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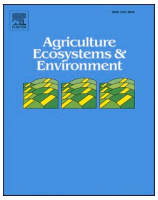

Karst ecosystem and environment: Characteristics, evolution processes, and sustainable development

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ABSTRACT

The studies in this Special Issue addressed environmental and ecological issues at the karst areas in the Southwest China. The contributions from these studies indicated that some active agricultural practices that were carried out in recent years reduced environmental risk and increased economic benefits at the karst areas. The results of ecosystem service value estimates in recent years showed improvements of ecosystem and environment in karst areas of China. Local farmers and government have realized the importance of protection of environment and ecosystem than before, which might promote to seek sustainable development goal in future. These studies have delivered new knowledgement that addressed the challenges of facilitating environmental sustainability with agricultural development in the karst region of South China. Meanwhile, further research should deepen science advances to improve the resilience of soil and water resources to agricultural practices in the fragile karst ecosystem.

1. Introduction

Karst areas are globally distributed and occupy about 15 % of Earth's surface, providing drinking water for more than 20 % of the world's population (Ford and Williams, 2007). The fragile eco-environment and the rapid water flow in the karst areas pose many challenges for the protection and management of environments in karst regions. Biogeochemical processes in karst ecosystems are both temporally and spatially heterogeneous (Liu, 2009; Brinkmann and Parise, 2012). Quantifying the amount of materials and contaminants delivered to aquatic environments is particularly challenging due to the considerable variability in factors that affect their mobility and transport processes.

The continuous outcrop of carbonate rocks in Southeast Asia is the largest karst area in the world, which has ecological environments with exceptional vulnerability to human activities (Liu, 2009; Jiang et al., 2014). The karst region of Southwest China provides a variety of ecosystem services, such as water supply, biomass production, land cover, soil erosion prevention, regulations of nutrient cycles and hydrologic functions, and carbon sequestration (Liu, 2007; Xu and Liu, 2017; Jiang et al., 2020). The continuous karst area in Southwest China is located in the center of the Southeast Asian Karst Region, with an area of approximately 5.5×10^5 km^2 and high population density above 100 persons per square kilometer. Agriculture is a major driving force to soil and nutrient loss, together with runoff and infiltration of pollutants affecting the water quality in the karst environment (Liu, 2007; Fleury, 2009; Li et al., 2020b). Therefore, the environment and ecology in the karst mountainous area were significantly impacted by subsistence-agriculture existing over thin soils developed in the terraced gentle hillslopes and valley floors.

In this Special Issue, scientists plan to share their innovative ideas from experimental and observational perspectives across field, catchment, and landscape levels in the karst system. This Special Issue mainly addresses the environmental quality of soil and water as well as the agroecosystem functions in the karst area of Southwest China. The major focuses of the Special Issue include: 1) soil loss and change of soil quality in the karst ecosystem and environment, 2) the variabilities of water quality and biological processes driven by natural factors and human activities, and 3) assessments of agroecosystem functions and strategies of sustainable development in the karst region of Southwest China.

2. Soil loss processes in the karst environment

Karst rocky desertification is a severe problem in southwestern China, showing a desert-like landscape with large soil loss and high ratio

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of exposure of bare rocks (Wang et al., 2004; Liu, 2009). Heavy soil erosion from the fragile and thin soil layer in the karst area is one of the most serious environmental problems, which is likely to destabilise the karst ecosystems. Therefore, it is necessary to understand soil loss processes and its evolutionary history as well as change of soil quality for sustainable development in the fragile karst system.

Three studies focus on soil loss caused by agricultural activities in the karst mountainous area, Southwest China. Cao et al. (2020a) performed an analysis of soil erosion and sedimentation processes based on ^{137}Cs and other fingerprint techniques in a small karst watershed. The historical records suggested that soil erosion was extremely sensitive to agricultural activities and land use change. Meanwhile, it was proved by another study, showing that the distribution pattern of soil erosion was dominated by agricultural activities in the karst watershed (Cao et al., 2020b). They found the extent of soil loss decreased with vegetation restoration based on approximately ten years of monitoring in six plots with different vegetation covers.

