LAND COVER AND USE CHANGES AND PREDICTED CLIMATE CHANGES IN ROMANIA: CONNECTIONS UNDERLINED BY THEIR SPATIAL DISTRIBUTIONS

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Abstract. While energy, land cover/use changes, climate change and their connections describe what the literature called "global change", the paper focuses on the relationships between the latest two components. Overall, three connections have been extensively documented: land cover/use changes lead to climate change, which in its turn produces other land cover/use changes, and additional ones are required to mitigate the effects of climate change. In this theoretical framework, this study utilizes a GIS-based methodology to explore the spatial relationship between 2100 predicted climate changes and 1990-2000 land cover/use changes, by underlying the cause, in Romania. The results exhibit clear patterns with respect to agriculture, indicating that one of the development regions, relying on subsistence agriculture, will be affected by climate change and floods, showing the potential of accumulating climate change effects that occurred elsewhere. Nevertheless, the results must be regarded with the caveats of methodological limitations and causal inferences based on spatial relationships.

Keywords: energy, CORINE, global change, landscape design, carbon cycle.

Rezumat. Modificări în acoperirea şi utilizarea terenului şi schimbările climatice prezise în România: conexiuni evidenţiate de distribuţiile spaţiale. În timp ce energia, modificările în acoperirea/utilizarea terenului, schimbările climatice şi conexiunile acestora descriu ceea ce literatura de specialitate a numit „schimbările globale", lucrarea de faţă se axează pe relaţia dintre ultimele două componente. Rezumând, trei conexiuni au fost bine documentate: modificările în acoperirea/utilizarea terenului conduc la schimbări climatice, care la rândul lor determină alte modificări ale acoperirii/utilizării terenului, şi noi modificări sunt necesare pentru a face faţă efectelor schimbărilor climatice. În acest cadru teoretic, studiul de faţă foloseşte o metodologie bazată pe Sistemele Informaţionale Geografice pentru a explora relaţia spaţială dintre predicţiile climatice pe 2100 şi modificările în acoperirea/utilizarea terenului din perioada 1990-2000, în funcţie de cauză, în România. Rezultatele prezintă configuraţii evidente în ceea ce priveşte agricultura, arătând că una dintre regiunile de dezvoltare care se bazează pe agricultura de subzistenţă va fi afectată de schimbările climatice şi inundaţii, demonstrând potenţialul de acumulare a efectelor schimbărilor climatice din alte zone. Cu toate acestea, rezultatele trebuie analizate sub rezerva limitărilor metodologice şi a inferenţelor cauzale bazate pe spaţialitate.

Cuvinte cheie: energie, CORINE, schimbări climatice, amenajarea teritoriului, ciclul carbonului.

INTRODUCTION

The term "global change" encompasses all man-generated impact affecting our planet, *i.e.*, land use changes, climate change and energy use (DALE *et al*., 2011). While the first two are the main focus of this paper, and particularly their relationships, energy is related to land cover and use through the concept of "primary eco-energy", referring to the initial energy of a system before the conscious human intervention over it and is inversely proportional with the degree of anthropization (PETRIŞOR & SÂRBU, 2010; IANOŞ *et al*., 2011). PETRIŞOR *et al*. (2010) define land use as a detailed typology of natural systems and the utilization of the artificial ones by human communities. In addition, the authors believe that when CORINE Land Cover data are used, land cover is described by the first level of the classification (CLC1) and land by the next levels (CLC2 and 3), depending on the extent of details.

The importance of climate change issues was underlined in numerous studies carried out during the last decades; these studies indicated effects on the spatial distribution, life cycle and biology of species (PEÑUELAS & FILELLA, 2001; PEÑUELAS *et al*., 2002; THOMAS *et al*., 2004; PARMESAN, 2006; PETRIŞOR, 2010; PETRIŞOR & MEIŢĂ, 2011), ecosystems and their functions (PETRIŞOR, 2010; PETRIŞOR & MEIŢĂ, 2011). Since the particular effects have already been documented, two examples are offered to illustrate the importance of climate change. The first one relates to the increased incidence of vector-borne diseases induced by climate change that altered the life cycle of intermediary hosts (PATZ *et al*., 2008; SÜSS *et al*., 2007). The second, known as "trophic asynchrony", consists of changed connected lifecycles, which result into the loss of the food source for some species (PEÑUELAS *et al*., 2002; PARMESAN, 2006). In addition to biological and ecological effects, economic and social effects have also been described (PETRIŞOR, 2010; HAIM *et al*., 2011; PETRIŞOR & MEIŢĂ, 2011).

