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Future GIS-Challenges in Modelling

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Abstract

We live in fast changing world. Actually we are confronted with profound changes of our societies as well as with changes of our natural site conditions. Therefore, the estimation of possible future situations and the deduction of adaptation strategies are of growing importance for planners and decision makers. Two important thematic fields for future challenges in GIS (Geographical Information System) based modelling are stressed in this paper - examples for possible solutions are given with regard to the:

'Integration of socioeconomic and natural site content' and the development of 'visions of spatial future patterns'

To be able to link both discipline fields – socioeconomic and natural science - in a GIS, the challenge is to establish a defined correlation of socioeconomic characteristics to a certain spatial unit. On a regional level here the example of farm types that are linked to landscape units based on the concept of cultural landscapes is given for a semiarid region in Northeastern Brazil.

Scenarios can help to sketch plausible pictures of the future. Mostly several (probable and/or extreme) scenarios with a certain number of time steps are used to describe the possible range of results. Models that use land use information as a data input need a spatial disaggregation of land use classes according to the suggestions of the respective scenarios. The presented „spatial scenario design model" (SSDM) is an effective tool to create new land use distribution situations.

2 New challenges in GIS and Modelling

Future GIS-challenges in modelling could include a wide range of aspects. Future challenges in GIS-modelling shown here from a landscape ecological perspective focus on decision support systems at a regional scale and with respect to decision support systems that can outline sustainable strategies in changing environments.

In the 'globalised' world of today, society and environment are undergoing a relatively fast and profound process of change. If decision makers want to head for a sustainable development, they need urgently more certainty towards a detailed view of the great variety of possible futures.

The demographic situation (economic changes are not be tackled here) is one of the main socio-economic key factors of change in land use. While in developing countries very high population growth rates are still held (even if it seems to slow down a little bit) in developed countries native population is significantly shrinking. Both of this contrasting tendencies will have their specific challenge. Additionally another global demographic influence is effective: according to UN-estimations, the urbanisation will continue to increase strongly. The world’s population exceeded the point where half of the population lives in urban areas already around the year 2000 A.D. For the year 2050 it is estimated that even two-thirds of the world population will be urbanized! Beside a widespread change of cultural behaviours this means that a more and more decreasing number of persons has to nourish a more and more increasing number of persons. Shrinking fertile areas will aggravate the respective situation. That will have severe implications on the future land use!

Beside socioeconomic development profound climate changes are expected. It is not discussed here about the degree of human activity implications in global climate change nor to which degree we are already in the thick of the change process. An economic indicator for expectable severe changes is given by the internet-site of the ‘Munich Re’ group (a re-assurance enterprise): they employ a special GIS-department to evaluate natural risks in all regions of the world based on observed damages or on an analysis of environmental information (see also at http://www.munichre.com).

Scientifically it is doubtless recognised that most world regions will be concerned by ‘global climate change’. But there still remains a huge uncertainty about the intensity and the detailed temporal and spatial patterns of the repercussions of an estimated world wide mean increase of greenhouse gas emissions. The estimated temperature increase ranges from 1.4°C up to 5.8°C and opens a great variety of possible developments and impacts. This range has to be narrowed and it’s implications have to be operationalised for decision makers.

So, it is here not the question how to prevent changes – it is assumed that they will happen. Here we follow to the vital interest to know possible ranges and how negative impacts of future environmental change can be minimised at preferably minimal costs. An example of that interest is given by the funding of the actual 6th EU Research Frame Programme. Here a focus is established on global climate change targeting to estimate impacts, to provide decision tools, to derive strategies and to develop instruments with respect to the management of the consequences of global climate change (http://www.cordis.europa.eu/sustdev/environment/ecosystems.htm). This addresses directly the development and the implementation of GIS-based modelling techniques. So two case studies for possible solutions to future GIS-challenges are given in the following: the first deals with the spatial integration of socio-economic and natural site aspects and the second case study emphasises the role of visions sketching future spatial land use patterns.

3 Integration of socioeconomic and natural site content by a regional landscape approach

To be able to integrate socioeconomic aspects using a GIS, they have to be related to spatial units. In the following it is shown how agroeconomic activities in the rural Sertão region of Northeastern Brazil were linked to landscape units.