It is challenging to estimate the processes and calculate the rate of soil loss in the karst zone. Soil loss was impacted by karst landforms with various features, such as steep slope, grike, depression, and underground cave and conduit systems. Heavy and moderate rainfall events could cause most of soil loss through surface runoff generation. Meanwhile, underground river could contribute 19.7 % of the annual sediment flux in the monitored karst watershed (Cao et al., 2020b). The ^{137}Cs records and stable carbon isotope of soil in the grikes suggested that the underground soil loss via the tapering grikes played an important role in the process of karst rocky desertification, contributing a lot to the overlying soil loss (Feng et al., 2020).

The change of soil quality and loss under various human disturbance in the fragile karst environment could be determined by geochemical tools. Liu et al. (2020) showed that soil organic carbon (SOC) storage was slowly restored and soil aggregation was rapidly recovered in 3–8 years at an agricultural abandoned land according to vertical δ^{13}C values and concentrations of SOC. Soil and related nutrients could easily flush away from the fragile and thin soil layer, which is detrimental to the stability of karst ecosystems. Elements and related ratios in the karst lake sediments reflected that high levels of agricultural nitrogen and phosphorous led to water quality deterioration during periods with high human activities and poor water-soil conservation measures (Chen et al., 2020). These results could help to improve soil protection and evaluate the effectiveness of various afforestation strategies under land use change in mountainous area, Southwest China.

3. Nutrient loss affected by agricultural activities in the karst environment

Karst landform is characterized by dissolution-generated conduits that would transport a lot of materials following soil erosion together with runoff and infiltration of pollutants (Liu, 2007; Fleury, 2009; Xu and Liu, 2017). Agriculture is a significant source of water pollution, such as fertilizer, pesticide, herbicide, and other pollutants, due to rapid transport of water in the fragile karst environment. Meanwhile, heavy nutrient loss would lead to low productivities of natural and agricultural ecosystems (Liu, 2009; Jiang et al., 2020; Li et al., 2020b). Characterizing nutrient distributions and movements in different waters reveals nutrient loss processes that helps evaluate water quality changes.

Chemistry and isotope of solutes in rainwater could provide source information that is further constrained by natural materials and agricultural releasing. Two studies showed water chemistry and stable isotopic compositions of materials in rainwater in a karst agricultural area and a typical karst virgin forest site, respectively (Zeng et al., 2020a, 2020b). The results suggested water chemistry was significantly impacted by agricultural sources due to high nitrogen detection in the rainwater, including water samples collected from the karst virgin forest. Meanwhile, the agricultural sources of dissolved loads in rainwater were evaluated by a mixing model based on stable Ca isotopes and nitrate isotopes, showing relative high contributions of agricultural activities for solutes of rainwater in summer.

Excessive fertilization would result in large export of nutrient from agricultural lands to rivers (Li et al., 2020a, Li et al., 2020b). It was found high rainfall events would cause rapid transport of large nutrients to drainage systems in karst terrain (Wang et al., 2020a). δ^{15}N and δ^{18}O values of nitrate suggested high proportions of nitrate following rain derived from chemical fertilizers. Meanwhile, the agricultural dry land on the hillside supplies a large applied nitrogen and phosphorous fertilizers transport during rainfall events, which is also demonstrated by Li et al., 2020a. The study reported that seasonal changes of particulate nutrient exports from intensive sugarcane growing catchments were dominated by summer surface runoff in southern subtropical China. Another study suggested that the flux of nutrients exports by runoff were mainly controlled by time and pattern of fertilization as well as ground cover (Li et al., 2020c). These studies suggested managing fertilization use was necessary to reduce nutrient losses in the fragile karst environment.

A lot of nitrogen and phosphorous in rivers transported into lakes and reservoirs would lead to eutrophication and water degradation. Jin et al. (2020) showed high contributions of manure and chemical fertilizers to nitrate in a small watershed based on a bayesian model with dual isotopes of nitrate, posing a potential threat to the water quality in the reservoir nearby. Meanwhile, anthropogenic inputs would enhance the biogeochemical processes in the reservoirs due to algae growth and thermal stratification (Yang et al., 2020). Thus, amending soil in the zones of lakeside and shore of reservoirs was proved to be an effective measure for simultaneous removal of ammonium and phosphate from agricultural runoff in the karst area, Southern China (Wang et al., 2020b). The measure of construction of buffer zones in lake or reservoir could be an important basis to reduce agricultural non-point source transporting into water bodies.

