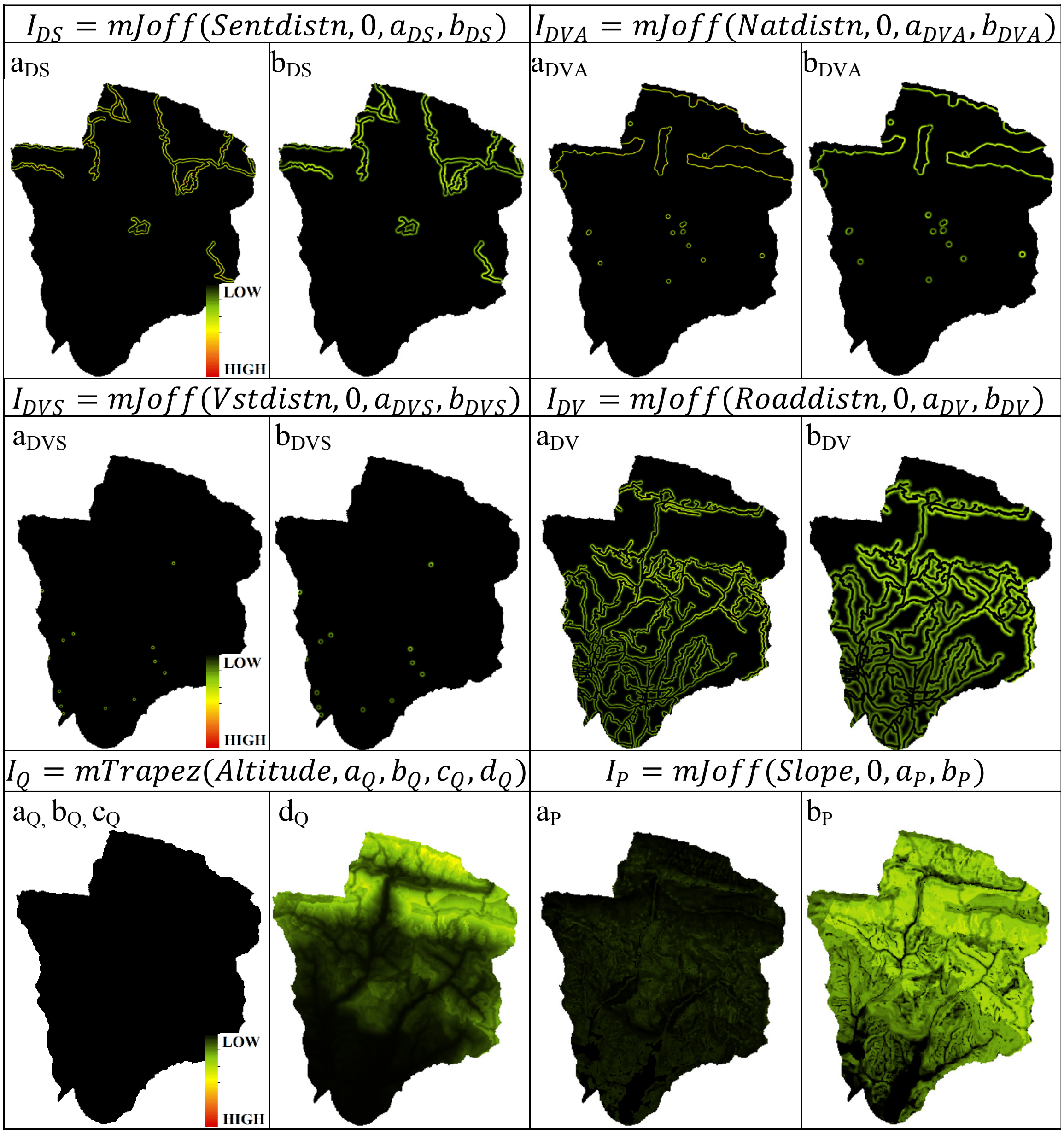
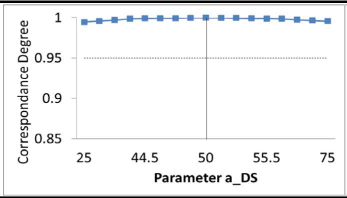
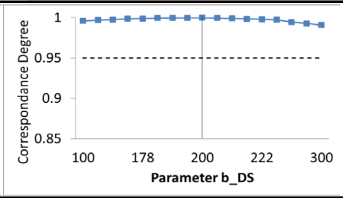
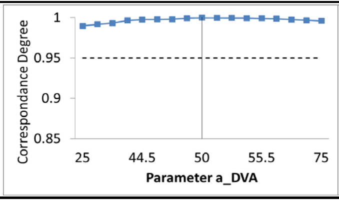
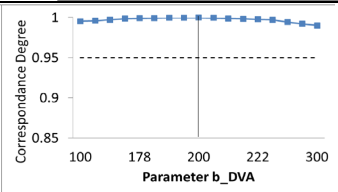
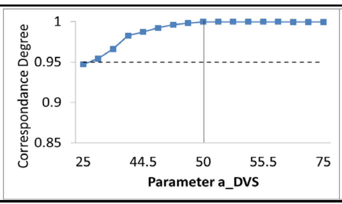
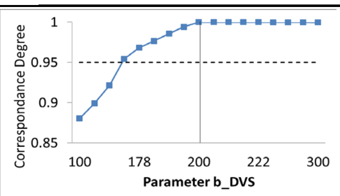
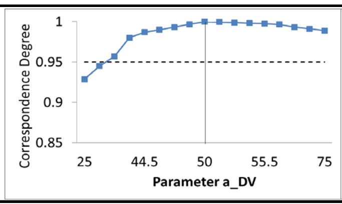
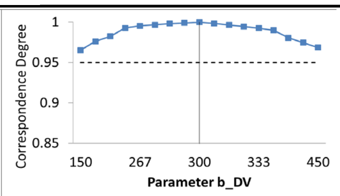
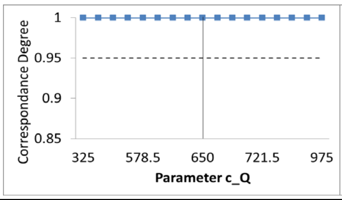
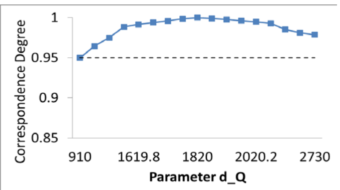
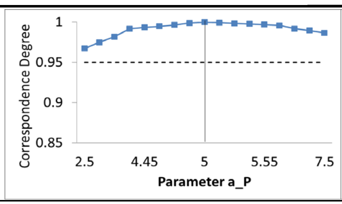
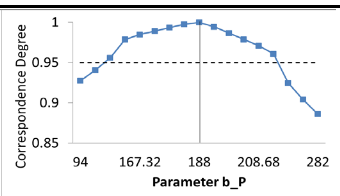


Figure 3– Maps of sensitivity coefficient (*SC*) for the parameters.

Table 2– Degree of correspondence of final evaluation maps with changing values for each parameter. The initial value and insensitivity range are also reported.

