



Remote Sensing of the Interaction between Human and Natural Ecosystems in Asia

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Abstract: Human and natural ecosystems refer to human–social–economic subsystems and natural–ecological subsystems and their interactions. Understanding the interactions between human and natural ecosystems is essential for regional sustainability. However, the coupled human–nature ecosystem is usually highly heterogeneous and both spatially and temporally complex, so it is difficult to accurately identify and quantify the interaction between human and natural ecosystems at a large scale. This results in a poor understanding and evaluation of its impact on regional sustainability. Therefore, given the increasing interaction between humans and the natural ecosystem, our Special Issue collated 11 contributions from Asian scholars focusing on the latest research advances in remote sensing technologies and their application to observing, understanding, modeling, and explaining the interaction between human and natural ecosystems. This research involves the development of innovative methods, indicators, and frameworks implementing different perspectives and spatio-temporal scales, covering urban, arid, plateau, watershed, and marine regions in Asia and promoting the sustainable development of regional human and natural ecosystems.

Keywords: remote sensing; interaction; coupled human–nature ecosystem; data-driven; regional sustainability



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1. Introduction

As society and the economy rapidly develop, the interaction between human and natural ecosystems is becoming more intensive, forming a coupled human–nature ecosystem [1,2]. The coupled human–nature ecosystem comprises human–social–economic subsystems and natural–ecological subsystems and their interactions, in which there is complex coupling between the various elements [3]. Increasing human activities in this coupled ecosystem, such as urban expansion and landscape adjustments, afforestation, disafforestation, and irrigation, have largely changed regional ecological structures, processes, and functions, with these changes in turn affecting regional social–economic development. Understanding the interaction between human and natural ecosystems is therefore essential for regional sustainability [4]. Remote sensing can monitor ecosystems from the site scale (at 1 m²) to the global scale with a high level of spatial and temporal detail and provides efficient tools for studying ecosystem structures and dynamics, as well as carbon–water cycles [5–7]. However, unlike typical natural ecosystems, the coupled human–nature ecosystem is usually diverse in its spatial and temporal complexity. Thus, accurately analyzing the interaction between human and natural ecosystems at a large scale is difficult, hampering our understanding of its implications for regional sustainability. Given the increasing interaction between human and natural ecosystems, developing remote sensing techniques that provide useful and usable information for comprehending and managing the coupled human–natural ecosystem has become urgent.

This Special Issue, “Remote Sensing of Interaction between Human and Natural Ecosystem”, is demonstrative of the broad interest of scholars and readers in the research

topic of remote sensing, which received almost 20k views before April 2024. This Special Issue focuses on the latest research advances in remote sensing technologies and their application to studying the interaction between human and natural ecosystems. We looked at novel methodological approaches, frameworks, and indicators for mapping (1) human activities (i.e., urbanization, urban greening, and ecological engineering) and (2) their impacts on regional ecology, climate, water resources, and social–economic development. Having invited studies during 2022–2023, we published 11 papers from 62 authors from Asia in this Special Issue, with the study areas covering Zhejiang Province (contribution 1), the Qinghai–Tibet Plateau (contributions 2 and 4), Northwest China (contribution 3), Central Asia (contribution 5), the eastern part of the Hu Line in mainland China (contribution 6), the Loess Plateau (contribution 7), Shandong Province (contribution 8), Guangdong Province (contribution 9 and 11), and the Middle and Lower Reaches of the Yellow River (contribution 10). These examples pertain to the current progress and discoveries in research on “the structural and spatio-temporal evolution of the built environment and urban–ecosystem coupling and coordination under urbanization” (4), “the terrestrial ecosystem, human disturbance, vegetation activities, and regional ecological patterns” (3), “the mechanisms of the interaction of the ecosystem, human health, and climate change” (2), and “human–marine interaction, marine monitoring, intelligent image recognition, and emergency response” (2). In the following section, we have summarized the key contributions of this Special Issue, concluding with future research directions.

