Editorial

Geospatial Modeling Approaches to Historical Settlement and Landscape Analysis

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Abstract: Landscapes and human settlements evolve over long periods of time. Land change, as one of the drivers of the ecological crisis in the Anthropocene, therefore, needs to be studied with a long-term perspective. Over the past decades, a substantial body of research has accumulated in the field of land change science. The quantitative geospatial analysis of land change, however, still faces many challenges; be that methodological or data accessibility related. This editorial introduces several scientific contributions to an open-access Special Issue on historical settlement and landscape analysis. The featured articles cover all phases of the analysis process in this field: from the exploration and geocoding of data sources and the acquisition and processing of data to the adequate visualization and application of the retrieved historical geoinformation for knowledge generation. The data used in this research include archival maps, cadastral and master plans, crowdsourced data, airborne LiDAR and satellite-based data products. From a geographical perspective, the issue covers urban and rural regions in Central Europe and North America as well as regions subject to highly dynamic urbanization in East Asia. In the view of global environmental challenges, both the need for long-term studies on land change within Earth system research and the current advancement in AI methods for the retrieval, processing and integration of historical geoinformation will further fuel this field of research.

Keywords: land change science; historical geoinformation; GIScience; spatiotemporal modeling

1. Introduction

Settlements and anthropogenic changes to landscapes can be perceived as visible traces of human activities on the land surface. They have gradually evolved over long periods of time. The intensity and ever-growing speed of changes have become one of the drivers of the ecological crisis, in particular during the Anthropocene. Hence, over the past decades a substantial body of research has accumulated studying the spatiotemporal development of settlements and landscapes. However, there are persistent challenges that prevent the research community from developing and implementing quantitative geospatial approaches. These challenges range from identifying effective ways to process and convert analogous, non-geocoded and heterogeneous data sources to the methodological issues in automated information extraction for large-scale applications to the interpretation of often fuzzy and low-quality datasets. Some of these challenges and unresolved issues related to the geospatial analysis of historical settlements and landscapes are addressed in an open-access Special Issue, which is introduced by this editorial. The Special Issue was initiated in conjunction with the International Land Use Symposium [1] held in Dresden, Germany in 2017. The symposium addressed scholars from the fields of spatial sciences, information sciences, computer science, environmental studies, geography, cartography, history, urban planning and architecture. In thematic sessions, invited contributions focused on the theoretical foundations of land change science, ontologies, reviews of the field, methodical issues including algorithms for data acquisition for multi-temporal and multi-scale data

integration, for uncertainty estimation in spatiotemporal modeling as well as application-oriented issues comprising ecosystems services, urban sprawl, historical demography, digital humanities and visualization across different spatial and temporal scales. Selected contributions were invited to be submitted to this Special Issue entitled the 'Historical settlement and landscape analysis'. In the following, we introduce and comment on the included contributions to this exciting field of study and provide some context related to the analytical foundations underlying this research, the challenges arising from it and future directions.

2. Challenges and Contributions

Historical settlement and landscape analysis faces several methodological or data accessibility-related challenges. This Special Issue contains eight open-access research articles that address different aspects along the data processing and analysis chain. This involves approaches for (1) data exploration and the geocoding of historical data sources, (2) the acquisition and extraction of data from its sources, as well as (3) the adequate visualization and the appropriate application of the retrieved historical geoinformation. In the following, we provide a synopsis of the various scientific contributions in this Special Issue with a view at these different phases.

2.1. Data Exploration and Geocoding

As described above, historical maps are the most frequently used data source for historical settlement and landscape analyses. Given the increasing number of publicly available archives of scanned maps and the advancement in computational analysis methods, these valuable sources of historical geoinformation will become even more important in the future. Uhl et al. [2] present a set of methods for systematic data mining and content retrieval in large collections of historical topographic map archives. Basic information on spatiotemporal coverage, approximate map content and spatial accuracy of georeferenced map sheets at different map scales are crucial for understanding parametrization issues and potential challenges in automating the information extraction process. The authors argue that such preliminary analytical steps are often neglected in the map processing literature but represent critical phases that lay the foundation for any further analysis. Thus, the authors demonstrate how such preliminary analyses can be systematically conducted using traditional analytical and cartographic techniques, as well as visual-analytical data mining tools. Exemplified for the United States Geological Survey topographic map archive for the states of California and Colorado and the Sanborn fire insurance map collection maintained by the U.S. Library of Congress, the study shows the great potential of metadata-based and low-level content-based image analyses for the exploration of large map archives in order to provide guidance for the design of training data collection as well as select an adequate information extraction method.

