Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 13	No. 1	pp. 113-118	2014

Original Research Paper

Eco-environmental Changes Mechanism in the Source Region of the Yangtze River, China

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com
Received: 17-6-2013
Accepted: 24-7-2013

Key Words:
Eco-environmental changes
Yangtze River
Source Region
Remote Sensing

ABSTRACT

The source region of the Yangtze River is in the hinterland of the Qinghai-Tibet Plateau. The source region is of great ecological significance to Qinghai-Tibet Plateau, and it is praised as the resources bank of biological species. The ecological environment in the source region of Yangtze River has deteriorated during the past decades. Based on land ecological classification and field investigation, two-phase Landsat TM/ETM remote sensing data obtained in 1995 and 2010 were compared. The spatial changes and dynamic transfers of land ecotypes in the source region were analysed in this paper by using the analytical methods. Results show that the environmental problems in the source region have been caused by the global climate changes and human activities, coupled with the harsh natural conditions and a fragile ecological system. These changes also affect the water environment and the social-economic development of the river basins. There is an urgent need to study possible rehabilitation measures for the eco-environment of the region so as to ensure a sustainable larger river discharge.

INTRODUCTION

The Yangtze River, the largest river in China, rises in the hinterland of Qinghai-Tibet Plateau. The source region of the Yangtze River was paid a close attention by the whole society, especially by science researchers in recent years because of its unique natural environment, peculiar water-conserve ecological functions, abundant natural resources, diversified biological species, and the great environmental impacts on the river basin (Cheng & Guo 2002, Dong et al. 2002, Wang et al. 2001). Countless rivers and creeks originate in the source region, which is praised as 'China's water tower'.

The natural environment of this area is unusually harsh and the eco-environment is extremely fragile. With the global climate changes and aggravation of unreasonable human activities, the primitive landscape and ecosystem were destroyed to some degree (Wang et al. 2001). Thus, a series of environmental problems appeared, such as grassland degradation, land desertification, soil erosion aggravation, and water yield reduction, etc. As a part of the whole river basin, changes of eco-environment and hydrographic conditions in the source region unavoidably have made a great impact on the middle and lower reaches of the Yangtze River. It is extremely urgent to analyse the reasons of these eco-environmental problems in the source region of the Yangtze River and take scientific measures to protect and improve the eco-environment so as to maintain the ecological balance and promote economic sustainable development of the basin.

THE STUDY AREA

The source region of the Yangtze River roughly lies between 33°30'-35°35'N and 90°93'-95°75'E (Wang et al. 2001), with a total area of $12.12\times10^4 km^2$ and with an average altitude above of 5,000 m (Fig. 1). The area slopes downward from west to east. The western region is a combined landform of low-mountains and wide valleys with lakes, and the southeast is a combined landform of high-mountains and canyons. The source region has a typical continental alpine climate, with the characteristics of cold, dry, and sharp difference in temperature, much wind and snow, and violent climate changes. Annual mean air temperature is -1.024°C, annual precipitation is 221.5mm-515mm, and annual evaporation is 1,300mm-1,400mm. Because of the abundant biological species, the source region is praised as "the resources bank of biological species". There are various wild plants, including more than one hundred kinds of wild Chinese medical herbs, such as *Glycyrrhiza uralensis*, *Cordyceps sinensis*, *Rheum palmatum*, *Przewalskia tangutica*, *Gentiana straminea*, *Saussurea medusa*, etc. The wild animal resources are rich, most of which are peculiar alpine species, such as *Equus hemionus*, *Bos grunniens*, *Pantholops hodgsoni*, *Cervus albirostris*, *P. uncia*, etc. Soil in the source region is dominated by alpine cold meadow soil and alpine cold swamp meadow soils. Permafrost in the source region is quite well developed and has formed extensively distributed permafrost landforms.