Joint effects of changed land cover and/or use and climate change affect the abiotic components of ecosystems, such as changing hydrological characteristics (JARSJÖ *et al*., 2011; MANGO *et al*., 2011; WILSON & WENG, 2011) or determining landslides (WINTER *et al*., 2010) and their biotic components, including impacts leading to the possible extinction of plant species (FEELEY & SILMAN, 2010) or birds (BENNING *et al*., 2002; JETZ *et al*., 2007) and loss of biodiversity (PIELKE *et al*., 2002), but favouring biological invaders (DALE *et al*., 2009), shits of spatial distributions (BENNING *et al*., 2002; PETRIŞOR, 2010) or changes in the specific composition and biomass of forests (THOMPSON *et al*., 2011). The functions of ecosystems are also affected; carbon cycles are changed (KAPLAN *et al*., 2011). Other effects include socio-economic changes (FORBES, 1999).

Of particular interest is the relationship between the two man-induced impacts. Some authors argue that it is important to know how much does clime change due to altered land cover and use as opposed to the emission of greenhouse gases (KALNAY & CAI, 2003; MAHMOOD *et al*., 2010) and correlate climate changes with land use changes (FEDDEMA *et al*., 2005; CHEVAL *et al*., 2011), while others say that assessing the discernible human influence on global climate does not account for the fact that large-scale land alterations occurred early in history and resulted into climate change (PIELKE, 2005). In fact, many authors agree on the fact that land cover and use changes lead to climate change by changing the water cycle (PIELKE, 2005), carbon cycle (DALE, 1997; PIELKE *et al*., 2002; OLOFSSON *et al*., 2005; DALE *et al*., 2011) or energy flows (PIELKE *et al*., 2002); to illustrate the statement, the loss of vegetation results into lower carbon sequestration and eventually to climate changes (FINDELL *et al*., 2007; MARTIN, 2008; DALE *et al*., 2011); urbanization results into "heat islands" (CHEVAL *et al*., 2009). On the same note, even more authors see wise land management, also called "landscape design" (DALE *et al*., 2011) as a way of adjusting to climate changes and mitigating their effects (THOMAS *et al*., 2004; MEDINA & TARLOCK, 2010; DALE *et al*., 2011).

Several authors have discussed in depth the causal implications of this relationship. DALE *et al*. (2011) show that there are three directions: some land cover and/or use changes are induced by climate changes; alterations in land cover and use influence the carbon cycle and result into climate change; and new changes are made in land cover and/or use to mitigate the effects of climate change. MENDELSOHN & DINAR (2009) show that altered land cover and/or use results into increased emissions of greenhouse gasses, leading to climate change. In its turn, climate change modifies the productivity of land and reclaims new land cover and/or use changes; and finally land cover and/or use changes allow for mitigating its effects. Moreover, HAIM *et al*. (2011) believe that some of the social effects of climate change are the migrations, which determine land cover and/or use changes due to the limited space.

All the considerations exposed above allow for modelling the relationships between energy, climate change, land use changes, natural systems and the human society in the conceptual chart displayed in figure 1.

