Soil erosion under different land uses in the riparian zone of the Three Gorges Reservoir, China

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Abstract Different land use and management practices have varying impacts on soil erosion. There are few reports concerning the land-use effects on soil erosion for the riparian zone of the Three Gorges Reservoir (TGR). The present study investigated soil erosion rates in artificial grassland, natural grassland, cropland, and bare land at the riparian zone in the middle reach of the TGR during 2008–2012. Fifteen experimental plots with different land use were set up to observe soil erosion rates with erosion pins. The results show that the maximum soil erosion rate was 94 887 t km^{-2} $year^{-1}$ in the conventional tillage farmland, followed by 92 423 t km^{-2} $year^{-1}$ in the bare land, 64 670 t km^{-2} $year^{-1}$ in the bunch planting farmland, 37 794 t km^{-2} $year^{-1}$ in the natural grassland, and the minimum soil erosion rate was 21 340 t km^{-2} $year^{-1}$ in the artificial grassland.

Key words Three Gorges Reservoir; riparian zone; land uses; soil erosion

INTRODUCTION

The riparian zone of a reservoir, having sharp biological and physical gradients, is ecologically fragile due to the perturbing effect of water level fluctuation (Thomas, 2008; Chang, 2011). Born & Stephenson (1973) considered soil erosion in the riparian zone as a natural consequence of impoundment of a waterway with substantial topographic relief. The new shoreline of the riparian zone is not adapted to its new environmental conditions and is easily eroded away. This appears to be the case at the Three Gorges Reservoir (TGR). Compared with other large reservoirs in the world, the riparian zone of the TGR is characterized by high annual hydro-fluctuation, heavy waves caused by busy shipping in the main stream, and a large area of fertilized cultivated land. After the impounding of TGR, great geomorphological changes were expected on the banks of the riparian zone (Zhang, 2009) due to the significant driving force of waves (Bao, 2010).

Soil erosion is a complex process that is influenced by soil type, topography, climate and land use. In areas where soil, climate and topography are similar, differences in erosion rates are commonly related to land use (Gumbs & Lindsay, 1982; Tania, 1998). In general, land use with less vegetation cover increases erosion potential (Thorne, 1990; Coops, 1996; Simon, 2002; Norbert, 2010). Land-use practices in the riparian zone changed dramatically after the 175-m-high impoundment of TGR. The main land-use types in the riparian zone include natural grassland, artificial grassland and seasonal cultivated land (Zheng, 2010; Ye, 2011). Published studies have highlighted concerns regarding vegetation rehabilitation, management practices, non-point pollution control and ecological degradation of the reservoir riparian zone (e.g. He *et al*., 2007; Thomas & Xie, 2008). However, studies are scarce on soil erosion in the riparian zone of the Three Gorges Reservoir and very little information is available about the effect of different land use on soil conservation.

Soil erosion along reaches with different riparian land uses was compared, with a specific focus on natural grassland, artificial grassland, seasonal cultivated land and bare land. The objectives of this study were to estimate the temporal variations of soil erosion following the short-term revegetation and investigate how different land-use practices affect soil erosion in the riparian zone.

SCENARIOS OF TGR AND STUDY AREA

The Three Gorges Reservoir, a multi-functional water control system built on the Upper Yangtze River, was fully operational in 2010. The reservoir is 600 km long with a surface area of 1060 km^2 and a water capacity of 39.3 billion m^3 at the highest water level of 175 m a.s.l. It plays a key role in flood control of the Yangtze River Basin. The water level fluctuates approximately 30 m $year^{-1}$, forming a riparian zone of 349 km^2. The study area is located in Zhong county (108°11′N, 30°26′E), Chongqing, China (Fig. 1) and has a sub-tropical monsoon climate with a daily mean temperature range from –4 to 44°C. The annual mean precipitation ranges from 886 to 1614 mm and 80% of the precipitation is concentrated in the period from April to October. The purple soil, developed from purple gritstone, is the typical soil type in the riparian zone of the Three Gorges Reservoir (Zhao *et al.*, 2007). The average soil pH in the region is 6.19 ± 0.07 and average soil water content is 18.93 ± 0.75%.