By China's environmental fragility division, the ecologi-

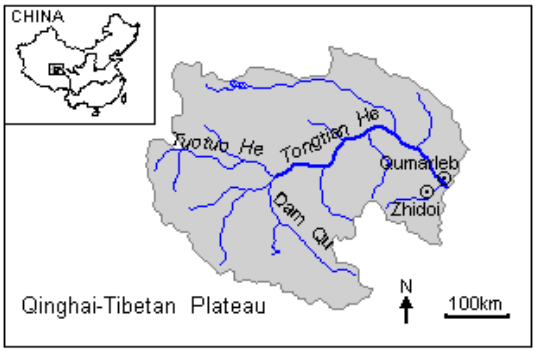

Fig. 1: Location of the source region of the Yangtze River and the study sites.

cal system of the source region belongs to Qinghai-Tibet Plateau alpine arid zone. By regional ecological district division, it belongs to Qiangtang grassland and desert ecological district of the semi-humid and semi-arid cold plateau ecosystem. The alpine cold and dry are the basic climate characteristics of the regional ecosystem, shaping its peculiar ecosystem structure thereby (Dong et al. 2002, Wang et al. 2001). According to land ecosystem division (Jorgenson et al. 1999, Xiao et al. 1997, Gai et al. 1999), the land in the study area can be divided into the grassland ecosystem, including alpine cold meadow (ACM), alpine cold steppe (ACST), alpine cold shrub (ACSH), and alpine cold swamp (ACSW), etc.; the forest ecosystem composed of timberland *Picea crassifolia*, sparse timberland *Sabina przewalskii* and a small amount of shrub timberland; the water area system composed of glaciers and permanent snows, lakes, rivers, etc.; and the other hard utilizing land system, including sandy land, salt lick, bottomlan, as well as bare rock and bare land (BR&L). Among them, grassland ecosystem accounts for 69.04% of the ecosystem present in the source region of the Yangtze River. Its structure, functions and material circulation are the core of ecosystem evolution in this area. Therefore, grassland ecology is the core of eco-environmental problems research in the source region of the Yangtze River. In grassland ecosystem, ACST and ACM are largest in area, composing the dominant part of the eco-environment, and the main carrier of grassland animal husbandry in this area. Alpine cold swamp meadow (ACSM) is an important ecotype in water-conservation and maintenance of biological diversity.

In order to explain the changing characteristics of the grassland ecosystem, based on the ecological division mentioned above, the main kind of grassland, such as the ACM and the ACST can be further divided into 3 kinds according to the different vegetative cover. They are the high vegetative cover ACST (vegetative cover over 50%), the middle vegetative cover ACST (vegetative cover 30-50%), and the low cover degree ACST (vegetative cover under 30%). As for the alpine cold meadow, they are the high vegetative cover ACM (vegetative cover over 70%), the middle vegetative cover ACM (vegetative cover 50-70 %), and the low cover degree ACM (vegetative cover under 50%).

MATERIALS AND METHODS

We mainly used the remote sensing techniques to contrast and analyse two-phase Landsat TM/ETM remote sensing data in 1995 and 2010 with the assistance of field investigation. The accurate geometric rectification was the preconditions of carrying out the compound analysis of the remote sensing images from different times and the remote sensing dynamic survey. In the present research, we have processed the TM/ETM image by radiated mark and geometric rectification, adopted the UTM geographic coordinates to rectify image, and utilized the topographic map (1:100,000) to do the image-map rectification. The RMS examination result expressed that the correctional errors are less than 1 pixel (30m). We acquired the standard false colour composite images of 432 wave bands by adopting the RGB colour composite project. At the same time, we had the color enhancement processing to the primitive TM/ETM image, including the linear drawing and the color composition. The resolution ratio of the TM/ETM primitive data was 30×30m. Through a few field explorations, we established the remote sensing image interpretation marking-database that has 14 types and 246 marking points, and with the grassland ecosystem as the core, worked out a project of the remote sensing data analysis of 8 types and 35 second types and got the conclusion of soil types distribution in the source region in 1995-2010.

We utilized the software system of ARC/INFO and ARCV-IEW to process the digital graphic, and adopted the methods of the land ecological patterns to analyse the spatial changes and dynamic transfer characteristics of land ecotypes from two aspects. The first is to analyse the spatial changes of land ecotypes and to show the characteristics of eco-environmental changes in the region in 1995-2010. The second is to use the transfer probability random models and to show the transfer direction and extent of various land ecotypes in the source region in 1995-2010 with the help of the transfer matrix methods.

