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Environmental impact of radionuclide migration in groundwater from a low-intermediate level radioactive waste repository

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Abstract: The radionuclide migration from a certain Chinese repository with low-intermediate level radioactive solid waste is studied. The migration in groundwater is analyzed and computed in detail. Under presumption of normal releasing, or the bottom of the repository has been marinated for one month with precipitation reaching 600 mm, once and a 6m aerated zone exists, a prediction for 7 radionuclides is conducted. It shows that the aerated zone is the primary barrier for migration. The migration for radionuclides ^{60}Co , ^{137}Cs , ^{90}Sr , ^{63}Ni , etc. will be retarded in it within 500 years. The concentration of ^{239}Pu will be decreased by amount of 6 order. Only ^3H and ^{14}C can migrate through the aerated zone. The radionuclides that go through the aerated zone and enter the aquifer will exist in spring, stream and sea. Based on this, the intake dose by residents in different age group resulting from drinking contaminated spring water, eating seafood is calculated. The results showed that the impact of the repository to the key resident group is lower than the limit in national repository regulation standard. This complies with the repository management target.

Key words: prediction of environmental impact; numerical calculation; nuclide; low-intermediate level radioactive waste disposal

The near-surface disposal is the mainly disposal method for low-intermediate level radioactive solid waste (LILW) in many countries. Usually, the disposal way in the disposal unit is the concrete solidification is put and piled in array, and the backfill and buffer material is filled between these solidifications. After a certain repository is full, the multi-barrier cover is contracted. So, the nuclides may enter environment through atmosphere, surface water and groundwater. But the groundwater is the main migration route (Wang, 1996; Fig.1). In 300—500 years after the closure of the disposal repository, the multiengineering barrier may be damaged gradually; the rainfall will infiltrate into repository, and the nuclides will leach from waste body. Then the nuclides will migration from repository bottom to aerated zone and aquifer, local resident may use it directly or indirectly, and this may have harmful impact to their health. This kind of impact needs to be analyzed and predicted.

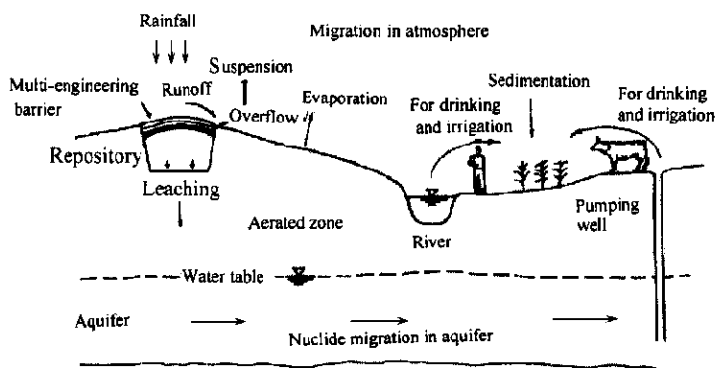


Fig. 1 Diagram of radionuclide migration path at LILW repository site

1 Nuclide migration in disposal repository and its sensitivity analysis

Take a certain LILW repository in China as example, it is assumed that only rainfall impact the repository, used the models (Wang, 1998). A compute code is developed. The release rates of ^{60}Co , ^{137}Cs , ^{90}Sr , ^{63}Ni , ^{239}Pu , ^{14}C and ^3H in the bottom of repository are calculated. The parameters used in calculation are from experimentation (Dearn, 1984). Since there is some uncertainty in using parameter, it is necessary to do sensitivity analysis.

Exploiting pattern and sustainable development of marginal lands in the Three Gorge Reservoir Areas

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Abstract: This paper studied the distribution and utilization status, reasonable exploitation patterns and potential productivity, and sustainable development of marginal lands in the Three Gorge Reservoir Areas. It has been pointed that problems of the soil fertility degradation, poor productivity in crop lands, natural disasters and environmental deterioration existed in all the exploited marginal lands. In order to maintain the sustainability of the marginal lands, following measure have been proposed: prohibiting cultivation in the crop lands with a slope more than 25°, restoring vegetation in the slope more than 25°, strengthening the basic agricultural construction, establishing the production base of woody feeds and oils, establishing a multi-dimensional management model with reasonable structure and optimum function for forestry, agriculture and fishing.

