Development of a High Performance Capabilities for Supporting Spatially-Explicit Uncertainty- and Sensitivity Analysis in Multi-Criteria Decision Making

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Spatial multi-criteria decision making (MCDM) applications often do not provide any detailed information about the robustness of results and uncertainties associated with input data. Applications from landscape assessment, natural hazard risk assessment for communities, identification of land use strategies for sustainable regional development, water resource management or habitat suitability in the context of environmental protection are just a few examples of domain areas where MCDM methodology continues to find use.

Therefore, the main objective of this exploratory research project is the development of scalable and adaptable capabilities to accelerate Spatially-Explicit Uncertainty and Sensitivity Analysis (SEUSA). A parallel algorithm design for the implementation of the SEUSA framework will allow reasonable computational times making this kind of spatial analysis applicable and attractive in the context of MCDM.

A spatial MCDM approach considered in this research involves a certain number of alternatives, which are evaluated on the basis of conflicting criteria. Criteria can be represented either as factor- or constraint maps (limitations). In general, a MCDM-based workflow involves the standardization of the criteria to achieve their comparability, expert preferences (weights) that represent the influence of the criteria, and mathematical functions (Weighted Linear Combination, Ideal Point, Ordered Weighted Averaging, Analytic Hierarchy Process etc.) to generate the suitability surface. Detailed information about the spatial MCDM workflow can be found in Malczewski (1999), Erlacher et al. (2009) and Malczewski and Rinner (2015).

One important part of this workflow is the sensitivity analysis to validate the robustness and stability of implemented MCDM models. Uncertainties can be caused by imprecise data or measurement errors, the standardization of criteria values, the implemented decisions rules, and the preferences of the experts expressed by cardinal weights. Uncertainty analysis quantifies the variability of model outcomes and sensitivity analysis focuses on identifying decision criteria or criteria weights that cause the variability (Ligmann-Zielinska and Jankowski, 2014). Spatially-explicit U-SA as research topic was illuminated and discussed in a small number of contributions (Ligmann-Zielinska and Jankowski, 2012; Feizizadeh et al., 2014; Ligman-Zielinska and Jankowski, 2014; Şalap-Ayça and Jankowski, 2016). These studies refer to a variance-based U-SA approach that includes the quasi-random Sobol’s experimental design for generating the weight samples and the Monte Carlo Simulation (MSC) to create the suitability surfaces according to the implemented decision rules. This approach explicitly accounts for the interaction of the input factors, which can be a time-consuming process especially in case of spatial data. The computational effort depends on the number of criteria, the number of raster cells (pixels) and the number of simulations.

First intermediate results were presented at the AAG conference 2016 in San Francisco and focused on the development of a GPU-based (Graphics Processing Units) prototype to accelerate the spatially-explicit U-SA. The implemented prototype refers to a land-allocation problem in order to prioritize agricultural land units based on environmental benefits (Şalap-Ayça and Jankowski, 2016). Details regarding the conceptual development and the CUDA implementations are described in Erlacher et al. (2016).

For the development of a scalable and adaptable approach to accelerate spatially-explicit U-SA several projects involving diverse application areas have to be investigated, in order to support different kinds of MCDM models and operations (local-, focal-, zonal and global raster- and vector analysis) as well as to identify limitations. The successful realization of the project will have a positive impact on future uses of MCDM methodology due to computational support for spatially-explicit uncertainty and sensitivity analysis.

In summary, the proposed research will support spatial decision support capabilities through increased traceability, objectivity, and transparency of results obtained from applications of MCDM.

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