LAND DEGRADATION & DEVELOPMENT

Land Degrad. Develop. **17**: 589–603 (2006)

Published online 23 February 2006 in Wiley InterScience (www.interscience.wiley.com). **DOI**: 10.1002/ldr.736

LAND USE AND SOIL EROSION IN THE UPPER REACHES OF THE YANGTZE RIVER: SOME SOCIO-ECONOMIC CONSIDERATIONS ON CHINA'S GRAIN-FOR-GREEN PROGRAMME

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Received 31 May 2005; Revised 21 September 2005; Accepted 20 November 2005

ABSTRACT

Soil erosion in the upper reaches of the Yangtze River in China is a major concern and the Central Government has initiated the Grain-for-Green Programme to convert farmland to forests and grassland to improve the environment. This paper analyses the relationship between land use and soil erosion in Zhongjiang, a typical agricultural county of Sichuan Province located in areas with severe soil erosion in the upper reaches of the Yangtze River. In our analysis, we use the ArcGIS spatial analysis module with detailed land-use data as well as data on slope conditions and soil erosion. Our research shows that the most serious soil erosion is occurring on agricultural land with a slope of $10\sim25$ degrees. Both farmland and permanent crops are affected by soil erosion, with almost the same percentage of soil erosion for corresponding slope conditions. Farmland with soil erosion accounts for 86·2 per cent of the total eroded agricultural land. In the farmland with soil erosion, 22·5 per cent have a slope of <5 degrees, 20·3 per cent have a slope of $5\sim10$ degrees, and 57·1 per cent have a slope of >10 degrees. On gentle slopes with less than 5 degrees inclination, some 6 per cent of the farmland had strong ($5000\sim8000\,t\,km^{-2}\,y^{-1}$) or very strong ($8000\sim15000\,t\,km^{-2}\,y^{-1}$) erosion. However, on steep slopes of more than 25 degrees, strong or very strong erosion was reported for more than 42 per cent of the farmland. These numbers explain why the task of soil and water conservation should be focused on the prevention of soil erosion on farmland with steep or very steep slopes. A Feasibility Index is developed and integrated socio-economic assessment on the feasibility of improving sloping farmland in 56 townships and towns is carried out. Finally, to ensure the success of the Grain-for-Green Programme, countermeasures to improve sloping farmland and control soil erosion are proposed according to the values of the Feasibility Index in the townships and towns. These include: (1) to terrace sloping farmland on a large scale and to convert farmland with a slope of over 25 degrees to forests or grassland; (2) to develop ecological agriculture combined with improving the sloping farmland and constructing prime farmland and to pay more attention to improving the technology for irrigation and cultivation techniques; and (3) to carry out soil conservation on steep-sloping farmland using suggested techniques. In addition, improving ecosystems and the inhabited environment through yard and garden construction for households is also an effective way to prevent soil erosion. Copyright © 2006 John Wiley & Sons, Ltd.

KEY WORDS: land use; soil erosion; sloping farmland; Grain-for-Green Programme; Yangtze River; GIS; China

INTRODUCTION

The relationship between land use and soil erosion has attracted the interest of a wide variety of researchers. Bakker *et al*. (2005) regard soil erosion as an important driver of land-use change. The research of Kakembo and

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Contract/grant sponsor: National Natural Science Foundation of China; contract/grant numbers: 40201001 and 40271010.
Contract/grant sponsor: Programme of Excellent Young Scientists of the Ministry of Land and Resources of China.

Rowntree (2003) raises questions regarding both the cause for land abandonment and the reasons for its vulnerability to erosion. Zhang *et al*. (2004) indicated that in cultivated fields coarser soil particles over time were attributed not only to soil erosion but also to mechanical eluviation as a result of farming activities. The effects of land use on soil erosion and soil nutrient content are also a focus of many field experiments (Fu *et al*., 2004; Wang *et al*., 2003a; Meng *et al*., 2001; Del *et al*., 1998). Various authors have used simulations and laboratory experiments to identify the relationship between land use and soil erosion (Boubakari and Morgan, 1999; Hessel *et al*., 2003). Furthermore, there is also relevant research concerning soil erosion and land-use policy, management and planning (Ritsema, 2003; Mushala, 1997; Van Rompaey *et al*., 2001).

Studies on soil erosion in the upper reaches of the Yangtze River are of particular relevance for our analysis. Through observations and analysis of soil-erosion test plots, Yang and Liang (2004) established a soil-loss equation adaptable to the conditions of Jinsha River Basin in Yunnan. They measured annual average soil losses on different land-use types and on sloping fields of various gradients in the basin, and thus classified the soil erosion intensities of the basin. Yang *et al*. (2004) found that increasingly intensive and unsustainable land-use practices, such as reclaiming land by destroying forests and farming on steep slopes, are common in this area, leading to severe eco-environmental degradation. Such degradation undermines sustainable land use and directly threatens the ecological security of the lower reaches of the river. Lu and Higgitt (1999) pointed out that the sediment yields in the upper Yangtze generally increase with precipitation, runoff and population density. Fan *et al*. (2004) monitored dynamic changes in soil erosion and assessed the contribution of soil sediments to rivers both pre-conservation and post-conservation in a small watershed in the middle and lower reaches of the Jialing River Basin. Zhang *et al*. (2002) suggested that the success or failure of reforestation projects could not be explained by either a single technical factor or a socio-economic one, but by a combination of both technical and socio-economic viability. The study of Zhang *et al*. (2003) indicated that the severity of soil erosion is strongly related to soil texture and slope gradient.

The upper reaches of the Yangtze River cover a region from Yichang of Hubei Province to the River's origin. The total area is about 1005 thousand km^2 with a total population of 160 million, which accounts for 58·9 per cent of the area and 35 per cent of the population in the valley, respectively (Li and Gu, 1992; Wang, 1998). Within this area, 90 per cent or more of the land is mountains and plateaus, in which the ecosystem is very fragile and subject to soil erosion due to inappropriate use of land. This includes land-use problems such as deforestation and land reclamation, farming of steep slopes and overgrazing. Soil erosion in the upper reaches of the Yangtze River affects about 35·2 million hectares (or 62·6 per cent of the area) with a total annual soil loss of 1410 million tonnes (or 62·9 per cent of the total) (Shi, 1998). Thus, the annual average soil erosion rate in the region is $40\,t\,ha^{-1}$.

Sheet and rill erosion accompanied by gully erosion are the major soil erosion processes in the upper reaches of the Yangtze River. Severe soil erosion, including landslides, has caused so many disasters that it has been identified as the most severe environmental problem in this area. It is not only a major obstacle to the productive agriculture and livelihood in this area, but also has greatly aggravated the floods in the Yangtze River valley (Yang and Liang, 2004). At present, the situation of economic development in the upper reaches is far inferior to that of the middle and lower reaches of the Yangtze River (Long and Li, 2005). Unfortunately, the eco-environmental situation is still worsening, especially due to accelerated rates of soil erosion, which is one of the biggest barriers to sustainable rural development. Inappropriate land use, with subsequent accelerated rates of soil erosion, was the main cause of frequent flooding in recent years. Especially, after the 1998 flooding of the Yangtze River valley, environmental problems such as soil erosion have become of greater concern to the government and the public. The United Nations Food and Agriculture Organization (FAO) declared soil erosion one of the important social, economic and ecological problems, seriously threatening land-use sustainability in China (FAO, 2004). Hence, sustainable land-use is a key countermeasure for soil and water conservation. In order to bring soil erosion and frequent flooding under control, the Chinese Government initiated the Grain-for-Green Programme, also called the Conversion of Cropland to Forests and Grassland Programme.