Key words: marginal lands; utilization pattern; sustainable development; Three Gorge Reservoir Area

Introduction

Marginal lands, which is a kind of ecotone, means transitional zone of two or more heterogeneous systems(Wu, 1998). Differences among ecological factors or systems properties in this zone can cause great variation in components and properties (such as vegetation type, population density and productivity) of the marginal zone and frailty of marginal lands. If the relative factors are coordinated each other and the development is reasonable, there exists a positive effect. If not, it will cause great soil erosion, vegetation destruction and disused land that can not be resumed in a short time.

In pace with completion of the Three Gorges Project, 5294000 hm² lands, including 1276000 hm² farmland and 5000 hm² orange fields, will be inundated, and 1131800 emigrants should be settled until A. D. 2009(Chen, 1997). In the past, economic development in the Three Gorge district was limited because of inaccessible and backward condition, adverse natural environment, large population(avg. 300 ind./hm²) and little investment. To avoid further pauperization, most emigrants will be settled in the hilly area of higher elevation and a few emigrants will migrate out of the reservoir area. The settlement task is arduous, and it has a bearing on success or failure of the Three Gorges Project and sustainable development of society, resources and economy in the Three Gorge district. Developing marginal lands reasonably is important to settle emigrants successfully and promote regional economic development. There are 1330000 hm² barren mountainous lands and shrub lands(Tang, 1997). Up to now, there are not any thorough studies on quality and development of marginal lands. So, reasonable exploitation and sustainable development of the marginal lands in the Three Gorges Reservoir Area were studied in this paper.

1 Marginal lands distribution and environmental characteristics

1.1 Basic conditions

The total areas of the Three Gorge district (38 counties or cities from Yichang County in Hubei Province to Chongqing City) is 8847140 hm², and mountainous lands, hilly lands and plains lands are accounted for 74%, 21.7% and 4.3% respectively. The total areas of the Three Gorge Reservoir Areas(19 counties or cities) is 7509813 hm², and mountainous lands, hilly lands and plains lands accounted for 78%, 18.2% and 3.8%, respectively. It is the moist subtropical monsoon climate, and water and heat are abundant in this area. The annual temperature averages 15—19℃. The accumulated temperature($\geq 10^{\circ}\text{C}$) is 5000—6000℃. The average annual precipitation is 1000—1300 mm, and the frost-free period is 290—340d. The population density in these areas averages 300 ind./km², and it averages 140—200 ind./km² in mountainous lands and hilly lands, and averages 300—600 ind./km² in valley and plains lands. The cultivated area per people averages 0.06 hm². The cultivated lands with slope above 25° is accounted for 46% and the average grain yield per unit area is 3450—4050 kg/hm²(Zhang, 1997).

1.2 Distribution and utilization of marginal lands

The area of undeveloped marginal lands in the Three Gorges district is about 2797440 hm², the area of undeveloped marginal lands in 19 counties or cities (The Three Gorges Reservoir Area) is about 2521060 hm², and 1854500 hm² marginal lands can be developed and utilized (Chen, 1997). Examples as grass slope and wastelands; the distribution of marginal lands is analyzed in Table 1.

There are 6049700 hm² cultivated lands in the Three Gorges district (38 counties or cities) and 4988753 hm² cultivated lands in the Three Gorges Reservoir Area (19 counties or cities). The cultivated lands distributed from elevation of 100m to 1400m (Table 2) and the cultivated lands with slope above 25° accounted for 46%. From the data in Table 2, it was obvious that the cultivation in this area was excessive (Harris, 1994).

In the Three Gorge Reservoir Areas, 71% cultivated lands is nonirrigated farmland and the else 29% is irrigated field. The proportions of nonirrigated farmlands distributing along different elevation are 0.5% (< 300m), 45.3% (300—500m), 42.6% (500m—1000m) and 11.6% (1000m—1400m). The proportions of irrigated field distributing along different elevation are 3%, 54.7%, 37.8% and 4.5%, respectively. For nonirrigated farmland, the distribution proportions of different slope are 15.5% (< 7°), 29.6% (7°—15°), 29.6% (15°—25°) and 17.6% (> 25°). Until 2009, when the Three Gorge Project is completed, 5294000 hm² lands will be inundated. Among the inundated lands, the area of cultivated lands