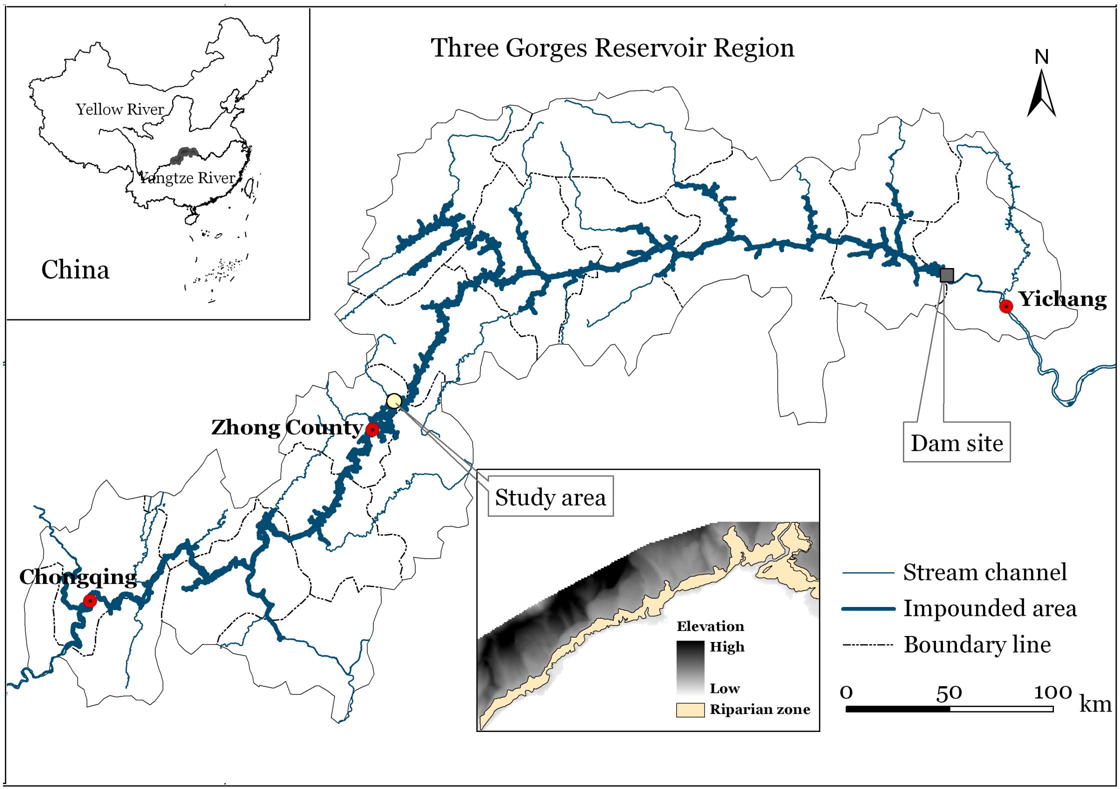

Fig. 1 Location of the study area and riparian zone of the Three Gorges Reservoir.

METHODS

Five major land-use patterns: natural grassland, artificial grassland, conventional tillage farmland, bunch planting farmland, and bare land were observed. The five sites lie on same sides of the Yangtze River, on a 15° slope, with no significant difference in elevation between the five sites. Steel rods (erosion pins), 700 mm long and 6 mm in diameter, were inserted perpendicularly into the bank face to measure soil erosion rates. Three erosion pin plots were stochastically assigned in each practice reach. Each erosion plot has 5 × 4 pins, 1 metre apart. These exposed pins' lengths were measured twice each year from May 2008 to May 2012, that is, before impoundment in the winter and when water levels fell in the next summer.

The soil dry bulk density was measured with the cylindrical sampler method (Blake & Hartge, 1986). The cores were 70 mm in diameter and 52 mm high (200 cm^3). Every sample had at least three replicates.

RESULTS AND DISCUSSION

Soil erosion rates

The erosion measured on the five land-use practices showed significant differences (ANOVA, $P < 0.01$). Except for the conventional tillage farmland, erosion rates in other land use are lower than the bare land (Table 1). The artificial grassland presented the lowest soil erosion rate, with an average value of 21 340 t km^{-2} year^{-1} in the four observation years, followed by the natural grassland and the bunch planting farmland, with average erosion of 37 794 and 64 670 t km^{-2} year^{-1}, respectively. The conventional tillage farmland has the greatest soil losses, averaging 94 887 t km^{-2} year^{-1}.

