Extent and degradation of peatlands on the Ruoergai Plateau (Tibet, China) assessed by remote sensing

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Summary

Remote sensing reveals that peatlands of the Ruoergai Plateau (Tibet, China) cover an area of 473,348 ha, i.e. 17.2 % of the Plateau. 109,612 ha (23 % of the peatland area) is still in good condition, the remainder (77 %) is in various stages of degradation. Comparison with older satellite images indicates that degraded peatlands were widespread before 1977, but that the area of degraded peatland has almost doubled in the last 30 years. 28,543 ha appear in better condition in 2007 than in 1977. This may be ascribed to classification fuzziness, but to some extent also to recent restoration measures.

Key index words: mountain peatland, inventory, classification, restoration, Landsat

Introduction

The Ruoergai Plateau (Tibet, China) contains the world's largest extent of high altitude peatlands. Although conveying the impression of unspoiled vastness, the peatlands are subject to heavy degradation with enormous socio-economic consequences (Joosten *et al.*, 2008).

This paper presents the preliminary results of a remote sensing study of the extent and degradation status of peatlands of the Ruoergai Plateau.

Study area

The Ruoergai Plateau (2,746,000 ha) is situated in the north-eastern part of the Tibetan Plateau at an altitude of 3,400 to 3,900 m asl. (Fig. 1). In contrast to the dry western parts of Tibet, the Ruoergai Plateau is influenced by the southwest monsoon and the Subtropical High Pressure (Zhou *et al.*, 2002). With a mean annual precipitation of 753 mm and a mean temperature of only 0.8 °C the climate is harsh with long, cold winters and relatively short summers (Lehmkuhl and Liu, 1994).

The Ruoergai Plateau appears as a fairly plane glacial landscape with small mountain ranges of some hundred metres height. Triassic sandstones and Tertiary sediments constitute the dominant bedrock (Lehmkuhl and Liu, 1994). Most valleys are backfilled by several metres of thick loess deposits and colluvial sediments (Kaiser *et al.*, 2007). Together with the humid climate these low permeable soils facilitated the development of peatlands that hold a major part of the Chinese peat resources with an estimated carbon content of 750 Mt (Björk, 1993).

The peatlands are of great importance for regulating hydrology. By keeping groundwater levels high, they improve the productivity of the upland rangelands. As the

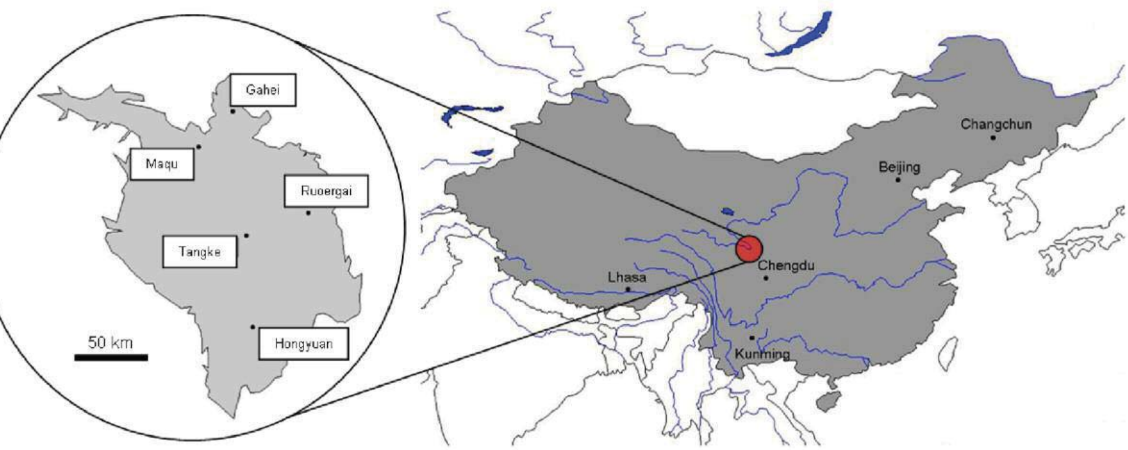

Figure 1. The situation of the Ruoergai Plateau in the headwaters of the Yellow River on the borders of the provinces Qinghai, Sichuan, and Gansu (32.2°-34.1°N / 102.1°-103.5°E).

headwater area of the Yellow (Huanghe) River, they influence downstream areas by retaining water during periods of high precipitation and slowly releasing it during periods of water shortage. The area holds numerous endangered and endemic species (Tsuyuzaki *et al.*, 1990; Schaller, 1998) and plays an important role for biodiversity conservation.

In spite of being rather fertile, the Ruoergai Plateau is one of the most remote and poorest regions of China (Yan *et al.*, 2005). Cattle husbandry (mainly yaks, but also sheep, horses and goats) is the main source of subsistence (Wu, 2000; Wiener *et al.*, 2003) and has over time developed as part of a unique cultural heritage.

