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Invited review

Global synthesis of the classifications, distributions, benefits and issues of terracing

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ABSTRACT

For thousands of years, humans have created different types of terraces in different sloping conditions, meant to mitigate flood risks, reduce soil erosion and conserve water. These anthropogenic landscapes can be found in tropical and subtropical rainforests, deserts, and arid and semiarid mountains across the globe. Despite the long history, the roles of and the mechanisms by which terracing improves ecosystem services (ESs) remain poorly understood. Using literature synthesis and quantitative analysis, the worldwide types, distributions, major benefits and issues of terracing are presented in this review. A key terracing indicator, defined as the ratio of different ESs under terraced and non-terraced slopes (δ), was used to quantify the role of terracing in providing ESs. Our results indicated that ESs provided by terracing was generally positive because the mean values of δ were mostly greater than one. The most prominent role of terracing was found in erosion control (11.46 ± 2.34), followed by runoff reduction (2.60 ± 1.79), biomass accumulation (1.94 ± 0.59), soil water recharge (1.20 ± 0.23), and nutrient enhancement (1.20 ± 0.48). Terracing, to a lesser extent, could also enhance the survival rates of plant seedlings, promote ecosystem restoration, and increase crop yields. While slopes experiencing severe human disturbance (e.g., overgrazing and deforestation) can generally become more stable after terracing, negative effects of terracing may occur in poorly-designed or poorly-managed terraces. Among the reasons are the lack of environmental legislation, changes in traditional concepts and lifestyles of local people, as well as price decreases for agricultural products. All of these can accelerate terrace abandonment and degradation. In light of these findings, possible solutions regarding socio-economic changes and techniques to improve already degraded terraces are discussed.

Contents

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1. Introduction

Terraces are considered as one of the most evident anthropogenic imprints on the landscape, covering a considerable part of terrestrial landscapes (Krahtopoulou and Frederick, 2008; Tarolli et al., 2014). Generally, this human-created landscape is more ubiquitous on hillslopes and other mountainous regions, although it is used extensively across diverse landscapes such as in areas where severe drought, water erosion, mass movement and landslides from steep slopes threaten the security of land productivity, the local environment and human infrastructure (Lasanta et al., 2001). Terraced slopes even became the ideal sites for early human settlement and agricultural activities (Stanchi et al., 2012), with ancient agricultural terraces (e.g., in the central Negev highlands) serving as pronounced evidences of ancient human history, diverse cultures and civilizations (Pietsch and Mabit, 2012; Calderon et al., 2015).

Terracing, referred to as horizontal human-made spaces created to permit or facilitate cultivation on sloping terrains such as on hills and mountains (Petanidou et al., 2008), has been practiced as a key management strategy to minimize climate or human-induced disasters in those fragile landscapes (Chen et al., 2007; Andrew and James, 2011; Li et al., 2014). Since terraces reduce slope steepness by dividing them into short gentle sections (Morgan and Condon, 1986; Van Dijk and Bruijnzeel, 2004; Li et al., 2014), they strongly affect soil hydrology, vegetation growth and biogeochemical cycles (Moser et al., 2009). Terracing has been used to conserve water, alleviate flooding risks, reduce erosion, expand high-quality croplands and restore degraded habitats (Van Dijk and Bruijnzeel, 2004; Bruins, 2012). More recently, this practice has been found to improve other ecosystem services (ESs), such as carbon sequestration, food security as well as recreation (Ore and Bruins, 2012; Garcia-Franco et al., 2014).

Despite its long history, the fundamental roles and mechanisms of terracing on improving ESs and preventing land-degradation remain poorly understood (Frei et al., 2010; Li et al., 2014). At the same time, the specific size, appearance, choice of construction material (i.e., earth, stone or brick), age, land use/vegetation cover, and spatiotemporal distribution of terracing may differ across various ecosystems, resulting in the variability of ESs provided by terracing. In other words, the effects of terracing on ecosystems and human welfare can become very complex, particularly when different plant species, land uses, topographies, field treatments, and cultures are involved (Hill and Peart, 1998; He et al., 2009). Issues and problems regarding terracing (from design, construction, maintenance cost, to the actual outputs including ESs) also remain, highlighting the need for additional research. So far there has been no systematic synthesis regarding worldwide distribution of terracing and associated ESs with specific types of terracing. By developing a simple key indicator, utilizing data synthesis from the literature and quantitative analysis approaches, we summarize and discuss the multiple effects of terracing practices on ESs and human welfare. The major benefits of terracing to ESs are classified and examined, and problems regarding terracing are also discussed, highlighting the major directions for future efforts.

2. Data sources and analytical methods

2.1. Literature review and terrace mapping

In this study, three key words (i.e., land terracing, terracing, and terrace) were used to search the existing literature from two sources: Web of Science and Google Scholar. The latter served as a supplemental tool to elicit more information. We only recorded research articles that focused on man-made terraces while articles focusing on terraced landscapes formed by non-human forces (e.g., geological terraces) were removed from the database. Therefore, out of 437 articles found during our initial search, we used a final number of 300 publications to generate the geographical distribution of global terrace practice (Fig. 1). We specifically selected ancient terraces that appeared in the World Heritage List and some other historical terraces recorded in the literature to highlight their significance on human history and to distinguish them from modern terraces (Table 1).

2.2. Data extraction and indicator determination

Quantitative studies regarding each of our selected ecosystem services (ESs) associated with terracing were based on 300 selected publications. A key indicator (δ), defined as the ratio of different ESs under terraced and non-terraced slopes, was used to quantify terracing benefits. Non-terraced slopes were considered as controls, and from this point on, they will be referred to as "slopes". A δ value of 1 (i.e., no difference between terraces and slopes) is used as the threshold to distinguish the impact of terracing. If the δ value is >1, terracing is considered to play a positive role. On the other hand, if the δ value is lower than 1, it is considered that terracing produces a negative impact. Scattered and frequency-distribution diagrams were then generated based on the values of δ for each ES. Similarly, the causes responsible for negative values were classified and plotted using bar chart and pie mapping methods based on the number of negative reports.

There were four major aspects of ESs that were characterized based on the aforementioned key indicator: (i) runoff reduction and water conservation parameters (e.g., runoff depth, runoff coefficient, soil moisture content, and water holding capacity), (ii) erosion and sediment yield (e.g., soil loss depth, erosion modulus, and sediment yield), (iii) soil nutrient variables (e.g., total N, total K, total P, available P, available K, NH_4, and organic matter), and (iv) carbon sequestration, biomass accumulation and agricultural production (e.g., plant survival rates, tree/crop height, DBH, crop yield, crop evapotranspiration, total plant dry matter, plant branch length, number of branches, canopy diameter, and aboveground or belowground biomass). While we also recorded soil physical parameters such as bulk density, pH, and porosity as proxies to soil health, we did not differentiate between different types of terraces because many of them play similar roles in providing ecosystem services. All of these data were classified according to each of the above-mentioned ESs and calculated using the following equations to examine the benefits of terracing:

$$\delta_{rr} = 1/\left[{}^{Rf_t}\Big/_{Rf_s}\right], \quad (1)$$