Soil erosion is also a serious concern in the middle and lower reaches of the Jialing River, a main tributary of the Yangtze River. The Jialing River Basin was one of the main source areas of the sediments in the Yangtze River Basin in the mid-1980s (Jing, 2002). The area of soil erosion was $6{\cdot}97 \times 10^4\,km^2$, taking up 63 per cent of the total area, and the soil erosion amount reached $3{\cdot}21 \times 10^6\,t\,y^{-1}$ in the Jialing River Basin in the mid-1980s (Fan *et al*., 2004). As an area with poor agricultural conditions and a degraded environment, it was considered a priority area for soil conservation in China in 1987 (Fan *et al*., 2004).

As soil erosion is closely related to land use, it varies much between different uses of land (Yang and Liang, 2004). However, there is limited knowledge of the specific relationship between land-use type and soil erosion. Therefore, as a typical agricultural county with severe soil erosion in the middle reaches of the Jialing River Basin, the Zhongjiang County was chosen as a case study. In this study, we used mapped data of local governments in a GIS-based spatially explicit analysis (Fan *et al*., 2004). The objectives of this study were: (1) to analyse the relationship between land use and soil erosion; and (2) to carry out integrated socio-economic assessment on the feasibility of improving sloping farmland, so as to provide a preliminary basis for establishing soil erosion prevention and control measures tailored to the different socio-economic conditions in this critical region.

MATERIALS AND METHODS

The Study Area

Zhongjiang County, the study area, is located inside the upper reaches of the Yangtze River (Plate I). It ranges from 104° 26′ E to 105° 10′ E, and from 30° 31′ N to 31° 37′ N. The topography in the study area is characterized by high altitude in the Northwest, declining towards the Southeast. Within this area, about 69 per cent of the land belongs to hilly areas, and 26 per cent, 3 per cent and 2 per cent belong to mountainous areas, plain areas and water bodies, respectively. Zhongjiang County has a subtropical monsoon climate; average annual temperature is 16·7°C; and the frost-free period has 286 days. The annual precipitation is 883 mm, more than 60 per cent of which occurs between June and August and frequently comes in heavy storms that create torrential runoff and erosion and render much of the rainfall ineffectual.

Zhongjiang County itself has an area of 2184·6 km^2 and an agricultural population of 1·2 million. Land use in Zhongjiang County is mainly for agriculture, with 77·82 per cent used directly for farming, 12·33 per cent used for forestry, and 0·90 per cent used for permanent crops.[1] According to the statistical data provided by the local land administration bureau, farmland in hilly and mountainous area comprises 77 per cent of the total farmland in Zhongjiang County. The soil erosion processes in Zhongjiang County is typical for sheet and rill erosion accompanied by gully erosion. Erosion affects 53 per cent of the region, and each year more than 11·25 million tonnes of soil are lost, of which the lost soil in dry land accounts for 31·2 per cent. Each year this causes a nutrient loss of N, P and K in the range of 19000 t, 21000 t and 2600 t, respectively.[2]

Data Source and Processing

Our main data sources are maps of land use, soil erosion, altitude (Digital Elevation Model; DEM), administrative area (in townships and towns), and socio-economic statistical data of Zhongjiang County. We have used a map of land use from the year 2000 at a 1:100 000 scale,[3] a map of soil erosion from 2000 at a 1:100 000 scale,[4] and a map of the administrative area from 2000.[5] All three maps were paper based, and had to be digitized and edited for use

[1]Land cultivated with crops that occupy the land for long periods and need not be replanted after each harvest; this category includes land under flowering shrubs, fruit trees, nut trees and vines, but excludes land under trees grown for wood or timber.
[2]Land Administration Bureau of Zhongjiang County. 1997. *Annals of Land in Zhongjiang County*.
[3]Land Administration Bureau of Zhongjiang County. 2000. *Land Use Map of Zhongjiang County*. The need for accurate and reliable data on China's land has recently caught the attention of the Chinese agricultural and land administrative authorities. A large-scale national land survey took place during 1984–1996. The purpose of the nation-wide survey was to gather systematic county-level data on the types, area, and location of land use as well as the distribution of land of different ownerships. The survey adopted a standardized land classification scheme consisting of eight 1-digit categories and forty-six 2-digit categories and was primarily based on the reading, verification, classification, and measurement of different land use from the most recent aerial photos, Landsat images, and maps available. Most of the land survey was conducted during 1990–1995, but it was subsequently decided that all surveys should be adjusted to the standard time of 31 October 1996 in a manner similar to the national population census (Lin and Ho, 2003). From then on, annual renewal of the information on land-use change has been carried out.
[4]Water Resources Bureau of Zhongjiang County. 2000. *Map of Soil Erosion Gradation in Zhongjiang County*.
[5]People's Government of Zhongjiang County. 2000. *Map of Administrative Area in Zhongjiang County*.

by ARC/INFO. The processed land-use map contains nine land-use types: farmland; permanent crops; forests and woodland; reforestation land; mined and special land; settlements and built-up land; water body; grassland; and unused land (Plate I).

The soil-erosion map in this study is the result of the second large-scale national soil erosion survey of China in 1999. The purpose of the nation-wide survey was to gather systematic county-level data on the types, intensity, area, and location of soil erosion. The survey in the study area adopted the gradation standards of soil-erosion intensity appropriate for Southwest China (Table I) and was primarily based on the reading, verification, classification, and measurement of different soil-erosion patterns in Landsat TM satellite images (mainly in 1995 and 1996), maps available (land-use map, topography map, geological map, soil map), and field data (e.g. run-off and soil loss experimental data) provide by local monitoring stations of soil and water conservation. An assessment of annual soil loss rates was carried out using the ^{137}Cs technique, which was applied in the upper reaches of the Yangtze River (Zhang *et al*., 2000). Tables II and III contain the gradation standards of sheet and rill erosion and gully erosion, respectively. In the finished product, the average location errors are less than 0·6 mm (about 2 pixels) on the soil-erosion map, and the out-door survey and random sample check (checked patches are no less than 5 per cent of the total patches) testified that the average accuracy for soil erosion intensity is 90 per cent (Zeng and Li, 2000). The degree of erosion in the map was classified into 5 levels: very slight; slight; moderate; strong; and very strong (no ultra-strong erosion occurs in Zhongjiang County).

There are 56 townships and towns in the administrative map. Socio-economic data containing population, average annual income of peasants, gross domestic product (GDP) and possessing grain in the level of townships and towns were obtained from the Bureau of Statistics of Zhongjiang County. DEM data at a 1:250 000 scale was obtained from the State Bureau of Surveying and Mapping of China, from which a slope-conditions map was

Table I. Gradation standards of soil erosion intensity (MWRC, 1997)

Degree of soil erosion	Average soil erosion modulus ($t\ km^{-2}\ y^{-1}$)	Average soil loss depth[a] ($mm\ y^{-1}$)
Very slight	< 500	< 0·37
Slight	500 ~ 2500	0·37 ~ 1·9
Moderate	2500 ~ 5000	1·9 ~ 3·7
Strong	5000 ~ 8000	3·7 ~ 5·9
Very strong	8000 ~ 15 000	5·9 ~ 11·1
Ultra-strong	> 15000	> 11·1

[a]The soil-loss depth was converted from the average soil volume weight (1·35 $g\ cm^{-3}$).