2. Contributions and Highlights of the Special Issue

2.1. *The Structural and Spatio-Temporal Evolution of the Built Environment and Urban–Ecosystem Coupling and Coordination under Urbanization*

Urbanization is a dynamic process through which the population continues to accumulate and rise in cities compared to in rural areas, reshaping both production and living spaces [8]. The structural and spatio-temporal evolution of the urban built environment is an embodiment of human society’s modernization and also reflective of regional development levels [9,10]. In previous research, socio-economic statistical data and medium- to high-resolution remote sensing data have been the main data sources for quantitative analysis of urbanization [11]. However, high-precision and high-resolution remotely sensed social data and relevant vector data are still lacking, and undoubtedly, accurately mapping the urban built environment is essential for monitoring urbanization and ecosystem research. In light of this, Xu et al. (contribution 9) used Landsat images combined with phenology, deep learning algorithms, and Google Earth Engine (GEE) to improve the Res-UNet++ structural model for mapping built-up land in Guangdong from 1991 to 2020, eventually developing a framework of remote sensing classification techniques using large-scale, extended time-series data. Compared with traditional statistical data and remote sensing data, night-time light data offer strong spatio-temporal continuity, wide spatial coverage, and high socio-economic correlation [12,13], permitting their use to extract the scope of development in cities, analyze their spatial aggregation [14], and measure urbanization levels [15]. For example, Fu et al. (contribution 1) analyzed the spatio-temporal evolution of urban–rural fringes and measured their correlation based on night-time light data. In doing so, they quantitatively confirmed the tendency for fringe areas to be expanded in small to medium-sized cities, elucidated the sway of time–cost distance and land resources in development, and provided a quantitative foundation for urban spatial planning and future regional development. Xie et al. (contribution 6) used night-time light data and railway data to perform structural identification in urban agglomeration, which had a higher accuracy rate than using a single data source. Coordinating the relationship between urban spaces–the ecosystem is not only a pragmatic imperative in further urbanization but also a pivotal pillar supporting urban spatial restructuring and the pursuit of green, low-carbon transformations [16]. Li et al. (contribution 4) emphasize that understanding the relationship between urbanization and the ecological environment is the basis for realizing regional sustainable development, taking Aba Autonomous Prefecture

in the eastern Qinghai–Tibet Plateau as a case study and exploring this relationship from 2001 to 2018 using a model of the degree of coordination, which is profoundly impactful for high-quality development in ecologically fragile areas.

2.2. The Terrestrial Ecosystem, Human Disturbance, Vegetation Activities, and Regional Ecological Patterns

Vegetation is a primary component of the terrestrial ecosystem and an important link connecting the atmosphere, the soil, the biosphere, and the hydrosphere [17], playing a key role in regulating climate, conserving water and soil, purifying the environment, maintaining biodiversity, and controlling the global carbon and nitrogen cycle [18]. However, human activities have greatly disturbed regional ecological patterns and the sustainable development of terrestrial ecosystems, including vegetation dynamics, since the Industrial Revolution. Guo et al. (contribution 2) took the G318 highway as a case study to analyze the compound effects of highway reconstruction and climate change on vegetation activity across the Qinghai–Tibet Plateau. Tu et al. (contribution 3) analyzed the effects of land cover changes on vegetation carbon sources/sinks in arid terrestrial ecosystems in Northwest China from 2001 to 2018, finding that cropland expansion and anthropogenic management dominated in the growth of carbon sequestration using vegetation in this area and that afforestation also improved the carbon sink capacity of terrestrial ecosystems. Indeed, accelerating the construction of ecological security networks in ecologically fragile areas is an urgent matter. Therefore, Wei et al. (contribution 7) proposed an ecological security pattern optimization scheme for the Loess Plateau in China and provided a frame for constructing an ecological security network and optimizing ecological space in the ecologically fragile areas of western China. Evidently, we also came across certain research topics that have not yet been studied, with, for example, small-scale natural rural ecosystems often overlooked by researchers. These micro geographical–economic–social–industrial systems under the rural ecosystem are subject to the influence of the regional geographical environment and human activity, and the spatio-temporal structure may introduce multiple uncertainties. Thus, human–Earth system resources should increasingly be integrated to alleviate the pressure on rural ecological environments, realize the diversified added value of rural resources, and enhance the vitality of rural habitats. In the future, integrating and building typical spatial models of the resource metabolism of rural systems using multi-source data information, such as remote sensing technology, geographic information data, and socio-economic data, will become a cutting-edge development direction in this field.

