Soil Erosion Regularity in Three Gorges Reservoir Area and its Controlling Measures

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Abstract: The Three Gorges Reservoir Area is one of the most severe soil erosion in China. Serious erosion has degraded the soil productivity, deteriorated the ecological environment, and influenced the service life of Three Gorges Reservoir. The natural and social-economic factors which influence the soil erosion in Three Gorges Reservoir Area include topography, geological situation, vegetation, rainfall characteristics, human activity, soil feature, such as infiltration, antiscour ability, etc. Based on the relationship between these factors and soil erosion, several laws of soil erosion are systematically expounded and summarized. Those are: (1) According to the difference of topography, geological situation, the form and degree of soil erosion, four regionalizations of erosion are divided; (2) With the degradation of vegetation, the erosion area and erosion intensity are developed and deteriorated; (3) The erosion types are gradually erosion (such as sheet erosion and gully erosion) and abrupt erosion (such as gravity erosion); （4）The peak of soil erosion in sloping farmland comes forth from April to May, while the peak in river channel comes forth from July to September；(5) Sediment source mainly comes from slope land, land slide, mountain slump, and debris-mud flow. On the bases of sufficiently understanding soil erosion laws of Three Gorges Reservoir area, the control countermeasures which includes vegetation restoration, terracing on the slope, soil reservoir construction and comprehensive control of small watershed are pointed out.
Keywords: three gorge area, soil erosion laws, regionalizations of erosion, control countermeasures

1 General situation of Three Gorges Reservoir Area

Three Gorges Reservoir Area ,which includes 19 counties and cities, is located at the conjunction of eastern Chongqing municipality and western Hubei province with a area of near 50,000km^2.The natural environmental characteristics of this region is complicated geologic structure and mountainous land forms with abundant humidity and heat energy. There are many high mountains such as Daba mountain, Wushan mountain and Qiyue mountain etc. The extreme peak is 2,796.8m, gradually reclining towards southeast. Yangtze River cut through Wushan mountain to form The Three Gorges well known all over the world. The annual mean temperature is 15℃—19℃ and ⩾10℃ accumulated temperature is 5,000℃—6,000℃. Annual rainfall is 1,000mm—1,300mm which is enough to crop growth. This region is also rich in biological resources. Statistically, there have 3,742 plant species. The number of subtropical forests, fruits, crops and domestic animals is more than those in middle-lower reaches of Yangtze River. However, because of unreasonable utilization, wild plants and animals are gradually extinguished.

2 Soil erosion regularity in three gorges reservoir area

2.1 Present situation of soil erosion in this area

Three Gorges Reservoir Area is one of the most serious soil erosion regions in China. The amount of eroded soil are up to 1.57 million tons every year. Erosion modulus is approximately up to 3,000t/(a·km^2) There has more than 40 million tons soil to be emptied into the Yangtze River every year, which accounts for 28% of total lost soils. Most of sediment comes from sloping farmlands. Most of sloping farmland are

scattered in hilly land and mountainous area. The amount of ⩾25° sloping farmland is accounting for 14.8% of total farmland. Sloping farmlands in this region possess the characteristics of poor quality, lower productivity and serious soil erosion. Besides, Gravitation erosion such as landslide and breakdown is also familiar. While gravitation erosion happening, the whole vegetations on sloping land are completely destroyed. As a result, erosion on slope is expanded and aggravated.

2.2 Factors influencing soil erosion

2.2.1 Natural factors

(1) Climate

Three Gorges Reservoir abounds with rainstorm in summer. Subtropical western pacific high pressure hovers over this region in summer to form high temperature and drought climate, but it also brings into humid air from south sea, which meets with southwest airstream from Guizhou and Hubei province to provide abundant humidity for precipitation. Most of rainfall happens from May to September, accounting for 60%—80% of annual rainfall. Rainfall usually falls in the form of rainstorm in summer. Intense-rainfall is a very important element for soil erosion.

(2) Geology and geomorphology

Mountainous and hilly landform lead to steep gradient on slopes and great fall from upper reaches to lower reaches. Transported sediments, along with surface runoff, empty into the Yangtze River from upland or upper reaches. Besides, large scope of slate, clay rock and purple shale which are subjective to water erosion. Moreover, the steeper the slope, the more serious the erosion, Particularly in broken rock belt and steep bank of river.

(3) Soil

Soil's properties, such as soil permeability, resistance of soil to soil erosion, anti-eroding ability of soil and thickness etc, have strong effects on erosive process. In this area, regionalized soils are yellow earth, yellow brown earth and Burozem (brown earth). Purple soil, chalky soil and paddy soil belong to non-regionalized soil. Because of its sticky and poor infiltration, yellow soil, yellow brown soil and chalky soil are liable to produce surface runoff. Though purple soil derived from mudstone, is of good infiltration, its layer is thinner. when vegetations destroyed and rainstorm happening, erosion is intense.