Table 1 Distribution of marginal lands in the Three Gorge Reservoir Area (hm²)

County or city	Area of marginal land	Percentage, % *
Yichang County	—	—
Xingshan County	946.67	0.40
Zigui County	—	—
Badong County	1893.33	1.00
Wushan County	1793.33	0.06
Wuxi County	20213.33	5.03
Fengjie County	13080.00	3.22
Yunyang County	—	—
Wanxian County	—	—
Wanxian City	—	—
Kai County	2406.67	0.61
Zhong County	—	—
Fengdu County	—	—
Shuzhu County	1673.33	0.70
Peiling City	—	—
Wuling County	1593.33	0.79
Changshou County	—	—
Jiangbei District	—	—
Ba County	—	—
The Three Gorges Reservoir Area	49553.33	0.80

* The percentage of marginal lands in total lands

Table 2 Distribution of cultivated lands with a different elevation in the Three Gorges Reservoir Area

Elevation, m	Cultivated lands, hm ²	Percentage, % *
< 500	278.8713	55.90
500—1000	183.5861	36.80
1000—1400	36.4179	7.30

* The percentage of cultivated lands in total cultivated lands

is 1276000 hm² and accounted for 24.1%, the area of woodlands (including economic forest) is 1744700 hm² and accounted for 32.9%, the area of grassland is 1014700 hm² and accounted for 19%, and the else area is 125800 hm² and accounted for 24% (Tang, 1997). Based on analysis of the data above-mentioned, 25.5% of existing cultivated lands will be inundated because of the Three Gorge Project, and most of the inundated lands is irrigated field and high yield nonirrigated farmlands (in the Three Gorges Reservoir Area). So, exploiting the

existing marginal lands directly influences the existence and development of the emigrants.

2 Exploiting pattern and latent productive capacity of the marginal land

2.1 Exploiting pattern of the marginal land

According to 1:50000 lands resource evaluation map of Zigui County in the Three Gorges Reservoir Area, 52000 hm² lands can be planed as soil and water conservation model, and it accounted for 22.9%, 48000 hm² lands can be planed as cultivated lands model for production, and it accounted for 21.2% and 127000 hm² lands can be planed as forestry management model (diversified production forest and perennial economic crops mainly), and it accounted for 55.9% (Zhang, 1997).

Table 3 shows that most of the undeveloped marginal land was suitable for woodland and reserve resource of

cultivated lands was poor in the Three Gorge Reservoir Area. There exists 974907 hm^2 forestlands in the Three Gorge Reservoir Area at present, and it accounted for 12.98 % of the total lands. 1854500 hm^2 marginal land, which can be exploited and utilized, is mainly located in steep slope of mountainous land, erosion area and outlying district. Water and heat conditions are fairly good in the Three Gorges Reservoir Area and they coordinate well, so it is suitable for growth and production. The biomass growth of forest is about $10\text{--}20 \text{ t}/(\text{hm}^2 \cdot \text{a})$ and the volume growth is $6\text{--}10 \text{ m}^3/(\text{hm}^2 \cdot \text{a})$, and the forest trees grow fast in this area. Because the climate is warm and moist in this area, litters are decomposed fast, surface slope is great, precipitation is centralized, water erosion is intensive and the proportion of rocky mountainous land is increased gradually, once the wrong development method is taken and artificial interference is intense, then, the vegetation soil will be deteriorated intensively. In the past 30 years (influenced by the policy "take food production as guiding principle" in 1960—1978), because of unreasonable development, the average decrement of surface soil was 3—5 cm, and it caused disappearance of soil humus layer, a scene of barren mountains everywhere and quality deterioration of farmland. From 1958 to 1985, the content of soil organic matter was decreased 0.5 %—1.0 % (Zhang, 1997). Therefore, it is important to determine the reasonable method of developing the marginal lands.