Parameter	Initial value	Unit	Insensitivity range (RI) min	Insensitivity range (RI) max
I_{DS}=mJoff($Sentdistn$, 0, a_{DS}, b_{DS})				
 	50 200	m m	- -	- -
I_{DVA}=mJoff($Natdistn$, 0, a_{DVA}, b_{DVA})				
 	50 200	m m	- -	- -
I_{DVS}=mJoff($Vstdistn$, 0, a_{DVS}, b_{DVS})				
 	50 200	m m	25 170	- -
I_{DV}= mJoff($Roaddistn$, 0, a_{DV}, b_{DV})				
 	50 300	m m	35 -	- -
I_Q=mTrapez($Altitude$, a_Q, b_Q, c_Q, d_Q) CD of a_Q, b_Q, always one because parameter is zero				
 	650 1820	m m	- 910	- -
I_P= mJoff($Slope$, 0, a_P, b_P)				
 	5 188	% %	- 132	- 217

4. Conclusions

The validation procedure, based on the sensitivity analysis methods, point out the most sensitive parameters, which have significant impact on the model output: their values should be selected with a high degree of accuracy while those which impact is slight enough could be considered as constant. Mapping of sensitivity allows graphical identification of the areas of high or low sensitivity. In the analysis of the *SC* maps, not only average values have to be considered, but also the maximum values are particularly interesting. Results obtained show that the response of the procedure to the changes is relatively stable and sensitivity is almost similar among the different parameters. Sensitivity analysis can be used to evaluate the reliability of the model by comparing, for each parameter, uncertainty range (*RU*), an interval within which a numerical result is expected to lie within a specified level of confidence, and the calculated range of insensitivity (*RI*). If $RU >> RI$ then it is to be retained that the procedure produces unpredictable results due to the excessive sensitivity. Otherwise, if $RU << RI$ we can consider that the procedure is too conservative, tending to damp the land variations, due to low sensitivity. The improvements that can be suggested are: a) in case of high sensitivity, reducing the number of classes in the final map and modifying the shape of the value functions by their parameters; b) in case of low sensitivity, increasing the number of classes in the final maps and proper modification of the parameters. Further development of the methodology will involve a method for combining sensitivity evaluation of each parameters into an overall model sensitivity index to establish the whole degree of validity. The *SemGrid* scripts developed for the land evaluation procedure and for the sensitivity analysis are available from the authors or from the *SemGrid* web site.

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Wainwright J., Mulligan M., 2004. John Wiley and Sons, USA.

Annex 1 – Sensitivity analysis procedure

```
'SemGrid 1.3.8 script (12-21-2010 13:07:12)
' PARAMETER SENSITIVITY ANALYSIS OF LAND EVALUATION
PROCEDURE
'======Identification of areas suitable for
agritourism=======
'1) Set of the procedure parameters
01_Set_param.cmf
'2) Run of the land evaluation procedure:calculation of
indicators & suitabilty index
02_1_Indicator_DS.cmf  "oppotunities for trekking"
02_2_Indicator_PC.cmf  "presence of alpine huts"
02_3_Indicator_DVA.cmf "site amenity"
02_4_Indicator_DVS.cmf "site historical interest"
02_5_Indicator_MD.cmf  "population wellness"
02_6_Indicator_US.cmf  "land use"
02_7_Indicator_Q.cmf   "suitability for agriculture activities"
02_8_Indicator_DV.cmf  "reachability"
02_9_Indicator_P.cmf   "suitability for settlements"
02_10_Indicator_AA.cmf "designation advantage"
02_11_vocagritur.cmf 0 "agritourism suitability index (VA)"
'3)Export of the indicator layers
03_export_layer.cmf
'=Parameter sensitivity analysis of the land eval.procedure=
'4)Calculation of SC(sensitivity coefficient)for continuous
VA
04_SC.cmf drop all
scalar drop
'5) Import of the indicator layers
05_import_layer.cmf
'6) Calculation of RI (range of insensitivity) for discrete
VA
06_0_Analisi_Discreto.cmf a_DS  "calculation RI for parmameter a_DS"
06_0_Analisi_Discreto.cmf b_DS
import DS.txt as(ArcGis) type(float) gen(DS) replace crun
06_0_Analisi_Discreto.cmf a_DVA
06_0_Analisi_Discreto.cmf b_DVA
import DVA.txt as(ArcGis) type(float) gen(DVA) replace
06_0_Analisi_Discreto.cmf a_DVS
06_0_Analisi_Discreto.cmf b_DVS
import DVS.txt as(ArcGis) type(float) gen(DVS) replace
06_0_Analisi_Discreto.cmf a_Q
06_0_Analisi_Discreto.cmf b_Q
06_0_Analisi_Discreto.cmf c_Q
06_0_Analisi_Discreto.cmf d_Q
import Q.txt as(ArcGis) type(float) gen(Q) replace
06_0_Analisi_Discreto.cmf a_DV
06_0_Analisi_Discreto.cmf b_DV
import DV.txt as(ArcGis) type(float) gen(DV) replace
06_0_Analisi_Discreto.cmf a_P
06_0_Analisi_Discreto.cmf b_P
display "================== END =================="
```

CHAPTER V – LAND EVALUATION TOOLS

1. Introduction

Coupling with multiple factors in a spatial and temporal context, land evaluation methods integrated with GIS tools are the foundation of decision-making (Chen, 2011). Being a necessary tool in many fields, such as resource investigation, environment observation and disaster prevention, urban planning and farm management, geographic information systems (GIS) have been considered particularly effective and practical, enhancing decision and policymaking process. Nowadays, there is an abundant supply of various GIS software, varying in complexity and capability to solve different tasks. Generally, they are distinguished between them as open and close source software (Neteler *et al.*, 2012), while Steiniger and Hay (2012) point out that it is more appropriate to distinguish software between free and proprietary in terms of freedom: free to be used, modified and distributed, which subsequently can be commercial and non-commercial ones. Following the suggestions, in this chapter, the free of cost, proprietary (close source) GIS *SemGrid*, developed at the Department of Agricultural and Environmental Sciences, is presented. The program allows working with grid map layers as managing datasets. It is supported by a number of scripts, which can be downloaded from the web and used to perform various land evaluation procedures. During the thesis development, a part of the research activity has been dedicated to the evaluation and testing of the *SemGrid* software. Moreover, some new specific commands have been implemented in order to perform the tasks related to the above discussed studies. Particularly, the commands `sunh`, `camc`, `marksim`, `markest` and several scripts have been developed.

While making decisions on land resources use, one of the most difficult challenges is addressing climate conditions and their variability over the time. This problem is largely the product of the high levels of uncertainty surrounding climate change and variability, as well as their potential consequences for landscapes and ecosystems (Squillace and Hood, 2012). Study and development of stochastic climatic models for risk evaluation in land systems has been for a long time one of the most important scientific issues (Jones *et al.*, 1970; Richardson, 1981; Larsen and Pense, 1982; Shu Geng *et al.*, 1985; Richardson and Nicks, 1990; Semenov *et al.*, 1998; Donatelli *et al.*, 2005; Donatelli *et al.*, 2009; Birt *et al.*, 2010). To this end, a new version of a stochastic weather generator Climak, previously created at the DISA (Danuso, 2002), was developed.

2. The raster GIS *SemGrid*

2.1 SemGrid framework

SemGrid is a simple raster GIS developed at the Department of Agricultural and Environmental Sciences (DISA) of the University of Udine (Italy) for didactical, land evaluation and land planning purposes, as well as management of the land information.

The first version of *SemGrid* was released in 2005. Since then, it has been improved and enhanced by development of new functions and extending its capabilities. Developed to facilitate the use of simulation models at land scale (Danuso and Sandra, 2006), presently *SemGrid* is fully functional, stand-alone free of cost software. The last version, *SemGrid* 1.5.3, has many features typical for raster GIS, such as import and export of grid layers of different formats (ArcGis, Surfer, GeoMedia, Idrisi, Grass, etc.); map production; map algebra, statistical analysis on grid layers; random variables generation; user defined functions generation and data management, overlay, distance calculation, point data spatialization, etc. Moreover, it allows fuzzy logic expert system development and application of Cellular Automata and Markov Chain estimation and simulation both in separated and integrated ways. Additionally, *SemGrid* implements Gstat (included in *SemGrid* installation), FragStats, which need to be downloaded from respective website (http://www.umass.edu/landeco/research/fragstats/fragstats.html) and installed separately, HyGrid2k2 by Federico Cazorzi for watershed hydrology simulation. One of the powerful features of *SemGrid* is the possibility to save all operations performed during the session in a separate file (*.cmf), thus creating a script. The script is a list of commands which allows development of entire procedures for land evaluation and modelling, which can be reused applying to other conditions by changing input data and parameters.

SemGrid works with grid projects as well as datasets. The *grid management* mode makes *SemGrid* working with grid projects as a raster GIS, while *data management* mode allows *SemGrid* to operate like a data management and statistical system to perform dataset handling and statistical analyses.