2.3. Interactions between the Ecosystem, Human Health, and Climate Change

Global climate change and environmental pollution have become pressing challenges in our society [19], with a continual need to improve our ability to measure and monitor these changes and assess the effectiveness of mitigation and adaptation measures. One specific perspective under this subtopic is the change in evapotranspiration (ET) in arid areas under global climate change. For example, in the arid areas of Central Asia, ET not only affects the dry and wet conditions but also profoundly influences society, the economy, and ecosystems. In order to understand the changing trends in and driving factors of evapotranspiration in Central Asia, Hao et al. (contribution 5) used estimated ET data and reanalysis to investigate spatio-temporal patterns. The goal of this research was to provide scientific support for the restoration of water resources and the evaluation of the sustainability of existing water resources, impacting government decision-making intentions and processes and their efficiency. Air pollution is another key consideration. Climate change affects the formation, transport, and removal of various air pollutants by changing meteorological conditions, thereby affecting both small-scale and global air quality [20,21] and thus influencing the atmospheric ecosystem and even human health. Air pollution is now the fourth major risk factor seriously affecting human health and sustainable development [22]. Thus, the threat of air pollutants to human health cannot be ignored. Zhao et al. (contribution 10) analyze the spatio-temporal distribution of and the

key factors influencing PM_{2.5} concentrations in the Yellow River Basin, imparting findings which policymakers can use to formulate policies to alleviate haze pollution. Undoubtedly, there are related research directions that have not been fully explored, which needs to be rectified. We expect that the discipline of remote sensing will be further integrated with research pertaining to “the mechanisms of the interaction of the ecosystem, human health, and climate change under the atmospheric environment” in the future. The continuous advancement of research relevant to the ecological development of civilization provides new possibilities to re-observe and better understand these mechanisms of interaction and gradually make our ecological environment healthier, cleaner, and more livable.

2.4. Human–Marine Interaction, Marine Monitoring, Intelligent Image Recognition, and Emergency Response

Studying marine remote sensing and the associated systems implicates marine resource sustainability and health conditions, marine development and protection, smart marine construction, the impacts of economic globalization and human activities on the sustainable use of marine resources, the environmental vulnerability of islands and coastal zones, and other practical issues [23–26]. Under this research theme, our Special Issue has attracted several valuable contributions concerning human–marine interactions, marine monitoring, intelligent image recognition, and emergency response. Human–marine relationships refer to interactions between human activities and the ocean (i.e., resources, the environment, disasters, and other structural elements) [27]. One of the most important aspects of this field is the quantitative evaluation of reclamation intensity based on regional planning theory and human–marine coordination. Liu et al. (contribution 8) took land reclamation using infilling in Shandong Province as an example, proposed a quantitative evaluation index system to effectively assess the intensity of reclamation activity (RAI), identified the spatio-temporal characteristics of the reclamation intensity, and determined the management priorities. This provided a theoretical basis for regional reclamation management and coastal environmental protection and management. Using radar remote sensing to monitor and identify maritime activities is an important technical method to ensure China’s further progress towards maritime power, which involves steadily promoting the acquisition of high-quality remote sensing images and the development of high-speed and high-precision processing technologies for remote sensing image capture [28]. Thus, Li et al. (contribution 11) proposed a marine oil spill detection scheme based on X-band shipborne radar images with machine learning, which showed improved intelligence over past methods and provided data support for marine oil spill emergency responses.

3. Summary and Future Directions

Under this Special Issue, these 11 bodies of work contribute at different temporal and spatial levels, spanning urban, arid, plateau, watershed, and marine regions. However, we must add that there are still several challenges emerging from the contributions to this Special Issue for future research to address.