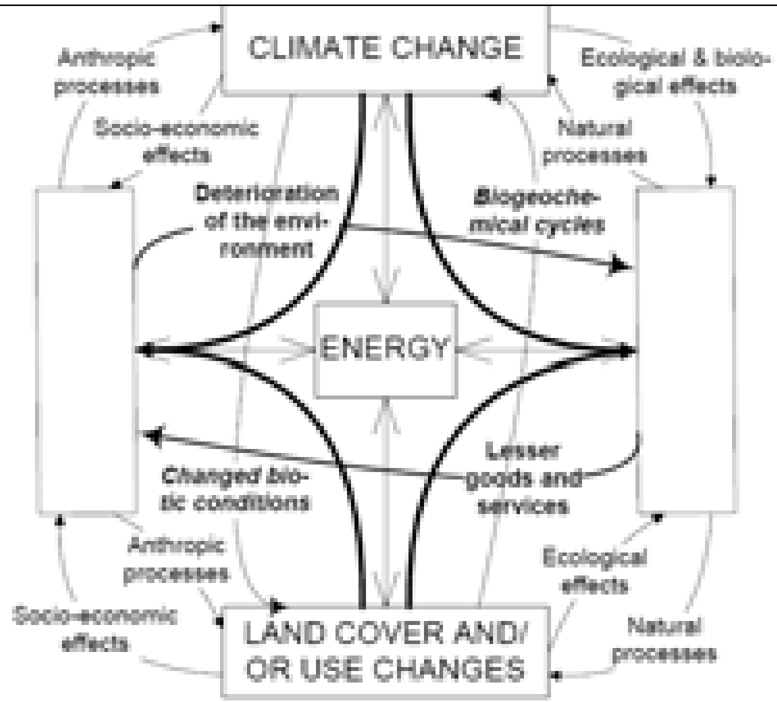

Figure 1. Conceptual model of the system of relationships between energy, land cover and/or use changes, climate change, natural ecological systems and the human society. / Figura 1. Model conceptual al sistemului de relaţii între energie, modificările acoperirii şi/sau utilizării terenului, schimbările climatice, sistemele ecologice naturale şi societatea omenească.

In order to model this relationship, a phenomenon covering large territories over a long time, many approaches have been proposed, and discussed by PETRIŞOR (2010). Among them, Geographical Information Systems seem to be an appropriate instrument (BENNING *et al*., 2002; PETRIŞOR, 2010; IANOŞ *et al*., 2011; PETRIŞOR & MEIȚĂ, 2011), especially provided the time and space scale of this analysis (PETRIŞOR, 2008).

The aim of this study is to create a methodology for assessing the possible spatial correlations between predicted climate change and previous changes in land cover and/or use changes, by underlying cause, over the territory of Romania. Of particular interest are land cover and/or use changes with a strong impact on climate change, such as urbanization and phenomena affecting forests (deforestation or forestation). The choice of Romania was determined due to the post-communist social and economic changes, which in their turn resulted into land cover and use changes (PETRIŞOR *et al*., 2010), particularly into massive forest cuts and urban sprawl.

DATA AND METHODS

The study uses two climate data sets, freely available from the University of Berkeley in a DIVA-GIS format (HIJMANS *et al*., 2001); current values can be found at http://biogeo.berkeley.edu/worldclim/diva/diva_worldclim_2-5m.zip and predictions at http://biogeo.berkeley.edu/worldclim/diva/diva_wc_ccm3_2-5m.zip. Current data are an output of the WorldClim project (HIJMANS *et al*., 2003), and 2100 predictions are based on double CO_2 concentrations and the CCM3 model (GOVINDASAMY *et al*., 2005). Both temperature and precipitation data were used to compute the difference between actual and predicted values for each 2.5 min × 2.5 min cell of the data grid. Due to the format, data had to be imported ArcView GIS 3.X, projected to Stereo 1970, and clipped for the Romanian boundaries.

Land cover and use data are also freely available from the European Environment Agency. Since climate simulations were produced after 2000, land cover and use changes data were used (http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-changes-clc1990-clc2000-seamless-vector-database-version-9-2007). After changing projection to Stereo 1970 and clipping for the Romanian boundaries, data processing included the addition of a new field, the underlying cause. This was determined based on the final land use.

Analyses consisted first of aggregating temperature and precipitation data into a single layer, "climate". Arc View modelling was used, with equal weights assigned to the data sets. High values indicate areas with low precipitations and high temperatures. Land cover and use data were used to produce interpolation maps using a radial basis function, modifying the method described in detail by PETRIŞOR *et al*. (2010). Predictions were possible only when at least ten areas affected by a single cause could be identified. The resulting prediction maps were overlaid unto the climate layer.

RESULTS AND DISCUSSIONS

Nine major causes of land cover/use changes were identified for the period 1990-2000: abandonment of agricultural land, development of agriculture, forestation (natural or by regeneration), flood, urbanization, construction of dams, deforestation, desertification and unknown phenomena. Only the first five causes had a sufficient coverage to apply the methodology presented above. The spatial distribution for each major underlying cause can be explained by socio-economic evolution of areas where peaks were found (PETRIŞOR *et al*., 2010). However, the detailed discussion exceeds the scope of the present paper.

