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Implementation of a landscape ecological use pattern model: Debris flow waste-shoal land use in the Yeyatang Basin, Yunnan Province, China

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ABSTRACT

Debris flow waste-shoal land (DFWSL) is a significant and potential land resource that is largely ignored in ecologically fragile mountainous areas. Yeyatang Basin, in Yunnan Province, China, is a typical mountainous debris flow area with a large amount of DFWSL. In order to achieve efficient use of DFWSL in this area, we built a demonstration plot and implemented a landscape ecological use pattern (LEUP) model for the DFWSL, with which we analyzed the economic, ecological, and social benefits. The results showed that the LEUP significantly improved incomes and vegetation coverage, and it reduced soil and water loss, controlled the debris flow, and ensured the safety of residents. To some extent, the LEUP alleviated the conflict between socioeconomic development and environmental protection and increased local employment opportunities, which could help to resolve the socioeconomic issues associated with rural hollow villages and left-behind children. The model demonstration results will provide a "road map" to wasteland use and serve as an important information resource for policymakers. Leaders should consider shifting their perspectives toward exploring land resources that had previously been deemed unavailable and pay more attention to the management and development of DFWSL, which could potentially enable the sustainable development of mountain ecosystems and economies, and enhance the prevention and control of natural disasters in mountainous regions.

1. Introduction

Currently, approximately one billion people reside in mountainous regions.[2] Ecosystem services from mountainous regions, including those involving food, energy, water, carbon sequestration, biodiversity, living spaces, and cultural services, are closely related to human welfare (Xu et al., 2011, 2015; Benton et al., 2018). Nonetheless, due to global climate change and destructive human activities, land degradation and pollution have aggravated the conflict among social development, scarce land resource utilization, and the preservation of ecological health in mountainous area. Globally, 4.9 billion ha of land are devoted to agriculture (approximately 38% of the total global land area), and it is predicted that by 2050, the food supply may need to increase by 60% (Alexandratos and Bruinsma, 2012), which would necessitate an increase in agricultural (arable) land by 10–26% (Schmitz et al., 2014). To overcome extreme limitations, an increase of 42% in farmland and 15% in rangeland will be required (Bajželj et al., 2014). Although the total area under cultivation is fixed, the demand for such land resources is increasing, and this is being driven by both population growth and economic development. Thus, it is likely that additional agricultural land development in mountainous regions will occur.

Available land resources in ecologically fragile areas are decreasing as a result of intensive human activities and natural disasters. In these areas, large populations need to survive and improve their quality of life, even at the expense of the environment, which means that it is difficult to balance the need for environmental protection with the need for local populations to earn a livelihood (Tallis et al., 2008; Cao et al., 2009; Zhong et al., 2013; Oort et al., 2015). Many researchers have attempted to develop strategies to ensure harmony between environmental protection and human development needs in ecologically fragile

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areas, and examples include the successful management and utilization of desert land in northwest China (Cao et al., 2018), reuse of mining wasteland (Liu et al., 2016), exploitation and utilization of karst land (Chen et al., 2017), and rational combination of mountain torrent areas and land resources in arid and semi-arid areas (Zhang et al., 2018). These successful case studies provide a “road map” to managing marginal land, which could be applicable to the use of debris flow waste-shoal land (DFWSL) in China.

As a country with a large population, China is facing land resource scarcity and rapid growth in societal demands (e.g., products and capital). The scarcity of land resources is prominent in mountainous regions, especially in disaster-stricken areas, where development occurs in a cycle of environmental degradation and poverty; specifically, the scarcity of land resources causes poverty, which results in excess land reclamation that causes soil degradation and further poverty (Yan and Qian, 2004; Cao et al., 2018). In addition, China often has debris-flow disasters, but these debris flows create DFWSL. Debris flow waste-shoal land has good photothermal conditions for plant growth, gentle topography (a gradient of approximately 5°), convenient transportation access points, ease of access to irrigation, and positive development and construction potential (Cui et al., 2009), with great possibilities for resolving land scarcity issues. People living in mountainous areas use DFWSL for crop cultivation; furthermore, such land can even be used for suburban-like, constructions, and rural tourism (Okunishi and Suwa, 2001; Sancho et al., 2008). These measures could potentially bring tangible benefits to the local populations in these areas. However, several major factors currently limit the development of DFWSL, such as disordered patterns of development and sand-petrochemical petrification, which have resulted in a gap between investments in development and financial returns. Priorities for these areas include curbing petrification, optimizing spatial layouts, establishing efficient development models, enhancing safety, and improving environmental protections during land exploitation, which will contribute to the proper allocation of resources (Yin et al., 1995; Antoine et al., 1997; Lambin, 1999).

In order to transform a wasteland into usable land, this study applied a landscape ecological use pattern (LEUP) model for the development of DFWSL in the Yeyatang Basin, Yunnan Province, China. This model used optimal spatial arrangements and followed basic patterns of landscape ecology consistent with the patch-corridor-matrix model, and the model promoted material and energy recycling, increases in the area of cultivated land and protection of the natural environment. The objectives of this study were to explore new paths for the development and use of marginal land resources and to find new ways to accelerate the transition to sustainable development in ecologically fragile mountainous regions (Future Earth, 2014). On the one hand, these measures could help to control the degree of exploitation in mountainous regions; on the other hand, they could improve the efficiency of land use in ecologically fragile areas, optimize the development and management of wasteland, ensure a minimum area of arable land, and finally, achieve sustainable use of marginal land resources in mountainous areas (He et al., 2018). Besides, this study also aimed to solve the discrepancy between the need for the protection of natural environmental resources and the need to increase rural farmers’ income through comprehensive management of a small basin.