Table 3 Exploiting pattern of marginal lands in the Three Gorge Reservoir Area

Exploiting pattern	Type or altitude, m	19 counties or cities in the Three Gorges Reservoir Area		38 counties or cities in the Three Gorges Reservoir Area	
		Area, hm^2	Percentage, % *	Area, hm^2	Percentage, % *
Lands of forest and herbage for soil and water conservation	Sward	3.07		3.64	
	Meadow	1.29		1.32	
	Total	4.36	0.58	4.96	0.56
Cultivated lands	>500	0.34		0.34	
	500—1000	1.00		1.23	
	<100	0.63		0.70	
	Total	1.97	0.26	2.27	0.26
Forest lands	<500	39.29		47.14	
	500—1000	74.09		91.29	
Exploiting pattern for wood	1000—1800	57.36		67.31	
Grain and oil could mitigate	>1800	8.38		10.21	
	Total	179.12	23.85	215.95	24.41

* The percentage of marginal lands in total lands

2.2 Existing problems of the exploiting marginal lands

In the past 30 years, 122073 hm^2 marginal lands had been developed in the Three Gorges Reservoir Area. Among the developed marginal lands, agriculture lands were 1149740 hm^2 and accounted for 94 %, and forestland (monocultured economic forest mainly) was 73300 hm^2 and accounted for 6 % (Tang, 1997). The existing problems were concluded as follows: (1) The productivity of cultivated land was low, soil fertility was declined gradually, and the area of cultivated land was decreased gradually. The average cultivated land per people was 0.06 hm^2 in the Three Gorges Reservoir Area and was lower than the national one (0.09 hm^2 in 1985). Most of the cultivated land was mountainous land and the average cultivate index was high as 23 %. There were three characteristics of the existing marginal land, which was developed for cultivated land: (a) the developed marginal land was scattered and could not be cultivate intensively; (b) most of the developed marginal land was located in mountain slope and the soil layer was thin. 91 % of the existing nonirrigated farmland was slope land, and 37.9 % had a soil layer with the depth lower than 30 cm; (c) it was thin and lean and it had a low productivity. The area of the cultivated land, which organic matter content was lower than 2 % and N content was lower than 0.1 %, accounted for 50 % or so. 35 % cultivated land had a quick-acting potassium (K_2O) content lower than 35 %. The calcareous soil, which was seriously sort of zinc, accounted for 38 %, and soil in the Three Gorge Reservoir Area was short of phosphorus generally. Calcareous alluvial soil and calcareous purple soil accounted for more than 65 % and it caused that low yield land accounted for 78 % in the whole area. Because of serious erosion and unreasonable management, soil fertility and cultivated land area were decreased year by year. The total decrement of cultivated land in the past 27 years was 73533 hm^2 , and 15300 hm^2 cultivated land was decreased in the past 7 years (Tang, 1997). (2) The natural calamity was frequent and the resistance of the developed marginal land was feeble. Influenced by the policy "take food production as guiding principle" in 1960—1978, great pieces of land was exploited unreasonably, and it caused frequent calamities.

Moreover, the land management was bad and the capital construction on farmland was not up to standard, so the resistance against calamities was feeble. For example, drought in hot season was the chief factor hindering stable yield of farmland in the Three Gorge Reservoir Area. In the past 30 years, the frequency of drought in hot season was 30%—50%, and it reached 50%—70% after 1980'. The output reduction of nonirrigated land was 5%—10%, and in some district, it was seriously over 20% (Chau, 1995). It was a gross intimidation for sustainable development of agriculture in the Three Gorge Reservoir Area. (3) The development of marginal lands was unreasonable and the ecological environment was deteriorated increasingly. Because there was no reasonable program for develop on marginal land, the development was bad, the land was excessively cultivated, and a large area of forest and grassland were destroyed, the natural environment was deteriorated. The percentage of forest cover had been dropped into lower than 10% in 1980 from 20% in 1950. Denotation caused severe soil erosion and soil degeneration. The soil erosion in Zigui County had been raised to 1259000 t/a in 1980 from 865000 t/a in 1956. The erosion area of forestland in the Three Gorges Reservoir Area had accounted for 23.2%; the erosion area of shrubbery land had accounted for 20.4%; the erosion area of grassland had accounted for 21.6%; the erosion area of fields land had been accounted for 22.55% (Du, 1994). All these caused more barren mountains, riverbed raising and severe deposits. It was also a chief factor hindering sustainable development in the Three Gorges Reservoir Area. (4) The superiority on comprehensive exploitation of marginal land was not outstanding. The Three Gorges Reservoir Area was located in subtropical zone, and the plant resources were rich. Furthermore, there existed a long history of managing citrus, mulberry, tea, tree, lacquer tree and tobacco. But the area for managing production forest and perennial economic crops only accounted for 8.35% of the total developed area and there existed some problems such as single product, low quality and economic benefit. So, regulating the industrial structure in the whole reservoir area, developing the comprehensive superiority of marginal land and establishing the diversified, high beneficial, stereoscopic managing base for agriculture, forestry, animal husbandry and fishery were main strategic measures for realizing the regional sustainable development in the reservoir area.