The spatial distribution of predicted climate change over the Romanian territory is consistent with previous findings (PETRIŞOR, 2010; PETRIŞOR & MEIŢĂ, 2011). The peak occurs in the north, and values decrease on a circular basis toward east, south and north. This spatial distribution suggests that mountain regions will be affected mostly (PETRIŞOR, 2010, 2011; PETRIŞOR & MEIŢĂ, 2011).

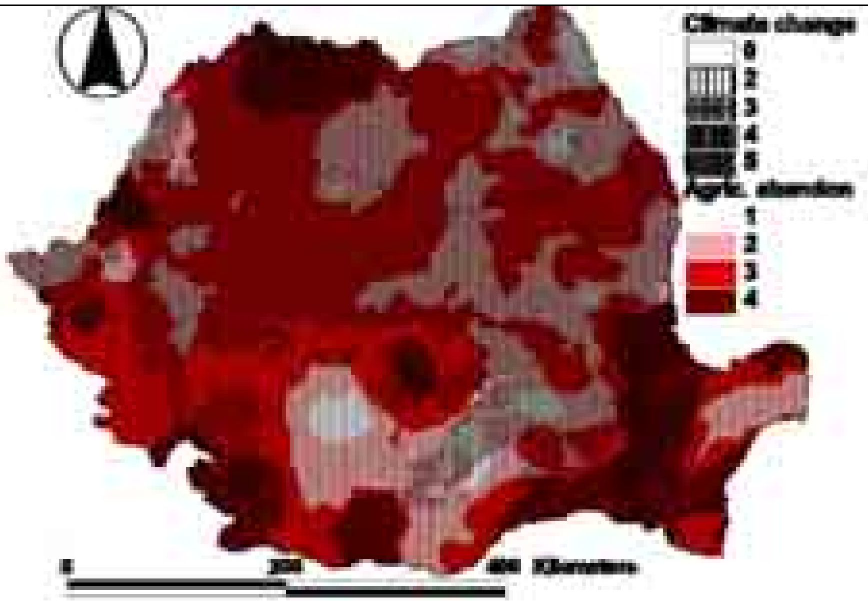

Figure 2. Changes in land cover and use due to agricultural abandon in Romania between 1990 and 2000 (shading show intensity) and predicted 2100 climate change (hatches indicate intensity). / Figura 2. Modificări în acoperirea şi utilizarea terenurilor datorate abandonului culturilor agricole în România în perioada 1990-2000 (culoarea indică intensitatea) şi predicţii climatice pentru 2100 (haşurile indică intensitatea) (original).

The spatial overlaid distributions are shown in figure 2 through 6. Different hatches symbolize the intensity of climate change (most dense hatching indicating high temperatures and lower precipitations), while the magnitude of land cover and use changes (indicated by total area affected) is represented for each underlying cause using darker shades for intense occurrences.

