Land Use Policy 61 (2017) 171–184

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

# Orienting rocky desertification towards sustainable land use: An advanced remote sensing tool to guide the conservation policy

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A R T I C L E I N F O

*Article history:*
Received 6 September 2016
Received in revised form 24 October 2016
Accepted 1 November 2016
Available online 22 November 2016

*Keywords:*
Land desertification
Rocky desertification monitoring
Sustainable land use management
Sub-pixel mapping
Spectral unmixing
Ecological restoration project
Land conservation policy

A B S T R A C T

Due to non-sustainable land management, desertification has been occurring widely across the world and continues to be a global land use problem. In this context, appropriate methodological tools, which can provide a biased estimation of desertification, are critical for learning from past failures and local successes in orienting desertification towards sustainable land use. This paper proposes a locally adaptive multiple endmember spectral mixture analysis (MESMA) algorithm to extract the rocky desertification information from medium resolution images at subpixel level and applies it to the case of Danjiangkou reservoir region (DRR), China. Quantitative comparisons show that the locally adaptive MESMA has achieved more accurate and reliable estimations of rocky desertification information in DRR than the traditional MESMA. An inversed U-shaped trend is observed for desertified land with different severity levels from 1987 and 2013 in DRR. In particular, the inflection point roughly emerged in period 2000–2005. Casual mechanism-based regressions demonstrate that such dynamics of rocky desertification are closely coupled with socioeconomic, biophysical, and policy factors. More specifically, we identify a significantly positive role of land conservation policy in combating and relieving rocky desertification in DRR. Positive effects are observed particularly through afforestation, investment, and professionals input. Based on the conclusions and lessons of DRR, I finally make relevant recommendations for formulating policies and strategies that attempt to orient desertification towards sustainable land use. The proposed locally adaptive MESMA can act as an advanced remote sensing tool to guide the conservation policy.



## 1. Introduction

### 1.1. Desertification: a global land use problem

Central to the food, water, and energy nexus, land has an essential role in securing food productivity, regulating water cycle, maintaining biodiversity, enhancing resilience to climate change, and supporting energy provisioning (Thomas et al., 2012). Due to non-sustainable land management, however, land degradation and its manifestation as desertification in arid, semiarid, and dry sub-humid regions have been occurring widely across the world. Desertification is defined as a persistent loss of ecosystem function and productivity due to diverse disturbances (e.g., soil fertility loss, soil erosion, vegetation cover loss, and plant species changes) from which the land cannot unaided recover (Bai et al., 2008; Safriel and Adeel, 2005). Global desertified land covers approximately 41% of the total terrestrial surface and affects more than two billion population (MEA, 2005), including Africa (Kiage, 2013), America (Vieira et al., 2015), Asia (Miao et al., 2015), Europe (Salvati and Bajocco, 2011), and Oceania (Williams, 2015). The figure is expected to increase substantially against the population growth and climate change (Reynolds et al., 2007; UNCCD, 2008). Desertification jeopardizes and disfunctions the biophysical and socioeconomic processes, making it among the most challenging environmental problems of the 21 st century (MEA, 2005; Reynolds et al., 2007; Vogt et al., 2011).

Past decades have seen great efforts to initialize national and international policies to combat desertification. Though more than 190 countries have acted actively, no substantial progress has been achieved towards controlling the desertification for the entire world. Vigorous scientific debate remains with respect to the measurement and causes of desertification, let alone the best mitigation solution. Existing thematic maps at global level are generally based on coarse resolution data and simply indicate the vulnerability to desertification, such as the USDA NRCS Desertification Vulnerability map (Eswaran and Reich, 2003), GLASOD (Thomas and Middleton, 1994), the United Nations World Atlas of Desertification

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http://dx.doi.org/10.1016/j.landusepol.2016.11.024
0264-8377/

(UNEP, 1997), the Millennium Ecosystem Assessment Desertification Synthesis (MEA, 2005), as well as those produced individually by Ramankutty and Foley (1999), Lepers et al. (2005), Campbell et al. (2008), and Cai et al. (2011). Moreover, these thematic maps differ in standard, accuracy, and consistence (Gibbs and Salmon, 2015; Vogt et al., 2011). It leads to the dilemma that there lacks of robust, spatially explicit, and producible methodologies and no formal indicators or benchmarks are available for monitoring the progress in combating desertification.

Since desertification continues to be a global land use problem, it requires urgently to develop robust and practical tools to capture the extent and severity of desertification. As such, the worldwide political discussions can formulate more efficient mitigation and adaption to desertification. Indeed, desertification is resulted from a number of biophysical processes and their complex interactions with multi-level anthropologic drivers, ranging from individual household level, whose land use practices are spontaneous but may be negligent and exploitative, to land use policy level at which land management strategies are planned but can be economy-oriented and discriminatory (Bai et al., 2008; Gao and Liu, 2010; Geist and Lambin, 2004; Nkonya et al., 2011; von Braun et al., 2012; Vu et al., 2014a). In several instances, individual households and policy makers have implemented sustainable land use practices and policies, which have prevented and slowed further degradation (Fleskens and Stringer, 2014). These isolated success stories are regarded to have great value as international references (Fleskens and Stringer, 2014). Scholars thus argue that we should move towards upscaled sustainable land use for addressing global challenges in the post-2015 era. In this context, appropriate methodological tools, which can provide a biased estimation of desertification, are critical for learning from past failures and local successes in orienting desertification towards sustainable land use.