2. Methods and materials

2.1. Study area

The demonstration plot for this study covered 3.33 ha and it is located in the Yeyatang watershed, Dongchuan District, Yunnan Province, China (103°03′56″–103°06′28″E, 26°02′30″–26°05′33″N, Fig. 1), at an altitude of 1394–2600 m. This watershed is situated in the Xiaojiang deep-seated fault zone and has a complex geology characterized by frequent tectonic activity and fractured rock strata.

The exposed soil is mainly krasnozem formed by strongly weathered basalt. The climate features distinctive dry and wet seasons, which are strongly influenced by a vertical climate zone. The average annual temperature is 20.2 °C, while the total annual precipitation is 691.3 mm, of which more than 85% is accounted for by rain during the monsoon season from May to October (Wu et al., 1990; He et al., 2016).

Debris flows have developed in this area and have formed large debris flow fans. As an example, in the Xiaojiang River Valley, the debris flow fan covers an area of 480 km^2 (Xu and Wang, 2001). The debris flow waste-shoal land is characterized by gentle slopes (5–10°), abundant water resources, convenient transportation access sites, and irrigation facilities (Cui et al., 2009). Moreover, the debris flow fans near water sources have relatively high agricultural potential in terms of crop production (Fig. 2). Since 1983, field observations have been made on the DFWSL in Yunnan’s Jiangjiagou area. During 1988–1996, cultivated land converted from DFWSL covered an area of 286 hm^2, and the land use rate was up to 72% (Hu, 1997). Currently, there are three main types of agricultural development for DFWSL, namely, long-term riverside, temporary riverside, and seasonal riverside development.

Long-term riverside DFWSL needs to be protected by embankments but has sustainable development potential. This land type is relatively stable (Fig. 3A) and associated with low risk, but it requires substantial investments and continuous maintenance. Temporary riverside DFWSL does not require dams and only needs debris flow fan terrain as a barrier. Farming can therefore occur at the proper time (Fig. 3B). This type of land requires a small investment, but it has a short lifespan; it is low cost, but high risk. Seasonal riverside DFWSL is available only during the dry season, from the end of November to the end of May in the next year. When a sufficiently large area of DFWSL is not flooded, watermelon or vegetables can be planted and harvested.

The rice yield on DFWSL in the Jiangjiagou area was 5800–12,150 kg/hm^2, and that of sweet potatoes was 50,520–72,030 kg/hm^2. This output is equivalent to five times the yield of sloping farmland and can provide subsistence for most people living in rural areas (Hu, 1997). Development on DFWSL has prevented water and soil loss, protected the natural environment, and boosted the local economy. However, the overall economic benefits remain low because of the use of traditional and intensive exploitation technologies, as well as the weather conditions.

2.2. Establishment of landscape ecological use patterns

2.2.1. Land consolidation

Although the slope of the DFWSL in the demonstration plot was relatively gentle, many uneven micro-landforms were encountered (e.g., ridges, trenches, and steps) during the process of development; these micro-landforms were the result of mudslide erosion and siltation (Fig. 4A–D). This land could not be used for cultivation without modification. Therefore, the undulating micro-terrain was flattened and beach terraces were built by using large rocks scattered on the surface as ridge stone (Fig. 4E & F). In conjunction with land consolidation, a canal system and field road were built for farming and field management.

Soil management techniques were applied to improve soil quality and overcome the challenges of abundant gravel, low clay and silt content, poor soil structure, and low cultivation potential. Stones were manually removed before cultivation and were continually removed during the annual cultivation process to improve the composition and structure of the soil (Fig. 4G). For DFWSL with coarser soil, mature soil from nearby areas was moved after land consolidation to make the soil loamier and more suitable for cultivation (Fig. 4H).

During flooding or debris flow, fine grain sediment and nutrients in the water were transported in the channel. A diversion canal built during land modification was used to carry the sediment to the land for siltation and sediment improvement purposes. This practice increased the proportion of fine grained soils in the DFWSL, improved the soil