In the foreseeable future, global climate change and sustainable development will remain as two central themes for our planet, with structural analysis, process interpretation, and trend forecasting of the relationship between humans and natural systems as the bases of their scientific study. Within the domain of information technology, particularly AI technology, remote sensing has become increasingly vital, encompassing not only geographic remote sensing based on satellite or aerial imagery but also remote social sensing, which includes mobile communication data and other societal aspects. This expansion has ushered remote sensing technology and applications into a new phase, characterized by both technological drive and ethical and legal considerations and constraints, such as data protection. Simultaneously, environmental ecosystems are facing impacts of climate change, especially extreme weather events, that have only amplified over time. These impacts manifest as disasters in some regions, while potentially bringing improved precipitation conditions and ecological system enhancements in others. Nevertheless, regardless of the

scenario, comprehensive research on human–natural system interactions, based on remote sensing or driven by remote sensing technology, remains key to scientific exploration in the near future. As applies to this Special Issue, we believe there are still numerous research topics that require further exploration. It is imperative to organize and mobilize scientists and researchers from relevant disciplines more extensively to continue in-depth investigations into the following themes:

The Integration and Application of Multi-Source Data: Incorporating diverse data sources such as satellite imagery, aerial photography, LiDAR data, and ground-based sensors can provide a more comprehensive understanding of human–natural ecosystem interactions. Future research could focus on developing advanced methodologies for integrating and analyzing these multi-source datasets. We need to strengthen the data and methodological research, optimizing remote sensing data processing methodology, creating novel types of remote sensing data, improving the resolution of remote sensing observation, and fully tapping into the information on human–natural relationships.

Machine Learning and AI Applications: Leveraging machine learning and artificial intelligence techniques for feature extraction, classification, and pattern recognition in remote sensing data will enhance our ability to detect and monitor–natural ecosystem interactions. Future research may explore the development of novel algorithms and models tailored to specific types of interaction.

High-Resolution Mapping: Advancements in sensor technology are continually improving the spatial and spectral resolution of remote sensing data. Future research could focus on exploiting high-resolution imaging capabilities to detect subtle changes in natural ecosystems caused by human activities, such as deforestation, urbanization, and land degradation. In particular, we need to strengthen the investigation of human–nature interactions and relationships at the small scale, such as in villages or even courtyards, creating more accurate remote sensing datasets and establishing multi-scale analysis systems for different temporal and spatial scales, to diversify and innovate within the research on human and natural ecosystems.

Long-Term Monitoring, Observation, and Analysis: Long-term monitoring of human–natural ecosystem interactions is crucial for understanding dynamic processes and trends. Future research may involve developing techniques for long-term analysis of remote sensing data to track changes over time and assess the impacts of human activities on natural ecosystems. Here, the most urgent consideration is promoting international networking and local observation stations, particularly in the fields of social-related remote sensing, for example, mobility within cities, local economic activities, and local cultural effects on development.

Interdisciplinary Approaches and Uncertainty Assessments: Collaboration between remote sensing scientists, ecologists, social scientists, and policymakers can facilitate a more holistic understanding of human–natural ecosystem interactions. Future research may focus on interdisciplinary approaches that combine remote sensing data with socio-economic data and stakeholder engagement to inform decision-making and sustainable management practices. Ensuring the accuracy and reliability of remote sensing-based assessments of human–natural ecosystem interactions is essential. Future research could focus on improving validation techniques and uncertainty quantification methods to enhance the robustness of remote sensing-derived information for decision support and policy formulation.

The Construction of a Multi-Objective Digital Base: Future research should consolidate comprehensive knowledge on geography, remote sensing, artificial intelligence and social and economic factors, constructing a multi-objective chain of data acquisition, information processing, knowledge generation, and intelligent applications to apply basic human–natural ecosystem monitoring. As a result, verification of the accessibility and reliability of information on human–land relationships can be supported by a solid digital base. It is expected that digital bases related to other fields, such as energy security, resource metabolism, and urban construction, will be constructed to provide higher-quality spatio-temporal information, support higher-level spatio-temporal analysis and thematic applications, and enable high-quality development in a range of industries.

Last but not least, international cooperation must be strengthened and global case studies encouraged. The majority of the studies in this Special Issue have been conducted in China, indicating the popularity of this topic in this region, but globalized perspective and actions are also vital future directions to establish broader academic cooperation and accelerate innovation and development in this field.

In addressing these research directions, actors can work together to advance our understanding of the complex interactions between human activities and natural ecosystems, ultimately contributing to more effective environmental management and conservation efforts.

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