Integrating soil and water resources in local development framework : the ASTUCE & TIC program

Fabienne Trolard[A], Alain Dangeard[B], Barbara Le Pors[C], Thomas Ménard[D], Bernard Descamps[E], Frédéric Baret[F], Raymond Bile[A], Nadine Brisson[G], Guilhem Bourrié[A], André Chanzy[F], Jean-François Closet[C], Marc Conruyt[A], Dominique Courault[F], Marie-Lorraine Dangeard[B], Philippe Dussouillez[D], Jules Fleury[D], Anthony Jan[A], Catherine Keller[D], Sarah Kirman-Meunier[C], Jean-Christophe Maho[C], Rachid Hadria[F], Françoise Ruget[F], Albert Olioso[F] and Sophie Viseur[H]

[A]INRA, UR1119 Géochimie des Sols et des Eaux, Europôle de l'Arbois, BP 80, Aix-en-Provence, France, Email trolard@aix.inra.fr
[B]MEED S.A., Paris, France, Email aldan@wanadoo.fr
[C]G2C Environnement, Venelles, France, Email jfcloset@g2c.fr
[D]Université Paul Cézanne, CEREGE, Aix-en-Provence, France, Email keller@cerege.fr
[E]OrangeLabs, France Télécom, Sophia-Antipolis, France, Email bernard.descamps@orange-ftgroup.com
[F] INRA, UMR114, Environnement Méditerranéen et Modélisation des Agrohydrosystèmes, Avignon, France, Email achanzy@avignon.inra.fr
[G]INRA, US1116, Agroclim, Avignon, France, Email nadine.brisson@avignon.inra.fr
[H]Université de Provence, Laboratoire de Géologie des systèmes Carbonatés, Marseille, France, Email Sophie.Viseur@univ-provence.fr

Abstract

Urban growth is a factor of productivity but urban spreading is a major threat for soil and water resources. Local development must consider a city with its hinterland (Figures 1 and 2). Soil and water resources are needed for food production, water supply and their degradation can impair the possibilities of cities to generate wealth and the economic resources for financing local development and managing public resources (Figure 3). Data are generally available but dispersed. There exist already numerous models, separately calibrated and checked, that allow the users to take into account land use change and climate change to evaluate the modifications of soil properties due to urbanization, the crop requirements of water and nutrients, the geochemical interactions between soils and water and economic models based upon cost/benefits approach. The ASTUCE & TIC program aims at showing that different models of the type above can be integrated to help policy-markers to cope more efficiently with urban spreading.

Key Words

Soil, water, cities, urbanization, development.

Introduction

Occurrence of crisis and transitions in food products, climates, environments and energies are abundantly described, analysed and commented on, especially in collective studies and consultations (e.g. Pachauri and Reisinger 2007; Taylor 2008). These crisis and transitions have in common that they concern the agricultural, urban and industrial domains simultaneously, the land uses and the division of the resources (water, foods, energy) which are in interrelationship ones to another. They contribute to come back to the first plan of the international concerns of the policy (FAO 2009). For these challenges, the efforts may care on the capacity to: (i) analyse the territories at different organisation levels; (ii) increase the capacity of expertise by working in different domains together; (iii) aggregate and make technological innovations of other sectors suitable for the development of new tools for analysis and expertise. Historically cities were built up in territories where Humans could find easily foods and water. The present urban spreading in the world threatens significantly and with irreversible impacts the most fertile and the most easily to work agricultural soils. This increases the energy demand, transport infrastructure, contributes to the green house gases emission and has a negative impact on the natural resources of the territories. Degradation of soils and waters thus impair the capacity of cities to develop and satisfy the needs of populations who live in. The legitimate claiming for an environmental planning based on the sustainability of the systems meets with numerous difficulties, e.g. benefits in short time in agriculture, financial deregulation in exchanges, migration of population to the cities… which are limiting factors for soil and water management.

In this context, the main goal of ASTUCE & TIC program is to build up an integrative approach of the landscape by mixing knowledge and know how developed until today independently in agronomy, soil science, geochemistry, geography, urbanization and economy. This method of integrating data can be used within the conceptual framework of the ECOLOC (Club du Sahel/OECD 2001) or Agenda 21, which combines study, debates encouraging ownership and policy discussion, and the implementation of development actions.