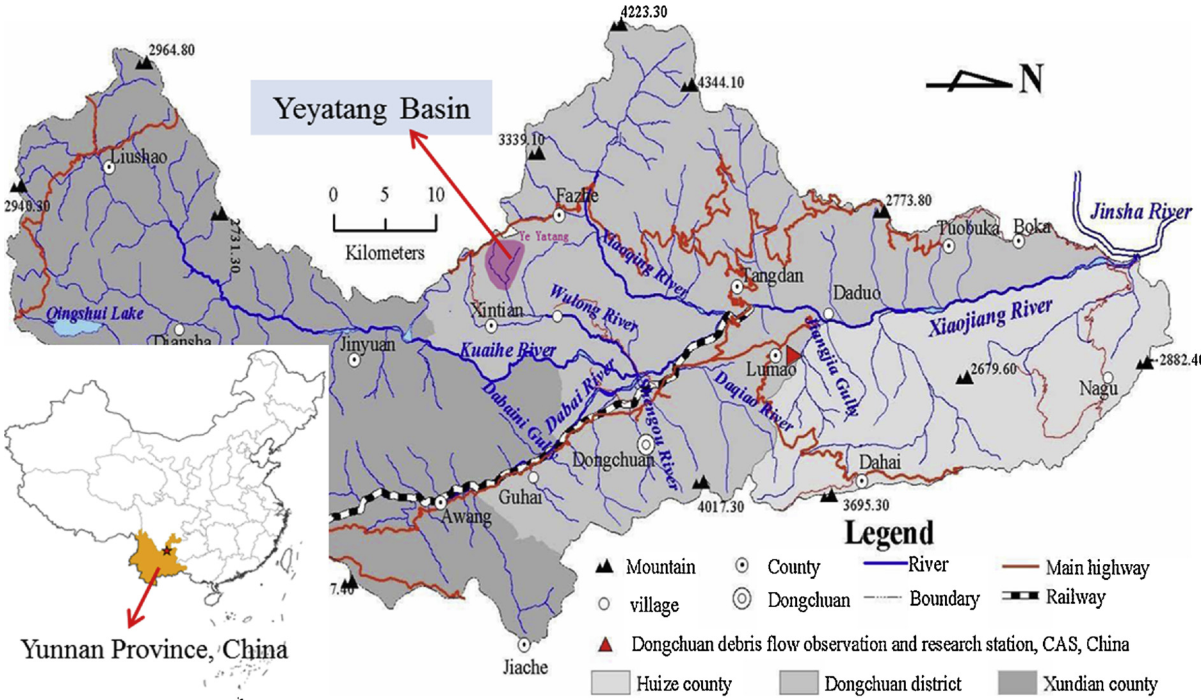

Fig. 1. Geographical location of the Yeyatang watershed.

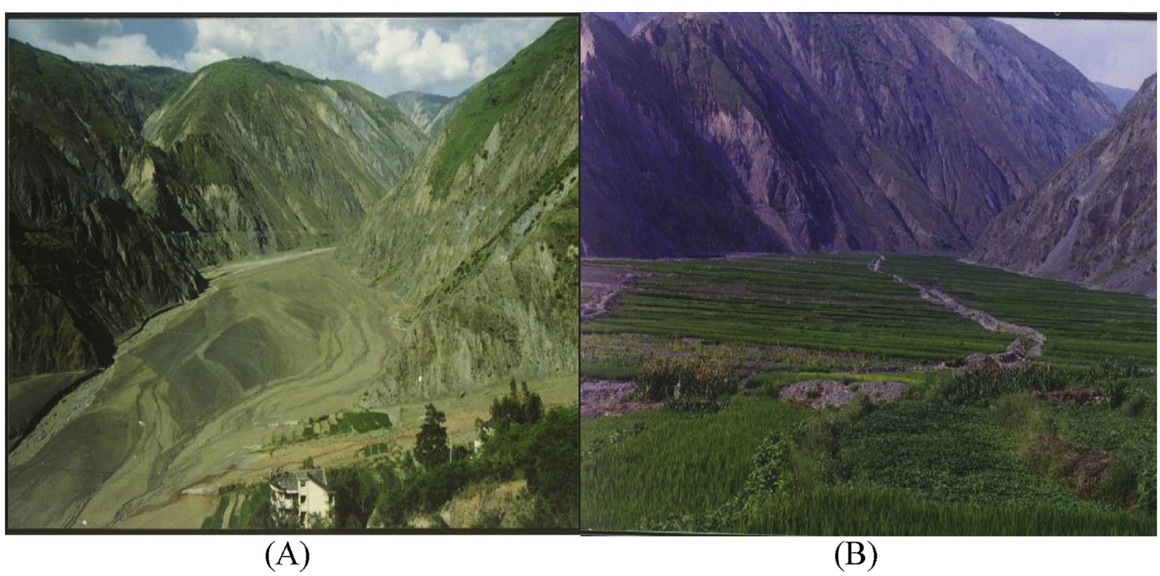

Fig. 2. Examples of various uses for debris flow waste-shoal land (DFWSL): (A) raw DFWSL in Dongchuan; and (B) crop cultivation on DFWSL in Dongchuan.

structure, and added nutrients that improved the soil quality (Fig. 5).

2.2.2. Overall layout and planning

After soil preparation, amelioration, and fertilization, crops (walnut, grape, and field crops) were interplanted (Fig. 6) by making full use of the light and heat resources at different levels. Additionally, forage grass (*Pennisetum sinese* Roxb) was planted on the ridges to fully use the land area and available sunlight; before the planted trees matured, there was more available light and heat. The forage grass was used as fish fodder and to protect the ridges from water and soil loss. Since it takes time for walnut trees and grapevines to mature, the planting designs in 2015 and 2016 were similar to that in 2014. When the walnut trees and grapevines matured (2017), the trees were tall enough to reduce light and heat on the lower slopes. Currently, forage grass is planted instead of peanuts and peas.

