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Cause Analysis of Gully Erosion in Yuanmou Basin of Jinshajiang Valley

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Abstract: Some factors (i.e. lithology, topography, climate, the change of population as well as land use during the past 50 years) that could have great influence on the development of gully in the arid-hot basin of Jinshajiang valley were investigated. The results show that the factors leading to the strong gully erosion in this area include: the widely distributed Yuanmou group stratum, which promotes the development of gully erosion; the unique geomorphologic configuration that is prone to rock fall and gully erosion; the strong and time-concentrated rainfall; the arid-humid alternate climate characteristics that prepares the ground for the development of fissures in soils; the arid-hot climate that goes against the growth and recovery of vegetation; and the unreasonable and abusive human activities.

Key words: lower reaches of Jinshajiang River; arid-hot valley; gully erosion; cause analysis

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0 Introduction

Gully erosion is an important form of soil erosion and gradually draws more and more attention from researchers at home and abroad in recent years. During the past twenty years, many researches of water erosion mainly paid attention to the process of sheet (inter-rill erosion) and rill erosion at the plot scale. However, some foreign researches have showed that the sheet and rill erosion measured on the runoff plot is not an ideal indicator of the total amount of soil erosion[1] and the gully erosion which develops at a larger scale is an important source of sediments[2-7]. Moreover, gully erosion plays a more important role in the soil erosion occurring in arid environment than it does in the humid environment[1,2] and gully erosion is also one of the key processes in soil degradation[8]. There were relatively few studies on gully erosion in China. Most of the researches were concentrated on the loess plateau and mainly focused on qualitative investigation as well as development of control measures. Some of the aerial photographs taken by these researchers at different time are investigated to assess the annual forward rate of the gullies[9-13]. There were also a few researches on gully erosion monitoring in the black soil region of northeastern China as well as the collapsed hills area in southern China[14,15]. There is a unique climate type and vulnerable ecological environment in the arid-hot valley located in the lower reaches of Jinshajiang River. In addition, the strong gully erosion has made this area a main soil erosion and sediment yielding area in the upper reaches of the Yangtze River. Gully erosion has made large amount of sediments entering the Jinshajiang River, which makes the sediment concentration of

Jinshajiang River have a rising tendency[16, 17]. Thus the discussion of the strong gully erosion in this area is of great practical significance to the soil conservation and the sustainable development in the upper reaches of the Yangtze River. According to Chai *et al*[18], the reason fundamentally led to the strong erosion in the lower reaches of Jinshajiang River lay in the development of fractured stratum along the fault, the state of being at the initial stage of geomorphy development and the arid-hot climate characteristic. However, the human activities only further worsen the situation in the context of strong erosion. The author's past researches in this area show that the unreasonable reclamation of cultivated sloppy land accelerated the development of gully[19] and then led to debris flow, landslide and rock fall. So it demonstrates that the human factors can, in certain circumstances, be as important as the natural environment factors in the process of the development of gully and should not be ignored. This paper mainly focuses on the geology, topography, climate, the change of land use as well as the regional socio-economic condition in the arid-hot Jinshajiang valley to form a comprehensive analysis and a deeper insight into the cause of gully development so as to seek for more effective control measures.

1 Study Area and Methods

1.1 General Description of Study Area

Yuanmou basin is located in Yuanmou county, Yunnan province, south of the lower reaches of Jinshajiang River. The Yuanmou group stratum is widely distributed in Yuanmou basin with a thickness of 673.6 m and has 4 sections with 28 layers. The Yuanmou group stratum is formed by the deposit of fluvial facies or lacustrine-swamp facies and fluvial-lacustrine alternative facies. The Yuanmou stratum can also be described as the inter-bedded strata consisting of sand layer, fine sand layer, clay layer, sub-clay layer and sandy gravel layer. The lithology of Yuanmou group stratum is loose and can easily be eroded. Because of the erosion by storm runoff, the eroded inferior land (including earthy forest) is well developed on the Yuanmou formation stratum which are results in channel erosion, especially the gully erosion. There is an arid-hot climate in Yuanmou basin, which has an average annual temperature of 21.8 ℃ and an average annual precipitation of 615.1 mm. The precipitation during rain season (from May to October) accounts for 90% of the total precipitation of the year. And it also has an arid season (from November to April), which lasts for about half of a year with an evaporation of 3 569.2 mm, which is about 5.8 times of the total during the whole year. The runoff in most of the gullies won't happen unless there is precipitation. The slopes are widely distributed in this area and the vegetation coverage here is low with a high population density. The Longchuan River, which is the first grade tributary of Jinshajiang River crosses the Yuanmou basin with a hydrometry station called "Xiao Huangguayuan" on it. However, the volume of sediment transport and average sediment concentration of the hydrometry station have showed an increasing trend during all the years between 1960 and 1990 and the volume of sediment transport has kept a significant increase since 1990[20].