A grid project (*.grp) is a set of grid layers needed for a specific planning or evaluation task, which is characterized by the same features (X origin, Y origin, number of columns of cells, number of rows of cells, cell size, etc.). A grid layer is an array of square cells of the same dimension that completely cover the study area, where each cell contains qualitative or quantitative information. Thus, land variables can be of *byte*, *float* (double), *int* (integer) or *string* types.

Datasets are the tables, the columns and rows of which contain variables and related observation data, with or without geographical reference (XY coordinate to declare the position of each observation). Datasets can be loaded and saved in three formats: standard dct file (*.dct), comma separated values (*.csv) and DBase III files (*.dbf).

SemGrid works also with "ambient" variables, which are the variables created and eliminated on the fly, and existing only during the working session. They are lost when the session is ended and *SemGrid* is closed. In order to get the ambient variables data, they are to be converted in the dataset and saved. The ambient variables can be of *scalar*, *string* and *matrix* type, and are managed by the proper commands. The *SemGrid* graphical user interface consists of the main dialogue window, the window of results and the command window (Figure 1).

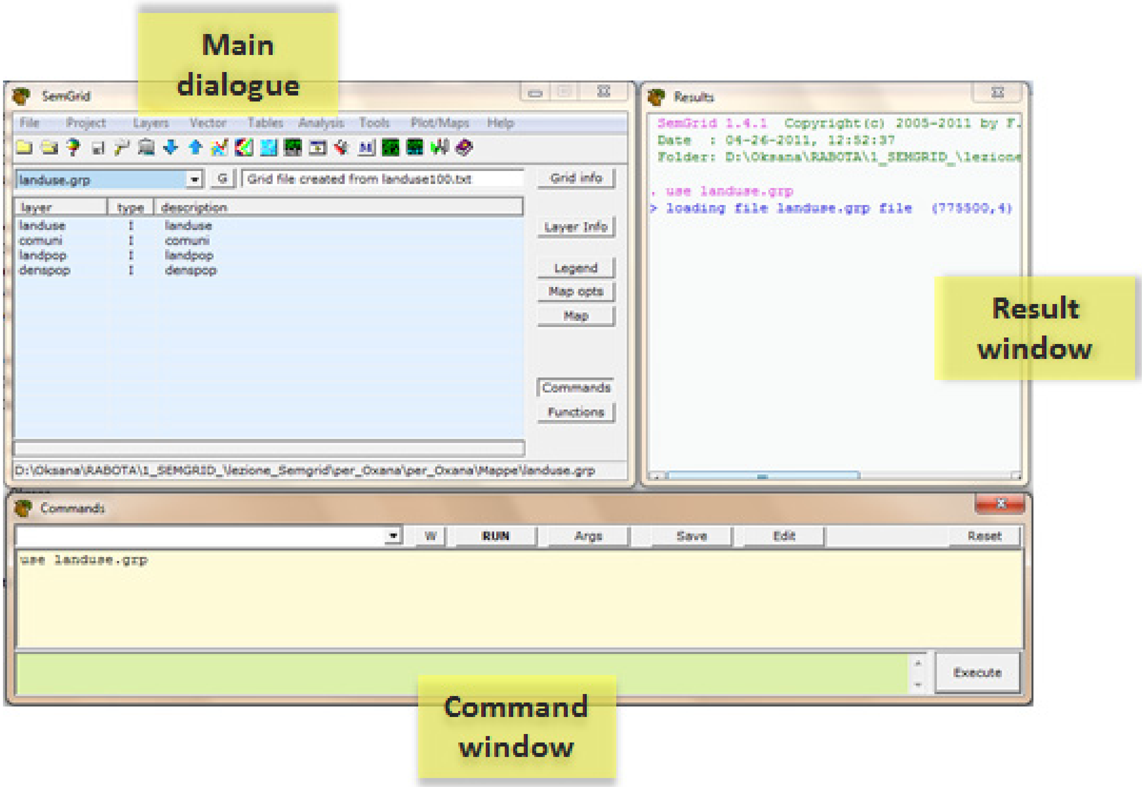

Figure 1. *SemGrid* graphical user interface.

The main dialogue window displays the layer in use and allows user to perform operations with it. The result window shows the output of the executed commands, as well as the errors occurred. The command window allows execution of operations by typing commands in command line, as well as management of script files.

2.2 SemGrid commands

The *SemGrid* operations can be executed either using dialogues of the graphical user interface or writing commands directly in the command window (to be noted, *SemGrid* is not case sensitive). Commands are the words of text requesting given to the application in order to perform certain actions. The structure of *SemGrid* commands is formed by a command name (`cmdname`) and options (`opt`) as follows:

```
cmdname opt1 opt2 opt3
```

Some of the most important *SemGrid* commands are listed in the Annex 1. Each option can be supported by none, one or more arguments depending on the option, which are typed inside parentheses and are separated by commas, without any space between them:

```
cmdname opt1(arg) opt2 opt3(arg1,arg2,arg3)
```

2.3 SemGrid scripts

SemGrid provides an opportunity to be used also in a batch mode, i.e., the user writes a list of commands (*script*) in a file (*.cmf) and submits the file to the program, executing all the commands of the procedure in one step. The procedure can be repeated many times changing, in case of need, the input parameters. The commands can contain macros. The macros are string variables, representing another variable, declared by `string` command and percent (%) symbols. During the command execution containing macros, the macros are substituted by the corresponding declared values – string or number arguments. The arguments can be inserted by the user before script execution via script argument window (Figure 2) or typed directly after the script name. The arguments render the procedures developed in *SemGrid* more general. Scripts are managed by the Command dialogue:

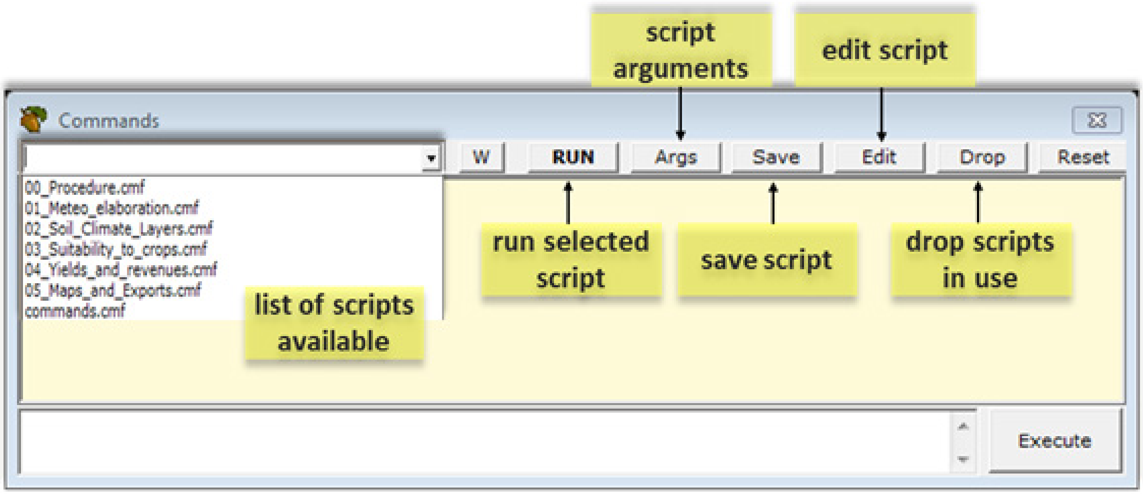

Figure 2 – *SemGrid* command window.

The command window shown in Figure 2 allows user to execute and manage operations with *SemGrid* via command line. The buttons of the window serve to create scripts, to save operations performed during the session, to edit the script files and to run it. Once script is executed, it is saved in the program memory in order to speed the work. Thus, after having modified a script, it is important to clear the memory by drop button. The reset button clears the scripts in the memory, but also ambient variables derived from the operation performed. The scripts saved are located in a specific folder, which is created by the program automatically within the working folder. Furthermore, the list of available scripts can be reached via command window. The structure of *SemGrid* script is presented in the Figure 3.