(4) Vegetation

It is well known that forest is the center of natural ecosystem. Forest could maintain ecological balance, reduce runoff and control soil erosion. As forest destroyed, disasters of flood and drought happened frequently and soil productivity was degraded seriously. Presently, forest coverage in this area is only 19.5%, even less than 5% along bank. Commercial forest is about 87% of total forest. The total area of economic forest, protection forest and fuel forest only accounts for 13% of total. Because of low forest coverage and irrational forest structure, accelerated erosion happens.

2.2.2 Anthropogenic activities

With the increase of population, Soil erosion is accelerated. In order to meet the needs of the people's everyday life, people unreasonably utilized the soil resources by cultivating sloping land, cutting forest and overgrazing, etc. All these aggregate soil erosion and environment degeneration and intensify contradiction between people and resources, environment and economy. Unreasonably utilizing soil resources by antrophy is another major cause for soil erosion.

(1) Plenty of sloping farmland and high reclamation rate

Poor productivity, scarce reserved cultivated land, people had to reclaim the sloping land. According to investigations, in mountainous area, when adding one person, sloping cultivated land must be added by 0.13ha—0.17 ha in correspond. As a result, reclaimation rate is higher and higher and soil erosion is more and more serious.

(2) Forest coverage declined rapidly due to cutting

The incidents of over cutting, destroying forest and grass took place frequently in this area because of want of fuel and commercial forest, particularly during cultural revolution. From 1950s to 1990s, the forest coverage reduced rapidly. Now, the forest coverage is by far lower than the critical coverage of 35%—40% for the safety of the Three Gorges Reservoir.

(3) Developing project without soil and water conservation measures.

Short of effective supervisor, in some district, large quantities of waste earths, waste stones, slays and sands were piled up randomly with the development of traffic, miner and water conservancy facilities.

2.3 Soil erosion regularity

2.3.1 Relationship between erosion and vegetation

The population in this area have been increased rapidly since 1950s. The mean density is up to 275 persons/km^2, Along the Yangtze River valley, density is more than 600 persons/km^2, whereas forest have been destroyed seriously. From 1950s to 1990s, forest coverage decreased by more than one-second (Table 1) . Particularly, influenced by anthropogenic activities, forest have been degraded more seriously. The general law of forest degradation is as follows: forest→shrub→grass→agricultural land. With the changes of land-use, soil erosion gradually developed from light erosion to intense erosion.

Table 1 Comparison of forest coverage between 1950s and 1990s (%)

County/city	1950s	1990s	District	1950s	1990s
Changshou	18.5	7.24	Yunyang	–	11.77
Fuling	–	12.3	Fengjie	32.3	25.25
Fengdu	23.7	16.56	Wushan	23.6	11.7
Shizhu	23.3	23.09	Wuxi	24	10.5
Wulong	–	27.84	Badong	–	22.71
Zhongxian	22.2	6.18	Zigui	–	21.04
Wanzhou	20	13.38	Xingshan	–	30.3
Kaixian	11	5.9	Yichang	–	30.94

The relationship between soil erosion and vegetation is obvious. According to the analysis of data from Sichuan province, under the condition of same rainfall, the runoff coefficient is 0.23 and 0.59 when vegetation coverage is 95% and 15% respectively. Generally speaking, prosperous forest is of multi-dimensional vegetations (forest, shrub, grass, residue, mulch). Subtropical evergreen forest, its vegetation coverage ranged from more than 90% to less than 30%. When coverage is more than 90%, erosion modulus is less than 500t/(km^2 • a)； coverage ranging from 90% to 70%, erosion modulus ranging from 500t/(km^2 • a) to 2,500t/(km^2 • a); coverage ranging from 70% to 50%, erosion modulus increased to 2,500t/(km^2 • a)—5,000t/(km^2 • a); when coverage is less than 30%, along with slope more than 25° , erosion modulus is 8,000t/(km^2 • a)—13,000t/(km^2 • a). Obviously, due to the decrease of vegetation, Soil erosion became more and more intense.

From the Table 2, we can conclude that with the decrease of forest coverage, erosion area and degree are increasing. Non-obvious and light erosion often took place in forest land; Moderate erosion happened in shrub land while intense erosion occurred in cultivated sloping land. So we should rationally utilize sloping farmland and control its soil erosion.

In term of the previous research, after the Three Gorges Reservoir have been constructed, Emigrants had to move to upland, which will lead to destruction of vegetation. Approximately, the amount of sediments produced by erosion will increased by $1{,}200 \times 10^4$ tons due to migration.