2.3 Latent productive capacity of the marginal land

Food was the main limiting factor of developing economics, and it was also the basic requirement for managing emigrants and realizing sustainable development in the the reservoir area. The basic method for resolving the food problem was depended on exploiting marginal land reasonably and increasing the yield of the developed land. The grain yield per unit area of 40% land in the Three Gorges Reservoir Area was 3450—4050 kg/hm², and it was equivalent to that of the mountainous land with the lowest yield in Jiangxi Province in 1998(State Statistical Bureau, 1998). The annual average income was 330—420 RMB Yuan, and it was equivalent to that in Guizhou Province and Tibetan Autonomous Region in 1997(State Statistical Bureau, 1998). The agriculture income was accounted for 65% of the total income. Among the agriculture income, 52% was come from main crops, and the income come from production forest and economic crops was lower than 4%(Tang, 1997). If construct of agriculture, forestry, animal husbandry and fishery was related reasonably and the cultivated land build was strengthened, it was possible to increase the productivity of the developed marginal land greatly.

There existed 2521060 hm² marginal land in the Three Gorge Reservoir Area. Among the marginal land, 1854500 hm² marginal land could be developed and utilized. 19660 hm² marginal land could be exploited as cultivated land(slope lower than 25°, elevation of 500m—1000m, soil layer depth above 20 cm for purple soil and above 50 cm for calcareous soil and granite soil), and it accounted for 0.78% of the marginal land in the reservoir area and 1.06% of the marginal land which could be developed in the reservoir area. 1791133 hm² marginal land could be exploited as forestland(slope above 25°, elevation of 500m—1800m), and it accounted for 71.05% and 96.59% respectively. 439000 hm² marginal land could be exploited as animal husbandry land(elevation above 1400m, thin soil depth), and it accounted for 1.74% and 2.37% respectively. If the marginal land was exploited reasonably, it could promote the economic prosperity greatly and had an important effect to protect the environment, resolve the food problem of the emigrants and keep the society steady.

3 Sustainable development of the land

3.1 Sustainable development mode and managing countermeasure in the low mountain area(below the elevation of 600m)

Zigui County is located in the mountain area in the western of Hubei Province. The total area of the Zigui County is 227000 hm². The area of the cropping land is 29700 hm², in which the dry land is 24800 hm². The area of the sloping field above 25° is 8533 hm². The area of the barren mountain is 34500 hm². The grain output is 144742t. The total agricultural output value is 197370000 RMB Yuan.

3.1.1 Developmental mode of agroforestry ecosystem

The low mountain of Three Gorge's river bottom below the elevation of 600m in Zigui County is 48000 hm², accounting for 21.2%. The cropping land is 6330 hm², accounting for 21.3%. The dry land is 4870 hm², accounting for 19.6%. The area of the slopping field above 25° is 2470 hm², accounting for 28.9%. The area of the barren mountain is 8000 hm², covering 23.2%. The grain output of this area accounts for 19.8%. The total agricultural output value accounts for 31.9%. The soil layer in this area is thick, which is advantageous to agriculture. This area is a dominant area increasing the output of food supplies, fishery and forestry. This area is a better base to develop agroforestry ecosystem. Agroforestry ecosystem is appropriately arrange agriculture, agronomic crop and fishery in the same area. The hydrothermal condition in this area is better. Agroforestry ecosystem can fully use the hydrothermal resource of an area and increase the utility rate of the resource. This managing method can greatly increase the economic output of this area, improve the ecological environment of the reservoir area and optimize the industrial structure of the reservoir area.

3.1.2 Spatial cultural developmental mode of the fishery

Most of low mountain area will be submerged after 2008. This area is the main area of develop high-efficiency fishery. After the dam of Three Gorges is built, there will be many bays. These bays will provide the site to develop high-efficiency of this area.