We used an area-weighted average method, analysed the general changes in vegetative cover cause by evolving landscapes. Let the area of the land ecotype i is Fi, the total coverage of land ecotype i be λi, and the regional area be A, the total vegetation cover at the end of time interval t is:

$$RC_t = \frac{1}{A}\sum_{j=1}^{n} F_{it}\lambda_i \quad ...(1)$$

The general change in vegetation cover over any time interval can be calculated as:

$$\Delta RC_t = \frac{1}{A}\left(\sum_{j=1}^{n} F_{it-1}\lambda_i - \sum_{j=1}^{n} F_{it}\lambda_i\right) \quad ...(2)$$

ECO-ENVIRONMENT CHANGES

Spatial changes of grassland: From Table 1, we can see that the ACST were severely degraded in the source region of the Yangtze River in 1995-2010 by the comparative analysis of the remote sensing satellite data. The distribution area of ACST whose vegetative cover was more than 30% was principally degraded. Its area decreased by 1,859.78km^2 and its extent decreased by 11.29%. The areas of the high vegetative cover ACM decreased by 557.47km^2. Its extent decreased by 3.57%. And the areas of the low vegetative cover ACM decreased by 789.08km^2. Its extent increased by 6.65%. On the contrary, the distribution area of ACST whose vegetative cover was less than 30% expanded significantly. The area increased by 2,295.6km^2 and its extent increased by 9.95%. The area of the middle cover degree ACM increased by 604.38km^2 and its extent increased by 5.15%. The changes of ACSM were very sensitive to environmental interference, and the distribution area of ACSM decreased by 2,030.30km^2 in 1995-2010 and its extent decreased by 28.11%. The results show that the high vegetative ACST degraded severely. The area of the low cover degree ACST expanded notably. The changes of ACSM that was sensitive to the climate changes were larger.

Spatial changes of water area system: At present, the area of glaciers and permanent snows in the source region of the Yangtze River is 1,266.57 km^2. By comparative analysis of the remote sensing satellite data in 1995-2010, we find that the glaciers and permanent snows were degenerating. From Fig. 2, we can see that the area of glaciers decreased by 0.80%. The rivers were shrinking away, and the area decreased by 0.37%. At the same time, because of a great deal inland lakes shrinking away, the water area of lakes decreased by 114.81 km^2, the extent decreased by 10.64% (The inland lakes decreased by 93.09%, and the outflow lakes decreased by 6.91%).

Spatial changes of unavailable land types: In 1995-2010, the area changes of unavailable land ecotypes were expanding to different degrees in the source region of the Yangtze River (Table 2). The development of land desertification was the most intensive among them. Its extent increased by 12.56 % (annual mean increase 0.84%). The development speed of land salinization was very quick. Its extent increased by 2.21% (annual mean increase 0.15%). The distribution area of BR&L and bottomland whose vegetative cover was less than 5% was increased by 9.20% (annual mean increase 0.61%). The results show that the development of the land desertification was very intensive in the source region of the Yangtze River in 1995-2010. The expansion extents of the land desertification, the land salinization and the land bared were all more than 2%. The land desertification was the most intensive among them.

Dynamic transfers of the grassland: From Table 3, we can see that 17% low vegetative cover ACST transferred in the source region of the Yangtze River in 1995-2010, of which 8% changed into bare rock, and 3% changed into sandy and bare land, only 4% changed into middle vegetative cover ACST. Twenty eight % high cover and 33% middle vegetative cover ACST transferred, of which 24% vegetative cover declined, and 1% was desertification. The decline in the vegetative cover was the main transfer direction of the ACST in the source region of the Yangtze River. Twenty three % low vegetative cover and 32% middle vegetative cover and 30% high vegetative cover ACM were transferred. Fourteen % low vegetative cover ACM changed into bare rock, and 6% changed into ACST. Eight % middle vegetative cover changed into low vegetative cover ACM, 16% changed into ACST, and 7% changed into bare rock. Thirteen % high vegetative cover ACM changed into low or middle vegetative cover ACM, 9% changed into ACST, and 7% changed into bare rock. The Shrub forest mainly distributes in the river valley and the shady mountain slopes of southeast mountainous country in the source region of the Yangtze River. Forty three % shrub forest transferred, among them, and 39% changed into ACM. Because of the swamp drying up, 42% ACSM transferred, among them, 29% changed into ACM, another 5% changed into ACST, and another 7% changed into bare rock.