Methods

Basic concepts

The basic concept is that urban growth cannot be considered independently of its surrounding rural areas, i.e. its “hinterland”. A city and its “hinterland” can be considered as a system consisting of several subsystems which exchange matter, such as water, dissolved elements, biomass, and information, such as internal and external signals (Figure 1). The topology of the relationships between the subsystems is an important property of the system (Figure 2). Data are generally available but in such a dispersed way that policy makers lack a synthetic view of the environmental impacts of their decisions.

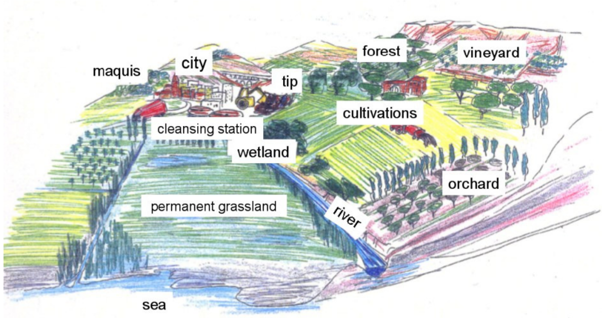

Figure 1. A city and its surrounding areas

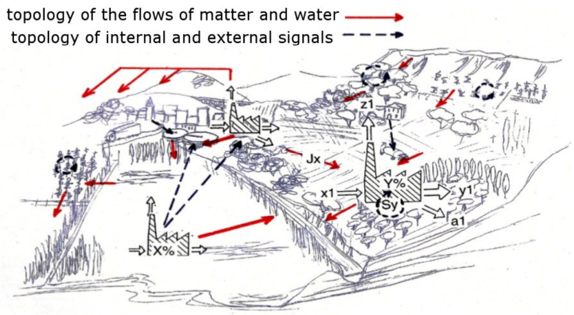

Figure 2. Fluxes and matter transformations in the city/hinterland viewed as a system

The now classical approach is: Driving force – Pressures – State – Impacts – Responses. Driving forces are twofold, population change and climate change, and result in land use changes from agriculture to urban use, including roads, airports etc. and a modification of water and soil resources that can be integrated in scenarii. These pressures modify the state of the system both in urban areas where soil permeability is impaired and soils are destroyed irreversibly, and in rural areas where food demand requires soil, water and nutrients. This results – through the modification of flux of water in the “critical zone” and of water quality through biogeochemical cycles in soils – in changes of the quantitative and qualitative inputs to groundwater. Eventually, different hazards are estimated: loss of soil resources and biodiversity, increase of runoff in non permeable areas, decrease of potability of water, decrease of food production and economic resources for the population, increase of water salinity and soil salinity, degradation of soil physical properties due to sodicity if swelling clay minerals are present. Ecosystem goods and services must thus be evaluated during the land transition dynamics in different domains and require a framework able to mobilize local authorities, academic organisations and private firms, ensuring the involvement of local actors from the very beginning of the study phase (Figure 3).

Demonstration area

The tools are tested on the Crau’s plain as an area of demonstration. This territory is localised in the Bouches-du-Rhône department in the south of France. The area covers 60,000 ha between the Rhône river at West, the Berre’s pond in East, the Alpilles mountains at North and Mediterranean Sea at South. The alluvial plain of Crau is divided into a semi-arid steppe of 9,200 ha with a remarkable ecosystem (a natural, cultural and economic exception at the departmental, national and European scales) and the Crau of the grasslands of 12,500 ha where is grown the renowned hay “foin de la Crau” AOC (Appellation d’Origine Contrôlée). Today the intensive fruit growing overrun the pastoral areas progressively. The Crau’s plain has a large underground water table. The waters of the Durance’s river constitute 70% of the input of this water table via the agricultural irrigation. This area of 20,000 ha determines the supply of drinking water to 250,000 inhabitants and of water to the large industries located in the south of the territory. This area is submitted to diverse pressures, all in relationships with the spreading of the cities: (i) urban and industrial pressures concentrated in the South in relationships with the Fos’s industrial zone; (ii) spreading of urbanization from the districts of Saint-Martin de Crau, Miramas, Salon-de-Provence and Arles; (iii) increase of pressures on the underground water table: uptake, urban sludge spreading, diffuse pollution; (iv) increase of greenhouse fruit production.