### 1.2. China's desertification and policy responses

China is one of the most vulnerable countries to desertification in the world. Almost all semi-arid, arid, and sub-humid regions are attracted by desertification in China (Yan and Cai, 2015). It is roughly estimated that over 200 million population and 16 million $km^2$ areas are susceptible to desertification (Wang et al., 2008). Desertification presents different characteristics across the Chinese vast territory (Zhu and Wang, 1993). In the northern China, aeolian desertification resulted from wind erosion is the dominant process of desertification. Aeolian desertified land increased at a rate of $1560\,km^2y^{-1}$ in period 1955–1975, $2100\,km^2y^{-1}$ in period 1976–1987, and $3600\,km^2y^{-1}$ in period 1988–2000 (Wang et al., 2004a, 2004b). Water and soil loss, resulting from irrational use of sloping land (e.g., Loess Plateau), is the principle process of desertification in the northwest plateau (Zhao et al., 2015). The desertified land suffering from soil erosion amounts to $45.4 \times 10^4\,km^2$, accounting for 71% of the total area of Loess Plateau. Salinization caused by unsustainable management and irrigation acts as the primary process of desertification in the north plain, northwest inland, and coastal areas. Rocky desertification due to intensive anthropogenic activities on ecologically fragile karst formations colonizes the seven provinces (Chongqing, Hubei, Hunan, Guangdong, Guangxi, Guizhou, Sichuan, and Yunnan) in southwest China. It is estimated that 5.8% of the total land in southwest China are covered by exposed or outcropped carbonate rock areas and the rocky desertified land reaches $13.0 \times 10^4\,km^2$ in 2005 (Yan and Cai, 2015). With the respect to the extent and severity, desertification in the southwestern, northeastern, and central zones is more serious than that in the northwest (Yan and Cai, 2015). As for the increasing trend, southwest and northeast are the hotspots of the newly desertified land (Yan and Cai, 2015). Desertification has posed great threat to China's environmental sustainability, socioeconomic development, and human well-being. Unfortunately, no reliable and unified data are available for long time-series and cross-regional comparisons. The trend and magnitude of desertification remain unclear in China. It therefore requires efficient tools to capture the desertification dynamics with high accurate estimations.

The Chinese government has set high priorities on agenda to combat desertification. Since the 1980s, a series of programs and policies have been launched to rehabilitate desertified land (Sun, 2015). The 'Three North' project of the agropastoral zone, titled as the Green Great Wall, has achieved 4069 million $km^2$ afforested area in northern China (Zha and Gao, 1997). To address the desertification in northwest China, the 'Grain for Green' program has been implemented, which calls for the conversion of farmland to forest on sloping land. The National Reform and Development Commission has carried out a number of ecological restoration projects to rehabilitate the karst desertified land in southwest China. These projects cover 100 counties, accounting for over 97% of total counties in southwest China (SFA, 2004). Scientific and political communities have acknowledged the role of these policies and programs in releasing desertification. As a consequence of policies and project-based initiatives, for example, desertification reversal has occurred in some parts of in the agropastoral zones (Gerile and Wulantuya, 2004; Jiang et al., 2014; Piao et al., 2005; Qi et al., 2012; Xue et al., 2005; Zhao et al., 2010; Zhou et al., 2012). It is reported that more than 70% of the most severe karst desertified surfaces have been rehabilitated. However, the central government has put overwhelming emphasis on the northwestern zones (e.g., Loess Plateau), and the central, southwestern, and northeastern zones are somewhat neglected. The extent and severity of desertification still expand in many regions, such as the Liao River watershed in the northeast, the middle part of Yellow River basin in the central China, the middle part of Yangtze River basin in the southwest, and the Pearl River watershed in the south (Jiang et al., 2014). The Chinese government still has to accomplish tremendous tasks for preventing further desertification. The lessons and successes of China's policy responses to desertification will be very helpful for global sustainable land use practice.

### 1.3. Present study

The present study focuses on the rocky desertification, the process of which the original vegetated karst surfaces transform into a non-vegetated landscape characterized by bare soils and rocks (Yuan, 1997). Rocky desertification is primarily observed in southwest China (Yuan, 1997), the Dinaric Karst (Gams and Gabrovec, 1999), and the European Mediterranean basin (Yassoglou, 2000). In addition, rocky desertification also occurs typically in the Gunung Sewu of Indonesia (Sunkar, 2008), Ryukyu Islands of Japan (Ford and Williams, 2007), Israel, Mexico, Guatemala, and Belize. In southwest China, more specifically, area exposed to carbonate rock amount to $50.6 \times 10^4\,km^2$ (26.0% of the total area), and rocky desertified land reach $11.4 \times 10^4\,km^2$ in 2000 (5.8% of the total area) (Jiang et al., 2014). Rock desertification in southwest China is primarily distributed in the Yangtze River Southwest drainage basin, the Transboundary River basin, and the Pearl River basin (Li et al., 2009; Bai et al., 2013). The present study explores one typical region in the Yangtze River Southwest drainage basin as the case—the Danjiangkou reservoir region (DRR). The DRR sits at the Qinli-Bashan Mountain region in northwest Hubei Province (Fig. 1) and is featured by sub-tropic karst landscapes. The DRR has a monsoon continental semi-humid climate with plenty rainfall and four distinctive seasons. Annual average temperature is 14.1–15.7 °C and annual average precipitation amounts to 800–1000 mm. Topography within the DRR is complicated and varied, with plains basins, mountains, and hills. The DRR is the water source for the mid-