2.4 Map tools

The actions with maps include legend display, querying current cell information, querying all information related to the cell, zooming to magnify and reduce the map size, modification of single cell value, saving maps as Bitmap or Jpeg. The Map tools dialogue (Figure 4) can be accessed by the button Map tools in the main dialogue of *SemGrid*. The options and the settings of map tools are to be made before the map creation. The dialogue of map tools allows inserting the legend, labels, and points from a point data file; setting bitmap as background image; inserting a compass; inserting a ruler; changing the color of no-data cells; inserting a grid.

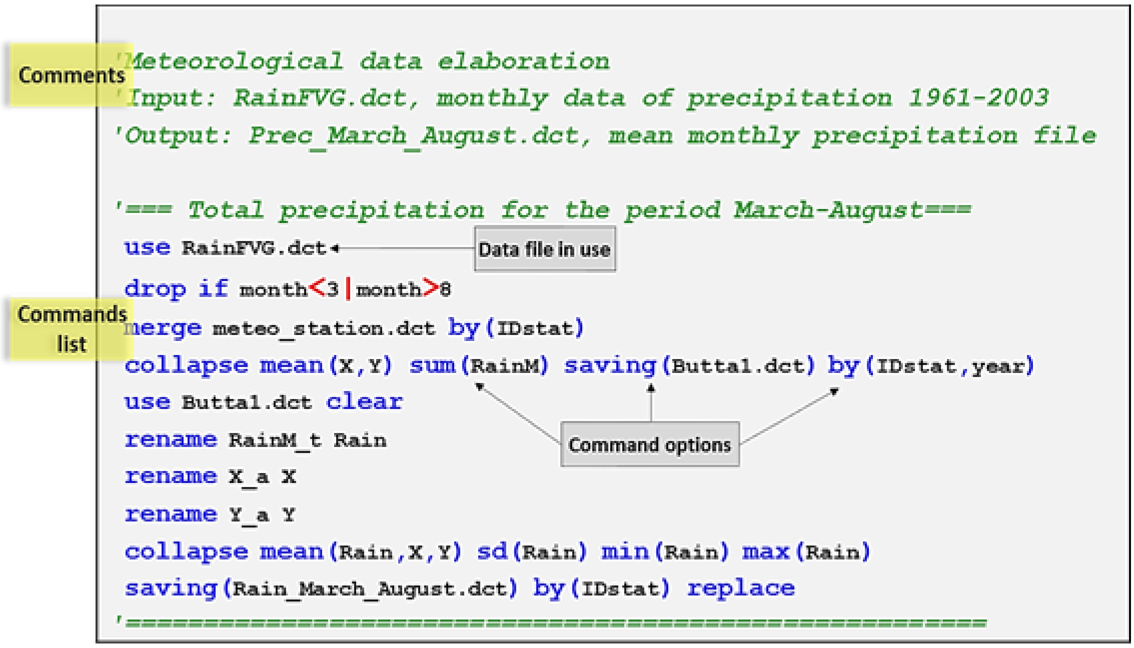

Figure 3 – Structure of the *SemGrid* script file.

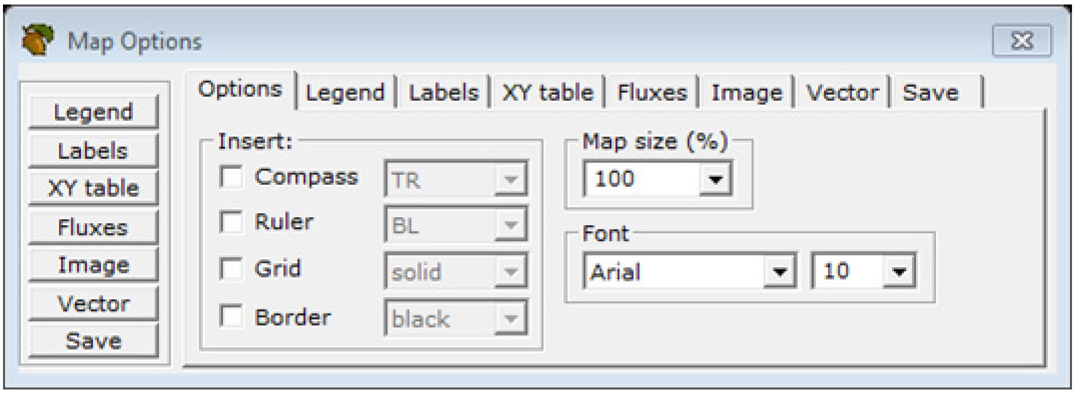

Figure 4 – *SemGrid* map tools dialogue.

3. The Climak 3 weather generator

3.1 Climak 3 framework

Weather generators (*WG*) are stochastic models, which produce meteorological data of indefinite length, on the base of climatic parameters estimated from historic meteorological data series. Developed in the early '90s the weather generator *Climak* (Danuso and Della Mea, 1994) generates daily data of precipitation, maximum and minimum temperatures, solar radiation and evapotranspiration. The new version (*Climak 3*) developed jointly with the weather generator CLIMA (Donatelli *et al*., 2005, Donatelli *et al*., 2009) using the SEMoLa language (Danuso, 2003) allows also the generation of wind speed data. Validation of Climak 3 was performed by generating meteorological data series and comparing them with the historical ones (Rocca *et al.*, 2012, Ginaldi *et al.*, 2012).

The weather generation procedure of *Climak 3* consists of two sequential steps: 1) estimation of climatic parameters from historical meteorological data, and 2) data generation based on the statistical parameters obtained. In *Climak 3* precipitations are not distinguished between solid (hail, snow) and liquid (rain) precipitations. The meteorological variables generated by *Climak 3* and related parameters are declared in Table 1.

Table 1 – *Climak 3* weather generator variables and related parameters.

Meteorological variable	Abbreviation	Unit	Model parameters *
Precipitation	*Prec*	mm	Pdd_i, Prd_i; Ag_i, Bg_i
Minimum temperature	*Tmin*	°C	A_i, B_i, C_i, D_i, E_i; Rn_i, SRn_i; $RRnn_i$
Maximum temperature	*Tmax*	°C	A_i, B_i, C_i, D_i, E_i; Rx_i, SRx_i; $RRnx_i$
Solar radiation	*Rg*	$MJ/m^2 \cdot d$	b_0, b_1; Ab_i, Bb_i
Evapotranspiration	*Etr*	mm	a_0, a_1, S_{etr}; c_0, c_1, S_{etp}, d_0,d_1
Wind speed	*Winds*	m/s	bw_0, bw_1, bw_2, bw_3, bw_4, bw_5; Rw

* *i* – month; see text for the meaning of the symbols

As a first step, *Climak 3* generates the occurrence of rainy or dry day and the rainfall amount, if the day is rainy. After rainfall generation, minimum and maximum air temperatures are generated, separately, for rainy and dry days. Solar radiation is obtained from the astronomical photoperiod (*Ph*) and from the daily thermal excursion.

The evapotranspiration is generated from the solar radiation data; if data of solar radiation are not available, evapotranspiration is obtained from photoperiod and maximum temperature. In the end, wind speed values are generated.

3.2 Estimation of climatic parameters from historical meteorological data

As a first step, *Climak 3* estimates the probability of rainy or dry day occurrence. The state of the day (rainy or dry), being a stochastic process, is represented by a first order Markov chain according to the dry to dry (*Pdd*), rainy to dry (*Prd*), dry to rainy (*Pdr*) and rainy to rainy (*Prr*) transition probabilities. The transition probabilities parameters are estimated from historical date, for each month, as:

$$P_{dd} = \frac{Ndd}{Nd} \qquad P_{dr} = 1 - Pdd \quad ; \quad P_{dd} = \frac{Nrd}{Nr} \qquad P_{rr} = 1 - Prd$$

where *Ndd* number of dry days in the month preceded by a dry day
Nd total number of dry days in the month
Nrd number of dry days in the month preceded by a rainy day
Nr total number of rainy days in the month

For rainy days the rainfall amount (*Prec*) is sampled from a Gamma probability density function:

$$Prec = \Gamma(A_g, B_g)$$

where A_g and B_g are the parameters, specific for each month estimated from historical date. Before estimating the parameters of the Gamma distribution, the sensitivity threshold of the instrument (S_{thr}=0.2) is subtracted from rainfall data, in order to obtain a distribution starting from 0. Then the Ag and Bg parameters are estimated, on a monthly basis, by the method of the moments:

$$A_g = \frac{M^2}{V} \quad ; \quad B_g = \frac{V}{M}$$

where *M* is the mean and *V* is the variance of the daily rainfall amounts.