Especially, if low energy driven traditional techniques are predominant, agriculture is mostly well adapted to the natural site specific resources. For a better understanding of this concept, a look back into the history of the agricultural history of Europe is helpful: here we have typical multidimensional “cultural landscapes” with very specific and well distinct shapes, agricultural products, techniques and farm types have been successfully established over centuries.

Transferring this idea of natural site adapted agroeconomic activities landscape types and related farm types had to be defined for a research model region in the semiarid North-eastern Brazil taken the municipality of Tauá (State of Ceará, approx. 4,000km^2) as example.

Soil types and topography led to four types of landscape units:

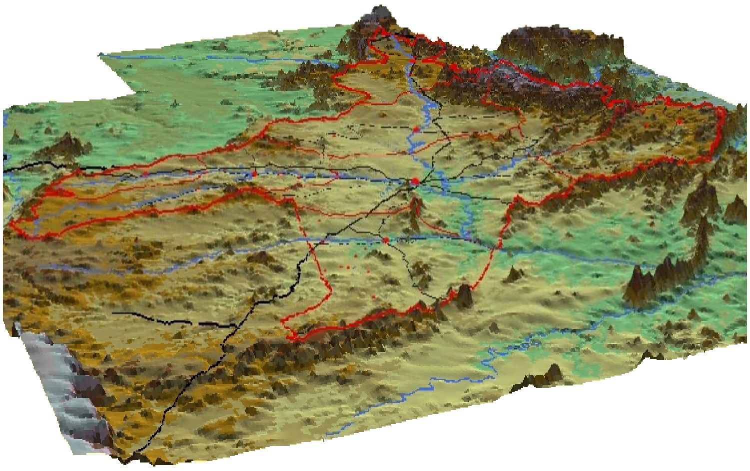


Fig. 1: 3-D model of Tauá municipality

- mountain areas, > 500m a.sl. with elevated precipitation
- two types of pediplain areas, differentiated according the soil fertility of the predominant soils
- alluvial areas with relatively good groundwater connectivity

To each of the landscape units two classes of farm types had been assigned: a market oriented and a subsistence farm type.

The resulting eight farm types were characterised e.g. by cropland area, crop selection, technology standard and the number of persons depending economically.

The quantified characterization of each feature of the farm types had been elaborated during an iterative process, in which the expertise of socioeconomic working groups (with a local interview-based farm survey) on the one side, had to be harmonized with official statistical data on the other side. Thus, the total number of clustered farms, virtual economically dependent persons, cultivated area of cropland, animal stocks etc. of all farm types had to result in the respective statistical numbers for the total municipality.

3.1 Characteristic site conditions for the farm types

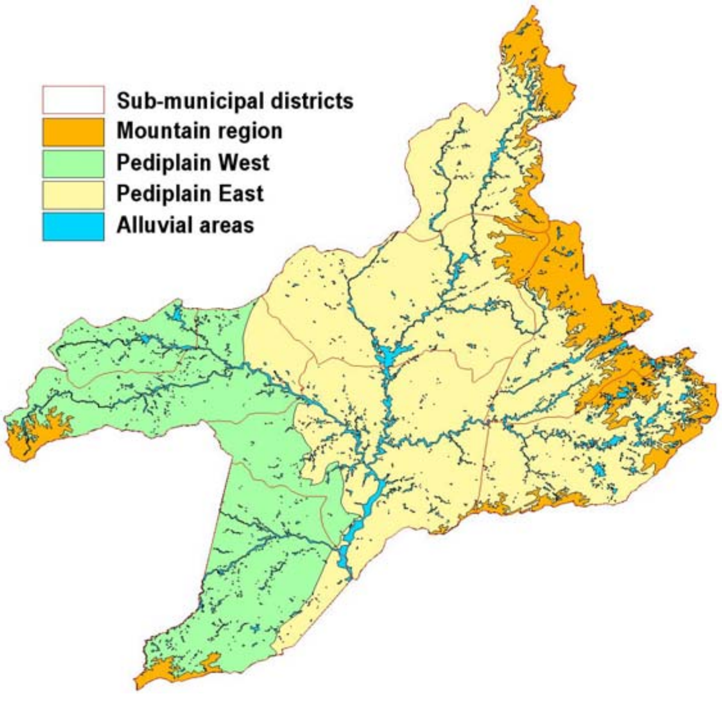


Fig. 2: Landscape units in Tauá

Mountain area farm types

Due to the slightly increased precipitation, mountain area farm types have a wider crop selection but due to the difficult topographic situation in average a smaller farm size.

