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Analysis on the Inducing Factors and Development Features for External Force Geological Disasters in Lujiang Segment of Nujiang

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Abstract: Main types of geological disaster in Lujiang segment of Nujiang are landslides, slides, mud-rock flow, unstable slope, active gullies and so forth. Among of them, mud-rock flow, slides and unstable slope are the most important. Based on field investigation and statistics analyses, it indicates that mud-rock flow mainly occurred both west and east sides of Nujiang and showed different distribution, controlled by tectonic. Distribution of slides has close relationship with human engineering activities. Atmospheric rainfall is important inducing factor of geological disasters which occurred frequently in rainy years and rain season of every year, and human's unreasonable engineering activities brought out occurrence of them.

Keywords: *Force geological disasters, Inducing factors, development feature, Lujiang segment of Nujiang*

1. Introduction

Lujiang segment of Nujiang is in Baoshan in western Yunnan, about 650km away from Kunming, capital of Yunnan province. There was less population in this area which mainly distributed in towns. Economy of the area focused around farming and relatively less industry, restricted by particular geological environment. Geological disasters are well developed in Lujiang segment, the scope and types of which was wide. They were very unfavorable to engineering construction and restricted development of transportation and social economy [1, 2, 3].

Investigation to geological disasters in the area began early. The first and second Yunnan Institute of Hydrogeology and Engineering Geology started comprehensive investigation to geological disasters in Yunnan province in 1990. Ministry of Land and Resources carried out county (city) investigation to geological disasters and division work in 1999. Yunnan South China Geological Survey Company undertook investigation to geological disasters in Longyang area of Baoshan city in Yunnan. These investigations basically found out types and quantities of geological disasters in the area.

Investigation of this paper mainly aimed at the following disasters: landslides, slides and mud-rock flow affecting railway building and construction. By now, geological hazard sites associated with exogenic force that had been found are as follows, 40 landslide sites, 62 slide sites, 21 debris flow gullies, 21 unstable slopes and 9 active gullies. This paper indicated development of geological disasters in survey area based on inducing factors including topography, landforms, stratum lithology, atmospheric rainfall and human's engineering activities [4,5,6]. It also provided basic geological materials and scientific basis for plan and construction of Dali-Ruili Railway.

2. Analysis on Main Inducing Factors of Geological Disasters

2.1. Topography and Landform Condition

Topography and landform are important factors affecting development of geological disasters [7]. Landform condition in research area is affected by tectonic activities. It was cut intensely, so the topography is very broken and relative height difference is big. And angles of gully mostly are larger than 35 degree. All of these provided fundamentals for the formation of exogenic force geological disasters.

The area has four geomorphic units. The first one is deep dissection high-middle mountain canyon distributed in Gaoligong Mountain in depth in western research area. Height of the summit is 3586.5m, about 3000m higher than the lowest altitude in research area. Cutting depth is more than 1000m summit of the mountain is pyramidal. Gradient of slope in V-shape river valley is between 40°-60°. The second one is medium dissection middle-low mountain distributed in eastern research area. Cutting depth is between 30°-50° and deluvium is thick. The third is erosion accumulation valley distributed in both sides of Lujiang in the middle of research area. The last is basin accumulation landform, mainly distributed among the above three landforms. Terrain slope influenced geographic disasters obviously. On the basis of slope, topography can be divided into cliff (slope is more than 40°), steep slope (slope is between 25° and 40°), gentle slope (slope is between 15° and 25°) and platform (slope is less than 15°). The number of geographic disasters in different topographies is not the same. Geological disaster sites were not observed in platforms.