The minimum and maximum temperatures are generated separately, considering the status of the day (rainy or dry), using related annual *trend* and the *residues* specific for each month. *Trend* is estimated as average daily minimum/maximum temperature for the dry/rainy days, obtained as a function of the date, by interpolating a second order Fourier series:

$$Trend = A + B \cdot \sin\left((Doy - C) \cdot \frac{2\pi}{365}\right) + D \cdot \sin\left((Doy - E) \cdot \frac{4\pi}{365}\right)$$

A mean annual minimum temperature (°C);
B semi-amplitude of the first term (°C);
C phase shift for the first term (days);
D semi-amplitude of the second term (°C);
E phase shift for the second term (days);
Doy day of the year (from 1 to 365 or 366).

Parameters *C* and *E,* estimated from historical data, are considered constant for all years because of the small variability observed, while means and standard deviations of *A*, *B* and *D* parameters are different in relation to the year and for the minimum/maximum and rainy/dry temperature combinations (*Tmin* trend for dry days, *Tmax* trend for dry days, *Tmin* trend for rainy days, *Tmax* trend for rainy days). These parameters were estimated by linear regression of the trend function (after linearization) of the observed temperatures vs. day of the year. Thus, for each year the annual trends of minimum and maximum air temperature on dry and rainy days are calculated. During generation these parameters were used for sampling from the normal probability distributions *N*(*MA*,*SA*), *N*(*MB*,*SB*) and *N*(*MD*,*SD*) (where *MA*, *MB* and *MD* are the mean values of *A*, *B* and *D*; *SA*, *SB* and *SD* are the standard deviations) at the beginning of each new year.

Residues for minimum temperature (*Rn*), specific for each month, are sampled from the autocorrelated normal distribution with mean zero and standard deviation *SRn*:

$$R_n = RR_{nn} \cdot R1_n + SR_n \cdot \sqrt{1 - RR_{nn}^2} \cdot N(0,1)$$

where *RRnn* is the autocorrelation coefficient, $R1_n$ is the residue of minimum temperature of the previous day, already generated and *N(0,1)* is the value sampled from a normal distribution with 0 for mean and 1 for standard deviation.

Residues for maximum temperature (*Rx*), also specific for each month, are sampled from the bivariate normal distribution with mean 0, standard deviation *SRx* and correlation coefficient *RRnx*, depending on the value of the minimum temperature residue *Rn*:

$$Rx = \frac{RR_{nx} \cdot SR_x \cdot R_n}{SR_n} + SR_x \cdot \sqrt{1 - RR_{nx}^2} \cdot N(0,1)$$

SRn, *RRnn*, *SRx* and *RRnx* parameters were estimated from the historical date.

Daily solar radiation is calculated on the base of the air temperature excursion as:

$$Rg = Rmax \cdot Rr$$

where *Rmax* is the annual trend of the maximum daily radiation, linearly related to the duration of the photoperiod (*Ph*) and considered constant for each day of the year. This is performed with the method described in Keisling (1982). The parameters of the linear relation between *Rmax* and *Ph* are obtained by selecting only the maximum values of the solar radiation in ten-day periods of the year.

$$Rmax = b_1 \cdot Ph + b_0$$

The ratio of the daily radiation and maximum radiation (*Rr=Rg/Rmax*) is the atmosphere transmittance, which varies from 0 to 1. This ratio is then divided into five air temperature excursion classes, within which it is found to be distributed according to the Beta probability distribution function (*pdf*), with parameters A_b and B_b, estimated from historical data sets.

For each class and from the ratio *Rr*, the two parameters of the Beta distribution are estimated using the moments:

$$A_b = M^2 \cdot \frac{1-M}{V} - M \qquad B_b = A_b \cdot \frac{1-M}{M}$$

where *M* and *V* are the mean and variance of *Rr* for each excursion class. After rainfall generation, the minimum and maximum temperatures are generated separately, considering the status of the day (rainy or dry).

The evapotranspiration shows the well-known good linear relation with the radiation (Doorembos and Pruitt, 1977); less good is the one with maximum air temperature and photoperiod. Since radiation data are often not available in the historical meteorological datasets, two different approaches for the evapotranspiration generation are adopted. The first one is if radiation is available with a more precise generation and the second one is using temperature and photoperiod:

1) With solar radiation data available: daily evapotranspiration is obtained as a linear function of the daily radiation (*Rg*) plus a residue obtained from a normal distribution (unique for all the months) with standard deviation *Setr*:

$$ET_r = a_1 \cdot Rg + a_0 + N(0, Setr)$$

2) If radiation data are not available: daily evapotranspiration is generated as a function of maximum air temperature (*Tmax*) and photoperiod (*Ph*):

$$Etr = c_1 \cdot Tmax \cdot Ph^2 + c_0 + N(0, Setp)$$

where *Setp* is the standard deviation of the residues, related to the photoperiod by a linear function, $Setp=d_1 \cdot Ph + d_0$.

Daily data of average wind speed (*Winds*) are generated considering four aspects defined through the analysis of meteorological series: wind speed data have an asymmetric distribution (of a logarithmic type), the historical records show the presence of an annual trend, the residues distribution vary from month to month and resulted to be auto-correlated with those of previous days. Thus, the model of wind generation was developed using logarithmically transformed data interpolating the trend with a third-degree polynomial function:

$$LW_s = bw_0 + bw_1 \cdot Doy + bw_2 \cdot Doy^2 + bw_3 \cdot Doy^3$$

where $bw_0 \dots bw_3$ are the parameters, estimated based on historical data. The residues from trend are obtained from the bivariate normal distribution of residues, autocorrelated with the residue of the previous day.

The performance of *Climak 3* was evaluated using meteorological data sets from different locations of Europe and South-America. Relatively long records of daily weather variables (minimum and maximum air temperature, precipitation, solar radiation, evapotranspiration) were provided by Joint Research Center (EU) and Regional Meteorological Service of the Friuli Venezia Giulia region (OSMER). Validation results obtained show that *Climak 3* can be considered as sufficiently accurate tool for the generation of meteorological data in temperate and cold climates. In general, the behavior of the model has been satisfactory but some aspects are still to be improved. The further works will be focused on the improvement of the estimation and/or generation procedures of evapotranspiration and radiation data, and on a better representation of the *Tmax* and *Tmin* variability. Moreover, it will be necessary to develop issues concerning downscaling of meteorological variables and the generation of extreme events, especially for precipitation and wind speed. In fact, wind speed model, at present, is not able to represent high speed values, observed in some locations.

Parameter estimation script, generation model and validation procedure are available from authors or the website
http://www.dpvta.uniud.it/~Danuso/docs/Climatica/Climatica_Home.html.