Table II. Gradation standards of sheet and rill erosion (MWRC, 1997)

Degree of soil erosion	Slope (degrees)	Degree of vegetation cover (%)
Very slight	< 5	> 75
Slight	5 ~ 8	60 ~ 75
Moderate	8 ~ 15	45 ~ 60
Strong	15 ~ 25	30 ~ 45
Very strong	25 ~ 35	< 30
Ultra-strong	> 35	

Table III. Gradation standards of gully erosion (MWRC, 1997)

Degree of soil erosion	Slight	Moderate	Strong	Very strong	Ultra-strong
Gully density ($km\ km^{-2}$)	1 ~ 2	2 ~ 3	3 ~ 5	5 ~ 7	> 7
Proportion of gully in the sloping area (%)	< 10	10 ~ 25	25 ~ 35	35 ~ 50	> 50

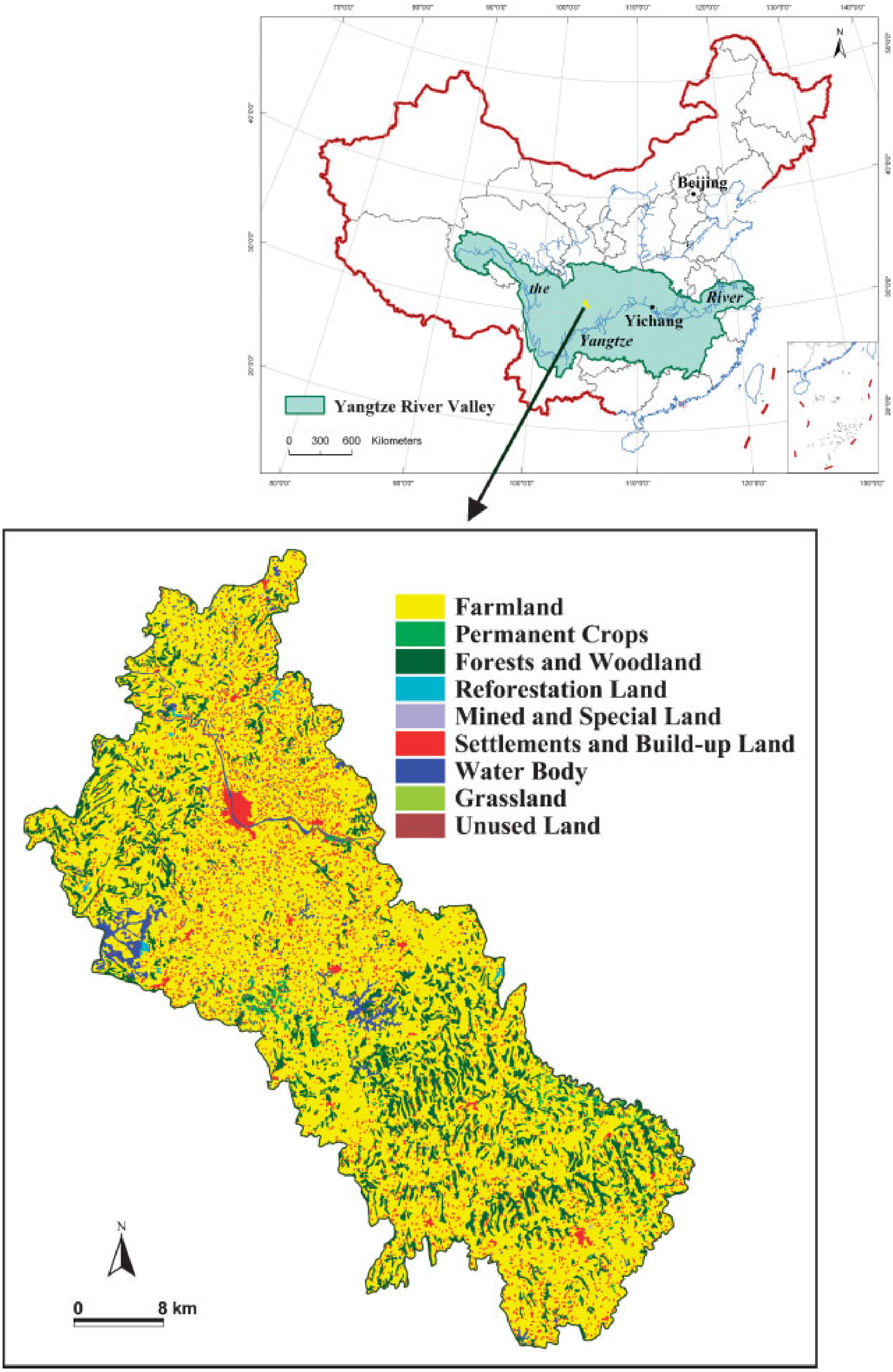

Plate I. Location map of the study area Zhongjiang County in the upper reaches of the Yangtze River.

derived by utilizing the 'SLOPE' function in the GRID module of ESRI's ArcGIS. According to local conditions of agricultural production, the slope degree was classified into 4 levels: $0\sim5$, $5\sim10$, $10\sim25$ and >25 degrees.

Methods

After being geometrically corrected and geo-referenced, the three maps of land use, soil erosion and slope conditions were used to detect the relationship between land use and soil erosion. Geographic information system (GIS) analysis was adopted for that purpose. In particular, the ESRI's ArcGIS spatial analysis module was used to aggregate, synthesize and analyse the databases, and to identify spatial relationships.

Socio-economic data were used to assess the feasibility of improving sloping farmland. Because the socio-economic data for the various indicators are in many different dimensions, it was impossible to directly compare the regional variation in the various measures. Therefore, they were transformed into common units by normalizing all measurements, according to the formula (1). The normalized values have a mean of zero and a standard deviation of 1 (Heilig, 2004).

$$Z = \frac{X - \mu}{\sigma} \tag{1}$$

Where Z is the standardized value of indicator; X is the value of original data; μ is the mean; and σ is the standard deviation.

We used the normalized values to calculate a Feasibility Index according to formula (2) (Wang *et al*., 2003b):

$$I = \sum_{i=1}^{n} Zi \cdot Wi \quad (i = 1, 2, \ldots, n) \tag{2}$$

Where I is the Feasibility Index; Z_i is the standardized value of indicator i; W_i is the weight for indicator i; and n is the number of indicators.

The weights for the indicators were determined by conducting semi-structured interviews, which were undertaken in open interviews. A questionnaire on the indicator weights was prepared and semi-structured interviews were conducted with 25 farmers by household survey and 8 experts during a small meeting.

RESULTS

Agricultural Land at Different Slope Conditions

By overlaying the two maps of land use and slope conditions, agricultural land at different slope rank was obtained (Table IV and Plate II). The agricultural land includes farmland, permanent crops, forests and woodland, reforestation land, grassland and unused land. The area of farmland with a slope of <5 degrees is 43 675 ha, which takes up 20 per cent of the total area; and the areas of farmland with slope at $10\sim25$ degrees and >25 degrees are 84 061 ha and 8323 ha, respectively, which account, for 38·5 per cent and 3·8 per cent of the total area, respectively (Table IV).