Today the peatlands of the Ruoergai Plateau show different stages of degradation. The root causes of this degradation may date back to the start of traditional grazing and deforestation of the uplands 5000 years ago. This caused a less regular water supply to the peatlands and the deposition of clastic sediments, and changed the original percolation mires to surface flow mires, which are much more sensitive to erosion by overgrazing and climate change (Schumann and Joosten, 2007; Joosten *et al.*, 2008).

Methods

To assess the area of peatland, slope values were calculated with a SRTM elevation model. As peatlands on the Ruoergai Plateau have more gentle slopes than their mineral surroundings, areas steeper than 1.95 ° were excluded from further classification. Landsat ETM images from June and July 2007 were subjected to threshold classification, using ground truth data of 316 sites obtained during a field campaign in September 2007 and general observations from 2005 and 2006.

Ground truth sites were classified as 'mires', i.e. peatlands with water saturated, loose peat and a dominance of peat forming vegetation, and 'degraded peatlands' with water levels below the peat surface, highly compressed peat, and without indicator species of durable wetness (i.e. *Utricularia intermedia*, *Eriophorum angustifolium*). Non-peatland areas were classified as 'rangeland' when their vegetation cover was more than 10 % and as 'sand' when it was less.

Half of the ground truth data were used to define the thresholds, whereas the others were used for validation. Thresholds were defined for the visible red (RED) and the near infrared (NIR), i.e. channel 3 and 4 of the Landsat ETM, as well as for the normalized vegetation index (NDVI, de Fries and Townsend, 1994). The NDVI is calculated as:

$$NDVI = (NIR-RED)/(NIR+RED)$$

Bare soil reflects stronger in the visible red than in the near infrared. Water does not reflect much in the visible red nor in the near infrared. High water levels are characterized by a low NDVI, while drier areas correspond to a high NDVI. The optimal classification values were identified during an iterative process leading to the values in Table 1. The results were validated by calculating an accuracy matrix (Table 2).

To quantify recent degradation, NDVI histograms from 1977 (Landsat MSS images) and 2007 (Landsat ETM images, Tab. 1) were compared for the 2007 peatland areas. An increase in NDVI from 1977 to 2007 was interpreted as a decrease in water level, i.e. mire degradation.

Results

Slopes steeper than 1.95 ° cover 1,955,271 ha (71 %) of the study area, whereas flatter areas cover 790,745 ha (29 %). The threshold analysis shows that peatlands (both mires and degraded peatlands) cover 473,348 ha or 17.2 % of the Ruoergai Plateau. 109,612 ha (23 % of the peatland area)

Table 1. Threshold classification values applied for the map units.

Map unit	slope (°)	RED	NDVI	NIR
Water	< 1.95	< 70	< -0.042	
Mire	< 1.95	< 70	-0.042 ≤ NDVI < 0.25	
Degraded peatland	< 1.95	< 70	0.25 ≤ NDVI < 0.45	
Rangeland	< 1.95	< 70	≥ 0.45	
Sand		≥ 70		< 100

Table 2. Accuracy matrix of the chosen threshold classification.

overall accuracy: 0,67		validation areas						
		water	mire	degr. peatland	rangeland	sand	sum rows	User's acc.
training areas	water	6	0	0	0	0	6	1
	mire	0	57	17	0	0	74	0,77
	degr. peatland	0	14	65	41	0	120	0,54
	rangeland	0	0	18	40	0	58	0,69
	sand	0	2	0	0	17	19	0,89
	sum column	6	73	100	81	17	total pixels in validation areas: 277	
	Producer's acc.	1,00	0,78	0,65	0,49	1,00		

were identified as 'mires', 363,736 ha (77 %) as 'degraded peatland' (Figure 2). The remaining flat areas were classified as 'rangeland' (268,954 ha), 'sand' (32,930 ha), and 'water' (15,513 ha).

Comparison of the 1977 and 2007 situation (Table 3), shows that in the last 30 years the area of degraded peatland has almost doubled. Only 17 % of the peatland area remained of good quality. An area of 28,543 ha shows less degradation in 2007 than in 1977.

Table 3. Areas assessed as 'mire' and 'degraded peatland' for 1977 and 2007.

1977	2007	Area (ha)	%
degraded peatland	degraded peatland	191,887	41
mire	degraded peatland	171,849	36
mire	mire	81,069	17
degraded peatland	mire	28,543	6
	Total	473,348	100

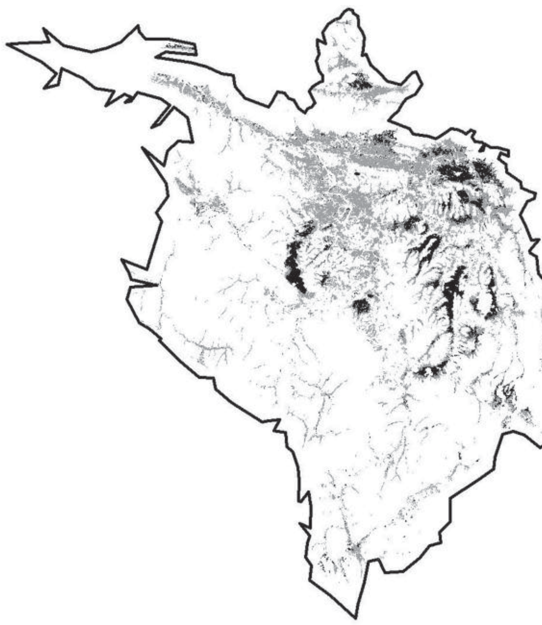

Figure 2. Distribution of *mires* (black) and *degraded peatlands* (grey) on the Rouergai Plateau.