Table 1: *Statistics of geo-hazards under different slope gradient*

Types	Cliff		Steep slope		Gentle slope		Total
	Number	Percent (%)	Number	Percent (%)	Number	Percent (%)	
landslides	10	25	18	45	12	30	40
slides	45	72.58	14	22.58	3	4.84	62
Unstable slope	11	52.38	8	38.10	2	9.52	21

2.2. Stratum Lithology

Eastern side of Nujiang belongs to Yunnan-Tibet stratigraphic macrozone, Qiangnan-Baoshan stratigraphic area and Baoshan stratigraphic subarea. The strata are mainly paleozoic and mesozoic. Lithology is mainly limestone, sandstone, mudstone and exposed basalt. Gaoligong Mountain in western side of Nujiang belongs to Tengchong stratigraphic subarea, where early-Sinian Gaoligong mountain group mainly exposed.

Stratum lithology is foundation of the development of geological disasters and main element influencing deformation of disaster main body. The type, scale and extent of force geological disasters are significantly different due to lithology

Table 2: *Statistics of geo-hazards under different stratum lithology*

Type	Loose soil		clasolite		Carbonate rock		total
	number	Percent (%)	Number	Percent (%)	Number	Percent (%)	
landslides	40	100					40
Slides	3	4.84	10	16.13	49	79.03	62
Unstable slope			7	33.33	15	71.43	21

(I) Loose soil: the loose soil, about 1 to 15m thick, are mainly Quaternary alluvial-proluvial silty clay, silt and residual gravels, which distributed widely at the bottom of slope and in both sides of gulley. There are 43 geo-hazard sites in this kind of loose soil, including 40 landslides and 3 slides. Unstable slope was not found.

(II) Carbonate rock: middle-thick and thick-bedded carbonate rock in the upper Triassic, Jurassic, Cretaceous and Tertiary was widely exposed in the region. The principle types of lithology are sandstone, interbed of siltstone and shale, coal bed and so on. They are mainly weak and relative solid rock which are not average. Rock mass in surface layer was easily weathered. So they frequently formed loose pile layer which has high permeability. underlie rock showed relative exclusion to water. Rainfall or surface water infiltrating to the ground lubricate the contact surface, which lead to landslide and transformation.

Fractures in solid rock are well developed and rock mass are very broken. Vertical-brittle and horizontal-creeping transformation is easily generated. These will lead to the formation of slide and unstable slop.

Besides, the goaf resulting from irrational mining can easily make the ground collapse. 17 geological hazards were discovered, where 10 slides and unstable slopes were included.

(III) Carbonate rock mainly includes dolomite, limestone and the like in lower of Permian and upper of triassic. They are thin-middle-thick, hard and sub-hard and middle-weak karstification. The unloading fractures are well developed because of the influence by natural weathering and human's engineering activities. So they easily formed colluvium or rocky slides. In this research, 64 geological hazards were discovered, including 49 land slide and 15 unstable slopes.

In conclusion, the development of geological hazards are controlled by formation lithology. The geological hazards in clastic rocks are mainly landslide, and then unstable slopes and slides; the slides are dominated in carbonate rocks and landslides are the most in loose soil in quaternary.

2.3 Rainfall

Rainfall is the main factor inducing geological hazards, such as landslides, slides and active gully and so on [8,9,10]. The research area characterized by more rainfall in summer and autumn, which is dominated by durative rain and heavy rain. Long-term rain made the slope body wet and slippery and cohesion reduce in it. When heavy rain falled, the rain would permeate into slope through fracture. So the slope body became heavier, which could result in the formation of geological hazards.

The influence of rainfall to slide was obvious. The slope body became heavier and resistance to shear in it dropped because of rain went deep into slope body, which would make landslide form and old landslide revive. Besides, the free surface formed in front of slide because of scour and erosion of rain to toe of slope, which influenced stability of landslide very much.

2.4 Human's Engineering Activities

There is a close relationship between human's engineering activities and the formation and development of geological hazards [11]. With the development of society and the growth of population, the territory and activity of human beings is constantly changing. Some engineering activities, such as mining, urban construction, construction of highway and water conservancy and hydropower, directly or indirectly induced geological disasters.