Western Pediplain farm types

The western pediplain is characterised by more fertile soils so that in general crop cultures are more frequent than in the Eastern part.

Eastern Pediplain farm types

The Eastern pediplain comprises mainly areas with fodder cultivation like Napier grass. Mean farm sizes are larger than in the Western Pediplain.

Alluvial farm types

This is the only farm type using irrigation. Farm size is small and cultivation is intense. Rise and vegetable for the market are the main products of this area.

3.2 Conclusion

The above shown approach enables the relative fine grained localisation of population, different farm types and their socioeconomic parameters as well as their demand on natural resources. For scenario purposes, characteristics may be changed and the respective effects could be calculated by agro-economic as well as by other models. The production chain and their socioeconomic characteristics are directly linked to natural resources.

4 GIS-based visions of future spatial land use patterns

Possible futures often are sketched in form of scenarios. Mostly, several scenarios with different storylines, running over many years, serve to create a database of results within a given (modelling) frame of conditions and assumptions to support decision making in spatial planning.
Thus, there is a growing need for GIS-based „Spatial Scenario Design Models“ (SSDM) which enable the translation of assumed future changes (e.g. in land use) in spatial patterns and time steps. Besides the “simple” mathematical dimension of a population growth rate or a change of the ratio of land use types, the *spatial distribution* of a future population or a future land use *pattern* within a larger region is of high importance. The given example illustrates the expansion development of farmland, plantation and settlement in West-Africa (Benin), driven by a strong population growth.

4.1 A typical scenario situation

For the EU-funded research project RIVERTWIN an integrated water resources management planning tool had to be set up. In total 11 different models (e.g. including aspects of climate, discharge, water demand and quality, agricultural yields, economic evaluation, etc.) contribute with their simulation results to an expert system called MOSDEW (Model for Sustainable Development of Water Resources). This decision support tool shows the impact of global climate change and socioeconomic changes respectively in hydrological, ecological and socioeconomic dimensions.

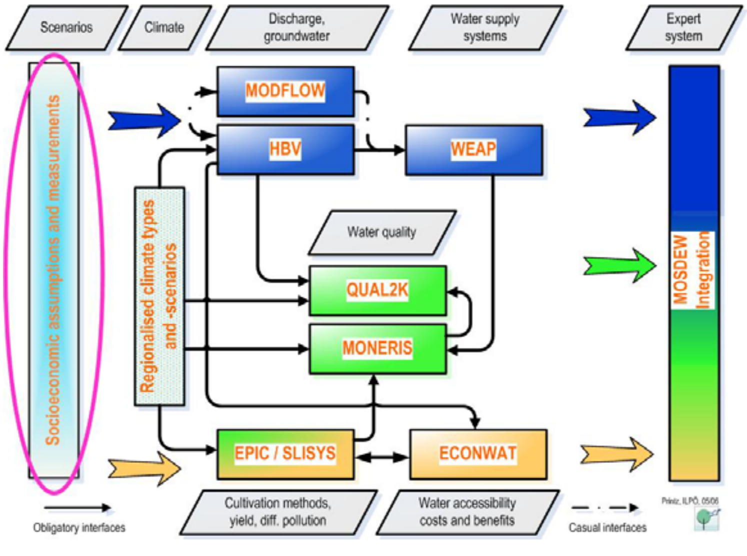


Fig. 3: Integrated coupling scheme (RIVERTWIN-Ouémé)

The integrated coupling concept was not a dynamical one – thus, results could not arbitrarily be created for each situation potentially to be expected. Instead - an obligatory modelling frame with well defined interface rules and modelling situations has been established for all sub-models. An important part of the modelling frame was the definition of future climate and socioeconomic situations that could be relevant to decision makers (s. figure 3). In the following only the (socioeconomic) scenario aspects on land use are explained.
The time horizon has been set to 28 years, starting with a reference year 2003 and ending with 2030. The validation has been done for the reference year using available statistical data, for calibration most models checked longer historic periods.