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Annex 1 – Basic *SemGrid* commands

Task	Command	Description
General	`about`	copyright information
	`dir`	display the files in the current directory
	`exit`	exit the program
	`set`	set up the modelling environment
Grids	`camc`	Cellular automata-Markov chain simulation (new)
	`export`	exports current grid layers in different formats
	`import`	imports to the current project, grids of different formats
	`map`	generates a map of a grid layer
	`overlay`	overlays different layers
	`resize`	resizes (clip or enlarge) the area of a grid project
	`insert`	inserts georeferenced points into current grid
	`distance`	creates a layer with minimum distance values
	`harvest`	generate layers with sum/mean of cells in neighbourhood
	`spread`	spread XY table data on grid layers (new)
	`spatial`	data spatialization (IDW,Voronoi)
	`sunh`	potential sunshine hours for grid cells with hillshading (new)
File management	`append`	add a dataset (by rows)
	`close`	close the open text file
	`collapse`	generate a dataset with statistics from the current
	`erase`	eliminate files from model and working directory
	`merge`	add a dataset (by columns)
	`open`	open a text file for text output
	`save`	save the current dataset
	`substitute`	string substitution (also regular expressions) in files
	`use`	load a new file
	`write`	write a line of text in the open file
Data display	`describe`	list variables and information of current dataset
	`header`	list, modifies and inserts header items and labels
	`list`	list values of variables
	`listc`	list values of variables, by column (1 obs per time)
Data managemet	`class`	create a code variable from a continuous variable
	`decode`	decode code and legend into categorical variable
	`drop`	erase variables/observation from current dataset
	`fgen`	fast generation of unary an binary operations
	`generate`	calculate new variables from math expressions
	`keep`	keep variables/observation of current dataset
	`legend`	display and modifies legends (codes, colour, labels)
	`replace`	Re-calculate variables (columns) or observ. (rows)
Variables	`matrix`	manage matrix ambient variables
	`scalar`	manage scalar (numerical) ambient variables
	`string`	manage string ambient variables
Statistics	`correlate`	correlation coefficients among variables
	`cumulate`	calculate empirical cumulated distributions
	`rank`	generate a variable with the statistical rank
	`summarize`	descriptive statistics (mean, standard dev., min., max.)
	`table`	create statistical tables from current variables
Utilities	`by`	repeat commands for by groups
	`cfor`	super-command to repeat SEMoLa commands
	`cif`	super-command for conditional execution of commands
	`markest`	estimate MC probability transition matrix among states
	`marksim`	Markov chain simulation
help	`help`	Command help