1.2 Methods

1.2.1 Sample gully selection

Based on the results of field survey in the entire area, we made continuous observations, which lasted for 8 years, of the gullies on the platform of Hongsha village in Yuanmou basin. We selected 9 out of all the gullies with different shape and land use. Among the 9 gullies, No.1 through No.4 are located near the platform with reforested *Leucaena* trees on it (the observation of gully No.2 was stopped 4 years later since the beginning), gully No.7 is located near the platform with mixed forest of reforested eucalyptus and leucaena on it. Gully No.5, No.6 and No.8 are located near the platform with cultivated land. Gully No.9 is located near the platform with *Tamarindus indica* Linn and grassland on it. We conducted the survey right before and after the rain season using the total station every year to get the head-ward erosion rate.

1.2.2 Soil physiochemical analysis

We collected soil samples near the gullies as well as in different soil layers of gully heads, based on the standard method used by Chinese Academy of Science in an ecological network detection[21], we analyzed the physical and chemical properties of these soil samples.

2 Results and Analysis

2.1 The Widely Distributed Yuanmou Group Stratum with Well Developed Gully Erosions

Factors that influence the degree of gully development and shape characteristics of gullies lie in the particle composition, diagenesis degree and weathering-erosion resistant capacity of the rocks.

The Yuanmou group stratum of the lower pleistocene series is widely distributed in Yuanmou basin. Because of the erosion resulted from storm runoff, there is well developed eroded inferior land (including earthy forest), which results in channel erosion, especially the gully erosion, on Yuanmou stratum. Through field survey and collecting soil samples in different soil layers we found that it was the interbedded strata of sand layer with clay layer, well developed vertical joints of soils, the high content of clay particles in the surface soils as well as well developed fissures that made the gullies well developed in this area. The characteristics of the stratum in Yuanmou was analyzed from the following aspects:

① The interbedded strata of sand layer with clay layer

The interbedded strata of sand layer with clay layer has great influence on the soil mechanical composition. The soils, most of which are fine sand have a high content of sand, in the place where sand layer is exposed on the ground surface. For example, the content of fine sand with diameter of 0.25-0.02 mm and 0.5-0.02 mm was 40%-65% and 44%-84% respectively (Table 1) in the gully No.4, No.5, No.7. This particle composition is similar to that of northern loess in China which makes the soils porous with a loose texture meanwhile can easily be eroded. The gully cliffs with clay layer at the upper part and fine sand layer at the lower part are objectively in favor of down and lateral erosion of waterfall, which makes the shape of gully cliff an up-convex-low-concave one, thus prepares the ground for the collapse of clay on the upper part of the gully cliff and gully No.3, No.8 serve just as a good example for this (Table 2). However, when fine sand layer is at the upper part with clay layer at the lower part, the downward infiltration of rainwater makes clay layer soak to form a slip plane, through which the gully cliffs consisting of fine sand can slip to the bottom of the gully, gully No.1, No.6, No.7 are just good cases at the point (Table 2).

② Well developed vertical joints of soils

Some gullies such as No.5 and No.9 have upright gully heads and cliffs. However most of the sample gullies only have upright gully cliffs on both sides. This phenomenon is due to the well developed vertical joints in Yuanmou group stratum and it is also the reason why the earthy forest occurs. As Yuanmou group stratum is a semi-diagenesis stratum, when the deposit, especially the deposit of fine sand layer, is getting thicker, the vertical space between soil particles becomes smaller under the influence of gravity so that the soil particles are tightly depressed. However, the horizontal space between soil particles doesn't vary that much as the vertical space does. In other words, the vertical fissures have actually developed. In rain season, the water and air flow downwards through these vertical fissures then dissolve calcium in the fissures and lead to subsurface erosion. In arid season or after rain, evaporation makes soils become dry and the vertical fissures are filled with salinities.The two processes (developments of vertical joints and salinities filling in the fissures) go on repeatedly to form giant vertical joints in Yuanmou group stratum. The occurrence of free surface on a single side of gully furthers the development of vertical joints in both sides of gully cliffs.

