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Sustainability of the use of natural capital in a city: Measuring the size and depth of urban ecological and water footprints

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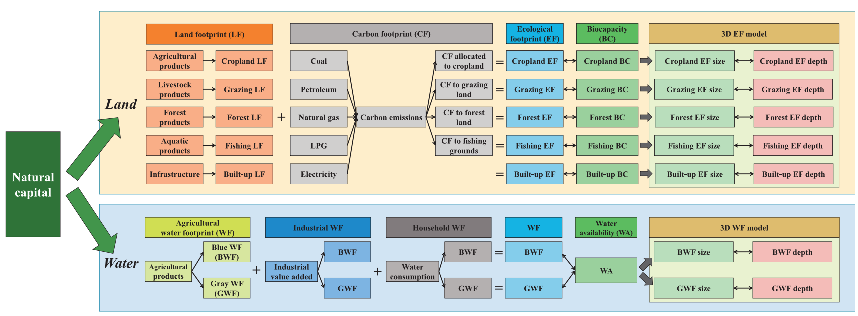
HIGHLIGHTS

- New model is to track the structural and characteristic dynamics of natural capital.
- The use of water and land as critical natural capital was investigated for Guiyang.
- The city has long been operating in a state of overshoot particularly for land use.
- Industrial use replaced agriculture as main driver of city's water unsustainability.
- Economic growth did not show signs of decoupling from land and water use.

GRAPHICAL ABSTRACT



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ABSTRACT

The Sustainable Development Goals (SDGs) are limited in their ability to measure progress towards environmental sustainability especially at the city level. The aim of this paper is to provide insights into an integrated assessment of urban sustainability, with emphasis on the significance of the maintenance of natural capital stocks. The use of water and land as critical natural capital in Guiyang, a southeast city in China was investigated by bringing together the ecological footprint (EF), water footprint (WF) and corresponding capacity indicators into an improved three-dimensional (i3D) model. Results showed that Guiyang has long been operating in a state of overshoot due to shortage of annual natural capital flows and accumulated depletion of stocks. This is particularly true for land use, whose stocks maintained a relatively stable level of depletion between 2000 and 2014. As of 2014, an EF depth of 6.45 was accumulated. With respect to water use, a shift in the city's role from creditor to debtor was observed in 2004. Industrial use of natural capital has more than tripled over the past 15 years and replaced agriculture to be the main driver of water unsustainability. Overall, Guiyang's economic growth did not show signs of decoupling from the EF and WF. These findings highlight the need for effective policies that would help Guiyang reduce dependency on the use of critical natural capital. Finally, this paper provided an in-depth discussion of the methodological strengths and limitations of the i3D model and concluded that it is able to track the structural and characteristic dynamics of both flows and stocks while avoiding burden shifting across various components within single forms of natural capital from a strong sustainability perspective. Our study enhances understanding of the critical role of natural capital in ensuring urban sustainability and improving human welfare in connection with SDGs.

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1. Introduction

The Sustainable Development Goals (SDGs) proposed by the United Nations (UN, 2015) include a suite of quantitative targets and indicators for the UN 2030 Agenda. Despite the considerable attention received worldwide, the SDGs have been criticized for their limited capacity to support measurement of genuine progress towards the goals, particularly at sub-national levels (Costanza et al., 2016; Reyers et al., 2017). This highlights the need for well-formulated metrics that could help policymakers better understand the progress on sustainable development regionally and locally. Footprints that have been broadly used to measure the three pillars of sustainability provide an interesting tool for studies on SDGs monitoring (Fang et al., 2016). For instance, Hoekstra et al. (2017) explicitly demonstrated how the water footprint can be instrumental in monitoring the progress towards SDG 6. Xiao et al. (2017) revealed the potential of various social footprints in achieving the SDGs 3, 5 and 16.

As the world's second-largest economy, China has been playing a key role in a globalized context. China's national plan on implementation of the 2030 Agenda for sustainable development has formulated a set of policies to embrace economically, socially and environmentally sustainable development. However, the relatively poor performance on environmental sustainability has posed a major barrier to China's sustainable development (Hirsh, 2014). In striving to promote environmental quality and resource efficiency, China has already launched concrete national strategies since the 2000s, such as “circular economy pilots”, “eco-cities”, and “low-carbon cities” projects (Yang and Li, 2013), with the aim of speeding up societal transition towards environmental sustainability, particularly at the city level.

Guiyang is the capital of Guizhou Province (Fig. 1) and one of the few Chinese cities that have been officially labeled with circular economy pilot, eco-city and low-carbon city concurrently, in which the Eco Forum Global Annual Conference has been successfully held since 2009. Our previous research indicated that, with the implementation of sustainable development strategies, a decoupling between economic growth and carbon emissions was somehow witnessed in Guiyang (Fang et al., 2017). This, however, does not necessarily imply a preferable urban transition, as the sole estimation of carbon emissions has proved insufficient in informing policymakers of the performance on environmental sustainability (Kalbar et al., 2017; Laurent et al., 2012). Overall, Guiyang's environmental sustainability performance remains largely unexplored, making it difficult to downscale SDGs to the local area where problem-driven policy actions most commonly occur.