Tab.1: Example of demographic key figures (Scenario Benin)

	Reference year	Scenarios	
		A (Alafia)	B (Wahala)
Demography	2003	2030	
Population	2 030 063	4 751 835	5 139 241
Population density	41	96	104
Mean annual pop-growth rate 2003 - 2030		3,20%	3,50%
Urban Population %	41,05%	60,00%	50,00%
Urban Population total no	833 323	2 851 101	2 569 620

Two contrasting scenario storylines for a future development had been chosen: a more optimistic and a more pessimistic scenario with respective differentiated economic growth.

With the optimistic, stronger economic growth scenario a less pronounced population growth rate, a higher degree of urbanization and a more intense use of natural resources including a growing demand of meat, fruit and premium agro-products were associated (s. table 1). In absence of available statistics of migration fluxes a total growth rate for the national population growth had been assumed, so that expected immigration effects was considered effectively.

4.2 The translation of socioeconomic changes in spatial patterns

After that definition and after the general stakeholder acceptance of the storyline assumptions and key sizes for the scenarios, the challenge was to translate these numbers into spatial sizes and patterns. The final geometry, where simulation results were represented consisted of 13 sub-basins within the largest Beninense river Ouémé. Therefore rules for a very fine-grained disaggregated population distribution had to be set up.

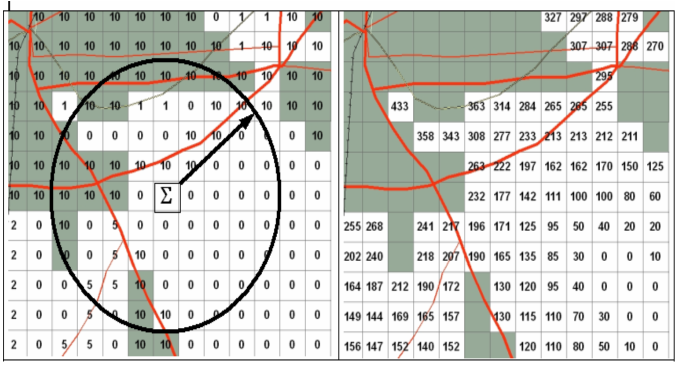
For that purpose the grid cell (300 x 300m) based "spatial scenario design model" (SSDM) was created.

As a prerequisite the spatial correlation of the rural and urban population to the land use units was established. Therefore a satellite image based interpretation of land use/land cover as well as statistical data had been available (for the reference year 2003). Thus, the area of arable land (a mosaic of cropland, fallow, and crop trees), of plantations and of urban settlement had been identified and per capita-coefficients for cropland, fallow land, plantation and urban settlement had been derived. These coefficients were fixed as quantitative spatial per-capita-demand throughout all scenario years.

Due to the more pronounced population growth and less urbanization rate the scenario B had a much higher demand for crop and plantation area, while in scenario A the cities increased significantly.

The demand for 'new' land use units has been calculated for each of the 28 years in both scenarios based on the coefficients. Defined conversion rules allowed the conversion mainly of the Natural Wood and Savannah classes into farmland classes.

For the chosen example the conversion of land use types was applied in four successive steps/levels. In each of the levels, convertible areas were assigned with preference values according to specific criteria. The number of cells, needed for the respective level, was converted according to a ranking preference value assigned to each grid cell.



	10	10	10	10	10	10	10	0	1	1	10	10
10	10	10	10	10	10	10	10	10	1	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	1	10	10	1	1	0	10	10	10	10	10
10	10	10	0	0	0	0	10	10	0	0	0	10
10	10	10	10	10	10	10	10	0	0	0	0	0
10	10	10	10	10	0	Σ	0	0	0	0	0	0
2	0	10	0	5	0	0	0	0	0	0	0	0
2	0	10	0	5	10	0	0	0	0	0	0	0
2	0	0	5	5	10	0	0	0	0	0	0	0
2	0	0	5	0	10	10	0	0	0	0	0	0
2	0	5	5	0	10	10	0	0	0	0	0	0

								327	297	288	279	
									307	307	288	270
										295		
		433			363	314	284	265	265	255		
			358	343	308	277	233	213	213	212	211	
					263	222	197	162	162	170	150	125
					232	177	142	111	100	100	80	60
255	268		241	217	196	171	125	95	50	40	20	20
202	240		218	207	190	165	135	85	30	0	0	10
164	187	212	190	172		130	120	95	40	0	0	0
149	144	169	165	157		130	115	110	70	30	0	0
156	147	152	140	152			120	110	80	50	10	0

Fig. 4: grid cell valorisation for urban transfer preference

1. Level:Distribution of urban population

According to the specific spatial demand (area/capita) the urban population of both of the scenarios (A and B) was distributed.