Agricultural Land with Different Degree of Soil Erosion

By overlaying the two maps of land use and soil erosion, agricultural land with different degree of soil erosion was obtained (Table V and Plate III). The total erosion area of agricultural land in Zhongjiang is 105 098 ha. From Table V it can be seen that the areas of farmland with very slight erosion, slight erosion, moderate erosion, strong erosion and very strong erosion are 29 792 ha, 22 546 ha, 18 669 ha, 17 940 ha and 1630 ha, respectively, which account for 28·3 per cent, 21·5 per cent, 17·8 per cent, 17·1 per cent and 1·6 per cent of the total erosion area of agricultural land, respectively. Farmland with strong or even very strong soil erosion mainly occurs in the

Table IV. Agricultural land at different slope conditions

Land-use type	Slope conditions							
	0∼5 degrees		5∼10 degrees		10∼25 degrees		> 25 degrees	
	Area (ha)	%[a]	Area (ha)	%	Area (ha)	%	Area (ha)	%
Farmland	43 675·4	25·7	33 949·3	20·0	84 061·0	49·4	8323·3	4·9
Permanent crops	601·9	30·5	397·9	20·2	877·2	44·5	93·9	4·8
Forests and woodland	2487·8	9·3	3434·4	12·9	17 024·9	64·0	3662·4	13·8
Reforestation land	11·1	3·4	21·3	6·6	226·2	69·7	65·8	20·3
Grassland	0·3	1·6	0·2	1·0	12·0	62·8	6·6	34·6
Unused land	89·8	98·6	0·4	0·4	0·8	0·9	0·1	0·1

[a]This is the percentage of the total area of a certain land-use type, e.g. farmland. For instance: almost 26% of all farmland has a slope of less than 5 degrees; and almost 5% has a slope of more than 25 degrees.

townships and towns of Wadian, Hexing, Huipeng, Jifeng, Shiquan, Jiguang, Shilong and Tongshan, of which Jifeng, Hexing and Tongshan have the most serious conditions (Plates I and III, and Figure 1).

Relationship Between Land Use and Soil Erosion

To analyse the relationship between land use and soil erosion we have overlaid all three maps of land use, soil erosion and slope conditions. Table VI gives the situation about land use and soil erosion at different slope conditions. From Table VI, we can draw the following conclusions:

(1) Soil erosion is more often happening on the agricultural land with slope of 10∼25 degrees, on which the percentages of soil erosion are 52·4 per cent, 51·3 per cent, 65·2 per cent, 71·5 per cent and 51·5 per cent for farmland, permanent crops, forests and woodland, reforestation land and grassland, respectively. Only unused land is an exception to this trend: 99·8 per cent of the soil erosion is happening on sites with a slope of < 5 degrees, which may be closely related to the specific site conditions.
(2) Farmland and permanent crops have similar situation of soil erosion, almost with the same percentage of soil erosion corresponding to slope condition. This indicates that soil erosion in the study area is mainly driven by human activities.
(3) Farmland with soil erosion accounts for 86·2 per cent of the total eroded agricultural land. In the farmland with soil erosion, 22·5 per cent has a slope of < 5 degrees, 20·3 per cent has a slope of 5∼10 degrees, and 57·1 per cent has a slope of > 10 degrees. On gentle slopes with less than 5 degrees inclination, some 6 per cent of the farmland had strong or very strong erosion. However, on steep slopes of more than 25 degrees, strong or very strong erosion was reported from more than 42 per cent of the farmland. Therefore, the task of soil and water conservation should be focused on the prevention of soil erosion on farmland with a slope of more than 10 degrees, especially with a slope of more than 25 degrees.

Socio-economic Assessment on the Feasibility of Improving Sloping Farmland

Local socio-economic conditions as well as physical conditions should be taken into account to improve sloping farmland. There are obvious differences in socio-economic conditions among the townships and towns in Zhongjiang County. Therefore, it is necessary to carry out socio-economic assessment to evaluate the feasibility in every township or town of improving sloping farmland and conserving soil and water.

Possessing grain has been playing an important role in meeting local people's food demands. Average income of peasants and the GDP in a township will determine the local capability to take some measures for soil and water conservation. Accordingly, Possessing grain per capita, average annual income of peasants per capita and GDP per capita were taken as indicators in assessing the feasibility of erosion-prevention measures in every township.

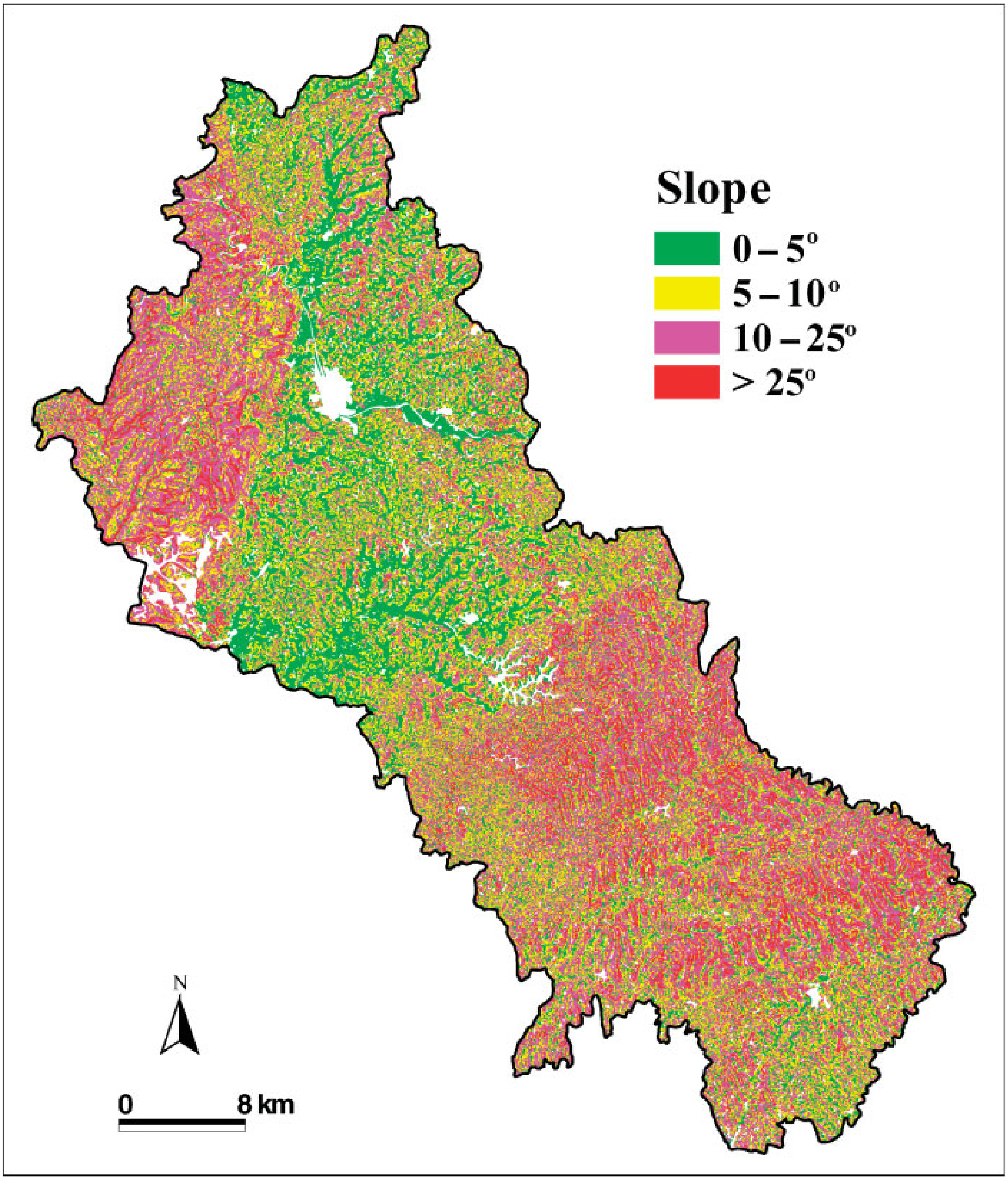

Plate II. Agricultural land of different slope conditions in Zhongjiang County.