The supporting facilities that have been built include reservoirs, irrigation systems, pig pens, chicken coops, and a marsh gas tank (Table 1). The diversion canal can be used for irrigation and the discharging of flood waters in the rainy season. The reservoir can be used as a pool to feed the fish and store water for crop irrigation during the dry season. One hectare of crops requires 75, 105, and 150 m^3 water for irrigation in an ordinary drought year, a severe drought year, and an extreme drought year, respectively. For the 3.33 ha on the DFWSL demonstration plot, 250-500 m^3 of irrigation water was required during the dry season. The reservoir was planned for a volume of more than 500 m^3 (preferably 800 m^3, but not too large to cause wastage) in consideration of the water required for fish farming and extreme drought years.

The farming practices recycled matter and energy. Forage grass was used as fodder for chickens, pigs, and fish. Poultry feces, walnut and

Fig. 3. Two main types of debris flow waste-shoal land (DFWSL) development patterns: (A) long-term riverside DFWSL and (B) temporary riverside DFWSL.

grape branches and leaves, trees, and straw were fermented in the marsh gas tank for energy generation. The remaining waste from the marsh gas tank and the substrate from the fishpond were returned into the soil as plant fertilizer. When the walnuts and grapes were in blossom, bees were used to produce honey (Fig. 7).

The LEUP emphasized the comprehensive functioning of the DFWSL's inner system and the recycling of matter and energy, and this optimization of the system operations was performed to improve the economic and environmental efficiency.

3. Results from benefit analyses

3.1. Economic cost–benefit analysis

The Yeyatang LEUP was planned and established in 2013. Subsequently, 3.33 ha of DFWSL was developed, and the construction fund reached 480,720 yuan in total (Table 1). The input and output details of the DFWSL LEUP from 2014 to 2017 are shown in Table 2.

According to Table 2, costs in the first year (2014) were high because of the purchase of walnut and grapevine seedlings. Since 2015, outlays have been directed to fertilizers and management. Grapes and walnuts began generating income in the second (2015) and third years (2016), respectively. Even though the walnuts and grapes did not generate any income during the first year (2014), there was a net income of 163,300 yuan. Each hectare generated 49,039.04 yuan, thus demonstrating positive economic returns. The gross net income of the following three years was favorable (457,000, 405,200, and 857,000 yuan, respectively). Income greatly increased after the first year following the reduced costs for seedlings and continuous improvements of the DFWSL. Moreover, the fertility of the DFWSL increased, and, as a result, peanut, pea, grape, and walnut yields gradually increased.

The income trend from 2014 to 2017 (Fig. 8) shows that the income of the demonstration plot did not increase smoothly over time. Compared with 2015, the gross income of 2016 decreased, which was partly due to reductions in meat prices and, more importantly, decreased yields of peanuts and peas (resulting from the shading from walnut trees and grapevines). As a result, the increased output from walnuts and grapes could not offset the decreased output from peanuts and peas. After crop conversion and lower meat prices, gross income increased again. Over the long-term, this income fluctuation was reasonable.

In summary, although initial costs were high, they were offset by considerable income in subsequent years. The income of the first two

Fig. 4. Original conditions and consolidation of the debris flow waste-shoal land (DFWSL) in the study area, with uneven micro-landforms, including (A, D) ridges, (B) gravel, and (C) trenches as well as (E, F) large stones for terraces. (G) The DFWSL was flattened, and (H) mature soil from nearby areas was moved to increase the composition of loamy soil.

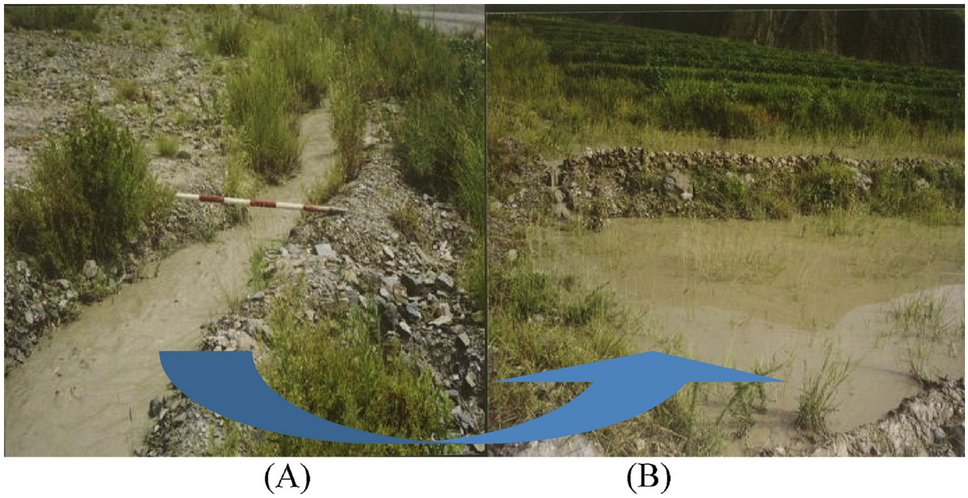

Fig. 5. Improvement of the debris flow waste-shoal land during the flood season: (A) mud and (B) silting.

years offset the cost of infrastructure, and the analysis results showed that this DFWSL LEUP had the advantages of a short investment period and quick economic returns.