Another challenge and preliminary step in the analysis of historical geoinformation is geocoding—the process of transforming relative spatial reference information into defined projections and thus to enable spatial analysis and cross-referencing based on maps. To facilitate this, Cura et al. [3] present a historical collaborative geocoding approach that explicitly deals with different characteristics of historical data including fuzzy dates, imprecision, sparseness and other uncertainty aspects. For this purpose, the authors develop a geocoding system based on a sound geohistorical object model which they tested on maps of the city of Paris for the 19th and 20th centuries. The approach consists of the following eight steps: scanning a historical map; geo-referencing the scans using hand-selected control points; estimating the temporal information and spatial accuracy of the map using historians' domain knowledge; extracting street names and axis geometry from the scan; extracting building numbers from the scan; generating missing building numbers; normalizing labels from historical maps; and creating geo-historical objects. As a result, a large percentage of addresses are geocoded in a relatively short time. In addition, several user interfaces are proposed for efficient geocoding and collaborative editing and for the

visualization of the results on current and historical maps. The authors state that the proposed geocoder can be transferred to other places, times and data types.

Another study maps anthropogenic landscape elements found outside the urban context. Chu et al. [4] present an approach to map historic coral walls formerly used as garden walls for planting on the Penghu Islands of the Taiwan Strait. These low walls were built to protect the agricultural fields from the strong winds. The detection approach is based on high-resolution Digital Elevation Models (DEM) generated using Light Detection and Ranging (LiDAR) Technology and is based on selected topographic parameters such as slope, curvature and openness. After applying classical filter techniques for edge detection, candidate line segments are extracted using Hough transformations. Subsequently, the line segments were assessed and low walls were detected via a decision tree algorithm, particularly the CART algorithm using topographic parameters. A comparison with reference data showed that the walls can be detected with an accuracy of 74%. Therefore, the automated approach presented offers an attractive option for mapping historical landscape elements. The authors argue that identifying historical features in general can be considered a crucial step in the preservation and restoration of historical property. They indicate that drone technology will play an increasingly important role in future work as it facilitates the generation of point clouds and the utilization of spectral information of acquired images.

2.2. Data Acquisition and Processing

Subsequent steps typically address the acquisition of historical data from the original data sources such as archival maps and its processing for various scientific domains. Kaim et al. [5] use archival maps of the 19th century to investigate the historical changes in the Wildland–Urban Interface (WUI), an area in which vegetation and built structures intermingle which has been described as a main cause and exposure hotspot for manifold environmental problems. The authors assess the change in the WUI in the Polish Carpathians between 1860 and 2013. The historical land use information was collected through on-screen digitization from the Austrian Second Military Survey maps (at a scale of 1:28,800), which are the generalized form of the cadastral mapping at a scale of 1:2880. The two study areas have very different land use histories. One experienced gradual forest increase and housing growth over time, while the second area was subject to a shock due to post-war resettlements, which triggered rapid reforestation. The findings show, that the WUI increased in both study areas (from 41 to 54% and from 12 to 33%, respectively), whereas the causes and processes of WUI growth were very different. While in one study area settlement development was the main driver of WUI increase over time, it was the forest regrowth in the other area. They also found that while the WUI was growing, the historically existing WUI in 1860 was relatively stable over time. In other words, most of the 1860 WUI was still WUI 150 years later, despite the substantial land use changes that took place in the region. This highlights the importance of historical land use legacies in the region on current land use patterns. Given the environmental problems associated with an increasing WUI and the fact that forest and settlement areas increase in many European mountain areas, the authors conclude that, especially in the context of climate change, there is a need for monitoring the WUI in other mountain ranges.

The contribution by Hecht et al. [6] explores whether and how accurately historical high-resolution patterns of population and dwelling density can be estimated automatically by analyzing multi-temporal geodata describing built environment morphology. Their approach uses current data on land use, 3D building stock data as well as historical land use information derived from topographic maps at a scale of 1:25,000 from multiple points in time. For the extraction of the building footprints, image processing methods such as segmentation and morphological filtering are used. Machine learning methods are utilized to identify the building types. In addition, for the large-scale mapping of dwellings and population, dasymetric refinement methods were applied using individual buildings as ancillary variables. The presented approach was tested on a study area in Germany consisting of 107 different municipalities. Historical population and settlement patterns

were generated for seven different points in time (every 10 years, from 1950 to 2010) at a spatial resolution of 100 m. A comparison of the estimates with current official data indicated some acceptable underestimation with increasing uncertainty the further back in time one goes. Nevertheless, the authors emphasize the added value and importance of the approach for various applied fields of inquiry.