The main infrastructures in research area include construction of road, farmland water conservancy and so on: the GZ65 highway run through the whole research area from northeast to southwest; County Road cross this area vertically and horizontally; farmland irrigation facility densely covered. Construction of road and canal in mountain area were usually around the mountain. This destroyed the completeness and stability of the original slope. Effective measures were not taken after the above activities. The sandstone piled on the slope would brought about formation of landslide and mud-rock flow etc. on the one hand, the increase of human's engineering activities made human's production and management convenient. On the other hand, the damage on surroundings that some imperfect and unscientific engineering activities brought about induced geological hazards.

Among the 153 geological hazard sites found in this investigation, 62 of them are closely related to human's activities, accounting for about 40.5 percent in total. The more frequent human's engineering activities, the more geological disasters were developed. Among the above sites, there were 28 slides and 16 unstable slopes, which were induced by digging of toe of slope when human built roads. And 6 slides and 12 landslides were due to human's quarrying of sand and stone.

3. The Development Characteristics of Geological Hazards

3.1. Development Characteristic of Landslides

(I) Scale of landslide

Among 40 landslide sites in research area, there are 2 large-scale landslides whose volume is large 100×104 m^3, accounting for 5 percent in total. There are 36 small-scale landslides, accounted for the biggest percentage as 90%.

Henggou large landslide is the biggest, whose volume is larger than 1000×104 m^3. Henggou village, in which most villagers had been moved, was built on the landslide body. In investigation, walls that cracked, rupture on voltage transformer and drunk trees had been found.

The sliding surface of Henggou large landslide consists of deluvial clay mixed by gallet. Rainfall which rushed landslide body increased the weight of it at the same time. The cut of the gully in front of Henggou deepened, which increased the free surface as a result. The slip was not oblivious and plenty of crack at the end of landslide body was found. It can be concluded that the development stage of Henggou landslide was the early stage of creep.

Figure 1 *Cracks on the transformer resulting from landslide in Henggou Village*

Most of landslide body was cropland. Once the landslide body continued to develop, it certainly would lead to economic and property losses. So this should be paid enough attention.

Other kinds of landslide body in other size in research area mainly distributed in gully area. The landslide body became unstable, because river washed both sides of it and scoured the bottom of slope, which finally would made the body slide. They also scattered both sides of road, for the reason that the bottom of slope lose its stability because of humans' harm on it

(II) Material composition of landslide

There were three kinds of material composition: soil, rock and mixture of them. There were 28 Landslides in soil and 11 in rock, accounting for 70 percent and 27.5 percent, respectively. The others are in the mixture of them, account for 2.5 percent in total.

The reason that the proportion of landslides in soil was the largest is maroon and mauve mud and muddy sand (which was called red bed in profession, research and application area) in Jurassic and Triassic layer were well developed. The sand and muddy sand is characterized by short depositional time, low intensity, weak resistance to weather and high sensitive to water. Their intensity also reduced continuously when they contact with water. So geological hazards, such as landslide, were very developed. Most landslides are ancient slide [12]. Their body had been washed away, leaving only slide bed, showing an obvious shape of chair.

3.2. Development Characteristic of Slide

(I) Scale of slide

Among 62 slides in research area, there was no super-huge slide. There was 1 huge slide whose volume is bigger than 10×104 m^3, accounting for 1.61 percent in total. 44 small-sized slides accounted for 70.97 percent, the largest proportion of all (Fig. 2).

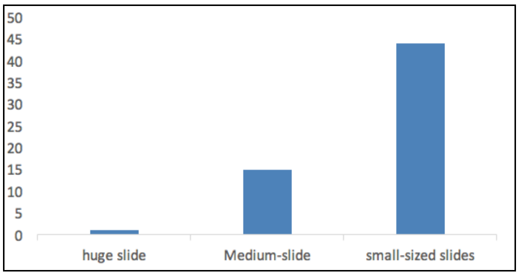


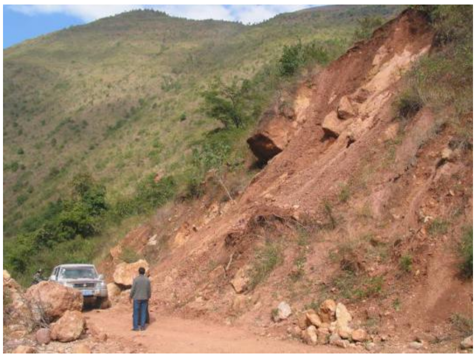
Figure 2 *Histogram of development scale of landslides*