Synthesizing the above narrations, in order to control soil erosion, we should, first and foremost, recover the vegetation in the Three Gorges Reservoir region.

2.3.2 Temporal and spatial distribution of erosion

To know the seasonal trends of soil erosion is very significant to draw up the erosion control measures. According to the data from Yangtze Water Resources Commission, the largest amount of sediments happened from July to September. The largest five months is from June to October. According to Yichang Hydrology Station’s data, from June to October, the amount of transported sediments is 89.8% of the whole year’s. Sediments allocation is different in different year. Data from Yichang Station

indicated that from July to September, the amount of sediments transported account for 75.3% in abundant year, 71.6% in medium year and 65.9% in fewer year, respectively.

Table 2 Erosion area and degree under different land-use

land-use	erosion degree		area(km^2)	percentage(%)
forest land			2,874.20	5.2
	non-obvious	erosion	734.30	1.3
	light	erosion	5,459.50	9.7
	moderate	erosion	395.60	0.7
	severe	erosion	1,993.40	3.6
	serious	erosion	1,160.25	2.1
forest land	intense	erosion	336.10	0.6
count			12,953.35	23.2
shrub land			5,459.50	9.7
	light	erosion	1,993.42	3.6
	moderate	erosion	139.00	2.5
	severe	erosion	1,160.26	2.1
	serious	erosion	455.60	0.8
	intense	erosion	612.10	1.1
			336.10	0.6
count			10,155.98	20.4
grass land	light	erosion	2,506.39	4.5
	moderate	erosion	4,233.01	7.5
	severe	erosion	2,117.00	3.8
	serious	erosion	2,394.99	4.3
	intense	erosion	835.46	1.5
count			12,086.85	21.6
Sloping farmland			59.90	0.1
			654.10	1.2
	light	erosion	1,345.70	2.4
	moderate	erosion	1,636.40	2.8
	severe	erosion	69.70	0.1
	serious	erosion	3,341.00	6.0
	intense	erosion	551.50	1.0
			503.50	0.9
			4,456.00	8.0
count			12,617.80	22.5
paddy field	siltation		6,127.00	11.0
			720.04	1.3
total			54,661.02	100.0

On sloping farmland, soil erosion is influenced not only by rainfall, but also by crop layout, species, growth season, and way of tillage. High crop coverage could protect the soil more perfectly than the low under rainstorm. In most regions, crops are harvested twice a year. when rain falling, the crop coverage is very fewer, only 50%—55%. The most serious erosion in cultivated land happened during May to June. Interplanting and intercropping can effectively increase coverage and reduce soil erosion. The sediments washed off in May and June almost silt in gully, small reservoir and dam. It is until rainstorm season that

the sediments are transported into the Yangtze River. So the maximum of sediment transport appears from July to September.

2.3.3 Sediment Sources

Statistically, annual erosive yield is about 157 million tons and the sediments transported into the River is about 40 million tons at present. Calculated by soil erosive grade in different land-use, the yearly erosive yield in forest, shrub, grass and sloping farmland accounting for total yearly erosive yield is 6.19%, 10.76%, 23.05% and 60.0%, respectively. (Table 3)

Table 3 The amount of sediments eroded and delivered in different land-use

land-use	Area (million km^2)	Percentage (%)	mean erosion modulus ($t/(km^2 \cdot a)$)	Annual erosion yield (million tons)	Percentage (%)	Delivery Ratio	Amount of sediments emptied into reservoir (million tons)	Percent-age (%)
Forest	0.013,0	23.3	750	9.75	6.19	0.25	2.437,5	5.95
Shrub	0.011,3	20.3	1,500	16.95	10.76	0.30	5.085,0	12.42
Grass	0.012,1	21.6	3,000	36.30	23.05	0.40	14.52	35.46
Sloping farmland	0.012,6	22.5	7,500	94.50	60.00	0.20	18.90	46.16
Paddy field	0.006,1	11.0	–	–	–	–	–	–
Aquatic area	0.000,7	1.3	–	–	–	–	–	–
Total	0.055,8	100.0	–	157.5	100	average 0.287,5	40.942,5	99.99

Soil erosion in Three Gorges Reservoir Area is distinct to the loess plateau. The lost mass are mainly composed of sands and gravel. So, the delivery ratio of 0.28 in the region is much more less than that of near 1 in the loess plateau. Besides, breakdown, landslide and debris-mud flow are another main sediments sources.