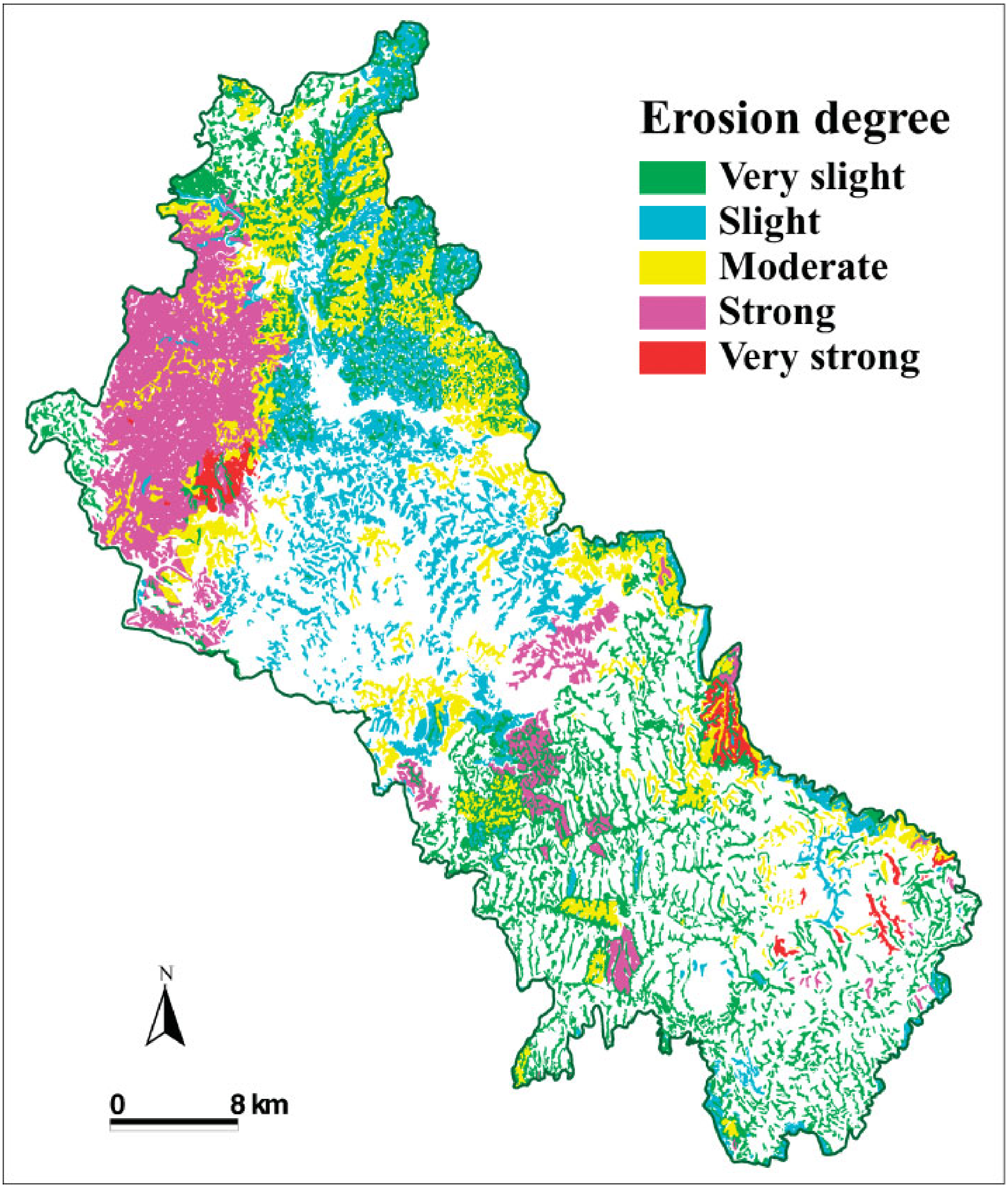

Plate III. Agricultural land with different degrees of soil erosion in Zhongjiang County.

Table V. Agricultural land with different degree of soil erosion

Land-use type	Degree of soil erosion											
	Very slight		Slight		Moderate		Strong		Very strong		Total	
	Area (ha)	%[a]	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Farmland	29 792·2	32·9	22 545·7	24·9	18 668·7	20·6	17 939·9	19·8	1629·5	1·8	90 576	86·18
Permanent crops	156·8	22·1	216·3	30·5	261·9	36·9	61·7	8·7	13·2	1·9	709·9	0·68
Forests and woodland	3648·6	27·0	1665·0	12·3	2972·1	22·0	4509·9	33·3	738·3	5·5	13 533·9	12·88
Reforestation land	24·4	9·5	49·7	19·4	100·4	39·1	82·3	32·0	0	0	256·8	0·24
Grassland	0	0	0	0	0	0	2·7	100	0	0	2·7	0·00
Unused land	0	0	17·1	91·0	1·7	9·0	0	0	0	0	18·8	0·02
Total	33 622·0	32·0	24 493·8	23·3	22 004·8	20·9	22 596·5	21·5	2381·0	2·3	105 098·1	100

[a]This is the percentage of the total area of a certain land-use type, e.g. permanent crops. For instance: 22·1% of the permanent crops are grown on land with very slight soil erosion.