Temporal variation of soil erosion

Figure 2 shows that the erosion rates of artificial grassland and natural grassland decrease over time. However, there is little change in the erosion rates of the bunch planting land, conventional tillage farmland and bare land, which sustained higher erosion rates. In the first observation year (May 2008 to May 2009) the erosion rate of artificial grassland was similar to that of natural grassland, and the difference between them is not significant (Turkey-Kramer method, $P > 0.05$). In the second to fourth years (May 2009 to May 2012), the erosion rates of the artificial grassland are significantly lower than those of the natural grassland (Turkey-Kramer method, $P < 0.05$). Meanwhile, significant differences in erosion rates are found between the practices with grassland and the agricultural uses for every year; artificial and natural grassland both had lower erosion rates over the four years.

Table 1 Soil erosion under different land uses at riparian zone of Three Gorges Reservoir.

Land-use types	Bulk density (g cm^{-3})	Erosion rate (cm year^{-1})	Erosion modulus (t km^{-2} year^{-1})
Artificial grassland	1.38	1.5	21 340
Natural grassland	1.41	2.6	37 794
Bunch planting	1.53	4.1	64 670
Conventional tillage farmland	1.56	5.9	94 887
Bare land	1.63	5.5	92 423

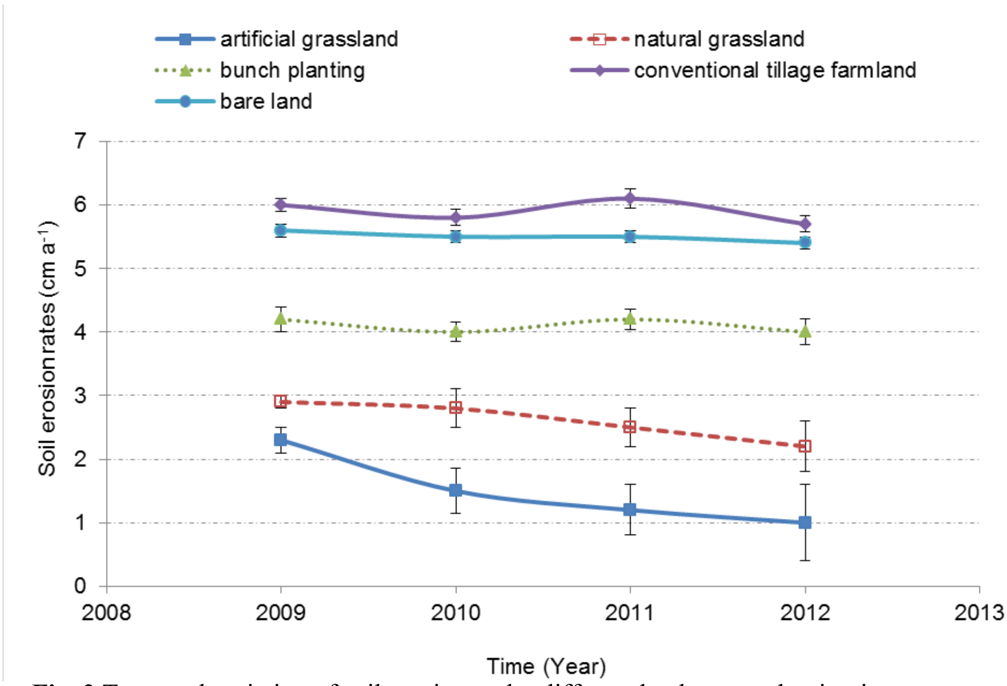

Fig. 2 Temporal variation of soil erosion under different land uses at the riparian zone.

CONCLUSIONS

Erosion rates under different land uses on the riparian zone of the Three Gorges Reservoir have revealed that most areas are suffering from serious soil loss. The soil erosion rates measured on the five land-use types show significant differences. The erosion rates under different land uses, in decreasing order are as follows: artificial grassland, natural grassland, bunch planting farmland, bare land and conventional tillage farmland. The highest soil erosion rate is 94 887 t km^{-2} $year^{-1}$ in the conventional tillage farmland, which is 73 547 t km^{-2} $year^{-1}$ more than from the artificial grassland. Over four years, the soil erosion rates decreased gradually in the grassland but remained steady in the conventional tillage farmland, bunch planting farmland and bare land. Hence, the grassland appears to be the most beneficial for soil conservation of the riparian zone.

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