③ High content of clay in surface soil with well developed fissures

Influenced by the arid-hot climate, the Vertisol and dry-red soil is (of both the Vertisol and dry-red soil are) well developed in Yuanmou basin, which has a high content of clay (particle diameter $<$ 0.002 mm). In most cases the content was higher than 30%. According to the soil sample measurements of soil profiles at different sampling depth (Table 3) from gully No.6, the particles with diameter smaller than 0.002 mm account for 27.59%-40.08% while the particles with a diameter smaller than 0.02 mm account for 68.63%-79.06%.

Table 1 Analysis of soil particle and the contents of organic matter (C_{org}) near some gullies

Gully No.	Depth of soil / cm	C_{org} /g•kg^{-1}	Particle composition /%						
			2-1 mm	1-0.5 mm	0.5-0.25 mm	0.25-0.1 mm	0.1-0.02 mm	0.02-0.002 mm	<0.002 mm
4	0-6	9.92	1.11	0.60	5.64	35.42	25.07	11.12	21.04
	6-30	6.22	0.87	0.70	9.46	37.70	24.38	8.92	17.97
	30-60	5.19	1.20	0.31	4.01	30.12	10.54	20.28	33.54
5	0-13	5.13	2.16	2.46	18.15	43.84	22.07	5.39	5.93
	13-24	4.26	2.21	2.28	18.16	39.94	20.48	8.60	8.33
	24-80	3.54	2.28	1.55	11.61	27.22	17.49	14.91	24.94
7	0-11	8.32	1.04	1.41	12.10	39.26	26.21	7.97	12.01
	11-50	6.07	0.63	0.86	12.88	40.58	23.01	8.90	13.14
	50-100	4.94	0.77	0.89	14.50	44.38	16.55	5.98	16.93

According to Huang *et al*.[22], the Vertisol in Yuanmou had a high content of clay (36.84%-53.33%) and the minerals in clay were mainly made up of montmorillonite, which makes soil swell after absorbing water and shrink intensively when it dries. This kind of soil has a degree of expansivity of 45.5%-60.5% and the soil reached its highest expansivity in 5-10 minutes after raining. The shrinking of soil formed cracks of 2-5 m long, 1-2 cm wide and absorbed water, it pushed the gully cliffs to have free surfaces to such a long distance that the cliff did not go back to its original position with dry soil. In this way the cracks in gully cliffs are formed. If sand fell into these cracks in gully cliffs, the process of the first swelling and then pushing would occur again and enlarge these cracks when it rained. If this process goes on repeatedly, it may form a crack of about 10-20 cm wide with a depth of several meters. The development of cracks on gully cliffs prepares the ground for the downwards infiltration of rainwater and gravity erosion such as rock fall.

Table 2 Analysis of soil particle composition and gully cliff feature at gully head

Gully No.	Depth of soil / cm	Particle composition / %							Type of gully cliff
		2-1 mm	1-0.5 mm	0.5-0.25 mm	0.25-0.05 mm	0.05-0.02 mm	0.02-0.002 mm	<0.002 mm	
1	0-15	0.95	0.22	12.60	44.20	9.74	9.28	23.01	A
	15-30	3.58	0.21	13.66	32.49	6.65	11.94	31.47	
	30-45	0.31	0.27	9.94	37.14	7.50	8.93	35.91	
	45-60	1.72	0.28	9.59	33.60	8.53	10.43	35.85	
3	0-15	0.87	0.09	1.24	18.10	21.74	38.82	19.14	B
	15-30	0.19	0.05	0.35	35.52	21.38	26.14	16.37	
	30-40	0.26	0.09	5.33	63.6	7.40	10.65	12.67	
5	0-15	0.85	0.18	1.55	57.75	10.73	10.65	18.29	C
	15-60	0.57	0.14	14.75	45.04	8.12	8.53	22.85	
	>60	0.50	0.08	10.65	32.94	11.52	9.50	34.81	
	>80	0.31	0.09	11.38	31.92	10.79	15.27	30.24	
6	0-15	1.96	0.24	7.20	39.89	15.25	16.14	19.32	A
	15-60	1.72	0.42	12.7	42.7	8.77	11.30	22.39	
	60-80	1.07	0.18	6.74	37.97	11.8	11.89	30.35	
	>80	0.36	0.12	70.48	7.72	4.86	9.08	7.38	
7	0-15	1.52	0.57	25.42	44.68	5.48	6.01	16.32	A
	15-30	1.46	0.49	16.69	35.42	8.88	12.56	24.5	
	30-50	1.24	2.76	8.17	18.84	7.36	13.38	48.25	
8	0-80	1.38	0.23	7.28	31.3	8.64	12.26	38.91	C
	80-115	0.13	0.03	3.31	14.71	6.13	31.18	44.51	
	115-160	2.00	0.48	5.72	17.26	21.68	26.12	26.74	
	160-250	—	—	4.83	69.22	4.18	14.15	7.62	
	250-310	—	—	0.65	57.57	6.66	29.91	5.21	
	>310	—	—	1.77	76.74	9.57	6.71	5.21	
9	0-15	0.27	0.08	3.83	34.48	8.43	9.40	43.51	B
	15-60	0.79	0.14	0.33	27.11	10.47	16.67	44.49	
	60-80	0.83	0.18	3.31	26.94	9.23	20.08	39.43	