Land use/cover changes caused by human activities in the karst region would change water quality and carbon biogeochemical cycling (Liu, 2009; Tong et al., 2020). A new study found that the tight coupling of C—N in a farmland converted from a forest ecosystem based on stable carbon and nitrogen isotopic proof (Liu et al., 2020). The results elucidated that the replacement of native forest by farmland or grassland would reduce soil N utilization efficiency. However, natural restoration of carbon (storage?) was found in a vegetated area recovered from a previously abandoned farmland through monitoring CO_2 in plant-soil-cave continuums at the karst region of Southwest China (Wang et al., 2020c). Thus, riverine water quality impacting by landscape pattern in the karst area was elucidated by analysis of water chemistry and empirical models (Xu et al., 2020). These studies reflected that land use change has a significant influence on environment and ecosystem in the karst area, Southwest China.

4. Understanding agroecosystem functions for sustainable development

The significant contradiction between people and land is exceptionally outstanding in the karst region at Southwest China, due to thin soil and low productivity of karst ecosystems and rapid population (Liu, 2009). The region has been experiencing rapid development and generated some environmental concerns, such as soil degradation and nutrient loss. Understanding multi-processes in the ecosystem could be useful to accurately assess the functions, including nutrient allocation in various ecosystem units and multi-processes conducted by ecosystem. Meanwhile, assessment of ecological service in the karst region of Southwest China is urgently needed to formulate measures for supporting sustainable development.

Biological nitrogen immobilization in the karst thin soil could reduce excessive fertilizer use and increase productivity. Xiao et al. (2020a) suggested that seasonal changes of diazotroph abundance and community composition after improving nutrients in fragile karst ecosystem by

planting legumes. Meanwhile, they found that phosphorus addition (not nitrogen) could lead to significant changes of diazotroph diversity and community composition in the karst soil with grass cover (Xiao et al., 2020b). The interactions between allocations of phosphorus and nitrogen are related to economic plant of Mulberry growth stage and environmental conditions in the karst system (Piao et al., 2020). These findings advance the understanding of agroecosystem functions to seek high productivity from infertile soil and economic development in the karst areas in the southwestern China.

Intensive agriculture is one of new developing trends in the countryside of Southwest China. Increase of farm size was supposed to be one of the effective measures to enhance crop yields and improve the utilization efficiency of fertilizers. However, Li et al., 2020a found significant nitrogen and phosphorous losses due to fast stream channel erosion in southern subtropics of China. The study provided a hint that local farmers and government should estimate the potential risk when renovating existing agricultural practices. A new investigation showed people including farmers and local leaders had environmental awareness (Oliver et al., 2020). However, small farm holders need more training to get more technology and farming knowledge for reducing side effects on environmental quality by agricultural practices based on catchment-wide survey.

Assessment of regional ecosystem services could be used to maximize the delivery of ecosystem service values and help to make suitable regional developing plans. The large change of ecosystem services in karst areas was found by calculation based on long term data of land use/land cover (LULC) by Hu et al. (2020). The results showed spatial heterogeneity and sensitivity of ecosystem service values to land use change in the karst areas of China. The major conversion of agricultural land into urban land changed the ecosystem service values of various karst regions. Meanwhile, ecological restoration and agricultural population transferring in recent years would enhance ecosystem resilience and sustainability in the karst mountainous area (Liu, 2009; Jiang et al., 2014; Hu et al., 2020; Li et al., 2020b; Tong et al., 2020).

5. Conclusions

The studies in this Special Issue focused on environmental and ecological issues at the karst areas in Southwest China. The studies revealed that soil loss processes and the change of soil quality in the fragile karst system over space and time. Meanwhile, high extent of nutrient losses with summer runoff was found and estimated in the studies, which hints that farmers and local government should consider field scientific experiments and local climatic conditions when managing fertilizer application and planning land use. The contributions from the studies suggested that some active agricultural practices that were carried out in recent years reduced environmental risk and increased economic benefits at the karst region. The results of ecosystem service value estimates in recent years indicated improvements of ecosystem and environment in karst areas of China. Local farmers and government have realized the importance of protection of environment and ecosystem than before, which might facilitate sustainable development. These studies have delivered new knowledgement that addressed the challenges of facilitating environmental sustainability with agricultural development in the karst region of Southwest China. Meanwhile, more research need to deepen need to deep science advances to improve the resilience of soil and water resources to agricultural practices in the fragile karst ecosystem.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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