Annex 2 – *Climak 3* parameter estimation script

For the commands descriptions refer to the Annex 1.

```
script def EstClimak
' SEMoLa 6.2.0 command file
' F. Danuso, 26 December 2010
' %1% first argument of the script (meteo datafile)
' %2% second argument (name of the parameter file, without extension)
' %3% third argument (latitude, degrees and decimals)
' %4% fourth argument (longitude, degrees and decimals)
' %5% fifth argument (altitude, meters)
 ' %6% sixth argument (working folder)
' Run as: script run Climak2_par_estimate udine.met udine
' Meteo file has to contains the following variables, in any order:
' year year (4 figures)
' doy day of the year (1-365 o 366)
' month month (1-12)
' rain daily rainfall (mm/d)
' tmin daily minimum temperature (°C)
' tmax daily maximum temperature (°C)
' PROCEDURE:
' 1) loads the historical meteo datafile
' 1) estimate parameters as scalars
' 2) loads a template of file red
' 3) fill with the scalar estimated parameters
set wd %6%
use %1% clear
sort year doy
' ======= FIND MAXIMUM MAXTEMP AND MINIMUN MINTEMP ===========
summarize tmin
scalar Stnmin=_min
summarize tmax
scalar Stxmax=_max
' ====== ESTIMATE RAINFALL PARAMETERS ========================
fgen int RainyDay=0 lab "Day type 0=dry 1=rainy"
replace RainyDay=1 if Rain>0
' shift rain +1 rain1
shift RainyDay +1 RainyDay1
gen rain02=rain-0.2 if Rain>0 ' toglie sensibilità strumento
' === PARAMETRI CATENA MARKOV - EVENTO PIOGGIA ====
gen transdd=1 if RainyDay=0&RainyDay1=0 lab "Transizioni dry-dry"
gen transrd=1 if RainyDay=0&RainyDay1=1 lab "Transizioni rainy-dry"
1_ParRainMonth 1
1_ParRainMonth 2
1_ParRainMonth 3
1_ParRainMonth 4
1_ParRainMonth 5
1_ParRainMonth 6
1_ParRainMonth 7
1_ParRainMonth 8
1_ParRainMonth 9
1_ParRainMonth 10
1_ParRainMonth 11
1_ParRainMonth 12
' - rain parameters are here as scalars
' ========= TEMPERATURE RESIDUAL ESTIMATION =========
use %1% clear ' carica dataset meteo
fgen int RainyDay=0 lab "Day type 0=dry 1=rainy"
replace RainyDay=1 if Rain>0
```

```
' ===== initialization ====
scalar K1=2*pi/365 ' per conversione Doy/radianti
scalar K2=2*pi/182.5
' =========== TEMPERATURE TREND PARAMETERS ESTIMATE =============
' - For the cumulation of the year by year values
scalar MAnd=0 ' 7.9817 "A parameter temp. trend Tn-dry" (°C)
scalar MAxd=0 ' 19.2434 "A parameter temp. trend Tx-dry" (°C)
scalar MAnr=0 ' 8.9404 "A parameter temp. trend Tn-rainy" (°C)
scalar MAxr=0 ' 17.4990 "A parameter temp. trend Tx-rainy" (°C)
scalar MBnd=0 ' 9.8306 "B parameter temp. trend Tn-dry" (°C)
scalar MBxd=0 ' 11.5617 "B parameter temp. trend Tx-dry" (°C)
scalar MBnr=0 ' 8.2443 "B parameter temp. trend Tn-rainy" (°C)
scalar MBxr=0 ' 10.1001 "B parameter temp. trend Tx-rainy" (°C)
scalar MCnd=0 ' 107.66 "C parameter-Tnd" (day)
scalar MCxd=0 ' 105.24 "C parameter-Txd" (day)
scalar MCnr=0 ' 112.46 "C parameter-Tnr" (day)
scalar MCxr=0 ' 112.13 "C parameter-Txr" (day)
scalar MDnd=0 ' 0.1010 "D parameter temp. trend Tn-dry" (°C)
scalar MDxd=0 ' 1.3201 "D parameter temp. trend Tx-dry" (°C)
scalar MDnr=0 ' 0.1769 "D parameter temp. trend Tn-rainy" (°C)
scalar MDxr=0 ' 0.6424 "D parameter temp. trend Tx-rainy" (°C)
scalar MEnd=0 ' 3.5864 "E parameter-Tnd" (day)
scalar MExd=0 ' 21.7668 "E parameter-Txd" (day)
scalar MEnr=0 ' 57.3033 "E parameter-Tnr" (day)
scalar MExr=0 ' 10.1469 "E parameter-Txr" (day)
scalar SAnd=0 ' 0.5643 "standard deviation of A Tn-dry" (°C)
scalar SAxd=0 ' 0.5283 "standard deviation of A Tx-dry" (°C)
scalar SAnr=0 ' 0.5998 "standard deviation of A Tn-rainy" (°C)
scalar SAxr=0 ' 0.2764 "standard deviation of A Tx-rainy" (°C)
scalar SBnd=0 ' 0.5090 "standard deviation of B Tn-dry" (°C)
scalar SBxd=0 ' 0.4850 "standard deviation of B Tx-dry" (°C)
scalar SBnr=0 ' 0.7509 "standard deviation of B Tn-rainy" (°C)
scalar SBxr=0 ' 0.4963 "standard deviation of B Tx-rainy" (°C)
scalar SDnd=0 ' 0.6583 "standard deviation of D Tn-dry" (°C)
scalar SDxd=0 ' 0.6378 "standard deviation of D Tx-dry" (°C)
scalar SDnr=0 ' 0.7333 "standard deviation of D Tn-rainy" (°C)
scalar SDxr=0 ' 0.7601 "standard deviation of D Tx-rainy" (°C)
' === for all the years ===
gen X1=sin(Doy*K1)
gen X2=cos(Doy*K1)
gen X3=sin(Doy*K2)
gen X4=cos(Doy*K2)
summarize Year
scalar Nyears=(_max-_min)+1 ' numbers of years
scalar Ystart=_min
scalar Yend=_max
'------------------parameter estimation for temp
' - set the variables for residuals
gen ResTminDry=. lab "Trend residuals for Tmin-Dry (C)"
gen ResTminWet=. lab "Trend residuals for Tmin-Wet (C)"
gen ResTmaxDry=. lab "Trend residuals for Tmax-Dry (C)"
gen ResTmaxWet=. lab "Trend residuals for Tmax-Wet (C)"
gen Trend=. lab "Trend for temperature residuals calculation"
regress Tmin X1 X2 X3 X4 if RainyDay=0
drop Ycal
scalar A3=_b[4,1]
scalar A4=_b[5,1]
'scalar sMDnd=A3
'scalar sMEnd=A4
scalar sMDnd=sqrt(A3*A3+A4*A4)
scalar sMEnd=acos(A3/sMDnd)/K2
```

```
'gen DEnd=sMDnd*cos(sMEnd*K2)*X3-sMDnd*sin(sMEnd*k2)*X4
regress Tmin X1 X2 X3 X4 if RainyDay=1
drop Ycal
scalar A3=_b[4,1]
scalar A4=_b[5,1]
'scalar sMDnr=A3
'scalar sMEnr=A4
scalar sMDnr=sqrt(A3*A3+A4*A4)
scalar sMEnr=acos(A3/sMDnr)/K2
'gen DEnr=sMDnr*cos(sMEnr*K2)*X3-sMDnr*sin(sMEnr*K2)*X4
'
regress Tmax X1 X2 X3 X4 if RainyDay=0
drop Ycal
scalar A3=_b[4,1]
scalar A4=_b[5,1]
'scalar sMDxd=A3
'scalar sMExd=A4
scalar sMDxd=sqrt(A3*A3+A4*A4)
scalar sMExd=acos(A3/sMDxd)/K2
'gen DExd=sMDxd*cos(sMExd*K2)*X3-sMDxd*sin(sMExd*K2)*X4
'
regress Tmax X1 X2 X3 X4 if RainyDay=1
drop Ycal
scalar A3=_b[4,1]
scalar A4=_b[5,1]
'scalar sMDxr=A3
'scalar sMExr=A4
scalar sMDxr=sqrt(A3*A3+A4*A4)
scalar sMExr=acos(A3/sMDxr)/K2
'gen DExr=sMDxr*cos(sMExr*K2)*X3-sMDxr*sin(sMExr*K2)*X4
cfor Y=_min TO _max: 2_ParTrendTempYears Y
fgen ResTminDry2=ResTminDry*ResTminDry
fgen ResTminWet2=ResTminWet*ResTminWet
fgen ResTmaxDry2=ResTmaxDry*ResTmaxDry
fgen ResTmaxWet2=ResTmaxWet*ResTmaxWet
' === Tmin - dry days =================
scalar sSAnd=sqrt((SAnd-MAnd*MAnd/Nyears)/(Nyears-1))
scalar sSBnd=sqrt((SBnd-MBnd*MBnd/Nyears)/(Nyears-1))
scalar sSDnd=sqrt((SDnd-MDnd*MDnd/Nyears)/(Nyears-1))
scalar sMAnd=MAnd/Nyears
scalar sMBnd=MBnd/Nyears
scalar sMCnd=MCnd/Nyears
'scalar sMDnd=MDnd/Nyears
'scalar sMEnd=MEnd
' === Tmin - Rainy days =================
scalar sSAnr=sqrt((SAnr-MAnr*MAnr/Nyears)/(Nyears-1))
scalar sSBnr=sqrt((SBnr-MBnr*MBnr/Nyears)/(Nyears-1))
scalar sSDnr=sqrt((SDnr-MDnr*MDnr/Nyears)/(Nyears-1))
scalar sMAnr=MAnr/Nyears
scalar sMBnr=MBnr/Nyears
scalar sMCnr=MCnr/Nyears
'scalar sMDnr=MDnr
'scalar sMEnr=MEnr
' === Tmax - dry days =================
scalar sSAxd=sqrt((SAxd-MAxd*MAxd/Nyears)/(Nyears-1))
scalar sSBxd=sqrt((SBxd-MBxd*MBxd/Nyears)/(Nyears-1))
scalar sSDxd=sqrt((SDxd-MDxd*MDxd/Nyears)/(Nyears-1))
scalar sMAxd=MAxd/Nyears
scalar sMBxd=MBxd/Nyears
scalar sMCxd=MCxd/Nyears
'scalar sMDxd=MDxd
```

```
'scalar sMExd=MExd
' === Tmax - Rainy days =================
scalar sSAxr=sqrt((SAxr-MAxr*MAxr/Nyears)/(Nyears-1))
scalar sSBxr=sqrt((SBxr-MBxr*MBxr/Nyears)/(Nyears-1))
scalar sSDxr=sqrt((SDxr-MDxr*MDxr/Nyears)/(Nyears-1))
scalar sMAxr=MAxr/Nyears
scalar sMBxr=MBxr/Nyears
scalar sMCxr=MCxr/Nyears
'scalar sMDxr=MDxr
'scalar sMExr=MExr
4_PaTempResMonth 1
4_PaTempResMonth 2
4_PaTempResMonth 3
4_PaTempResMonth 4
4_PaTempResMonth 5
4_PaTempResMonth 6
4_PaTempResMonth 7
4_PaTempResMonth 8
4_PaTempResMonth 9
4_PaTempResMonth 10
4_PaTempResMonth 11
4_PaTempResMonth 12
'- temperature parameters are here as scalars
'========= daylength (h) ==================================
' Daylength (hours) calculation from day of the year (DOY)
' Ref: KEISLING T.C., 1982 (Agron.J.)
' Aut: F.Danuso (20/11/95)
scalar h3=pi/180
scalar LATR=%3%*h3 ' converts to radians
scalar al=90*h3 ' zenithal distance (rad)
gen M=(0.9856*Doy-3.251)*h3 ' mean sun anomaly (rad)
gen L6=M+h3*(1.916*SIN(M)+0.02*SIN(2*M)+282.565)
gen dec=0.39779*SIN(l6) ' sine obliquity
replace dec=ATN(dec/SQRT(1-dec*dec)) ' declination (rad)
gen zk=(SIN(LATR)/COS(LATR))*(SIN(dec)/COS(dec))
gen fot=COS(al)/(COS(LATR)*COS(dec))-zk
gen DayLen=2/15*(-ATN(fot/SQRT(1-fot*fot))/h3+90) ' daylength (hours)
header varlab DayLen "Daylength (h)"
drop M L6 dec zk fot  ' ===== RadTop Solar radiation at top of
atmosphere" (MJ/m^2/d) ========
scalar KSun=1377*10^-6 ' Solar constant" (MJ/m^2/s)
scalar ConvTime=3600 ' Conv. fact. hours to seconds" (s/h)
scalar SunDec=(-23.45*COS(2*pi*(doy+10)/365))*h3 ' Sun declination"
(deg*h3=rad)
gen
RadTop=Ksun*ConvTime*(DayLen*SIN(LATR)*SIN(SunDec)+24/pi*COS(LATR)*COS(
SunDec*(1-(TAN(LATR))^2*(TAN(SunDec)^2))^0.5))
save BufferMeteo replace ' to be deleted
'========== Radiation ================
3_ParRadiation %3% %1% ' Latitude and meteo_dataset
'============ Evapotraspiration ==========
use %1% clear
regress Etr rg
scalar sA0=_b[1,1]
scalar sA1=_b[2,1]
fgen resEtr=Etr-Ycal
summarize resEtr
scalar sSetr=_sd
'============Winds===================
set capture on
summarize Winds ' when Winds is missing
```

```
string Oshibka=_Rmsg
set capture off cif Oshibka="" : script run 5_ParWinds
cif Oshibka<>"" : script run 6_ParWindsZero
' da fare protezione anche per Rg ed ETr
' =========== LOADS PARAMETERS IN PARFILE ==============
use Climak3.par clear ' template
header label "Climak parameters for "%1%
' lat
replace FirstYear=Ystart in 4
replace LastYear=Yend in 4
replace lat=%3% in 4 replace lon=%4% in 4
replace alt=%5% in 4
' --- Load parameters for rain events ---
---------------------------------------------
' ================== end ===================================
end script
```

CHAPTER VI – GENERAL CONCLUSIONS

The aim of this chapter is to provide general conclusions about the methods and approaches presented and discussed throughout the thesis. Being used as a mean of production and spatial basis, land resources are experiencing excessive pressure while supporting world population. Under conditions of high demand and limited resources, a good management becomes particularly important, providing effective and efficient use of available resources minimizing their degradation. Decision on the land destinations should be made on the basis of comprehensive analysis of land characteristics, functions and external conditions, assessment of land behaviour under different types of use, favouring positive effects, and reducing the negative ones.