Discussion

The total area of peatlands of 473,348 ha corresponds well with published estimates of 4,000-4,900 km^2 (Björk, 1993; Zhou *et al.*, 2002). With a total peatland area in China of 34,770 km^2 (Chai, 1980), the Ruoergai Plateau thus holds, on 0.3 % of the area, almost 14 % of the peatlands of China.

The value of 473,348 ha suggests an unrealistic accuracy. With the exclusion of steep slopes, some smaller peatlands (spring mires, slope mires) will have been overlooked. Furthermore the pixel size of 30x30 m causes fuzziness in the classification. Inaccuracies will also result from unclear distinction of degraded peatland and rangeland (cf. Table 2), both on the ground (e.g. through lack of information on surficial peats), and on the images (choice of threshold values). These inaccuracies will be addressed by further ground truthing.

For 2007 only 109,612 ha (23.2 %) of the total peatland area of the Ruoergai Plateau have been classified as mires, whereas the major part (363,736 ha) was classified as degraded (Table 3). These figures illustrate the enormous dimension of peatland degradation, even on 'top of the world'.

Large parts of the area classified as degraded peatland in 2007 seem to have been degraded already in 1977 (Table 2). This corresponds to the hypothesis of Joosten *et al.* (2008) that the establishment of the grazing culture had made the peatlands prone to degradation long before the recent intensification of peatland use.

With the construction of roads in the 1950s the Ruoergai Plateau had been opened to settlers. From 1956 until the end of the Cultural Revolution (1966-1976) huge efforts were made to enhance meat and milk production by replacing traditional husbandry by a more market-oriented economy. The abolition of the traditional system of summer and winter ranges led to increased degradation by reduced livestock mobility (Cincotta *et al.*, 1992).

Our analysis shows that since 1977 the area of degraded peatland has almost doubled. With the new Household Contract Responsibility System (1978) farmers got the right to plan farm work and sell their products independently (Ho, 1998). Dramatically increasing livestock numbers on the Ruoergai Plateau led to a substantial decrease of pasture area per animal (Lehmkuhl, 1993). Overgrazing and the resulting decrease in pasture quality (Yan *et al.*, 2005; Gao *et al.*, 2007) fuelled the demand for new rangeland (Wiener *et al.*, 2003; Wang *et al.*, 2006) and since the 1970s almost 50 % of the Ruoergai peatlands were drained (Yang, 2000). The NDVI analysis shows that degradation since 1977 was concentrated along the margins of the mires.

Remarkable are the 28,543 ha that appear degraded in 1977 but look much better in 2007. To some extent this may be caused by wrong classification (cf. Table 2), e.g. where severely grazed and in 1977 apparently 'degraded' land was not yet grazed in June/July 2007 when the satellite images were taken. Some improvement, however, may result from recent restoration measures. The refilling of Lake Gahei in Luqu by the diversion of a river, for example, has led to rewetting of large expanses of mire. Similarly, rewetting of Riganqiao peatland (Wa Qui) locally resulted in a substantial improvement of the mire condition (Schumann and Joosten, 2007).

Conclusion

Landsat imagery analysis enables rapid assessment of extent and degradation status of the high altitude peatlands of the Ruoergai Plateau and shows that from a total area of almost 4,750 km^2 currently over 75 % are degraded, i.e. eroding and oxidizing.

To maintain and restore their hydrological functions, biodiversity, and carbon stores, the remaining mires must urgently be protected and degraded peatlands must be restored. Indeed the Chinese authorities have adopted the Ruoergai peatlands as a key priority in the Chinese National Wetland Conservation Action Plan (State Forestry Administration, 2002). They have introduced a ban on draining wetlands, started to fill in drainage ditches, and designated five nature reserves covering about 0.5 million ha on the Plateau (Schumann and Joosten, 2007). Landsat imagery analysis may assist in identifying priority areas for protection and restoration measures on the extensive and difficultly accessible Ruoergai Plateau.

Acknowledgements

We thank Wetlands International China, the Global Environment Centre (Malaysia), the Sichuan Provincial Workstation for Wildlife Resources Survey Conservation and Management, and the Gansu Wildlife Administration Bureau for facilitating field work and providing good company, and UNEP-GEF and the EU-China-Biodiversity Project (ECBP) for financial support.

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