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Soil quality assessment in different climate zones of China's Wenchuan earthquake affected region

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ABSTRACT

China's 2008 8.0 Ms Wenchuan earthquake and subsequent secondary geo-hazards caused widespread damage to vegetation-soil system in northwest China. In order to evaluate changes in soil quality status after damage, we established four treatments in the earthquake-affected area, including disturbed and treated sites in a dry hot climate (D-t), undisturbed sites in a dry hot climate (D-ud), disturbed and treated sites in a subtropical humid monsoon climate (S-t), and undisturbed sites in a subtropical humid monsoon climate (S-ud). Forty-eight soil samples were collected and analyzed for 27 soil physical, chemical, and biological properties. Principal components analysis (PCA) was conducted with 26 variables in significant differences except total potassium among D-t, D-ud, S-t, and S-ud. A minimum data set of soil indicators was established with available potassium (AK), K^+, total salt content (TSC), and total phosphorus (TP) based on PCA results. Using the Integrated Quality Index (IQI) equation, we calculated the soil quality index (SQI). S-ud, S-t, D-ud, and D-t had mean SQI scores of 0.566, 0.275, 0.537, and 0.374, respectively. Our results showed that undisturbed sites had better soil quality compared to disturbed and treated sites based on their superior physical indicators, superior nutrient conditions, and higher microbial carbon source metabolic diversity, especially in the subtropical humid monsoon climate with frequent rainfall. The SQI reflects the variations observed in earthquake-affected area and may be considered as a suitable technique for detecting changes in soils. Our results will also supply the fundamental data for evaluating the effects, design, and implementation of restoration programs.

1. Introduction

Across the globe, tectonic plate activity and sudden dislocations within the Earth's crust can cause strong earthquakes. This impacts vegetation structure and function through the initial soil disturbance and subsequent geo-hazards that then induce diversity reduction, vegetative biomass loss, and soil fertility declines (Allen et al., 1999; Cheng et al., 2012; Cui et al., 2012; Zhang et al., 2011). After serious natural or anthropogenic disturbances—including earthquakes, avalanches, fire, typhoons, drought, as well as road construction, ecological restoration is generally regarded as a slow process, dependent on many factors such as climate, soil properties, slope gradient, and the degree of damage (Garwood et al., 1979; Chou et al., 2009; Rodríguez Rodríguez et al., 2005; van Bloem et al., 2003; Cheng et al., 2012). Humans have carried out cost-effective projects involving biological and engineering countermeasures to prevent further deterioration and to improve recovery success (Rodrigues et al., 2009; Mitsch and JØrgensen, 2004; Lin et al., 2005; Millington et al., 2013).

Although some researchers debate the necessity, probability of success, and efficacy of such restoration projects (Del Moral and Walker, 2007; Cao et al., 2010), vegetation restoration programs are still commonly used as a regular method of ecological restoration in degraded lands (Stokes et al., 2010). Undoubtedly, there are opposing research results in different areas. For example, some researchers have pointed out that reforestation can control soil erosion and accelerate vegetation succession with increased vegetation cover (Fernandez-Abascal et al., 2003; Lin et al., 2014). However, the United States Department of Agriculture

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(USDA) found that seeding exotic plant species on damaged lands after the Mount St. Helens eruption did not reduce erosion, and even limited conifer regeneration (Del Moral and Walker, 2007). Hence, it is necessary to critically evaluate results and improve the design and implementation of restoration programs (Zhang et al., 2014). Our research contributes to the growing body of knowledge on suitable restoration protocols in the wake of large disturbance.

As the basic foundation for most plants across the globe, undisturbed and well-structured soils can maintain ecosystem sustainability, stability, and equilibrium (Rodríguez Rodríguez et al., 2005). However, during major earthquakes in mountainous regions, the original nutritient-rich and well-formed soil is easily disturbed or buried by earthquake-induced geo-hazards, which undermine surface soil structure. This causes serious soil erosion, resulting in increased soil aeration and infiltration capacity, and diminishing hydrological adjusting function, drainage, bulk density, and temperature (Vittoz et al., 2001; Cui et al., 2012). One such earthquake is the 8.0 Ms Wenchuan Earthquake, which struck Wenchuan County, Sichuan Province, Southwestern of China on May 12, 2008. In addition to killing at least 68,000 people, causing an estimated 23 billion RMB in direct economic loss of forest systems, and producing 3.422 billion tons of debris (Cui et al., 2012), the earthquake also caused vegetation destruction across 32.867×10^4 ha in Sichuan province (Forestry Department of Sichuan Province, 2008). In response to the Wenchuan earthquake, the Chinese government has carried out a recovery plan with nearly 1020.5 billion RMB in the earthquake-affected areas (Xinhuanet, 2011; Zhang et al., 2014). While there has been some research on ecosystem changes in the Wenchuan Earthquake-affected area during its ecological protection and restoration (Peng et al., 2013; Zhang et al., 2014), little research has been done to evaluate soil deterioration and recovery potential, soil management practices, and the applicability of geotechnical and biological measures in the disturbed area.