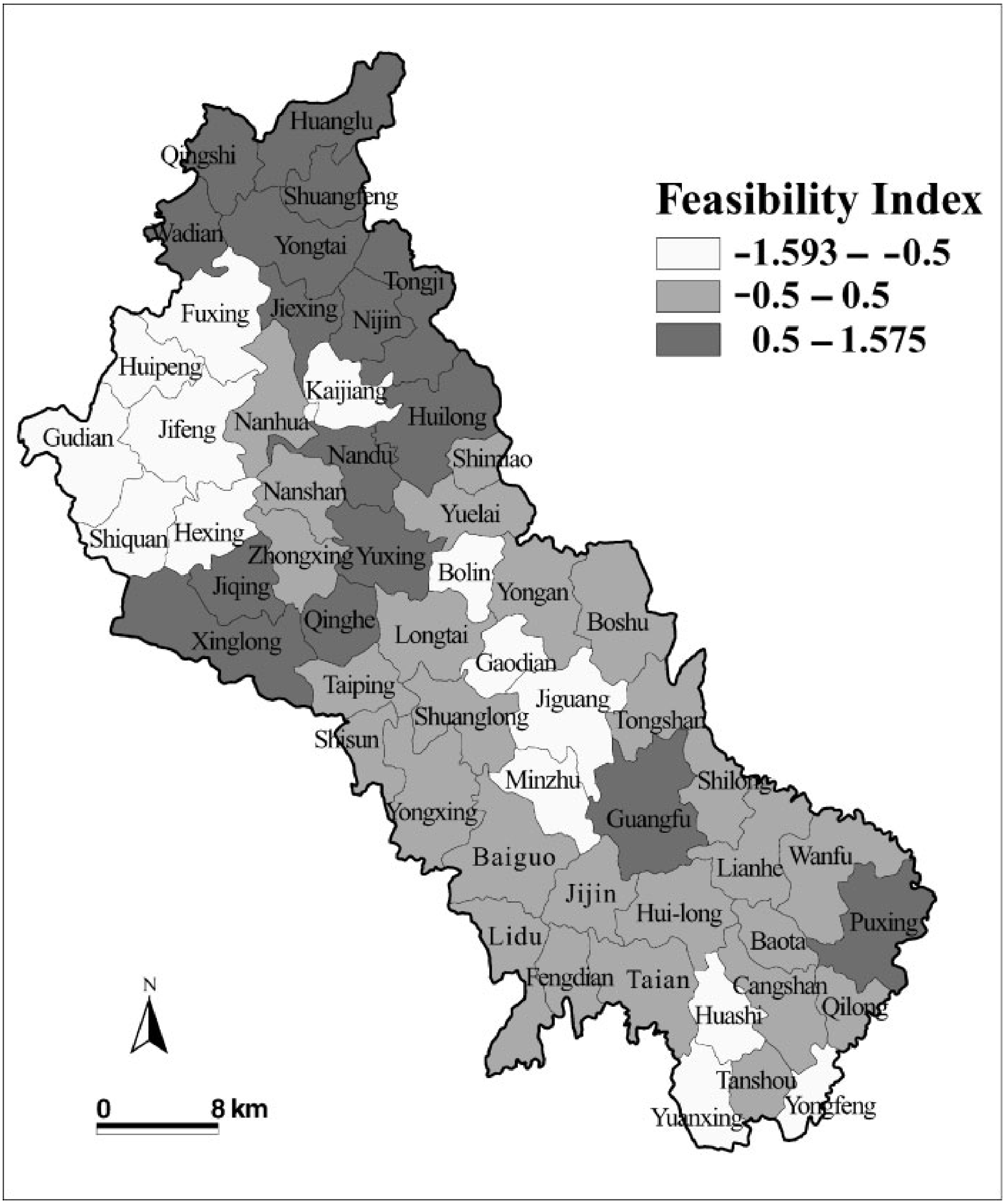

Figure 1. Socio-economic assessment on the feasibility of erosion-prevention measures in the townships and towns of Zhongjiang County.

Table VII shows the results of our feasibility assessment. The ‘join’ function in ArcView GIS was used to combine the integrated indices of assessment results and the map data of the administrative areas. The feasibility indices of all the 56 townships and towns were classified into 3 levels, i.e. less than −0·5, −0·5–0·5 and greater than 0·5 (Figure 1).

Table VI. Land use and soil erosion at different slope conditions

Land-use type	Soil erosion	Slope								Sum		% of eroded agricultural land
		0∼5 degrees		5∼10 degrees		10∼25 degrees		> 25 degrees				
		Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	
Farmland	Very slight/slight	15 892·56	77·8	11 593·49	63·1	23 222·57	48·9	1614·18	37·5	52 322·80	57·8	86·161
	Moderate	3269·26	16·0	3869·91	21·1	10 669·35	22·5	855·25	19·9	18 663·76	20·6	
	Strong/very strong	1261·45	6·2	2907·17	15·8	13 566·22	28·6	1832·19	42·6	19 567·02	21·6	
	Sum	20 423·27	100·0	18 370·57	100·0	47 458·13	100·0	4301·62	100·0	90 553·58	100·0	
	% of total		22·5		20·3		52·4		4·8		100·0	
Permanent crops	Very slight/slight	109·36	67·8	83·62	57·4	166·19	45·7	13·96	35·7	373·12	52·6	0·675
	Moderate	47·15	29·2	52·86	36·3	142·82	39·2	19·03	48·7	261·86	36·9	
	Strong/very strong	4·69	2·9	9·15	6·3	55·04	15·1	6·06	15·5	74·95	10·6	
	Sum	161·20	100·0	145·63	100·0	364·04	100·0	39·05	100·0	709·92	100·0	
	% of total		22·7		20·5		51·3		5·5		100·0	
Forests and woodland	Very slight/slight	619·84	58·3	816·36	47·2	3289·61	37·3	586·74	30·7	5312·55	39·3	12·874
	Moderate	252·24	23·7	385·73	22·3	1971·40	22·3	361·10	18·9	2970·47	22·0	
	Strong/very strong	192·02	18·0	525·90	30·4	3567·79	40·4	961·81	50·4	5247·52	38·8	
	Sum	1064·10	100·0	1728·00	100·0	8828·80	100·0	1909·65	100·0	13 530·54	100·0	
	% of total		7·9		12·8		65·2		14·1		100·0	
Reforestation land	Very slight/slight	3·52	34·5	5·25	28·5	58·83	32·0	6·56	14·7	74·16	28·9	0·244
	Moderate	3·32	32·5	3·36	18·3	72·14	39·3	21·55	48·4	100·38	39·1	
	Strong/very strong	3·38	33·0	9·80	53·2	52·67	28·7	16·43	36·9	82·27	32·0	
	Sum	10·21	100·0	18·41	100·0	183·65	100·0	44·54	100·0	256·81	100·0	
	% of total		4·0		7·2		71·5		17·3		100·0	
Grassland	Very slight/slight	0	0	0	0	0	0	0	0	0	0	0·003
	Moderate	0	0	0	0	0	0	0	0	0	0	
	Strong/very strong	0·06	100·0	0	0	1·40	100·0	1·25	100·0	2·71	100·0	
	Sum	0·06	100·0	0	0	1·40	100·0	1·25	100·0	2·71	100·0	
	% of total		2·4		0		51·5		46·1		100·0	
Unused land	Very slight/slight	17·11	90·8	0·04	100·0	0	0	0	0	17·15	90·8	0·018
	Moderate	1·74	9·2	0	0	0	0	0	0	1·74	9·2	
	Strong/very strong	0	0	0	0	0	0	0	0	0	0	
	Sum	18·85	100·0	0·04	100·0	0	0	0	0	18·89	100·0	
	% of total		99·8		0·2		0		0		100·0	

Table VII. Original data and their standardized values for the indicators and the Feasibility Index value of each township[a]