3.2. Ecological benefit analysis

The LEUP in this study represents a microcosm for the reclamation and utilization of DFWSL in the Yeyatang Basin, which has been focused on the dual goals of economic development and environmental protection. By planting trees and grass, forest and grass cover in the basin have increased from 19.5 to 30.7% and 29.7 to 37.6%, respectively. According to local observation data collected over 5 years, water and soil conservation forests, commercial forests, and shrubs (herbs) helped to maintain 38, 36, and 28 t/hm^2 water, respectively. In comparison with traditional crop patterns (e.g., peanuts, corn, potatoes), the loss of soil and water under the LEUP was reduced by approximately 15–20%.

The LEUP also promoted the improvement of land quality in the DFWSL. The physical and chemical properties of the soil were greatly improved through flood diversion, siltation, and fertilization techniques with organic and inorganic fertilizers (e.g., straw returned to the fields); in particular, the soil texture changed significantly from sandy to silty loam. In addition, coacervate, clay, total nitrogen, and effective nitrogen increased over time when the soil layer increased from 5 to 35 cm and the gravel content changed from 60 to 1% (Wang et al., 2003).

3.3. Social benefit analysis

The success of the DFWSL LEUP was also reflected in social benefits. The first benefit achieved was to ensure the safety of the lives and property of the 41 households (168 people) near the demonstration plot. Secondly, roads were made more accessible because of the development and exploitation of the DFWSL. In addition, the industrial infrastructure was improved; agriculture in the study region played an important role and accounted for 98% of the total industrial output value. Nonetheless, rural tourism in the area has developed since the commencement of the LEUP. Specifically, agricultural tourism in the demonstration plot started in 2014, thus initiating the local development of eco-agricultural tourism activities; in 2015, only 156 tourists visited the village, but by 2016 the number of visitors had quadrupled. In the following years, the number of visitors and revenue continued to increase. At the same time, as a result of construction needs and considerable economic benefits, a large number of local villagers have returned and remained.

4. Discussion

4.1. Comparisons between our study and other similar areas

With global climate change, population growth and urbanization accelerating, the exploitation and utilization of DFWSL could provide sufficient construction space for further industrialization and residential developments while also providing for effective buffer space for ecological systems, thus becoming leading strategy to solve the problem of protecting cultivated land and ensuring development in mountainous areas. The Pokhara Valley is an intermountain fluvial basin occupying the midsection of the Seti River in the Lesser Himalayas of Nepal. It holds a large volume of layered clastic deposits of gravel, silt and clay of Quaternary age (Yamanaka et al., 1982; Gautam et al., 2000). This area, like the Yeyatang Basin, is located in an ecologically fragile area and subject to frequent landslides and debris flows. However, the built-up area has been expanding rapidly in Pokhara and they have ignored the need to control for disasters and protect the ecological environment. Thus, multiple hazards and risks are rapidly increasing in Pokhara in conjunction with unsustainable land use practices, particularly the increase in built-up areas (Rimal et al., 2015).

In contrast, the LEUP of DFWSL in the Yeyatang Basin has taken into account ecological security issues (e.g., many ecological and engineering measures were used to protect the ecological environment, Fig. 9) in conjunction with economic development. Apart from the direct benefits above, there were also indirect benefits. This approach has transformed the concept of land use and improved awareness of rural revitalization and development, which has encouraged attention and devotion to the development of eco-friendly models in mountainous areas. This is because the utilization of barren land in mountainous regions plays a crucial role in prospering rural economies over the long term. Liu and Li (2017) called attention to rural development, highlighting the necessity of meeting the needs of global urbanization through rural revival. From the above analysis, it can be seen that the LEUP of DFWSL brought about considerable economic and social benefits to the study area, promoted the stability of the natural environment, and, to a certain extent, realized ecological benefits. With the attainment of these benefits, migrant workers can increasingly be attracted back to their hometowns. This can solve the problems related to shortages of the rural labor force, hollow villages, and left-behind children (Liu et al., 2013), and it can also promote the stability of the local social environments (Long et al., 2009; Liu et al., 2010, 2011), the alleviation of poverty, and the use of innovative land land policies (Zhou et al., 2018).