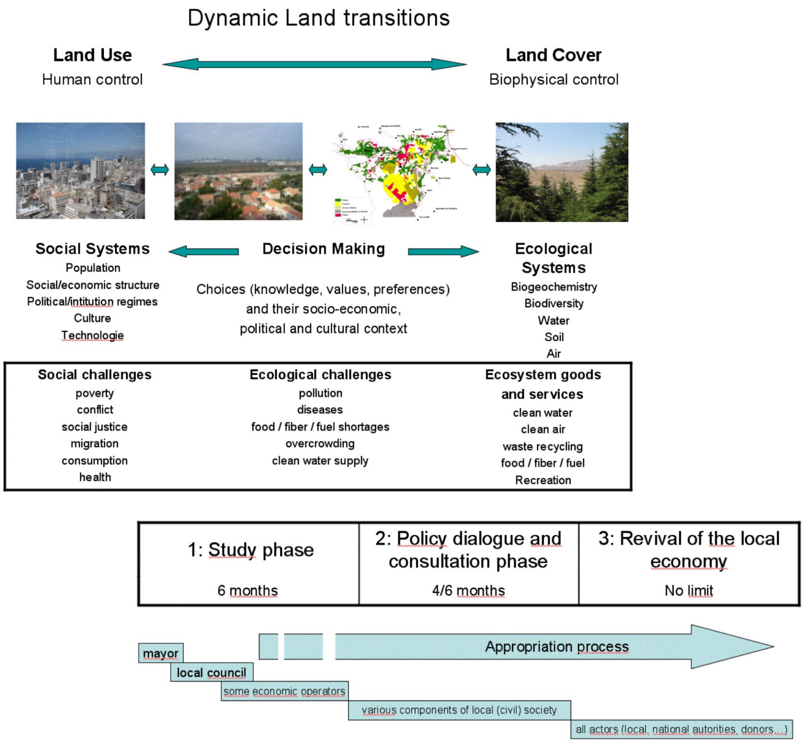

Figure 3. Analysis of land use changes and challenges and operational steps to apply this approach to a city and its hinterland (combined from Club du Sahel/OECD, 2001 and Global Land Project, IGBP, Aspinall 2009)

Results

The preliminary results are only available, as the study has been undertaken at the beginning of 2008. The models were chosen as explained hereafter to give birth to a partly integrated approach. This integrated approach is based upon modelling of land use changes, urbanization, soil changes in urban areas, crop models, geochemical interactions between soil and water and cost/benefits.

Land use changes are modelled on the basis of cellular automates, allowing to calibrate the rules of land use changes and to simulate the future changes on the basis on geographical data bases, both of spatial and socio-economic nature, of the accessibility of transportation networks, of land planning (zoning). Given its situation, properties and local dynamics, the model estimates for each cell the probability of the land use to change. After comparison of different models (MEPLAN, METRONAMICA, SLEUTH, SPACELLE) the model chosen here is METRONAMICA™, on the basis of speed of calculation and precision.

Changes of soil properties in urban areas are assessed in the following ways: (i) artificialised areas are classified in several types following an object oriented classification; (ii) soil water proofing is estimated for each class objects; (iii) soil quality is globally estimated using the water holding capacity as a synthetic index of soil quality, this being completed with secondary constraints (slope, hydromorphy, salinity). Soil pollution is evaluated for point-polluted areas.

Crop models are used to evaluate: (i) the ability of surrounding agricultural areas to provide foods; (ii) the water and nutrients requirements; (iii) the flow of water drainage below the root zone; (iv) the carbon budget in the topsoil. The model chosen is STICS as it is used by a large community (Brisson *et al.* 2003). It allows the users to compute the different terms of the water balance (soil moisture, evapotranspiration, drainage and runoff), the carbon and nitrogen budget, and the plant growth. This model incorporates crop system characteristics and can accept remote sensing data such as Leaf Area Index (LAI) as input. It has been recently used to model crop response to climate change (Brisson 2008).

Biogeochemical cycles in soils modify water quality and make groundwater potable. The input of water drainage to the groundwater is thus one of the essential ecosystem services. Well-managed agricultural areas protect water quality. The model chosen is PHREEQC as it is used by a large international community (Parkhurst and Appelo 1999). The input data of PHREEQC are water quality entering soil and crop model outputs, while output data of the PHREEQC model are water quality of groundwater, its safety, its salinity, its alkalinity and pH, soil salinity and soil sodicity. Soil salinity affects adversely soil fertility, while soil sodicity impairs the physical properties of soils, if swelling clay is present, due to the low permeability of sodic swelling clays.