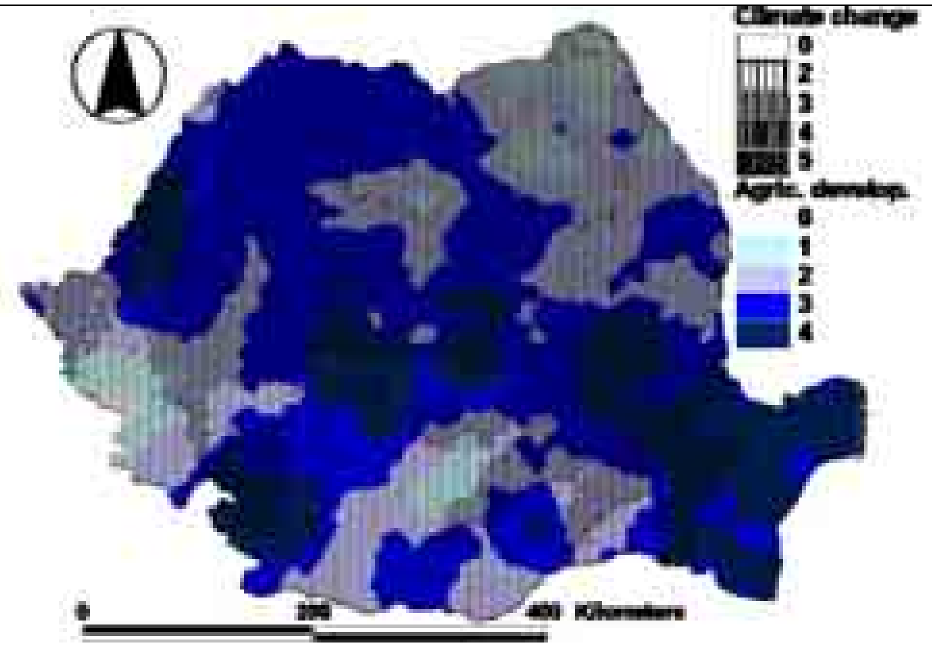

Figure 3. Changes in land cover and use due to the development of agriculture in Romania between 1990 and 2000 (shading show intensity) and predicted 2100 climate change (hatches indicate intensity). / Figura 3. Modificări în acoperirea şi utilizarea terenurilor datorate dezvoltării agriculturii în România în perioada 1990-2000 (culoarea indică intensitatea) şi predicții climatice pentru 2100 (haşurile indică intensitatea) (original).

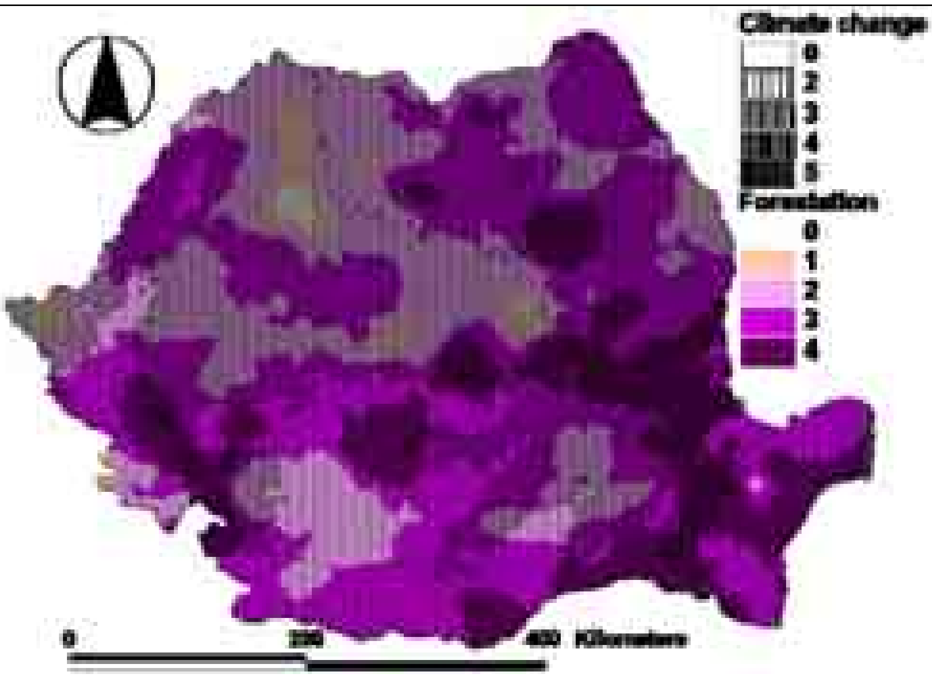

Figure 4. Changes in land cover and use due to forestation in Romania between 1990 and 2000 (shading show intensity) and predicted 2100 climate change (hatches indicate intensity). / Figura 4. Modificări în acoperirea şi utilizarea terenurilor datorate împăduririlor în România în perioada 1990-2000 (culoarea indică intensitatea) şi predicții climatice pentru 2100 (haşurile indică intensitatea) (original).