Dynamic transfers of other land ecotypes: Compared with the grassland ecosystem, the transferring extent of other land ecotypes is smaller in the source region of the Yangtze River in 1995-2010 (Table 4). Particularly the glacier and the BR&L, only 4% and 5% transferred respectively, among them, the 4% glacier changed into BR&L, and 4% BR&L changed into ACST. Eighteen % river changed into other land ecotypes, of which 8% changed into BR & L, and 9% changed into ACST. Fifteen % lake area transferred, among them, 6% changed into ACST, 7% changed into BR & L, and 2% changed into salt lick and sandy land. Twenty % sandy land transferred, of which 15% (area 427.81km^2) changed into the half fixed and fixed sand dune with the emergence of low cover degree ACST, and 4% (area 108.7km^2) changed into BR & L. At the same period, 1016.54 km^2 other land types changed into sandy land, the total amount increased 480.66 km^2. The transferring extent of

Table 1: The distribution area of grassland types in the source region of the Yangtze River in 1995-2010 (unit: km^2).

Time and Variety Extent	Grassland Types					
	Hi-middle. ACST	Low. ACST	High. ACM	Middle. ACM	Low. ACM	ACSM
1995	16,460.24	23,074.45	15,612.31	11,781.06	11,859.33	7,222.15
2010	14,600.46	25,370.05	15,054.84	12,385.44	11,070.25	5,191.85
Rate of Change (%)	-11.29	9.95	-3.57	5.15	-6.65	-28.11

*alpine cold meadow (ACM), alpine cold steppe (ACST), alpine cold swamp meadow (ACSM).

Table 2: The area changes of unavailable land types in 1995-2010 (unit: km^2).

Time and Variety Extent	Grassland Types		
	Sandy land	Salt lick	BR&L, bottomland
1995	2,956.68	139.37	25,305.87
2010	3,328.03	142.46	27,634.76
Rate of Change (%)	12.56	2.21	9.20

Table 3: Transfer matrix of grassland types in the source region of the Yangtze River in 1995-2010 (%).

1995	2010										
	High ACST	High ACM	Middle ACST	Middle ACM	Low ACST	Low ACM	Shrub forest	ACSM	River	Sandy & bare land	Bare rock
High ACST	72	0	13	0	11	0	0	0	1	1	2
High ACM	5	70	2	9	2	4	0	0	1	0	7
Middle ACST	3	0	67	0	24	0	0	0	1	1	4
Middle ACM	1	0	11	68	4	8	0	0	1	0	7
Low ACST	1	0	4	0	83	0	0	0	1	3	8
Low ACM	0	0	2	0	6	77	0	0	1	0	14
Shrub forest	0	14	0	2	0	23	57	0	3	0	1
ACSM	1	21	1	5	3	3	0	58	1	0	7

Table 4: The direction and extent of other land ecotypes' transfers in 1995-2010 (unit: km^2).

1995	2010								
	Glacier	River	Lake	Sandy land	Salt lick	BR&L	Low ACST	Middle ACST	High ACST
Glacier	96	0	0	0	0	4	0	0	0
River	0	82	0	1	0	8	6	2	1
Lake	0	0	85	1	1	7	4	1	1
Sandy land	0	1	0	80	0	4	12	2	1
Salt lick	0	1	1	5	75	11	5	2	0
BR&L	0	1	0	0	0	95	3	1	0

salinization is obvious, 11% changed into BR & L, 5% changed into sandy land, and 7% changed into ACST.