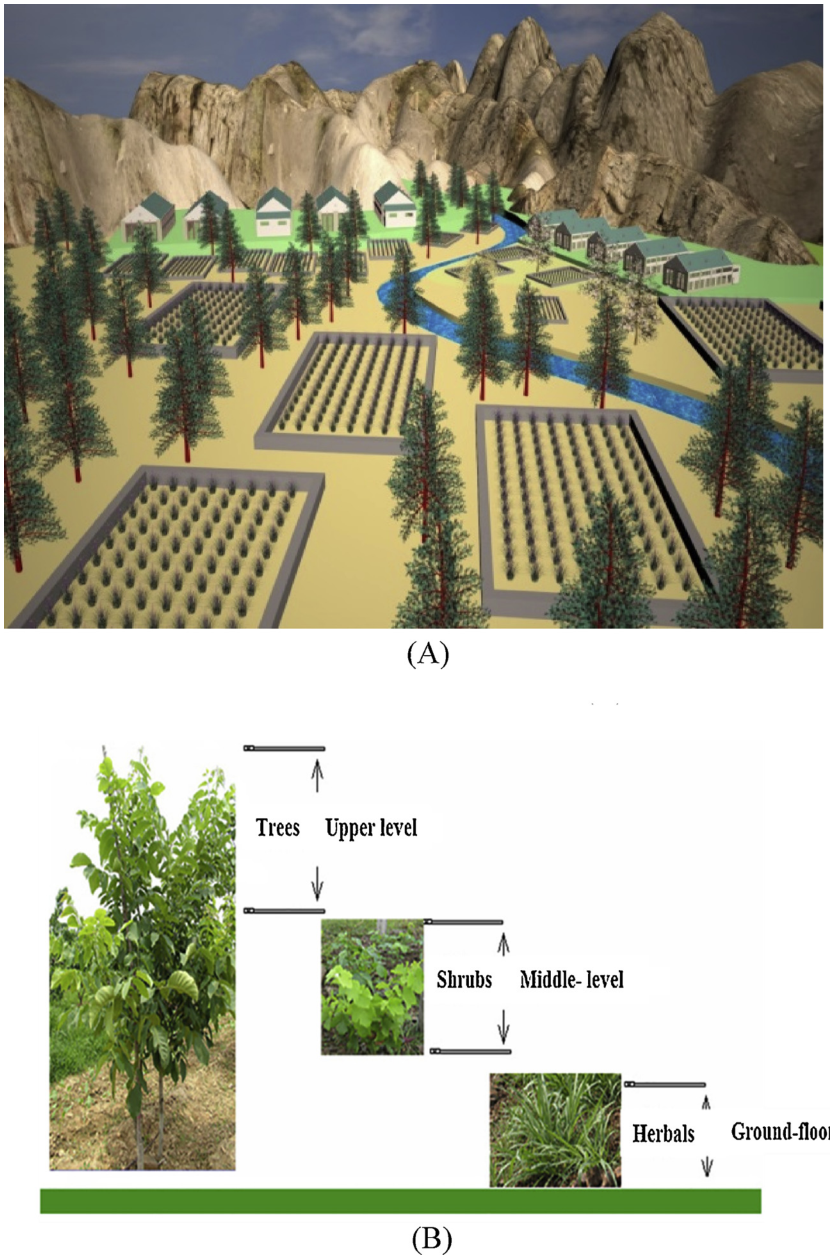

Fig. 6. (A) Layout of the demonstration plot showing a panorama of the landscape-eco types of the debris flow waste-shoal land, including houses, trees and shrubs, canal, and cropland; (B) stratified planting for optimal use of light and heat.

Table 1
Infrastructure investments in the debris flow waste-shoal land in 2013. # represents no available data.

Facility	Number	Unit	Cost (Yuan)
Reservoir	3	#	230,000
Diversion canal	200	m	2,000
Land smoothing	3.3	ha	18,720
Soil replacement	3.3	ha	7,500
Piggery	2,000	m^2	220,000
Methane tank	1	#	2,500
Total	#	#	480,720

In fact, land use planners in the Wudu District, Gansu Province, China have also increasely emphasized the need for disaster prevention and environmental management (He et al., 2018). At present, whether in Wudu or Dongchuan, the development and use of DFWSL has basically formed a pattern of developing with protective measures in place (Fig. 10), and this pattern supports a safe environment and the integrity of the land use system; the upstream management ensures the safety of the downstream area, and the construction of water canals and roads in the downstream area ensures the effective use of the DFWSL. The upstream management includes ecological engineering (e.g., contour hedgerows) and geotechnical engineering (e.g., slit dams) projects, which are adopted to manage soil and water loss, and further ensure the safe use of DFWSL in debris flow areas.

4.2. Comparisons between the proposed LEUP and previous DFWSL use in this area

The research on the development and utilization of DFWSL in China was originally conducted in the Jiangjiagou Basin (Yunnan Province, China), where debris flows occur and propagate. From 1983 to 1987, some scholars scientifically demonstrated and analyzed the prospects

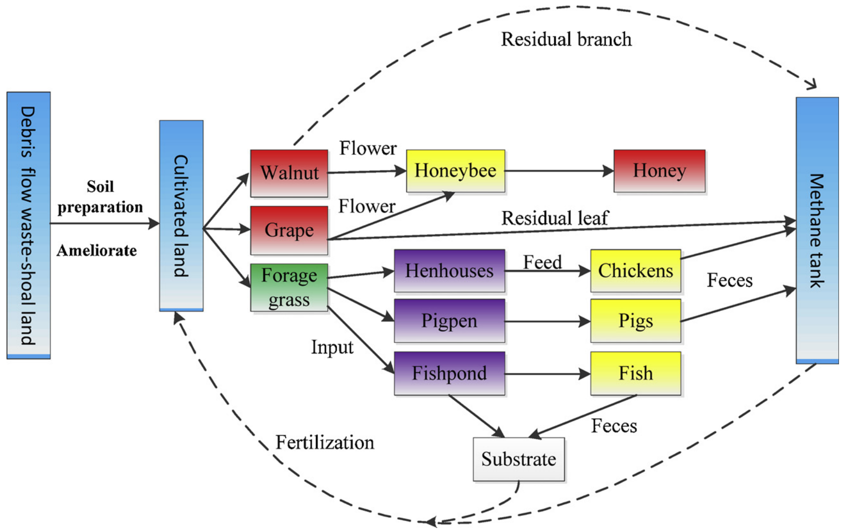

Fig. 7. Operational routes of the landscape ecological use pattern model in the debris flow waste-shoal land showing the recycling of matter and energy (He et al., 2018).