Land resources should be used according to their capacity and availability, paying thorough attention to the specific characteristic and function of the land. For this aim, different methods, approaches and techniques have been developed and applied. Availability of prepared and ready to use procedures enhances promotion of sustainable management, providing ordinary users with the possibility to implement these procedures without direct involvement of field experts and specific knowledge related to computer information technology required for the development of algorithms and scripts. The results of implementation by the independent users can contribute not only to the improvement of the land organization and management, but also to the development of the evaluation approaches *per se*, by considering the knowledge and experience obtained from the applications of the procedure.

Aimed at supporting decision-making process and providing better land management and land governance, land evaluation procedures discussed in this thesis were developed to forecast land use change processes by representing evolution of agricultural and forest and seminatural areas due to expansion of the urban areas and evaluation of land suitability for the agricultural tourism. Assessment of land evaluation procedures, the validation of which in the classical way is difficult enough, is also addressed.

The results obtained from the case studies have proved effectiveness and reliability, even though some aspects need to be additionally improved and examined. Generally, further developments will concern procedure elaboration by means of their application to other conditions and study areas, their extension by taking into account new evaluation criteria and indicators (to improve land evaluation procedure for *CAMC*), development of more precise evaluation procedure in order to perform thorough landscape assessment of the areas concerned suitable for agritourism activity, development of additional scripts to perform sensitivity analysis of other incomes of uncertainty in land evaluation procedures, e.g. indicator weights, value functions, etc.

The *CAMC* procedure developed has proved to be capable of representing in a satisfactory realistic manner the evolution of the territory. The results obtained allow the model developed to be considered reliable enough for the selected study area. In order to improve it, additional information about forces and constraints, such as land use policies currently in force, land use plans, other factors influencing the process of land use change are to be considered. In particular, constraints deriving from planning and environmental policies could be easily implemented in the land evaluation procedure and represented as Boolean land use suitability maps. The use of more detailed maps is also essential for the better performance. To be noted, the *CAMC* was not intended to be a model as such, but rather as an approach or a framework, through which required indicators can be implemented in order to represent complex processes of the land use system. Current *CAMC* indicators were employed with a view to demonstrate the approach workflow. At the moment, the main lack of the *CAMC* model is that, in case the results obtained are not satisfactory enough, its parameters must be adjusted manually according to the indications provided by the map comparison. Further development will be focused on implementation of an automatic parameter calibration algorithm.

The procedure, being able to take into account main driving factors and forces of the system evolution, can be used to evaluate future scenarios and policies on land use, and to estimate and test factors that lead to land use change/cover transformation. Even discrepancies between simulated and original maps can give useful information and insights about the driving forces for the changes, highlighting non-evident phenomena.

While developing rural areas and livelihood of rural people, thorough attention should be paid to the management and organization of the land resources, which are the main source of income for the people involved in agricultural activity. As one of the strategies to reduce poverty of rural people, the agricultural or rural tourism is being implemented and developed in various regions of the world. In order to provide successful implementation of the agricultural tourism, areas with highest potential for this activity are to be identified. To this end, fuzzy-based evaluation procedure was developed. Applied to the area of Dzhidinsky region of the Republic of Buryatia, the procedure identifies the areas with the highest potential for agritourism development considering site location, amenity and compatibility with environment (land use compatibility, suitability for agricultural activity, etc.).

According to the results obtained, the areas suitable for agritourism activity in Dzhidinsky region are concentrated in the south-eastern part of the region, which is conditioned by the presence of agricultural areas in that zone, gentle slopes, as well as closeness to the roads, settlements and natural landmarks. However, the biggest part of the region is still occupied by the areas inappropriate for this kind of activity. More than half of the total area belongs to the classes below the middle one. This can be justified, primarily, by the low infrastructure development conditioned by small population, and vast areas of the forest lands considered unsuitable during the evaluation.

The results of the procedure application will provide decision makers with valuable information about the prospects of agritourism implementation. For instance, some lands can meet criteria related to reachability and amenity, but mismatch the final one of the compatibility. This means that this type of land is to be avoided; otherwise the land owner must be warned that implementation and development of the agritourism on this land will require significant costs associated with land reclamation and restoration. It would be preferable that for agritourism activity the lands of classes higher than the moderate one are considered, thus avoiding additional expenses and providing its successful implementation. However, regardless of the suitability class, significant attention is to be paid primarily to the environment, in order to avoid its degradation and pollution.

Uncertainty in land evaluation results can derive from input maps, subjective parameters, weights and thresholds, and the indicator aggregation method. The selection of value functions and their parameters is responsibility of the land analyst, while the weights selection pertains to the decision maker. Since the selection of parameters of value functions is subjectively given by the analyst, it can be strongly questioned by stakeholders. Unfortunately, in land evaluation procedures, it is almost impossible to perform empirical validation based on measurements; thus, sensitivity analysis can be a useful tool for testing the model.

The proposed method validates the land evaluation procedures based on the spatial sensitivity analysis, considering the influence of the parameter values on the resulting land evaluation map and pointing out the most sensitive parameters. Those that have significant impact on the model output should be selected with a high degree of accuracy, while those the impact of which is slight enough could be considered as constant. Mapping of sensitivity allows graphical identification of the areas of high or low sensitivity. In the analysis of the *SC* maps, not only average values have to be considered, but also the maximum values are of particular interest.

Sensitivity analysis can be used to evaluate the reliability of the model by comparing, for each parameter, the uncertainty range (*RU*), and the calculated range of insensitivity (*RI*). If *RU*>>*RI*, then it is to be retained that the procedure produces unpredictable results due to the excessive sensitivity. Otherwise, if *RU*<<*RI*, we can consider that the procedure is too conservative, tending to damp the land variations due to low sensitivity. The improvements that can be suggested are: a) in case of high sensitivity, reducing the number of classes in the final map and modifying the shape of the value functions by their parameters; b) in case of low sensitivity, increasing the number of classes in the final maps and proper modification of the parameters. Further development of the methodology will involve a method for combining sensitivity evaluation of each parameters into an overall model sensitivity index to establish the whole degree of validity. The *SemGrid* scripts developed for the land evaluation procedure and for the sensitivity analysis are available from the authors or from the *SemGrid* web site.

The procedures developed are free: free of charge and free to be modified. The procedures were implemented using multi-criteria approach, taking into account the importance of different criteria and the data availability. The number of evaluation criteria and related indicators can be easily extended, but to a certain limit. While selecting evaluation criteria and related indicators, it is necessary to keep in mind that there is no need to take into account all factors and attributes that may have influence on the system, firstly, because of its impossibility, secondly, because the factors do not possess the same degree of importance. Carrying out a significant array of data, there is a risk to create a too complicated "overloaded" model, resulting in too much time consuming, unless there is a strong confidence about the factors significance. Moreover, while performing evaluation, some factors can contribute the same information to the final result, being correlated. Thus, in conclusion, while establishing evaluation criteria and implementing related indicators, it is important to perform a thorough analysis and selection of relevant and representative indicators, which will be calculated on properly prepared and processed land information.

Annex 1

Research works published or submitted during the PhD program

Bashanova O., Beshentsev A.N., Dugarova D., Danuso F., 2012. Fuzzy set model to identify areas suitable for agricultural tourism in Buryatia. Submitted to the Journal of Environmental Management.

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