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Review

Rocky desertification in Southwest China: Impacts, causes, and restoration

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ABSTRACT

Rocky desertification, which is relatively less well known than desertification, refers to the processes and human activities that transform a karst area covered by vegetation and soil into a rocky landscape. It has occurred in various countries and regions, including the European Mediterranean and Dinaric Karst regions of the Balkan Peninsula, Southwest China on a large scale, and alarmingly, even in tropical rainforests such as Haiti and Barbados, and has had tremendous negative impacts to the environment and social and economic conditions at local and regional scales. The goal of this paper is to provide a thorough review of the impacts, causes, and restoration measures of rocky desertification based on decades of studies in the southwest karst area of China and reviews of studies in Europe and other parts of the world. The low soil formation rate and high permeability of carbonate rocks create a fragile and vulnerable environment that is susceptible to deforestation and soil erosion. Other natural processes related to hydrology and ecology could exacerbate rocky desertification. However, disturbances from a wide variety of human activities are ultimately responsible for rocky desertification wherever it has occurred. This review shows that reforestation can be successful in Southwest China and even in the Dinaric Karst region when the land, people, water, and other resources are managed cohesively. However, new challenges may arise as more frequent droughts and extreme floods induced by global climate change and variability may slow the recovery process or even expand rocky desertification. This review is intended to bring attention to this challenging issue and provide information needed to advance research and engineering practices to combat rocky desertification and to aid in sustainable development.

Contents

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1. Introduction

Desertification has long been recognized as a major economic, social, and environmental problem of concern to many countries in all regions of the world. A Plan of Action to Combat Desertification (PACD) was adopted at the United Nations Conference on Desertification (UNCOD) in 1978 (UNCCD, 1994). In 1994 the United Nations Convention to Combat Desertification (UNCCD) defined desertification as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities." However, this definition was considered biased (Yassoglou, 1999) since desertification has taken place under humid climates in Scotland and Iceland and in the tropical forest region in South Africa (Glantz and Orlovsky, 1983). Some karst areas in the Europe Mediterranean region fall into this dryland category because of its less than 0.65 aridity index.

Rocky desertification is used to characterize the processes that transform a karst area covered by vegetation and soil into a rocky landscape almost devoid of soil and vegetation (Yuan, 1997). It has occurred largely in the European Mediterranean basin (Yassoglou, 2000), the Dinaric Karst (Gams and Gabrovec, 1999), and in Southwest China (Yuan, 1997) due to extensive human activities on ecologically fragile carbonate rock formations. It has also occurred in other countries or regions in the world, such as in Belize, Guatemala, Mexico of North America, Israel of the Middle East, and East and Southeast Asia, including the Ryukyu Islands of Japan (Ford and Williams, 2007) and Gunung Sewu of Indonesia (Sunkar, 2008). Land degradation or even desertification is occurring in some of the Caribbean island countries such as Barbados (The Government of Barbados, 2002) and Haiti (Williams, 2011), where demands on land resources are high.

The Dinaric Karst in the Balkans covers an area of 60,000 square kilometers (km^2). The bare and stony epikarst, i.e. highly weathered carbonate bedrock exposed at the surface, largely devoid of trees and shrubs on rugged limestone terrains in the north westernmost plateau Kras (Carso in Italian, Karst in German) of the Dinaric Karst ridges was the origin of "karst" (Kranjc, 2012). Gams' (1991) research on Rillenkarren showed that the forest on the plateau Kras was destroyed and bare rock started to appear on the surface around 3000 to 3500 years BP, due to human activities such as stockbreeding and seasonal movement of people with their livestock between summer and winter pastures, slash-and-burn agriculture, firewood gathering, construction and different branches of industry, shipbuilding and metallurgy, and wars (Kranjc, 2012). The plateau Kras became a rock desert in the 18th century. Modern efforts toward reforestation began in the 18th century and successfully turned the rocky desert into dense pine forests. The forest in the plateau Kras increased from 20% in 1900 to 51% in 1989 (Gams, 1991). The chronology of desertification in the European Mediterranean region, including southern France, Spain, Italy, and Greece, is similar to the Dinaric Karst region. Yassoglou (2000) found that human disturbance to the land began around 8000 years BP. Desertification may have occurred after the Neolithic Age in the period 4000–3000 years BP due to intense human activities such as population growth, expanded agriculture, and deforestation in coastal areas where limestone formations lie. Yassoglou's (2000) study also showed that human disturbances had spatial and temporal variability throughout the region.