Grid cells which were located closest to the existing land use class "settlement" and to roads (including the weighting of their hierarchy) got the highest preference value for conversion. An aggregated value has been calculated for each grid cell for a 4 cells-radius. For settlement conversion there was no restriction to any land use class.

2. Level: Distribution of plantation

It was assumed that within the plantation class fruit trees 2003 had a proportion of 40%, while 60% of plantation was for (subsistence) Teak wood. In scenario A the area for export oriented fruit trees expanded 5 times, in scenario B it was kept at the same level as in 2003. However, the (subsistence) Teak proportion grew in both scenarios by an area per rural population coefficient.

The conversion preference for the plantation land use class increased according to the proximity to roads and existing plantations. Only former mosaic areas could be transformed (no direct transformation from natural woods).

3. Level: Distribution of mosaic area

The “natural” wood and savannah types were disposed for “slash and burn” conversion into the farmland class.

Satellite image land use interpretation offered “only” a mosaic (=mixture) of cropland and fallow land (partially as agro-forestry). However, the length of the non-productive fallow period in tropical areas is very important for the calculation of the demand on cropland area on one hand and for soil fertility on the other. It was assumed that if the reserves of convertible natural wood for slash and burn were shrinking, an increasing population had to emigrate and/or intensify the production. Especially in the reference area of the Ouémé River basin in Benin, a strong North-South gradient was observed (the South was actually much more intensified).

Based on agriculture statistics of the reference year 2003 the specific proportion cropland/fallow land was estimated for each department. The resulting coefficient for the mean cropland demand had been fixed for both of the scenarios. Also a specific fallow coefficient was calculated, dynamically adapted for each scenario. This means that at the end of the scenario period fallow proportion has decreased by approx. 60% - in other words, the length of fallow period sank by approx. 40%.

The demand for cropland and fallow land were finally combined with the mosaic class. The conversion of a cell into the mosaic class was done with preference to areas close to the road and in proximity to existing mosaic land.

A further challenge was the handling of nature protection zones within the study area. Already nowadays, these areas are (illegally) invaded. It was assumed that a higher population pressure will lead to increased invasions. However, the conversion preference for protected areas was set to 50% in relation to non protected areas. By that way at least the great protection areas had still a real protected core (for the given time frame), while at the margins and along the roads growing invasion tendencies are implemented.

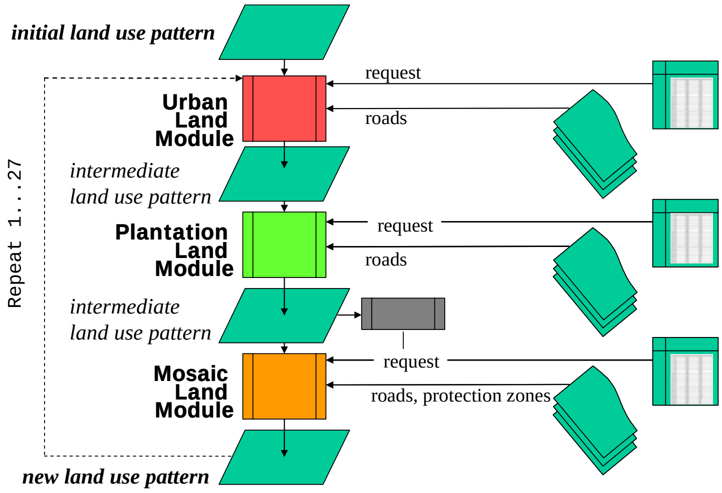


Fig. 5: request series for simulation run

Figure 5 shows the systematic request series that is run for each simulation year.