Township or town	Indicator						Feasibility Index value (I)[e]
	Possessing grain per capita ($W = 0{\cdot}386$)[b]		Average annual income of peasants per capita ($W = 0{\cdot}32$)		GDP per capita W = 0·294)		
	Original data (kg)	Standardized value (Z)[c]	Original data (RMB¥)[d]	Standardized value (Z)	Original data (RMB¥)	Standardized value (Z)	
Huanglu	549	1·783	2328	1·148	2918	0·440	1·185
Qingshi	481	0·953	2209	0·533	2803	0·252	0·613
Shuangfeng	531	1·564	2335	1·185	2260	−0·638	0·795
Wadian	584	2·210	2103	−0·015	3232	0·954	1·129
Yongtai	464	0·746	2312	1·066	3051	0·658	0·822
Tongji	470	0·819	2538	2·234	3779	1·850	1·575
Fuxing	345	−0·706	1889	−1·122	2326	−0·530	−0·787
Jiexing	351	−0·633	2554	2·317	4747	3·436	1·507
Nijin	430	0·331	2231	0·647	3879	2·014	0·927
Huipeng	405	0·026	1821	−1·473	2087	−0·921	−0·732
Nanhua	243	−1·951	2241	0·698	4104	2·383	0·171
Kaijiang	96	−3·745	2570	2·400	2786	0·224	−0·612
Huilong	442	0·477	2219	0·585	3175	0·861	0·625
Jifeng	235	−2·049	1848	−1·334	1870	−1·277	−1·593
Gudian	356	−0·572	1791	−1·628	2115	−0·875	−0·999
Nandu	365	−0·462	2243	0·709	4210	2·556	0·800
Shimiao	435	0·392	2068	−0·196	2642	−0·012	0·085
Nanshan	420	0·209	2034	−0·372	2098	−0·903	−0·304
Shiquan	277	−1·536	1857	−1·287	2356	−0·481	−1·146
Yuelai	403	0·001	2054	−0·269	2338	−0·510	−0·235
Hexing	363	−0·487	1797	−1·597	1758	−1·460	−1·128
Yuxing	456	0·648	2466	1·862	2697	0·078	0·869
Zhongxing	348	−0·670	2143	0·192	2274	−0·615	−0·378
Jiqing	444	0·502	2310	1·055	3193	0·891	0·793
Bolin	375	−0·340	2117	0·057	1825	−1·350	−0·510
Yongan	384	−0·230	2062	−0·227	2778	0·211	−0·100
Boshu	398	−0·060	2019	−0·450	2221	−0·702	−0·373
Xinglong	381	−0·267	2421	1·629	3635	1·615	0·893
Qinghe	465	0·758	2332	1·169	2541	−0·177	0·615
Longtai	350	−0·645	2343	1·226	3045	0·648	0·334

Gaodian	348	−0·670	1829	−1·432	2254	−0·648	−0·907
Taiping	418	0·185	2274	0·869	2288	−0·592	0·175
Jiguang	358	−0·548	1971	−0·698	2307	−0·561	−0·600
Tongshan	422	0·233	2001	−0·543	2090	−0·916	−0·353
Shuanglong	337	−0·804	2148	0·218	2553	−0·158	−0·287
Shisun	378	−0·304	2074	−0·165	2548	−0·166	−0·219
Yongxing	372	−0·377	2080	−0·134	2354	−0·484	−0·331
Shilong	425	0·270	2014	−0·475	2607	−0·069	−0·068
Guangfu	399	−0·047	2177	0·367	3586	1·534	0·550
Minzhu	317	−1·048	1974	−0·682	2189	−0·754	−0·845
Baiguo	360	−0·523	2046	−0·310	2481	−0·276	−0·382
Lianhe	506	1·259	2017	−0·460	2688	0·063	0·357
Wanfu	495	1·124	2030	−0·393	2555	−0·155	0·263
Jijin	428	0·307	2016	−0·465	2325	−0·531	−0·187
Hui-long	460	0·697	2191	0·440	2660	0·017	0·415
Puxing	595	2·345	2151	0·233	2655	0·009	0·982
Lidu	497	1·149	2078	−0·144	2593	−0·092	0·370
Baota	435	0·392	1935	−0·884	2534	−0·189	−0·187
Fengdian	431	0·343	2092	−0·072	2453	−0·322	0·015
Cangshan	321	−0·999	2073	−0·170	2807	0·258	−0·364
Taian	426	0·282	1941	−0·853	2316	−0·546	−0·325
Huashi	381	−0·267	1996	−0·568	2177	−0·774	−0·512
Qilong	404	0·014	2097	−0·046	2573	−0·125	−0·046
Yuanxing	379	−0·291	1907	−1·029	2190	−0·752	−0·663
Tanshou	454	0·624	1955	−0·780	2225	−0·695	−0·213
Yongfeng	386	−0·206	1858	−1·282	2131	−0·849	−0·739

[a]Data are from the Bureau of Statistics of Zhongjiang County, 2002; [b]The weights for the indicators were derived from interviews: we asked 8 experts and 25 local farmers to evaluate the relative weight of each indicator, and the weights (W) are the average value of the 33 interviewers; [c]Standardized value (Z) is calculated by formula (1); [d]Exchange rate US$ to RMB¥: 1 to 8·3; [e]Feasibility Index value (I) is calculated by formula (2).

DISCUSSION

Grain-for-Green Programme

The planting of annual crops and livestock grazing on deforested lands with a slope of more than 25 degrees has led to accelerated rates of soil erosion in China. China has 6·067 million hectares of steep-sloping farmlands of over 25 degrees, most of which is located in the Yangtze River and Yellow River basins (SFA, 2000). In order to bring soil erosion and frequent flooding under control, the Chinese Government initiated the Grain-for-Green Programme, also called the Conversion of Cropland to Forests and Grassland Programme. The main feature of this programme is the provision of free grain and cash payments for participating farmers if they convert cultivated and grazing land to forests and grassland. The annual grain payment (that is, unprocessed grain for human consumption) made to participants in the Yangtze River Basin is 150 kg per annum per mu (1 mu = 0·067 ha [0·067 ha]) of converted land. The payment of grain and cash for the conversion of cropland to grassland is made for two years, while for the conversion of cropland to forests of commercial tree species the period of payment is five years. If the forests are planted primarily for ecological benefits, payments will be made for eight years. The Chinese Government considers the payment of grain to be valued at 1·4 RMB¥ (1 RMB¥ = 8·3 US$) per kg. Funds for this programme are provided by the Central Government (State Council, 2002).

Critics of the Grain-for-Green Programme have argued that it only improves the local environment without fundamentally improving the livelihoods of the farmers involved. In fact, what should the farmers do once the payments of grain and cash are stopped after five or eight years? Most likely they will have to go back to farming or livestock grazing to make a living. There is a clear need to integrate long-term benefits with short-term improvements, and to balance economic benefits and ecological benefits in soil and water conservation. Economic development should be considered an essential component of erosion control (Wen, 1993; Fischer *et al*., 1997). Therefore, the Grain-for-Green Programme and the measures for water and soil conservation should not simply rely on providing farmers list short-term subsidies. Instead it is necessary to improve cultivation techniques, optimize the local agricultural structure and improve the livelihoods of the farmers by introducing non-agricultural sources of income in the long run.