It has been internationally acknowledged that the maintenance of critical natural capital is essential for environmental sustainability (Ekins et al., 2003; Pelenc and Ballet, 2015). Critical natural capital can be defined as stocks of natural resources or environmental assets (e.g., land, water, atmosphere, ecosystems) which provide human society with flows of goods and services that are indispensable and cannot be substituted by other forms of natural or other capital (De Groot et al., 2003; Ekins et al., 2003). As a result, it is necessary to identify undesirable environmental challenges for prioritization with a consideration of natural capital. Given the karst geology of Guiyang threatened with heavy soil erosion and rocky desertification (Yuan, 1988), land and water—the two forms of critical natural capital, are likely to be the limiting factors for environmental sustainability of the city. This brings the ecological footprint and water footprint into focus, as they are found to be complementary in assessing the sustainability of use of natural capital in terms of land and water (Hoekstra, 2009).

The ecological footprint (EF) is normally defined as a measure of biologically productive land area required to produce biotic resources (e.g., food, timber) that humanity consumes and to neutralize carbon emissions that humanity emits. It aggregates human demand for a variety of land use types (including cropland, grazing land, forest land, fishing grounds, built-up land and carbon uptake land) into a single composite indicator (Wackernagel and Rees, 1997). In this paper, the first five components are referred to as land footprint (LF), and the last one is referred to as carbon footprint (CF), which differs in nature from the classical CF expressed in a CO_2-equivalent mass unit. These so-called LF and CF look at some crucial effects of anthropogenic interference with the planet's environment from two distinct perspectives, by summing them up many highly heterogeneous components are combined in order to constitute an overall estimate of EF (Hoekstra, 2009; Kitzes and Wackernagel, 2009). The EF is further compared with the available supply of these land use types, namely biocapacity (BC) (Borucke et al., 2013). The difference between EF and BC reflects a form of sustainability gap denoting the extent to which a population is approaching or exceeding the regenerative capacity of the biosphere. Although focusing on one main aspect of environmental sustainability by design, the ecological footprint analysis (EFA) has reached great popularity among science, policy, and in the media over the last decade as an informative sustainability metric and its applications have been extended to different scales ranging from the global to products and the individual (Herva et al., 2012; Wiedmann and Barrett, 2010). The prominent virtues of the EFA line in its conceptual clarity, methodological simplicity, and global comparability of analytical results. Recently, the

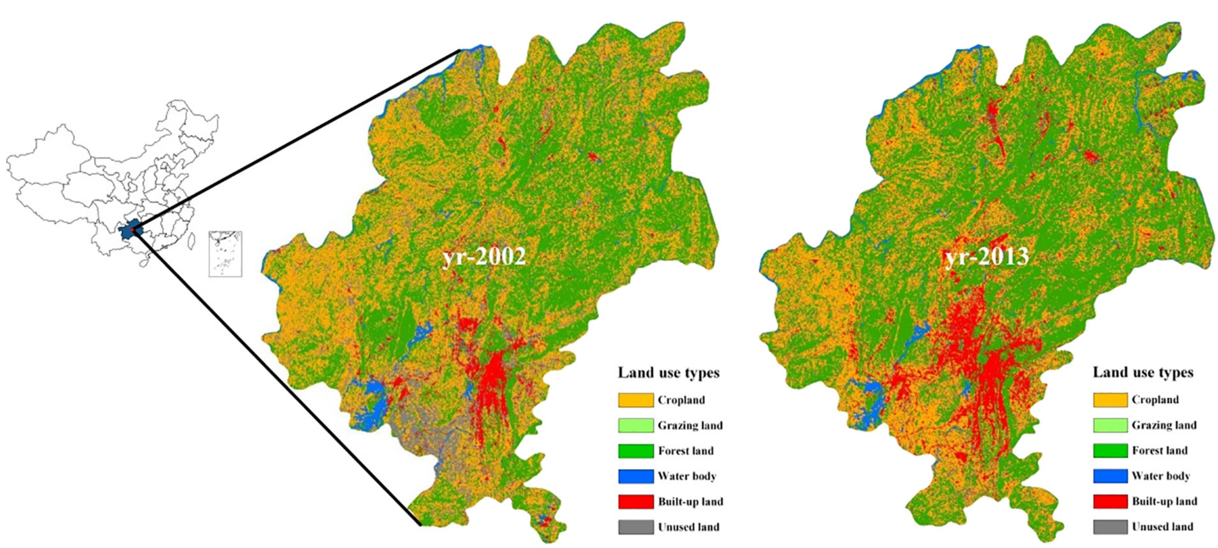

Fig. 1. Location and land use change in Guiyang.