2.3. Visualization and Application

The final phase along the data processing and analysis chain focuses on aspects related to the visualization and application of the retrieved spatiotemporal information in historical analyses. For example, the study by Schiewe [7] addresses the visual processing in historic settlement and landscape analysis. For this purpose, a typology of tasks that are frequently performed in connection with the analysis of urban or landscape changes was first developed. The article describes 13 different tasks, which can be assigned to three different output clauses: "What", "Where" and "When". For each of the tasks, recommendations for visualizations of changes between two points in time are presented and discussed. The author argues that these basic tasks can provide a valuable basis for more complex workflows in a visual analysis environment. After presenting the task-oriented visualization options, the author discusses the importance of appropriate preprocessing of the data with an emphasis on the preservation of spatial relationships. The author exemplifies the approach on a data classification approach prior to choropleth mapping which preserves the local extremes in the maps.

Bogucka and Jahnke [8] focus on change as an inherent feature of the landscape and compare spatiotemporal visualization techniques in terms of their ability to provide an adequate overview of dynamic interactions between tangible and intangible landscape elements. In particular, they are interested in assessing the feasibility of the space-time cube concept and slider-based visualizations in landscape representation. The Royal Castle in Warsaw is used as a case study for this analysis. The London Charter for the Computer-Based Visualization of Cultural Heritage is utilized as a relevant document to get a deeper understanding of user-centered design requirements. Benchmark tasks, feedback and eye tracking tests are applied to examine the suitability of different approaches for cultural heritage visualizations. Based on feedback from domain experts and participants, the space-time cube is identified as a promising technique for effective landscape visualization over a period of several hundred years. With regard to the form and color of landscape objects, they report that the users actually prefer more realistic textures on the buildings. According to the authors, further work is needed with regard to the implementation of other interactive functionalities that support the understanding of the contents of space-time cubes.

An interesting example for the application and practical value of historical geoinformation is described by Xie et al. [9]. In this study, the authors assess the impact of previous land use plans for providing evidence-based input for better informed impact assessment in future master planning in Shenzhen and other world cities, particularly in developing and emerging countries. The urban expansion in these regions has been accelerated during the last few decades. Therefore, the authors use satellite-based data products such as the Global Human Settlement Layer (GSHL), which provides multi-temporal data on built-up areas and population starting in 1975 with worldwide coverage. The study draws on the generic methods and procedures provided by the Impact Assessment Guidelines of the European Commission. The built-up intensity and population mapping using time-specific categorizations supplemented by the quantitative assessment of high urban concentrations (hUCs) that are based on time-specific thresholding allows the identification of settlement development patterns and a quantitative description of polycentricity over time. Given the worldwide coverage of the consistent dataset, the authors propose to test the methodology over larger geographic extents as well as conduct comparative studies in other regions of the world.

3. Conclusions

Approaches to the analysis of historical geoinformation offer unprecedented insights into the spatially explicit development of landscapes and human settlement patterns. With the increasing spatial and temporal scopes of studies, however, there are also new requirements and challenges. With the explosion of available historical geospatial data, previously underreported or even neglected pre-analysis steps such as data exploration and geocoding have evolved into a small research field of their own. This field has seen advances through the use of visual-analytical data mining techniques or collaborative methods such as crowdsourcing. Furthermore, with the increasing amount of large-scale heterogeneous data sources, there is a growing need for the automation of information extraction approaches. Another critical aspect is the explicit consideration and communication of the uncertainties inherent to historical data in a way that is common standard in different research areas. This affects and influences not only data visualization and spatiotemporal modeling, but also all subsequent applied research that uses the data. Given the environmental challenges we face at the global scale, both the need for long-term studies on land change within Earth system research and the current advancement in AI methods for the retrieval of historical geoinformation, in conjunction with an increasing number of accessible geo-coded documents, will further fuel this field of research. On behalf of all the authors who contributed to this Special Issue, we, as guest editors, hope to have raised awareness for this long-standing research and wish to encourage further efforts in this impactful field of study.

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