(II) Dynamic genetic types of slide

On the basis of dynamic, slides could be divided into two types: natural dynamic types and artificial dynamics types. According to investigation, their development characteristic can be summarized as follows:

Steep slope cut by river on both sides of Natural dynamics gully would collapse due to the shear failure when fractures in it connected.

Slide was in upper reaches of the stream. Slide rock was big. Length, width and thickness of slide was 80m, 50m and 5m respectively. There was intense weathering chippings filling the slide body besides huge rock (Fig. 3).



\ ***Figure 3.*** *Landslide on eastern side of road in Wujiangzhuang Village*

Due to Dredging and Erosion of small river to slope foot, vertical cut was deep and faults were well developed. Two group faults cut bedrock into diamond-shape. Fault planes were straight and smooth. Well-developed fractures along slope made the slope become dangerous, showing signs of landslide, which could provide material source for formation of debris flow.

The man induced slide is mainly cutting slope, because human's engineering activities broke the balance of slope body.

From Fig.3, we can see that falling rocks scattering roadside were big and blocked roads. The slide happened for a short time judged from color of rock. This phenomenon was very common in research area. The slide would happen because the slope became sharp when human built roads and cut slope, combined other induced factors, such as rainfall and explosions and so forth. Slide could bring traffic unconvenience and even endanger human lives and properties security. So the stability of slope should be considered when human build roads.

3.3 Development Characteristics of Mud Slide

The whole survey area controlled by Nujiang fault have formed as follows the west part is higher and the east part is lower. The final activity of the western branch of Nujiang fault in middle Pleistocene resulted in a differential fluctuation.

Field survey on debris flow gully showed that debris flow gullies Daojie Mapsheet mainly distributed in Laobai River, Malang river and Bajiaolin River. And gullies on Maguang Mapsheet mainly distributed in Baiyan, Longjing River and Shanxin river. There were also small-sized gullies in eastern and western coasts of the Nujiang River.

Based on field survey and remote sensing image, we could see that debris flows had centralized distribution on both sides of river gullies in which fault tectonic zone were densely distributed. They mainly distributed in steep slope of middle mountain. Main types of debris flows were gullies and the gullies were mainly "V" shape and wide "U" shape valley. Most gradients of the slope were between 30°and 50°.

In structural belts, debris flow gullies often concentrated in metamorphic rock series, alternating beds of layered sandstone, siltstone and mudstone, weak rock series like limestone in the Mesozoic era, and the distribution area of Quaternary sediments. Since Bad Geological Phenomenon in these areas were middle-developed to better-developed, and vegetation cover was bad, together with there was human economic activities in debris flow valley, all these factors offered abundant material source for debris flow.

Because the material in valley were mainly mudstone, shale, sandstone, and mixture of weathered rock mass of mixed granite and water, in which clay content is relatively high, most of them formed viscous debris flow, and small part turbulent ones.

The area is located in Low latitude plateau monsoon climatic region, where the dry and rain seasons were distinctive. Rain seasons have dense rainfall and precipitation over strong rainfall mainly concentrated in flood season, namely, from June to August. The strong and heavy rainfall provided abundant water source for the development of debris flow in research area [13, 14].

3.4 Development Characteristics of Unstable Slope

Unstable slope is the most hidden peril and precursor of the occurrence of geological disasters. Landslide, debris flow, slide and so on is the final result of the deformation of unstable slope. 10 sites of unstable slope outcropped in research area, accounted for 11.36% in total, could be considered one type of geological disasters. Most of unstable slope was slope zones which affected or endangered road, town, bridge and river course.