A.Slope ; B.Upright; C. Up-convex-low-concave

Table 3 Analysis of soil particle near gully No.6

Depth of soil / cm	C_{org} /g•kg^{-1}	Particle composition /%						
		2-1 mm	1-0.5 mm	0.5-0.25 mm	0.25-0.1 mm	0.1-0.02 mm	0.02-0.002 mm	<0.002 mm
0-15	5.65	0.91	0.38	1.50	5.39	23.19	41.04	27.59
15-30	4.64	0.70	0.20	1.09	4.70	19.63	41.93	31.75

2.2 The Rock Fall and Gully Erosion Prone Topography

The profile of Longchuan River valley has many obvious topography changes from riverbed to hillside such as the transition zones between riverbed and riverbank, the transition zones between the platforms or the transition zones between the posterior borders of terraces and platforms. These zones are all gully erosion, rock fall and landslide prone zones because they are all the zones sensitive to hydrodynamic force[23].

Because of the difference between neoteetonics and long term of erosion, the mountainous and hilly regions as well as steep slopes are all widely distributed in the area being studied. The area of slope land with a gradient steeper than 15° is 1 146.74 km^2 and it accounts for 56.72% of the total land area in Yuanmou. The area of slope land with a gradient steeper than 25° is 471.08 km^2 and it accounts for 23.30% of the total land area. The area of slope land with a gradient steeper than 35° is 175.32 km^2 and it accounts for 8.67% of the total land area. The steep gradients intensify the water erosion thus makes the gully well developed with large area of slope land degrading to bare soil or inferior land.

2.3 The Arid-Hot and Arid-Humid Alternation and Time-Concentrated Precipitation Climate

The basic environment characteristic of the area being studied is of the arid-hot climate**,** which has a similar temperature level to that of north tropical areas and its degree of aridity has met the standards of a semi-arid climate. The temperature in the hottest and coldest months in Yuanmou are 27.0 ℃ and 15.0 ℃ respectively. The accumulated temperature of those higher than 10 ℃ totals up to 7 996 ℃. There are 7 months during a whole year which have an average degree of aridity greater than 2.0 and the evaporation during the period from June to August is 105 mm, which is higher than precipitation during the same time period.

The arid-hot ecological environment with the half year long arid season as well as the strong evaporation which is 6 times more than the precipitation together make the strong evaporation on the surface of soils. In addition, the decrease of overburden layer and vegetation coverage makes the content of water in soil a very low level. The surface soil whose depth is between 0 and 60 cm have a 6 to 7 months or even more than 8 months of annual soil wilting moisture thus it is impossible for some shallow rooted plants to survive. The poor condition of vegetation coverage in this area is mainly due to the limited and light temperature potential productivity caused by the poor precipitation in arid season and low content of water in soil.

There are distinguishable arid and humid seasons in Yuanmou. The arid season lasts for half year long. During the period from March to May the monthly average temperature is 21.8-27.0 ℃ with a total precipitation of 56.7 mm and the evaporation is 27.2 times of the precipitation, which is 1 542.5 mm. The climate of alternate arid and humid seasons prepares ground for the development of fissures in soils. The half year long arid season makes the soil have such a low level content of water, which results in the weakest join forces between the soil particles. Most of the soils have a loose texture, especially the fine sand layers. And some rock falls from the upper part of the gully cliff happen right in the arid season.

The highest ground temperature in Yuamou is above 76 ℃(76.9 ℃, May) and the average ground temperature during the whole year is above 45 ℃. The average ground temperature in 4-5 months out of the whole year can even be equal to or higher than 70 ℃. The highest air temperature in Yuanmou is 42 ℃ and the number of days which have an air temperature equal to or higher than 35 ℃ may be 36 days a year. The temperature is so high that it not only intensifies the respiration and the consumption of organic matters of plants, but also combines with aridity to scorch the seedlings or even let them dry to death. This situation makes the recovery of vegetation very difficult, thus accelerates the developments of gully erosion.