Taking Measures Suited to Local Socio-economic Conditions to Improve Sloping Farmland

In the townships and towns with a Feasibility Index above 0·5, such as Wadian, Huanglu and Tongji (Figure 1), sloping farmland should be terraced on a large scale. Prime farmland[6] needs to be constructed and increased so as to ensure the progress of the Grain-for-Green Programme, and mitigate issues of grain shortage in the future. It is necessary to change sloping farmland to terrace over a large area and introduce appropriate irrigation systems (Heilig *et al*., 2000). Farmland with a slope over 25 degrees should be converted to forests or grassland, since it is usually too steep for terraced agriculture. Problems exist with forest plantations and other erosion control projects that require several years to produce noticeable benefits. Therefore, planting shrubs and grasses can provide benefits to local residents in a short time, by providing opportunities for animal husbandry and household energy. Moreover, the microclimatic conditions near a bare soil surface can be hostile and unfavourable to seedling establishment in this climate, and it is imperative that the microclimatic conditions near the ground surface be improved during seedling establishment. This can be done by providing surface ground cover. At the same time as tree seedling planting, shrubs are planted to reduce water runoff and soil erosion, while increasing soil water storage (Zhang *et al*., 2002). In fact, shrub planting and grasslands also have more rapid conservation effects than tree planting. Experimental results show that, in Sichuan Province, planting pasture on sloping farmland with a slope over 25 degrees can decrease soil loss by about 15 $t\,ha^{-1}\,y^{-1}$ (Guo and Li, 1999). Association with shrubs

[6]Prime farmland, also called basic farmland, consists of: (1) agricultural production bases (crops such as cotton, edible oils, and other high-quality agricultural products) approved by government; (2) farmland with high productivity and a good irrigation system and that has been exploited; (3) vegetation production bases for large and middle cities; and (4) experimental fields for science and educational purposes (Ding, 2003).

and grasses has been demonstrated in the upper Yantze River Basin: trees were transplanted in 3–4 m rows with a tree spacing of 1–2 m; shrubs were directly planted in rows between the rows of trees with 0·3–0·5 m spacing; and a natural grass cover was allowed to establish itself over the rest of the area (Zhang *et al*., 2002). Therefore, more attention should be paid to afforestation combined with planting of shrubs and grasses for carrying out the Grain-for-Green Programme.

In the townships and towns with a Feasibility Index between −0·5 and 0·5, such as Shilong and Longtai (Figure 1), it is necessary to develop ecological agriculture in combination with improving the sloping farmland and constructing prime farmland (Cai *et al*., 2000). Steep-sloping farmland should be converted to forests or grassland only step by step, to prevent a drastic decline of the grain output. Because the socio-economic ability (according to the Feasibility Index) is not strong, more attention should be paid to improving the technology for irrigation and cultivation techniques.

Townships and towns with a Feasibility Index below −0·5, are in a particularly bad position. They have the most serious soil erosion and the lowest socio-economic ability to improve the situation (Plate III and Figure 1). For example, in most parts of Jifeng (with the lowest Feasibility Index value of −1·593) and Hexing (with a Feasibility Index value of −1·128), the soil erosion degree is very strong (Plate III and Figure 1), while their socio-economic situation is at the poorest level (Table VII). For example, possessing grain per capita, average annual income of peasants per capita and GDP per capita in Jifeng are only 235 kg, 1848 RMB¥, and 1870 RMB¥, respectively. There is a lot of steep-sloping farmlands in these townships and towns. We found some steep-sloping farmlands in Jifeng and Hexing with a slope over 40 degrees, which was still being cultivated using traditional cultivation techniques. Therefore, soil conservation on steep-sloping farmland is the most important measure to improve the situation. More advanced techniques of conservation cultivation could greatly reduce soil erosion and increase crop yields on the steep-sloping farmland (Wen, 1993; Shi, 1998). These techniques include contour ridge cultivation, pit-cultivation, improving soils by applying fertilizers using a multi-application method and small amounts for every application, crop rotations, intercropping, etc. It would be unwise to convert sloping farmland in these townships to forests or grassland in the near future because of the poor production techniques and the inferior socio-economic situation, which may lead to serious grain shortages. Only after improvement of the socio-economic situation can sloping farmland be converted to forests or grassland in a Grain-for-Green Programme.

Improving Ecosystems and Inhabited Environment Through Yard and Garden Construction for Households

At present, the rural housing land[7] per capita in Zhongjiang County is 178 m^2, which is far above the 20–30 m^2 per capita in Sichuan Province.[8] However, yard and garden construction for households to improve ecosystems and the inhabited environment has been overlooked, even some barren land existing in a few yards and gardens. In fact, fruit-tree planting would be helpful to raise income and avoid soil erosion (Chen *et al*., 2001). Therefore, fruit-tree and grass planting in the yard and the areas surrounding the house are effective soil-conservation methods. Accordingly, concerned local management departments should pay more attention to guiding and carrying out scientific village design, so as to promote the construction of yards and gardens and optimize villager's living conditions.

CONCLUSIONS

Through analysing the relationship between land use and soil erosion, our research shows that the task of soil and water conservation in Zhongjiang County must be focused on the prevention of soil erosion on the sloping farmland. Local socio-economic conditions as well as physical conditions should be taken into account to improve

[7]Rural housing land refers to the land utilized by rural residents for dwelling and living, i.e. land for building house and other structures or affiliated facilities. According to China's farmers living customs have been formulated for a long time, rural housing land usually includes (Long and Li, 2005): (1) land for dwelling and living, such as living house, kitchen, room for livestock (e.g. pigsty, sheepfold, stable and cowshed), warehouse, room for storing farm machinery, toilet; (2) surrounding afforested land, such as bamboo forest, forest tree, flower nursery; and (3) other land for service facilities of living, such as cellar, well, methane-generating pit (usually for lighting and cooking).
[8]People's Government of Zhongjiang County. 1999. *General Land Use Planning in Zhongjiang County, Sichuan Province from 1997 to 2010*.

sloping farmland. Different measures for soil conservation should be implemented according to socio-economic differences in the ability to improve sloping farmland: in the townships and towns with a Feasibility Index above 0·5, sloping farmland should be terraced on a large scale, and farmland with a slope over 25 degrees should be converted to forests or grassland; with a Feasibility Index between −0·5 and 0·5, it is necessary to develop ecological agriculture combined with improving the sloping farmland and constructing prime farmland, and more attention should be paid to improving the technology for irrigation and cultivation techniques; with a Feasibility Index below −0·5, soil conservation in steep-sloping farmland is the most important measure to improve the situation, for which suggested techniques include contour ridge cultivation, pit-cultivation, improving soils by applying fertilizers using a multi-application method and small amounts for every application, crop rotations, intercropping, etc. In addition, improving ecosystems and the inhabited environment through yard and garden construction for households is also an effective way to prevent soil erosion.

The Grain-for-Green Programme and the measures for water and soil conservation should not simply rely on providing farmers with short-term subsidies, but enhance the quality of farmland, optimize local agricultural structure and improve the livelihoods of the farmers in the long run. It is necessary to integrate long-term ecology with short-term benefits for farmers.

ACKNOWLEDGEMENTS

This work was supported by the National Natural Science Foundation of China (Grant No. 40201001 and 40271010) and Programme of Excellent Young Scientists of the Ministry of Land and Resources of China. Part of the project was carried out at the IIASA Research Activity on Sustainable Rural Development (SRD). We thank Dr Jun Wan of Peking University for supporting data process and Professor Yili Zhang of IGSNRR, CAS for valuable suggestions on this manuscript. Last, but not least, the support provided by interviewed experts and local farmers and the authorities is gratefully acknowledged. The constructive comments of three anonymous reviewers are appreciated.

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