Soil quality is the basis for improving sustainable land use management (McGrath and Zhang, 2003; Qi et al., 2009), evaluating the sustainability of soil management practices (Smith et al., 1994; Gong et al., 2015), and providing early warning signs of adverse trends (Bindraban et al., 2000). Researchers used several soil quality evaluation methods, such as soil quality index (SQI) methods (Doran et al., 1994), fuzzy association rules (Xue et al., 2010), and management assessment framework to assess soil quality based on soil properties (Karlen et al., 2008; Wienhold et al., 2009). Moreover, in order to reduce the need to determine many soil indicators, specialists used principal components analysis to identify and determine a minimum data set (MDS), which can adequately represent the total data set (Rezaei et al., 2006; Andrews et al., 2004; Yao et al., 2013; Liu et al., 2014). Due to its simplicity and integrative information for soil indicators (Mohanty et al., 2007), SQI is the most common soil quality evaluation method (Andrews et al., 2002).

The aim of this study was to estimate the impacts of major earthquakes on soil quality using Wenchuan earthquake-affected area as a case study. The objectives are to (1) evaluate soil quality of disturbed and treated and undisturbed sites in the Wenchuan earthquake-affected area, (2) assess the damage to soil quality caused by earthquake, and (3) determine which soil factors might limit the recovery process.

2. Materials and methods

2.1. Study area and experimental design

The study was carried out in the edge of the Qinghai-Tibet Plateau transition zone and Northeast of Sichuan basin (30°45′–33°03′N and 102°49′–105°38′E) in Sichuan Province, China, which mainly has dry hot and subtropical humid monsoon climates. Because of the large area of earthquake-affected region, two representative regions were selected for soil sampling in the Weizhou town of Wenchuan (dry hot climate) and the Hangwang town of Mianzhu (subtropical humid monsoon climate), Sichuan Province (Fig. 1), where the Japan International Cooperation

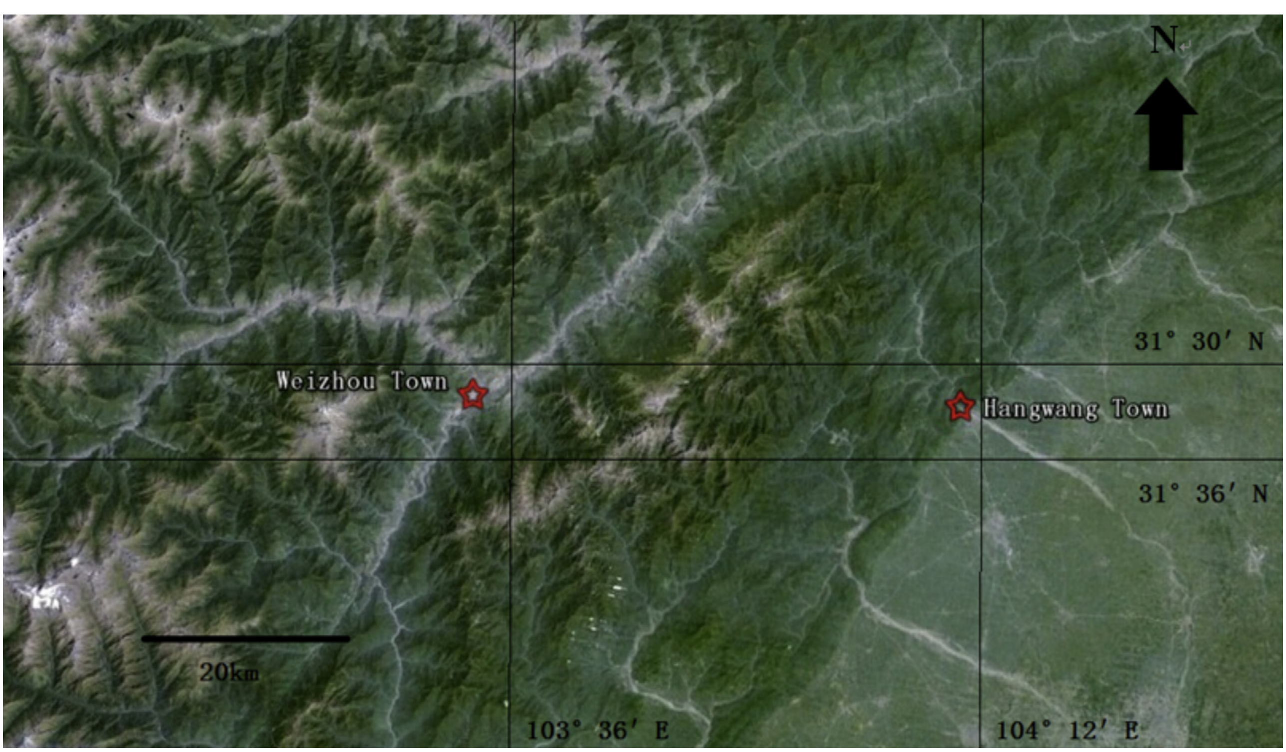

Fig. 1. Geographic location of two typical climate zones (pentagram).