Rocky desertification has become the primary ecological disaster which has significantly hindered the economic growth in Southwest China and has a direct impact on the 1.7 million people living in the region (Jiang and Yuan, 2003). Although China does not have a record of ancient history of human disturbance to the land in its southwest karst region, the famous ancient geographer of the Ming Dynasty, Xu Xiake, described the rocky mountains almost without any forest or vegetation cover when he traveled to Guizhou on April 15, 1638 in "Xu Xiake's Travels." The "Great Leap Forward" from 1958 to 1961 resulted in large-scale rocky desertification when almost all trees were stripped to make charcoal for iron production across China. Cao et al. (2009) showed that the rocky desertification area expanded drastically by 3.76 times from 1970 to 2005 in Guizhou province.

A large number of studies have investigated the causes and impacts of rocky desertification, as well as issues in the physical sciences such as hydrology, soil erosion, sedimentation, water resources in terms of quantity and quality, and ecosystems in the world (NATO, 2003; Wang et al., 2004a,b; Millennium Ecosystem Assessment, 2005; NATO, 2007; UNECSO, 2009; Jiang et al., 2011). The goal of this paper is to present a comprehensive review of the causes, impacts, and restoration measures of rocky desertification from several decades of studies in the Southwest Karst region of China and from published works for some typical karst regions around the world.

2. Rocky desertification in Southwest China

China has approximately 3.44 million km^2 of karst areas (buried, covered, and exposed carbonate rock areas), about 36% of its total land, and 15.6% of all the 22 million km^2 karst areas in the world. The seven provinces including Yunnan, Guizhou, Guangdong, Chongqing, Hunan, Hubei, and Sichuan and the Guangxi Zhuang autonomous region in Southwest China have about 0.51 million km^2 of exposed/outcropped carbonate rock areas, 5.8% of the total land. As shown in Table 1 rocky desertification reached 35.6% of the exposed carbonate rock areas in Yunan in 2000, averaged to about 22% in the region. Up to 82% of the rock desertification areas are in Yunan, Guizhou, and Guangxi.

The severity of rocky desertification is classified into four categories in China: (1) no desertification when exposed bare rocks compose less than 30% of the land; (2) light desertification when exposed rocks compose between 30 and 50%; (3) moderate desertification with exposed rock between 50 and 70%; and (4) severe desertification with exposed rock greater than 70% as shown in Fig. 1. Remote sensing and GIS technologies were used to identify areas where rocky desertification has occurred in Southwest China (Li et al., 2008; Bai et al., 2011). The distribution of rocky desertification classifications in the three major river basins and their major tributary drainage basins in Southwest China are shown in Fig. 2 and summarized in Table 2. The rocky desertification area in the Yangtze River Southwest drainage basin is about 3.95% of its total land and 15.44% of the exposed carbonate area. For the Pearl River Basin, 95% of the rocky desertification area is located in the headwater Xi River subbasin, where 15.7% of the subbasin area or 33.2% of the exposed carbonate rock area was turned to desertification. Even though the exposed carbonate rock areas in each of the three transboundary river basins encompass less than 10%, 55% of the exposed carbonate rock areas have become desertification areas.

3. Environmental, social, and economic impacts

Rocky desertification is the ultimate result of deforestation and soil loss in the carbonate rock areas. It has tremendously affected the hydrologic, soil, and ecologic conditions at various scales and consequently causes more geologic hazards such as droughts, floods, landslides, and land subsidence. On a larger scale it even affects the carbon balance and regional climate conditions. The expansion of rocky desertification has put more strain on people's lives in areas where they are already living below the poverty line.

3.1. Environmental impacts

Rocky desertification has resulted in the loss of biomass in karst systems, changes in the physiological and ecological characteristics of plant communities, and the loss of forest and vegetation cover (Table 3). Ecologically, it has resulted in changes in germplasm and species composition and loss of species diversity in the system. Rocky desertification destroyed not only tall vegetation but also moss and algae on rock surfaces, which are pioneer species for vegetation growth.