2.4 The Intensified Developments of Gully Caused by Human Activities

The erosion in Yuanmou basin is mainly caused by water erosion and what makes the gully erosion of this area different from that of semi-arid or arid regions in northern part of China lies in the fact that the hydrodynamic force plays a dominant role in gully erosion here. Although there are 6-7 months in a year when degree of aridity has met the standard of being a semi-arid climate, the annual average precipitation is far greater than that in the semi-arid regions in northern part of China. The highest annual average precipitation in Yuanmou valley is more than 600 mm. In certain regions it even is up to 700 mm above. In addition, there are advantageous hydrothermal conditions in the plateau basin which forms the river valley a relatively high population.

Because of the changes of geomorphology patterns in the geologic period, the climate in Yuanmou valley tends to become arid and hot. However, the climate in Yuanmou valley has not changed much since the neolithic age. According to the observation information from the Yuanmou meteorological station, the climate has not changed a lot during the past fifty years. Although the annual average temperature and annual precipitation have a relatively great inter-annual variation, its tendency is not very significant. In addition, the annual evaporation tends to become small in recent years. In other words, the climate is becoming more moderate. Unfortunately, the natural environment in this area is getting worse and soil degradation is going on while vegetation coverage is experiencing a sharp decrease. The quality of grassland becomes worse and soil erosion is of more severity. The soil erosion was due to human factors such as reclamation of slope cultivated land, exploitation of forests and overgrazing.

The four years long continuous observation of 17 gully heads in 9 gullies showed that the land use in the catchment of gully had significant influence on the development of gully. In other words, the head-ward erosion rate was determined by the types of land use in the catchment. Among the different land uses, the bare soil had the highest head-ward erosion rate and the cultivated land was in the next place while the forest and grassland had a relatively lower erosion rate[24]. However there was a fast growth in the population of Yuanmou (Fig.1) and the growth was mainly concentrated in the arid-hot valley in Yuanmou basin whose altitude was below 1 350 m. The increased population demanded more cultivated land. This situation forced the local people to intensify the reclamation of bare and uncultivated slope which quickly enlarged the area of cultivated land. The unreasonable reclamation of slope intensified the development of gullies which made the lands degrade and be abandoned later for being out of productivity. Therefore new reclamation of cultivatable land would be again put forward thus intensifies the soil erosion.

At the same time, the forest coverage in this area had significantly decreased due to the rising demand for more timber for construction and firewood caused by the sharp growth in population as well as the failure in policy making. The forest coverage had been 12.8% during the early 1950s. However, in 1973 and 1985, the number had decreased to 6.3% and 5.2% respectively. Then due to the strengthened ecological construction, the forest coverage has been somewhat steady at about 5.2%[20]. However, there was still over exploitation of trees and even the use of tree roots as firewood because of the scarcity of fuel. Once being destroyed, the forest coverage is difficult to be recovered due to the arid-hot climate characteristics and then gully erosion was intensified.

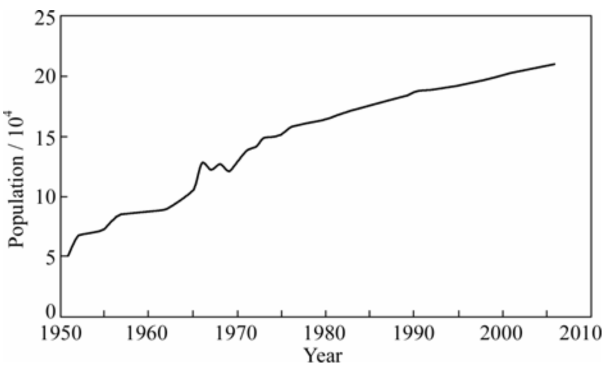

Fig.1 The change of population quantity in Yuanmou county

With the fast growth in population and economic development, husbandry in Yuanmou also experienced a rapid development. The livestock amount seriously exceeded the grazing capacity of the grasslands, which led to the degradation of the grasslands and soil erosion. In 1983, the livestock amount in the grasslands was 6.27×10^4 cattle unit and after 10 years of overgrazing, both the quality of grasslands and the yield of grass somewhat decreased[25]. What is more, some of the grasslands have degraded to become deserted land. Until 1992, there was 7.9×10^4 cattle unit and 9.98×10^4 sheep unit, which equaled to 1.16×10^4 cattle unit[26]. The total amount of livestock in 1992 was 9.06×10^4 cattle unit which was 2.73×10^4 more than that of 1983 indicated serious overgrazing on the grasslands. The grassland on mountain and slope was not well managed and the grazing was out of control as well. Because of the long-term overgrazing without control the gully erosion had been further intensified.

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