Economic model is based upon a costs/benefits approach; built capital and environmental assets (forests, biodiversity, soils, water) must be considered together as part of economic patrimony of territories. This aims at demonstrating which local, regional or national decisions can be effective to counteract the degradation of natural patrimony due to land use and climate changes. Outputs of METRONAMICA™, STICS and PHREEQC are converted in economic values to give indicators.

A geomodel is used to integrate the results and obtain a spatial distribution of the data to test and develop scenarii, rather than a GIS representation. The major limitation of GIS is that these models are static and do not take into account the dynamics of the objects (e.g. soils). They give only a snapshot of the surface: representation of data by splitting them into information layers result in the loss of the intrinsic properties of the objects or subsystems. Instead, geomodels take into account the 3D geometry of geosystems, their heterogeneities (faults, folds, thickness of strata) and different types of data (geology, geophysics, geochemistry). Their development was funded by petroleum and mining industries and can be adapted to environmental dynamics (Bile *et al.* 2009). The geomodel retained is gOcad™ (Mallet, 2002).

Conclusion

The first results show that different tools can be interfaced so that output of a model is the input of another, and that dynamic data can be obtained at compatible times and frequencies. The economic analysis shows that for the territory studied the future development will be hindered by the shortage of available resources. Integration of available data on the basis of already existing tools is thus useful to help policy makers to face the ill-mastered consequences of urban spreading. This approach can be used within strategies of local development framework associating local public authorities, local or national academic organizations and local actors from the study phase to dissemination and debates.

Acknowledgments

The support of French government (Fonds unique interministériel de soutien aux programmes de recherche et développement coopératifs des pôles de compétitivité, Direction Générale des Entreprises du Ministère de l'Economie, des Finances et de l'Industrie) and Provence-Alpes-Côte d'Azur region are gratefully acknowledged.

References

Aspinall R (2009) *Global Land Project: Major scientific questions for coupled modeling of land systems,* In: 'Regional aspects of climate-terrestrial-hydrologic interactions in non-boreal Eastern Europe' (Eds P Groisman, YaS Ivanov). (Springer-Verlag: Berlin).

Bile R, Viseur S, Trolard F, Revil A, Bourrié G (2009) gOcad modeling of self-potential data for 3-D reconstitution of soil heterogeneity and paleochannels in the Rhône river delta. In '29th gOcad Meeting Proceedings', (Ed G Caumon), (Nancy School of Geology: Nancy).

Brisson N (2008) Modéliser la réponse des cultures à la contrainte hydrique avec le modèle STICS pour comparer des stratégies et anticiper les changements climatiques, *Innovations Agronomiques* **2**, 9-18.

Brisson N, Gary C, Juste E, Roche R, Mary B, Ripoche D, Zimmer D, Sierra J, Bertuzzi P, Burger P, Bussière F, Cabidoche YM, Cellier P, Debaeke P, Gaudilère JP, Maraux F, Seguin B, Sinoquet H (2003) An overview of the crop model STICS, *European Journal of Agronomy* **18**, 309-332.

Club du Sahel/OECD (2001) Managing the economy locally in Africa, ECOLOC Handbook, Assessing local economics and their prospects, Vol. 1, Summary, Programme de Développement Municipal, Club du Sahel/OECD, SAH/D, 511, Paris.

FAO (2009) The state of food insecurity in the World 2009. (FAO: Roma).

Mallet JL (2002) Geomodeling, Applied Geostatistics Series, Oxford University Press, New York.

Pachauri RK, Reisinger A (2007) Climate change 2007: synthesis report. (IPCC: Geneva).

Parkhurst DL, Appelo CAJ (1999) User's guide to PHREEQC (Version 2), A computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations. *Water-Resources Investigation Report 99-4259*, U.S. Department of the Interior, U.S. Geological Survey, Denver, Colorado.

Taylor M (2008) Perspectives des technologies de l'énergie 2008 – Scénarios et stratégies à l'horizon 2050. (Agence Internationale de l'Energie: Paris).