ANALYSIS OF ECO-ENVIRONMENTAL PROBLEMS

In recent years, the primitive eco-environment in the source region of the Yangtze River has suffered destruction of certain degree because of natural factors and unreasonable human activities (Cheng & Liang 1998, Cheng & Wang 1998). It was mainly the forest and grassland degradation, land desertification, soil erosion aggravation, and water yield reduction, etc. High and middle cover ACST and high cover ACM degraded obviously. They decreased respectively by 11.29% and 3.57%. The degradation of ACSM was remarkable, which decreased by 28.11%. The development trend of grassland was from high covering ACST to low covering ACST, and desertification, naked soil and rock evolution at the same time. The land desertification was very significant. The expanding range of land desertification, land salinization and naked land were above 2%, among them, the land desertification was most serious. The glaciers and permanent snows were shrinking backward, of which the shrink-

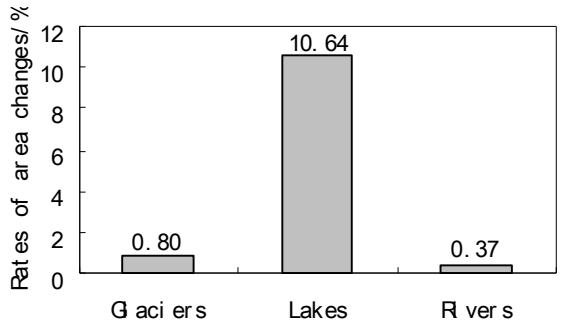

Fig. 2: The area changes of glaciers, lakes and rivers in 1995-2010 (%).

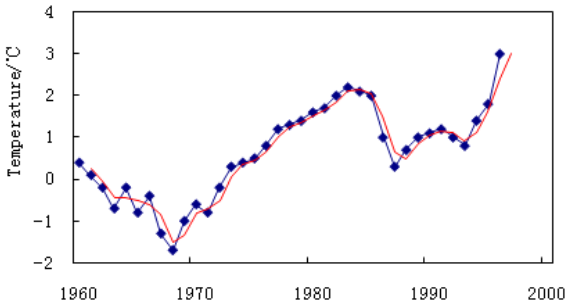

Fig. 3: Climate changes in the source region of the Yangtze River.

ing range of the glaciers was 0.8%. The area of river water was decreased by 0.37%. The water area of lakes decreased by 10.64%, and the area of inland lakes was reducing as the main fact (93.09%). As a part of the whole river basin, these outstanding eco-environmental problems seriously restricted sustainable development of the source region of the Yangtze River and even the whole river basin. The changes of eco-environment and hydrographic conditions in the source region brought calamity to the lower reaches of the Yangtze River. The disastrous flood in 1998 had claimed lives and households of thousands of people in the lower reaches.

The climate characteristics of the source region of the Yangtze River are cold, dry, and windy. The grass grows slowly and the carrying capacity of the grassland is very low. It is one of the most fragile areas of China's eco-environment. From the characteristics of land cover changes in the source region in the past 15 years, we have found that many factors caused the eco-environmental degradation of this area, including natural factors (the climate changes), ferocious rat-caused damages and unreasonable human activities which aggravated the process of eco-environmental degradation.

Climate changes: Climate change and its impact on the environmental condition have attracted a great deal of interest (Berger et al. 1987, Karl et al. 1995). Climate changes have induced certain environmental evolutions. In the most recent five decades, the climate in the source region of the Yangtze River has been showing a warming trend (Fig. 3). On the average, the temperature in the Yangtze River basin increased by 0.2°C for each ten year period. In the past 15 years, the annual mean rainfall of the source region of the Yangtze River has increased as a whole, but the increase of the distribution was mainly in winter and spring. The rainfall in summer playing an important role in the vegetation growing shows a tendency to reduce obviously. The climate changes have been unfavourable for the vegetation of ACST and ACSM. Because of the temperature rise, especially the temperature of summer rise, it enables the increase of the evaporating intensity. At the same time, the rainfall does not increased but reduced. The area of high-middle cover degree ACST and high cover degree ACM degraded notably because of drought. The tendency of warming will accelerate glaciers and permanent snows to melt, and make the glaciers bottom and permanent snows appear shrinking. With the water yield reduction, the eco-environment of the source region of the Yangtze River basin was worse, which made the land desertification and soil erosion even more rapid.