3.1.3 Developmental mode of tourism of reservoir bank-establishment of green belt of reservoir bank-environmental protection in the low mountain

After the dam of Three Gorges is built, the low mountain will become the main area of sightseeing and living area of the residents. Following the quick development of tourism and the number of the residents, there will be some new pollution around reservoir. There are some countermeasures to decrease and avoid new pollution: increase the establishment of green belt and develop clean environmental industry.

3.2 Sustainable development mode and managing countermeasure in the middle mountain (elevation of 600—1200m)

The land area of middle mountain of Zigui County (at the elevation of 600—1200m) is 126700 hm², accounting for 55.9% of the total area of Zigui County. The area of the cropping land accounts for 59% of the whole cropping lands. The area of dry land accounts for 57% of the whole dry land. The area of the slopping field above 25° accounts for 50.8% of the whole slopping field above 25°. The area of the barren mountain accounts for 61.9% of the whole barren mountain. The grain output accounts for 62.2%. The total agricultural output accounts for 54.7%. Therefore this area is the main area of current agricultural management. This area is also the main area of destroying the vegetation of the reservoir area and of serious soil erosion. The main countermeasure to develop and protect Three Gorge Reservoir Area is to discuss a reasonable sustainable development mode.

3.2.1 Agricultural development mode of woody food-oil type

The land planned as woody food-oil type in Zigui County is mostly located in the middle mountain, whose area is 13870 hm². This part of land is distributed the sloping land less than 25°. Limited to regional geographic condition, if this area is developed as farming land, there will be serious soil erosion and it will increase the deteriorative speed of the ecosystem of the reservoir area. In this area, the local government should support farmer's specialized management, develop economic forestry and perennial economic crops, establish woody food-oil type complex ecosystem, and control soil erosion, maintain the physical and chemical characteristics, improve the benign cycle of the ecosystem. Developing economic forestry is the main developmental mode of the reservoir land. The cropping land in Three Gorges Reservoir Area is limited. The yielding potential of the crop is also limited. Through developing of forestry and establishing woody food-oil yielding base, relieve the contradiction between migrate and land. Therefore, reasonably developing the sloping land less than 25° and establishing the yielding base of economic forestry and perennial economic crops are the main methods to realize the sustainable development in the middle mountain area in Three Gorges.

3.2.2 Managing and developmental mode of elaborate agriculture(vegetable)

Because of the special weather and the limitation of hydrothermal condition, the mild area in the middle mountain in Zigui County can develop green elaborate agriculture and not-season green elaborate vegetable. This is the main measure to increase the the economic efficiency of the middle mountain area.

3.2.3 Multi-developmental mode of high-yield and stable-yield economic forestry

The middle mountain area in Zigui County is the poorest area. This area is less than 25° are distributed by low-economic value and single citrus forestry. Changing low-efficiency economic forestry and establishing high-yield and stable-yield economic multi-forestry is the main measure to cast off poverty and become better off.

3.2.4 Development mode of biodiversity protected type by closing hillsides to facilitate afforestation

The area of the sloping land above 25° in the middle mountain of Zigui County is about 4330 hm². The area of

the barren mountain is about 21330 hm². Developing this area will cause serious soil erosion and enlarge the deteriorative speed of the ecological environment. The managing countermeasure of this area should be the development mode of biodiversity protected type by closing of hillsides to facilitate forestation.

3.3 Sustainable development mode and managing countermeasure in the high mountain area (above the elevation of 1200m)

The land area of the high mountain above 1200m in Zigui County is 52000 hm², accounting for 22.9% of the whole land area. The area of the cropping land accounts for 19.7% of the whole cropping land. The area of the dry land accounts for 23.4% of the whole dry land. The area of sloping land above 25° accounts for 20.3% of the whole sloping land. The area of the barren mountain accounts for 14.9% of the whole barren area. The grain output accounts for 18.0%. The total agricultural output value accounts for 13.4%. The main stake of this area is tobacco and tealeaf. To develop the sloping land less than 25° reasonably and establish a multi-developmental mode of economic forestry-economic crops-medical materials complex ecosystem are the main measures to improve the economic efficiency and to protect the ecological environment of this area.