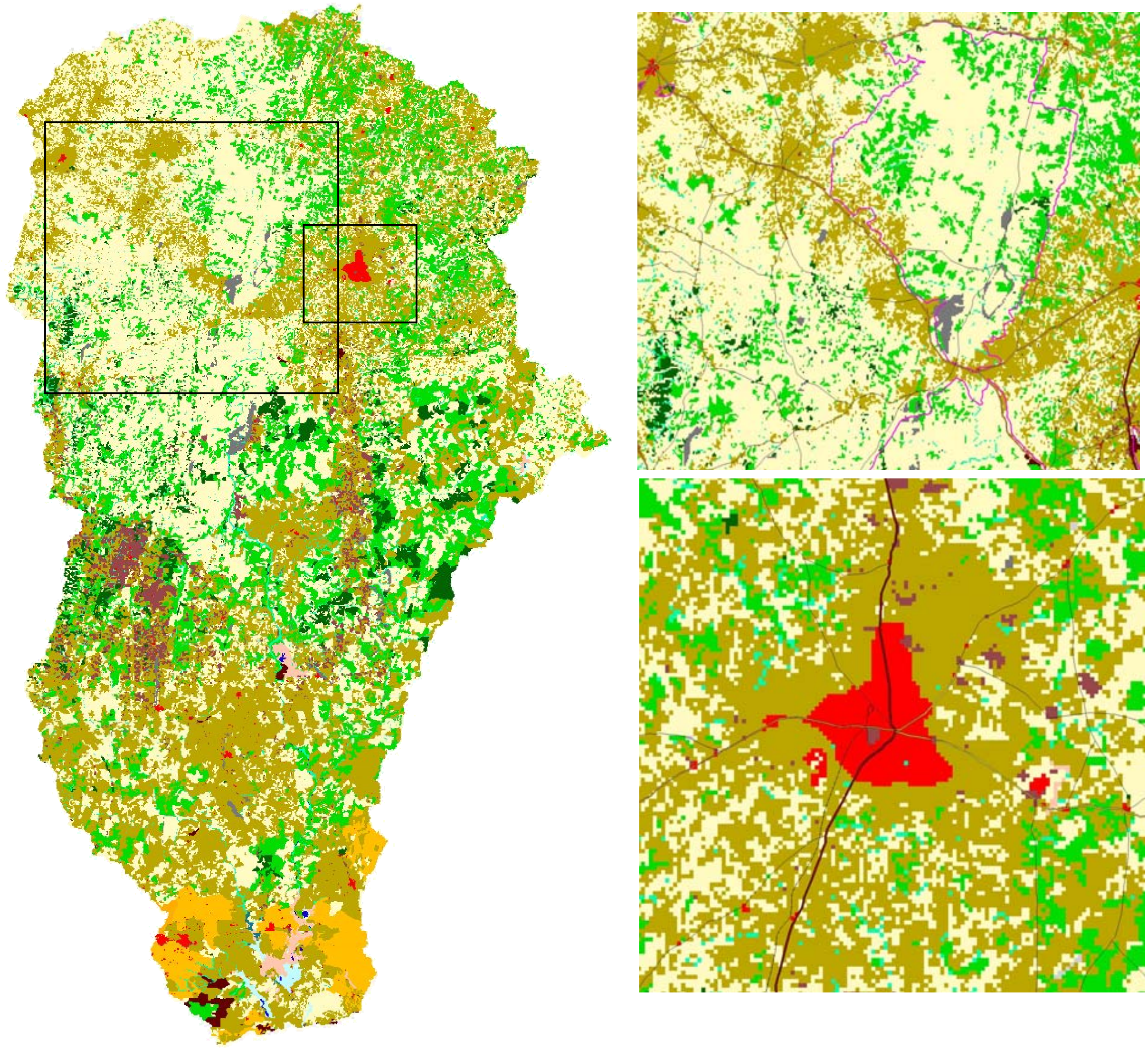


Fig. 6: Actual land use pattern 2003 (left-total Ouémé River basin, black boxes are zoom details on the right); rural area in Upper Ouémé (above right, pink lines are protection zones); urban area of City of Parakou (below right). Light Brown area is mosaic land, dark Brown is plantation, Ochre is Savannah, Green are forests, Red is settlement, see also Fig. 7.

4.3 Conclusion

The comparison in between Fig. 6 and 7 shows the increase of plantation, mosaic of cropland and settlement mainly in the North of the Ouémé River basin. Apparently, only few Savannah and forest areas are left, protection zones are still respected but invaded at boundaries and along the roads (s. also fig.7 above right).

The re-application of the per-capita-coefficient for cropland or settlement may even be used for a recalculation of final scenario population within regional administrative units such as departments.