The spatial distributions allow for identifying areas where the two overlaid features coincide. Low agricultural abandon corresponds to an increased intensity of climate change in the south-west of the country, where the main form of agriculture is subsistence agriculture. For this particular reason, crops were not abandoned, but due to the climate change, already noticeable in terms of local effects, the agricultural yield appears to be insufficient and the area is underdeveloped (DOBRIN *et al*., 2010). The maximum values of agricultural abandon occur along the final portion of the Danube, and correspond to the former lakes that were converted during the communist period in agricultural areas. However, after the rise of salts by capillarity they lost the agricultural potential and were abandoned. Currently they undergo ecological restoration in order to return to the original role.

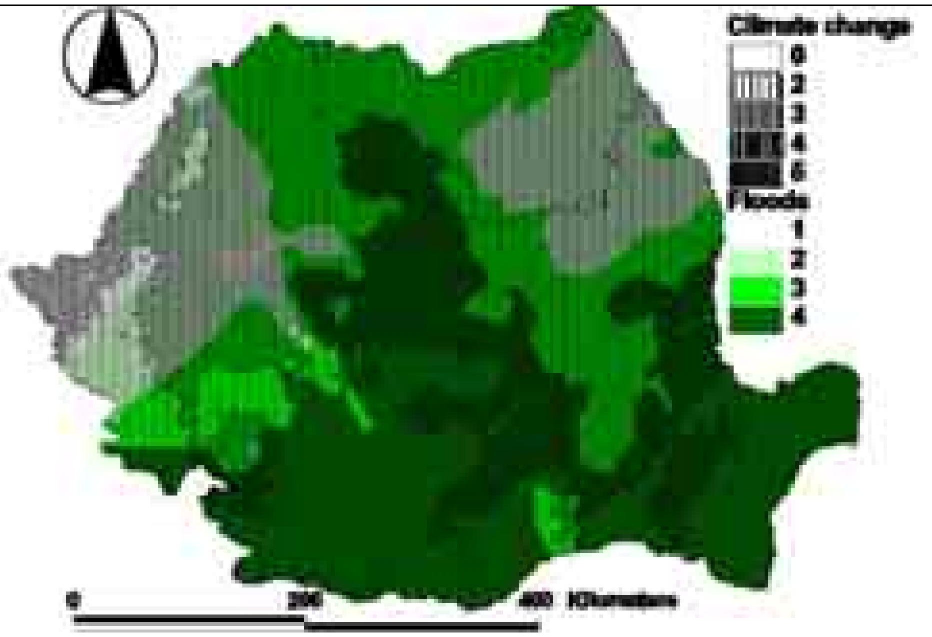

Figure 5. Changes in land cover and use due to floods in Romania between 1990 and 2000 (shading show intensity) and predicted 2100 climate change (hatches indicate intensity). / Figura 5. Modificări în acoperirea şi utilizarea terenurilor datorate inundaţiilor în România în perioada 1990-2000 (culoarea indică intensitatea) şi predicţii climatice pentru 2100 (haşurile indică intensitatea) (original).