for the use of this area, and the availability of DFWSL gained recognition through a series of observations on the distribution of DFWSL in the Jiangjiagou Basin (Wu et al., 1990; Tian, 1991, 1994). During 1988–1996, the DFWSL in the basin was transformed into 286 ha of cultivated land with a utilization rate of 72%. The annual yield of the paddy fields developed on DFWSL in the Jiangjiagou Basin reached 10,500 kg/hm^2 (Hu, 1997); in 1997, the price of rice was 1.6 yuan/kg, which resulted in a total income of 16,800 yuan. By comparison, although the LEUP in this study required high investment costs (145,672.73 yuan/ha) and the income was 49,039.04 yuan/ha in the early stages, the income reached to 257,357.36 yuan/ha in later stages, meanwhile the income of local sloping farmland is only 7500 yuan/ha.

As a result of the recycling of material and energy, it is evident that the DFWSL LEUP is more efficient than the previously implemented DFWSL use pattern, as well as the local sloping farmland. As a further example, the demonstration plot covered 3.33 ha and needed 30,000 kg dry material per ha and 99,900 kg dry farm manure per year; the pigs and chickens generated 107,500 kg manure per year, which met the need of the demonstration plot.

Furthermore, the LEUP stimulated agricultural tourism. Flower viewing in spring, fruit-picking in autumn, and farm stays can also be developed. Successful rural tourism can increase the demand for agricultural products, which can promote more investment in agriculture. This development model is flexible in regard to local conditions, so that construction and operations on the DFWSL can meet the development needs of local populations. For example, in the Wudu District, China, DFWSL has been developed into greenhouses for vegetable production, which can also bring about economic, ecological and social benefits.

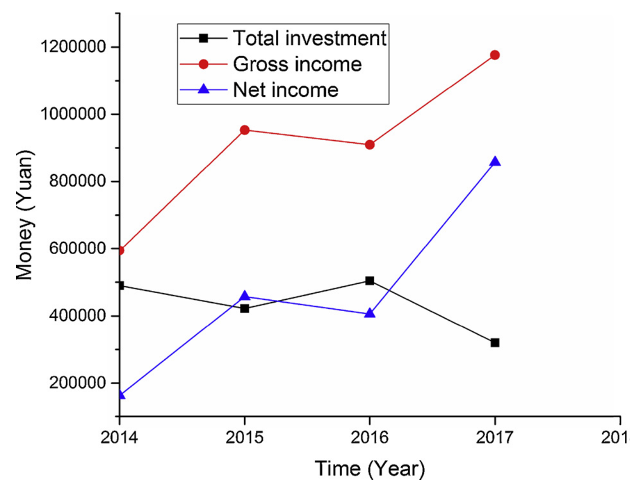

Fig. 8. Input and output trends of the landscape ecological use pattern from 2014 to 2017.

Table 2
Inputs and outputs for the landscape ecological use pattern of debris flow waste-shoal land in the study area from 2014 to 2017. “A” indicates invested funds (yuan), and “B” indicates income (yuan); # represents no available data; other inputs mainly include electricity, land rent, and maintenance costs.

Time (Year)	2014		2015		2016		2017	
	A	B	A	B	A	B	A	B
Walnuts	38,750	0	1,250	0	1,750	15,000	1,750	375,000
Grapes	91,500	0	2,000	20,000	2,500	60,000	3,000	160,000
Peanuts	6,300	100,000	6,300	140,000	6,300	80,000	0	0
Forage grass	250	0	250	0	250	0	2,500	0
Peas	6,600	28,000	6,600	34,400	6,600	25,600	0	0
Fish	20,000	72,000	23,000	84,000	23,000	84,000	23,000	84,000
Chickens	306,000	405,000	357,000	525,000	357,000	525,000	182,000	437,500
Pigs	15,750	108,000	20,450	150,000	17,450	120,000	17,450	120,000
Service charge	59,600	#	74,000	#	74,000	#	74,000	#
Other inputs	4,950	#	5,550	#	15,550	#	15,550	#
Total input	549,700	#	496,400	#	504,400	#	319,500	#
Total output	#	**713**,000	#	**953**,400	#	**909**,600	#	**1176**,500
Net output	163,300		457,000		405,200		857,000	

Fig. 9. Various measures for ecological preservation: (A, B) slope ecological protection measures; (C, D) check dam; and (E, F) drainage groove.

This model has been found to not only improve the quality of DFWSL (Koonin, 2006; Wiegmann et al., 2008; Milbrandt and Overend, 2009; Vuichard et al., 2009), but also increase ecological restoration opportunities and the maximization of economic and social benefits; in summary, it enables communities to achieve sustainable development (Xu et al., 2011). For example, structures that combined vegetation with discharge trenches and reservoirs were able to slow the flow velocity of slope runoff, decrease erosion and scouring, and simultaneously increase water infiltration by reducing surface runoff. In fact, the use and exploitation of DFWSL is a constant process of improvement. To achieve further development, the integrated management of ecological governance and land use should be taken seriously, and emphasis should be placed on the risks associated with the use of abandoned or marginal land due to the serious impacts of soil and water loss (Doorn and Bakker, 2007; Nunes et al., 2011).