Unstable slope in north of Datian village

Features and damage of the unstable slope: the slope was located in the western road between Datian village and Fashui village. There was poor vegetation and few weeds on the slope body. The slope was 12m long, 60m wide and 10 high. Road construction brought about the formation of the slope, whose gradient was big (about 71°).

Fallen clods and stone could be seen at trailing edge of slope body. The lower segment of the slope body showed a shape of "talus".

Stability and development trend of slope: the activities of slope were obvious, especially in rain season. It could bring about landslides which would block roads. All of these may bring huge inconvenience to traffic and endanger human's life and property safety.

Cause analysis: According to our survey, it can be concluded that, the slope became steeper because of road construction. Such unstable slope belts could be seen along the road between Datian Village and Fashui Village, together with the influence of rainfall, all of these made slope extremely unstable and made slide and landslide very likely happen when it rained. strengthening measures and building retaining wall was advised.

3.5 Development Characteristics of Active Gully

Active gully is the early stage of gully and it is developing. So its damage is greater.

Active gully is the trench brought about by washing of discontinuous flowing water on the ground. Gully cuts ground, which would make the ground broken and difficult to use. Severe soil loss would bring difficulties to construction at developmental gully belts.

Active gullies mainly distributed in thick eluvial layer, which had loose lithological characteristics and strong weathering, and quaternary loose alluvial alluvial terrace (Fig.4). In places with poor vegetation, loose material and a certain slope, the shape of gully was related to its developing time. And the undulation shape of the ground, such as gradient and shape of slope, also directly influenced the shape and combined shape of gully.

Figure 4 *Developmental stages of active gully in Shangxia Yuding Village*

The active gullies on the northern bank of Shuichang River on north side of Shangxia Yuding Village were developed in the clastic limestone of Psh in the upper Permian, which was very broken. As the typical active gullies, three stages of them had been well displayed.

In early stage, streams converged and cut slope surface. As a result, the tiny gullies formed. There was obvious slope break showing a shallow V-shape between the gullies and bilateral slope surface.

In middle stage, the V-shape gullies became wider and deeper, showing sharp and narrow V-shape. New gullies kept on being developed on the surface of water flow. The gullies increased rapidly and expanded their range due to headward erosion. The break between the gullies and slope was very obvious. The developed carbonate rocks dissolved when meeting water, which led to the upper collapse. Though it seemed like landslide, its formation mechanism was distinct from that of landslide.

In late stage, the gullies in aging period showed concave type curve of steep upper and less steep lower. The whole section showed linear groove shape. Gully bottom became flat and longitudinal section became gentle gradually. Both the range and scale reached maximum.

Because development of gullies was related to time, the potential damage in the future should be considered in research on active gullies. For example, affordability of gullies and erosion of rainfall after construction should be taken into consideration. While, soil loss and destruction of farmland should be considered after slope reclamation. Measures, such as guiding water flow, should be taken to prevent the above damage.

4. Conclusion

The geological disasters in survey area were influenced by the following factors: topography and geomorphology, stratum lithology, population distribution, precipitation condition and human activity intensity, etc. Regional difference of distribution of the disasters was obvious.

(I) Geological disasters formed zonal concentrated distribution on both sides of Nujiang river and its branches. Disasters in deep dissection high-middle mountain canyon in the west bank of Nujiang river were debris flow, slide and unstable slope resulting from road construction. While disasters in medium dissection middle-low mountain in the east bank of Nujiang river were mainly landslide, slide and active gullies. Distribution density of geological disasters in the banded zone was different, where disasters concentrated in two sides of gullies and areas where human activities were intensive.

(II) In the whole survey area, the areas of unstable, basically stable, stable area respectively were 121.04 km^2 (16%), 189.98km^2 (24%), 609.7km^2 (60%).

(III) Fatalness coefficient of external forces geological disasters in our survey area is very low, so the area was stable as a whole. Among 40 landslide sites in research area, the percentages of low risk, lower risk, high risk were 69%, 20%, 11%, respectively. And among 62 slide sites, the percentages of above three degrees respectively were 13.51%, 32.44%, and 54.05%.

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