3.4 Sustainable developmental strategy of land resource

The chief aim on sustainable development of the marginal land in the Three Gorge Reservoir Area ought to be settling the emigrants properly, ensuring successful completion of the Three George water control project, protecting the environment and promoting the economic prosperity in the reservoir area. The Three Gorges Reservoir could supply manifold benefits including power, fishery, tourism and employment. But developing the benefit property was depending on the stability of the environment in the reservoir area and the upper reach area in a large degree. Exploiting the marginal land reasonably or not was directly influenced the regional environment. So, the reservoir area and the upper reaches area had to be thought as a great ecosystem, and it was important to keep a dynamic balance between developing economics and protecting environment, regulating the construct of forestry, agriculture, animal husbandry and fishery, exploiting the marginal land reasonably and decreasing soil erosion. If not, the unreasonable exploiting would have a long or an irreversible harm. To reach the sustainable development of the marginal land, the measures as follows should be taken.

3.4.1 No cultivating in slope land with a slope above 25°

Cultivating the slope land with a slope above 25° would cause severe erosion, worsen the environment and shorten the tenure of the reservoir. It was important to specialize the agriculture managing, develop production forest and perennial economic crops, build the stereoscopic, complex ecosystem, control soil erosion, and keep the organic matter and physicochemical properties of soil. Then, a fine circle in the ecosystem could be reached (Chau, 1995).

3.4.2 Strengthening the basic building for agriculture lands, building the high and stable yield product base

There were many reasons for low yield of the land in the reservoir area, but one of the chief reason was that the basic building for agriculture land was not up to standard, and it caused that the resistance against calamities of the cultivated lands was feeble. So, strengthening the basic building for cultivated land and increasing the productivity of the marginal land were the chief measure to resolve the food problem of the emigrants.

3.4.3 Enlarging the area for production forest, building the woody grain and oil crops product base

Developing production forest was the chief measure of exploiting the marginal land. Up to now, 73400 hm² citrus forest was developed. Since 1985, 50000000 RMB Yuan had been invested to build the product base for planting citrus, tea, mulberry, pear, chestnut, grape and medicinal plants. It had reached great success, and the average income after development increased to 1100 RMB Yuan from 330 RMB Yuan before development (Chen, 1997). The cultivated land was lack in the reservoir area and the latent capacity of main crops product was limited, but developing forestry and building product base of woody grain and oil could mitigate the soil problem. So, exploiting the marginal land reasonably and building the product base for production forest and perennial economic crops were also the main measure to realize the sustainable development in the Three Gorges Reservoir Area or even the whole Three Gorge district.

3.4.4 Regulating construct of forestry, agriculture, animal husbandry and fishery in the reservoir area, building the stereoscopic managing model

In view of the properties of the environment and resources in the reservoir area, developing single industrial or single production management would limit the economics development and cause soil fertility decrement and frequent calamities. Combining forestry, agriculture, animal husbandry and fishery, and building diversified stereoscopic managing model were the only way to accelerate the economics development, utilize the natural resources better, keep the ecological balance and reach the regional sustainable development in the reservoir area.

3.4.5 Building the shelter-forest system in the reservoir area, exploiting the reservoir resources reasonably

After the complement of the Three Gorge dam, the water storage area would be 115000 hm². The reservoir had

a long and narrow shape from Yichang City, Hubei Province. The watershed area of the reservoir was 6400000 hm², among them, mountainous land, hill and plain land accounted for 74%, 21.7% and 4.3% respectively (Chen, 1997). The terrain caused rapid runoff and severely influenced the water supply to the marginal land. So, to prevent erosion and protect environment in the reservoir area, it was very important to build the shelter-forest system. Furthermore, 29 big reservoir bends would be shaped after the complement of the dam. The reasonable development of these reservoir bends would take a positive effect to promote economics development, protect ecological environment, develop tourism, settle emigrants and increase the emigrants' living standard.

The reasonable development of the marginal land was not destruction of the environment in the reservoir area. It was the chief measure to protect the environment and the main way to realize the sustainable development in the reservoir area. It required a systemic program to protect the soil, exploit the marginal land and develop the forestry. Cultivating should be limited rigorously in plain land and slope land with a slope lower than 25°. The basic building of agriculture land should be strengthened. Barren mountains and grass slope higher than 1400m should be utilized reasonably and be suitable for animal husbandry. It was also important to exploit reservoir resources reasonably and build the stereoscopic managing base of forestry, agriculture, animal husbandry and fishery.

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