3 Prevention measures for soil erosion

3.1 Turning sloping farmland into terrace

There are large amount of sloping farmlands in this area. Sloping farmland in this area is about 80%—90% of total dry farmland. Whereas the terrace is less than 10%. People used to cultivate up-and down. In order to control soil erosion and increase crop yield, we must turn the sloping farmland into terrace. It is investigated that soil erosion on terrace was 93.6% less than that on sloping farmland. The mechanism involves two aspects, on one hand, terrace cut slope length short, back up runoff, reduce the coverage area, increase the soil infiltration and retard the flow velocity. On the other hand, crops in terrace grow well, improve the soil structure. In one word, soil erosion-resistance was improved in essence.

3.2 Reconstructing vegetation

Reconstructing vegetation is a low-cost, effective and high-benefit measure.

(1) Closing afforestation

It is well known that, in light erosion district, closing hillside (to livestock grazing and fuel gathering)to facilitate afforestation is a most effective and lowest cost method in controlling soil erosion. There are two forms of closing, Namely, completely closing and partly closing. During completely

closing, No cutting, No pruning. But during partly closing, grazing is approved. Three or five years later, the benefit will be seen obviously.

(2) Combining engineering measures into forest measures

In sever erosion district, the soil water content in summer is less than 10%, which hindering the growth of vegetation. In order to improve water condition, we should construct sloping control engineering, such as horizontal ditch and tableland. These will provide good condition for vegetation growth. Correspondly, vegetations fixed soil tightly and conserved water. For example, in 1994, sloping control engineering were arranged in severe erosion limestone district of Guanxing town of chongqing, After that, plenty of trees were planted in this region. According to observation, several years after control, runoff yield decreased by 60%, sediment yield decreased by 70% while soil water content increased from 9% to 14%.

(3) Building shelter-forest and fuel-forest

It is the best way to plant shelter and fuel forest in some moderate-severe erosion district prohibited to cultivate or graze. It not only achieve obviously ecologic benefit in short time, but also strengthen the potential productivity. The target is to set up a multi-species, multi-type and multi-layer forest ecosystem and to resolve fuel sources in rural area.

(4) Planting grassland and shrub

Intense erosion land is always of the characteristics of drought and infertile. If we only plant tree, the survival rate is very lower, and surface runoff is still serious. However, shrub and grass, such as five-leaved chaste tree and lily magnolia, are of shallow-root, simple –structure and strong barren-resistance. As long as we administrate elaborately, the coverage of shrub-grass could be more than 80.0% in one year, As a result, soil and water could be conserved, and fuel and fodder could be provided to feed domestic fowl, as well.

(5) Developing economic fruit, exploiting resources comprehensively

Economic fruits have been developed in Three Gorges Reservoir Area for a long time. There have some specific, unique and fine varieties such as shaddock of liangping and changshou, Tung tree of wanxian and American ginseng of Fenjie and wuxi, and so on. To develop economic fruit could combine erosion control with economic development and benefit the local people, as well.

3.3 Small watershed comprehensive control

Small watershed is a independent land unit. Small watershed comprehensive control is the basic erosion control methods. On this process, we must adhere to four principles.

Firstly, the principle of comprehensive control on the medium-large scale. Concentrating funds, labors and time in small watershed to ensure erosion effect.

Secondly, the principle of forming a complete set of mountain, water, forest, field and road erosion control.

Thirdly, the principle of the equal importance of economic benefit, ecologic benefit and social benefit.

Finally, the principle of allying advanced science and technology such as RS and GIS in the control.

3.4 Improving sloping farmland fertility, constructing soil reservoir

Most of sloping farmland are of thin-thickness, coarse soil texture and poor water and fertility holding capacity. In other word, soil quality is very poor. The famous pedologist Prof. Hou Guangjiong, put forward the scientific conclusion of “ecologic flood-control and till-less agriculture”. The former stresses on building shelter-forest and the later on constructing soil reservoir through deepening soil layer and fertilizing soil to improve its water-holding capacity. For example, when the soil thickness up to 40cm, the field water-holding capacity will increase 5%, the soil could conserve 886.5m^3 water per hectare.

3.5 Perfecting precautionary and supervisory measures

(1) Setting up supervisory network and technique service system in counties and towns;

(2) Strengthening soil erosion control measures simultaneously during exploiture and construction;
(3) Planting trees in and around the road and slope;
(4) Strengthening soil conservation during expanding town and mining;
(5) Setting up and improving regulations to ratify soil and water conservation program on capital construction;
(6) Setting up precautious and protective district.

3.6 Advocating straw manuring

To return straw back can obviously increase soil organic matter, improve soil physical and chemical structure, regulate soil nutrient and improve soil biological activity. If cooperated with applying muck and beancake, interplanting and intercropping, the multiple crop index will be increased rapidly.

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