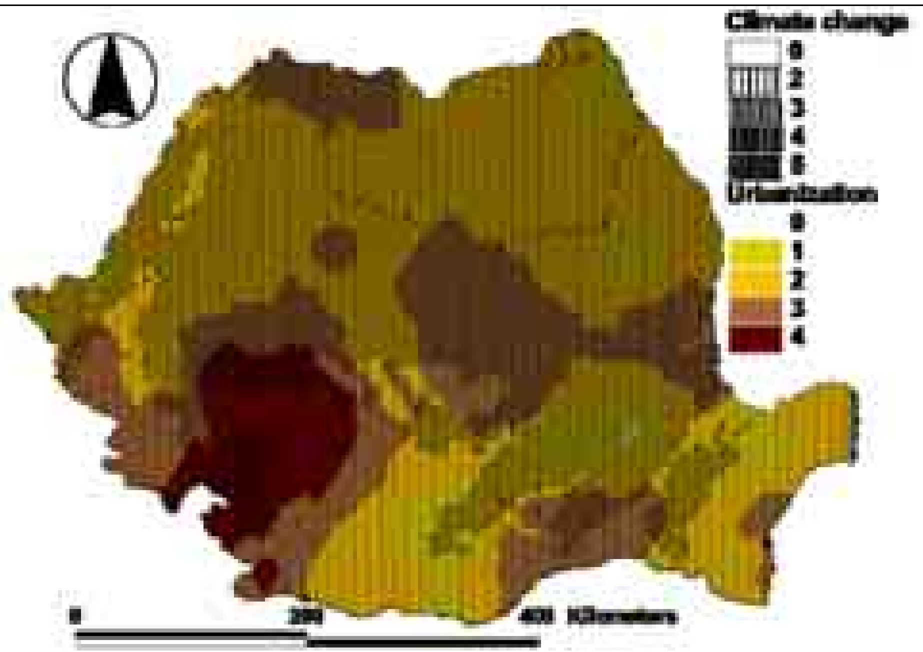

Figure 6. Changes in land cover and use due to urbanization in Romania between 1990 and 2000 (shading show intensity) and predicted 2100 climate change (hatches indicate intensity). / Figura 6. Modificări în acoperirea şi utilizarea terenurilor datorate urbanizării în România în perioada 1990-2000 (culoarea indică intensitatea) şi predicţii climatice pentru 2100 (haşurile indică intensitatea) (original).

On the opposite side, lowest values of agricultural development are located in the same area, fact explained by the already felt effects of climate change, and also in the west of the country, another area used for agriculture in the past. Agriculture is developed from east to the west exactly in the areas exposed to high intensity climate change, suggesting its harmful potential over agriculture (MEIŢĂ *et al*., 2011).

The spatial distribution of forestation processes does not appear to be linked to climate changes. In this case, the methodology is arguable, as it could suggest active interventions to mitigate the effects of climate change. In fact, satellite data cannot distinguish between natural regeneration and plantation of forests.

Floods seem to be the best tied to climate change, as they also exhibit a concentric spatial distribution. The area affected by floods seems to correspond to a low intensity of climate change. This could look at a first sight paradoxical, but it has to be stressed out that the floods occurred by accumulation of waters streaming into the Danube towards the south and east of the country. For this reason, the area not affected directly by predicted climate changes suffered from the accumulation of the effects produced elsewhere.

Urbanization reaches its peak in the south-west. In fact, this is a methodological artefact. The area is characterized by intense land use changes due to the abandonment of former mining cities that lost their industrial function (PETRIŞOR *et al*., 2010; IANOŞ, 2000). Since land cover and use changes are analysed all together, the peak might suggest that the area was undergoing urbanization, when in fact it was de-urbanized. Nevertheless, there is no clear pattern with respect to the relationship between urbanization (or de-urbanization) and climate change. The explanation consists of the small area of Romanian cities compared to the entire territory, which masks the effects at this spatial scale.

The implications of these results relate to landscape design (DALE *et al*., 2011). The envisaged effects of climate change can be mitigating by relocating specific land uses to regions where the effects of climate change are not likely to impair their functioning. Agriculture should be developed in areas that are not prone to being affected by climate change. At the same time, water course works (dams, consolidations of banks etc.) are required not only where higher precipitations are expected, but also where waters are likely to accumulate. Additional research, using tools such as watershed analysis, could pinpoint the areas where interventions are urgent.

The main limitation of the study is conceptual and involves causality. While causality is materialized in a spatial relationship, the reverse is not necessarily true, meaning that the associations detected by simply looking at spatial proximity might be spurious. For this reason, the study presented in this paper should be taken as an exploratory analysis. Nevertheless, the causal implications do not diminish the value of the findings confirmed by previous results.

Other limitations concern limitations of the methodologies used. For example, establishing five classes of the intensity of climate changes might be "too much", given the reduced range of temperature and precipitation values. Similarly, the interpolation techniques tend to be over-generalizing, and the results should not be interpreted as precise limits, as they lack the precise geographical relevance (PETRIŞOR *et al*., 2010).

CONCLUSIONS

The paper aimed to detect spatial connections between the spatial distributions of predicted climate change and land cover and/or use changes by their underlying cause. The main causes identified were abandonment of agricultural land, development of agriculture, forestation (natural or by regeneration), flood and urbanization. The only ones clearly connected to climate change are the two phenomena related to agriculture; they suggest that the areas of Romania where the subsistence agriculture is the main provider of incomes have already suffered due to clime change, and the forecast is not optimistic. At the same time, adverse effects of climate change can occur elsewhere, by accumulation, as it happened to the floods. Nevertheless, the conclusions must be regarded with the caveats of the causal implications and methodological limitations.

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