The above shown approach enables the construction of variant spatial land use change patterns due to population growth. Spatial effects of transfer rules can be quickly identified, comprehensively discussed and altered for a commonly accepted spatial vision of a future land use map. Maps created by SSDM supply vital input data for all kind of models calculating environmental impacts induced by land use change. Thus, SSDM contributes substantially to communication and participation in relevant planning processes.

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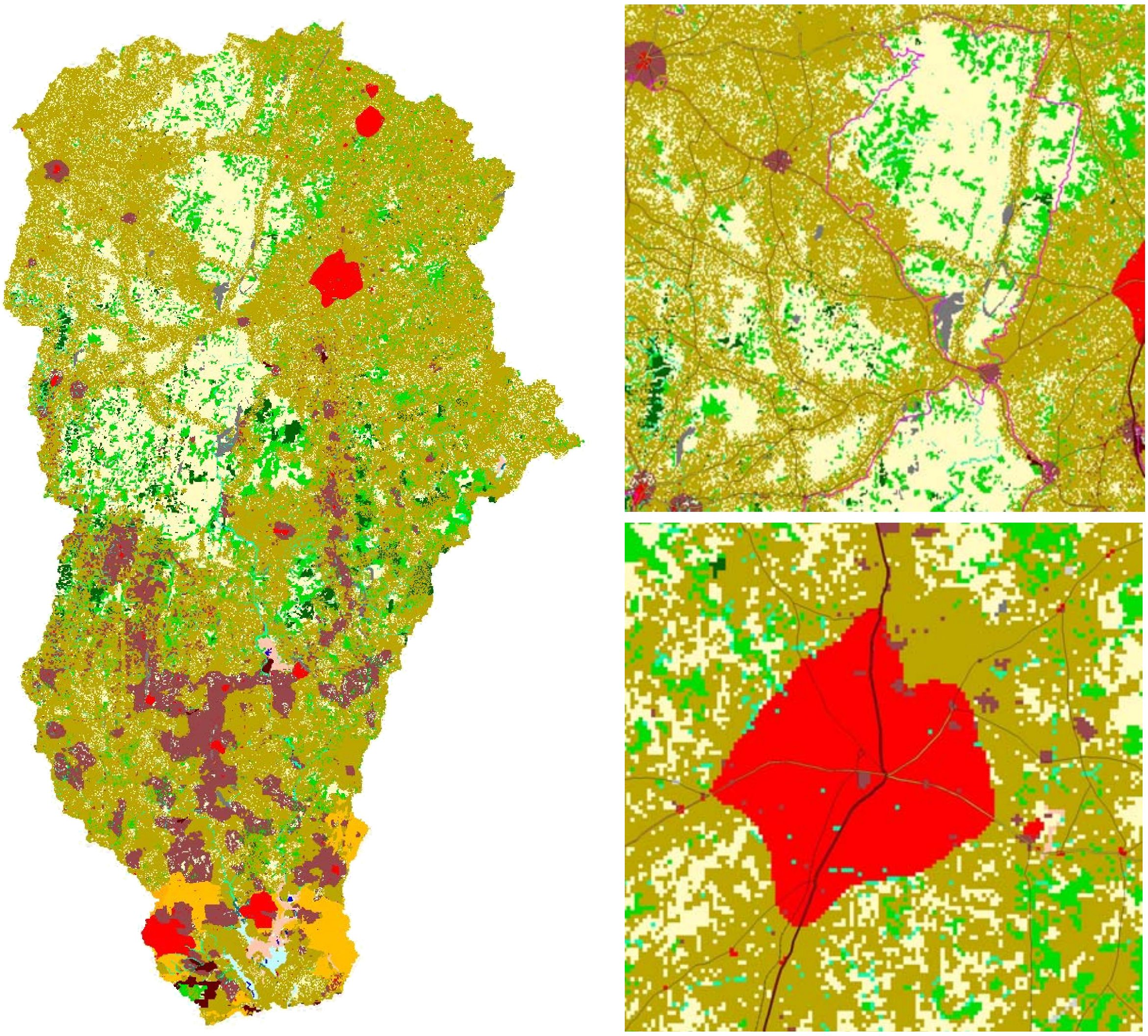

Fig. 7: Scenario land use pattern 2030 (left-total Ouémé River basin, scenario B); rural area in Upper Ouémé, (above right, scenario B 2030); urban area of City of Parakou (below right, scenario A 2030) Same colours as in Fig. 6

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