Rat-caused damages: Because the grassland was in degradation and desertification, hawks and foxes that are the natural enemy of mice have lost the conditions of surviving and dwindled in numbers. The mice are indulging in wilful persecution in the source region of the Yangtze River. For example, the *Ochotona curzoniae*, the *Myospalas baileyi*, and the *Microtus oeconomus* have increased sharply, of which the *Ochotona curzoniae* is the most dangerous and the *Myospalas baileyi* take the second place (Xu et al. 2004). The rat-caused damage is a natural enemy for the grassland. It impacts on the grassland vegetation in many aspects. Rats gnaw the stem and leaves of plants, reducing natural grass resources directly. For example, the *Ochotona curzoniae* and the *Microtus oeconomus* regard the stems, leaves, flowers and fruits of various good grass as their main food. They excavate the cave, and destroy the grassland. The *Myospalas baileyi* lives underground, has very strong ability to excavate and gnaw the plant rhizome, cuts off the plant root system, puts a large number of heart soil out of the ground to form many mounds and these mounds press and bury the vegetation. The rat-caused damages have caused the decline of the grassland cover, the good grass reduction, the poisonous grass increase, and the grassland productivity drop. In the source region of the Yangtze River, 37.5% grassland degraded, of which 10% changed into "back-soil flats" and bare land. The statistics show that 50% "back-soil" grassland resulted from the reason of the rat-caused damages. Take Zhidoi and Qumaleb County for example, the number of *Ochotona curzoniae* was the 120/hm^2, and its cave was average 1624/hm^2. The rat-caused damages not only destroyed the grassland resource, but also reduced the ability of the self-restraint humidity in the grassland, which is unfavourable for the productivity of grassland ecosystem to be im-

proved and kept up in this area.

Unreasonable human activities: Limited by natural conditions and fragile eco-environment, the stock capacity of most grassland in the area of the Yangtze River is low. As a result of overgrazing, lack of scientific management and protective measures, much grassland was in degradation in different degrees. Since 80's of the 20th century, only pursuing the amount of livestock in a lot of pastoral area, overgrazing, the livestock, such as cattle and sheep, etc., gnaw and trample on the grassland repeatedly without the chance of rehabilitation, which leads to the grassland and eco-environment degradation.

Gold mining was another important reason of eco-environment destruction in this area. The source region of the Yangtze River is rich in gold, and famous for its large area of alluvial gold of high quality. Since 1980s, a large number of gold-diggers have crowded into the source region of the Yangtze River. They dug and quarried the gold excessively without any control in some areas, which has not only destroyed the gold resources, but also led to more serious consequence that ruined the grassland resources, destroyed the beneficial cycle of the ecosystem, and caused the land desertification and soil erosion.

Additionally, excessive collection of Chinese herbal medical materials and cutting of the firewood without control accelerated the grassland degradation. The source region of the Yangtze River is abundant in medical plant resources, so a large number of peasants and herdsmen collect the crude medicinal materials from the grassland of this area (Wu 2000), such as *Glycyrrhiza uralensis*, *Cordyceps sinensis*, *Rheum palmatum*, *Saussurea medusa*, etc., which formed countless small mounds and pits spreading all over the place. The vegetation was destroyed seriously, leaving the hidden danger for the grassland ecosystem. Meanwhile, in order to solve the fuel shortages, the sparse bushes, such as the *Salixoritrepha* bushes, were cut down as fuel wood without planning. Thus, the vegetation was destroyed and the land desertification was aggravated.

DISCUSSION AND CONCLUSIONS

The source region of the Yangtze River has unique natural environment, abundant natural resources, and diversified biological species; but the natural environment of this area is unusually harsh and the eco-environment is extremely fragile. In the past 15 years, the primitive eco-environment in the source region of Yangtze River has suffered destruction of certain degrees because of natural factors and unreasonable human activities. They are mainly the forest and grassland degradation, the land desertification, the soil erosion, the water resources reduction, etc. These outstanding problems seriously restricted sustainable development of the source region of the Yangtze River and even the whole river basin. It is important to take scientific measures to protect and improve the eco-environment so as to maintain the ecological balance and promote the sustainable development of economy in the source region of the Yangtze River.

ACKNOWLEDGEMENT

This research was financially supported by the Project of Anhui Education Department (2009sk241) and the Project of Hefei University (07RC23). This research was undertaken in cooperation with Institute of Geographical Sciences and Natural Resources Research, CAS. The work was facilitated by the Qinghai Department of Lands, Environment and Resources.

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