4.3. Remaining issues and development proposals

Despite the successful exploitation and use of DFWSL, there are remaining issues that must be addressed. First, there is a lack of scientifically informed systematic theories of development. These theories should include theories of dissipative structures, ecological catastrophes, ecological and healthy developments, and the valuations of ecosystem services. Second, there is a lack of information concerning construction and spatial management of DFWSL in the debris flow area. Furthermore, because of less focus on the development and use of DFWSL, there is presently a lack of legal systems and financial subsidies to strengthen spatial planning.

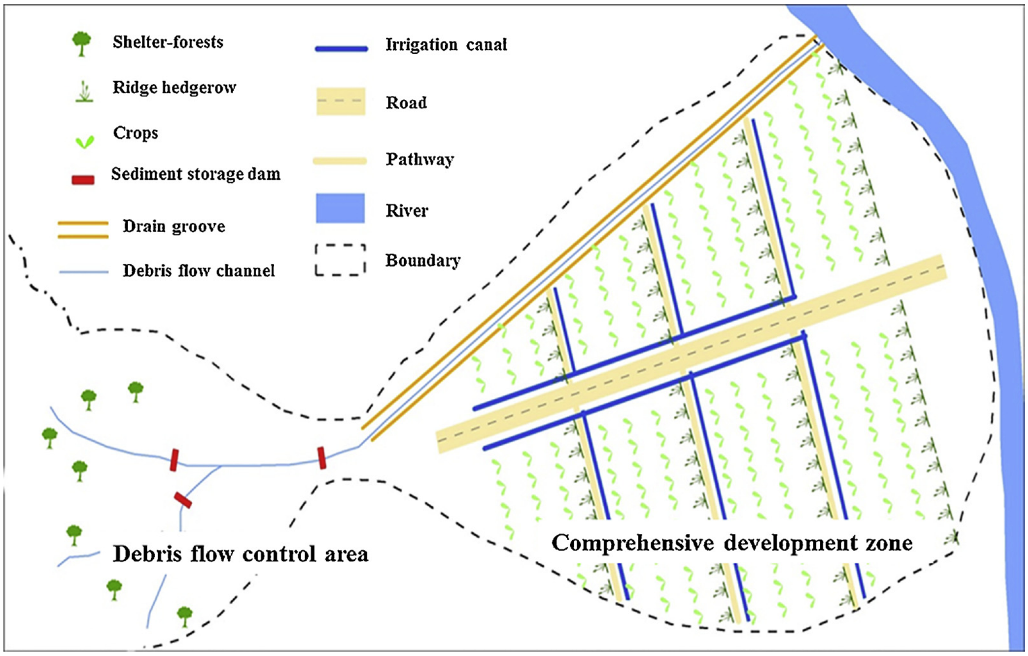

Fig. 10. Schematic diagram of safe and efficient development and utilization of debris flow waste-shoal land (DFWSL).

Land use in other countries differs from that of China. However, our study provides inspiration and implications for the broader use of marginal land such as DFWSL in ecologically fragile areas. The government must guide publicity and investments in such a way that encourages public participation; only through deliberate steering can governments ensure that all participants will benefit from the results (Johnson and Priest, 2008) and achieve effective, efficient and fair resource management (Walshe and Nunn, 2012). Moreover, relevant regulations (e.g., marginal land supervision laws and safety development regulations) should be established to strengthen the planning and management of the development and use of DFWSL, and relevant regulators are needed to supervise and manage DFWSL use so as to administratively ensure that human activities are reasonably regulated (Peng and Mu, 2011; Liu et al., 2014). Research can provide guidance for the development of policies that can successfully manage increasingly scarce land (Cao et al., 2009). More importantly, financial support should be provided in the early stages, including both government and private funding. To some extent, private funding is advantageous because private investments are usually based upon careful examination of the long-term return on investment in order to produce sustainable business models (Cao and Zheng, 2016). Consequently, private funding may be more economically efficient than government funding.

5. Conclusion

In practice, the LEUP of DFWSL was successful in improving land development and use. Through the land preparation and overall layout, the LEUP model implemented in the Yeyatang Basin was not only to increase the quantity and quality of land resources in the mountainous area, but also to protect the ecological environment, to build new countryside, to coordinate urban and rural developments, and to promote comprehensive land consolidation. In addition, the implementation of this model helped to retain the local people in the area, thus helping to address the issue of rural hollow villages and left-behind children. Through this study, we provide a novel and practical example of marginal land use for other countries or regions.

In summary, the LEUP model that was tested in the Yeyatang Basin was found to be worthwhile of promotion. At present, the participants generally include the government and local populations. In the future, more private enterprises should be involved. In ecologically fragile areas, the combination of theories and practices of land use and landscape ecology, alongside consideration for both risks that need to be controlled and development, represent future trend in the development and use of waste land, as this is a requirement for sustainable development. The development of DFWSL must be informed by ecological risk evaluations and proposed rescue plans, as well as be supported by research and input from experts and public participation, after which land development can be carried out.

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