ISSN 2616-5872 Vol. 7, Issue 1: 37-41, DOI: 10.25236/AJEE.2025.070104

Comprehensive Benefits of Soil and Water Conservation in Small Watersheds in Karst Desertification Areas of Guangxi

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Abstract: *Guangxi faces the challenge of karst desertification during its economic and social development, which poses a potential threat to the local environment. This paper takes the Tuokan small watershed in Tiandeng County, Guangxi, as an example. The Tuokan small watershed is a typical karst landform area, with desertification covering 62.9% of the total watershed area. Locally, vegetation coverage has been gradually restored through afforestation and mountain closure for forest cultivation. Pioneer plants and drought-tolerant native plants suitable for the local environment have been selected for planting, and unreasonable land use practices have been addressed through converting farmland to forest and grazing land to grassland. Through setting up observation points in slope runoff areas, the runoff characteristics of different land types were observed in detail. The observation results show that the Tuokan small watershed faces varying degrees of soil erosion issues, but after treatment, land productivity and land use efficiency have significantly improved, vegetation coverage has notably increased, and the overall treatment effect is favorable.*

Keywords: *Guangxi karst desertification areas; small watershed; soil and water conservation; comprehensive benefits*

1. Introduction

While the Guangxi region of China has made continuous progress in economic development, it has also prioritized natural environmental protection. However, due to the region's unique natural landscape, karst desertification phenomena have emerged during economic development, which is relatively typical. The karst desertification in Guangxi has squeezed the living space of local people, decreasing the available land area, which is unfavorable to the effective economic development of the region. Therefore, efforts are currently being made in Guangxi to strengthen the active control of karst desertification, promote soil and water conservation in small watersheds, and enhance the rational planning of land space. These efforts aim to effectively protect local forest resources and mitigate the adverse effects of desertification[1].

2. Tuokan Karst Desertification Area

The Tuokan small watershed in Tiandeng County, Guangxi, is a typical karst landform area. Due to long-term human activities and natural factors, the area has experienced severe karst desertification. Desertification has led to ecological degradation, severely affecting the production and daily life of local residents. According to monitoring results from Tiandeng County on karst desertification, the desertified area in the Tuokan small watershed is 1,997.9 hectares, accounting for 62.9% of the total watershed area. Local management practices have involved afforestation, mountain closure for forest cultivation, and the gradual restoration of vegetation coverage. Pioneer and drought-resistant native plants suitable for the local environment have been selected for planting. Unreasonable land use practices have been addressed through converting farmland to forest and grazing land to grassland. Human activities on the land have been reduced to minimize further desertification, and soil and water conservation efforts have been strengthened. The construction of terracing and water storage facilities, such as reservoirs, has helped reduce soil erosion. Water-saving irrigation techniques have been promoted, and subsidies have been provided to farmers participating in desertification control. Economic incentives have been jointly adopted to guide farmers in participating in the governance efforts[2].

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3. Design of Soil and Water Conservation in Tuokan Karst Desertification Area

Each land type was measured three times, with a 1m×1m×1m runoff collection pit set up. The measurement area was 100m², with a length of 20m and a width of 5m. The observation period was from May 2023 to November 2023, with a focus on the rainy season from June to October. During this period, rainfall amount and intensity were observed. The criteria for identifying light rain, moderate rain, heavy rain, and torrential rain were as follows: <5.0mm, 5.014.9mm, 15.029.9mm, and >30.0mm, respectively. During the observation process, a 60cm×40cm single brick separation was used, and drainage ditches were set up. See Table 1.

Table 1. Design of Slope Runoff Observation Area

Name	Slope (°)	Main Crop	Total Vegetation Coverage (%)	Slope Position	Soil Type	Altitude (m)
Terraced Field	20	Chrysanthemum (Seedling)	38	Lower Slope	Red Soil	38
Water Conservation Forest	17	Yunnan Pine	91	Middle Slope	Red Soil	2048
Sloping Farmland	20	Chrysanthemum (Seedling)	38	Lower Slope	Red Soil	2031
Fruit Orchard	19	Walnut	81	Middle Slope	Red Soil	2048
Abandoned Grassland	17	St. John's Wort	42	Upper Slope	Red Soil	2048

Runoff was measured using a steel ruler to calculate the water surface depth in the collection pits, allowing the runoff volume after treatment to be determined. For sediment observation, the water samples in the collection pits were thoroughly mixed. Three standard sampling containers were measured to determine sediment content. Runoff data was accumulated over a 10-day observation period.

4. Results of the Comprehensive Benefits of Soil and Water Conservation in the Tuokan Karst Desertification Area

4.1 Analysis of Soil and Water Loss

The Tuokan small watershed in Tian'e County, Guangxi, includes land types such as sparse young forests, sloping farmland, and barren grasslands. During the process of karst desertification, varying degrees of soil and water loss occurred [3]. The overall soil and water loss in the watershed is shown in Table 2.

Table 2. Soil and Water Loss in the Tuokan Small Watershed, Tian'e County, Guangxi

Degree of Soil and Water Loss	Sparse Young Forest		Sloping Farmland		Barren Grassland	
	Area (hm²)	Proportion (%)	Area (hm²)	Proportion (%)	Area (hm²)	Proportion (%)
Total	760.7	-	-	-	398.37	-
Mild	760.7	100	88.28	23.2	156.56	39.3
Moderate	-	-	277.41	72.9	171.70	43.1
Severe	-	-	14.84	3.9	70.11	17.6
Very Severe	-	-	0	-	-	-
Drastic	-	-	0	-	-	-

The total cultivated land area in the Tuokan small watershed is 1,095.41 hm². Among this, cultivated land with a slope of less than 5° accounts for 672.54 hm², representing 61.4% of the total cultivated land area. This relatively flat land is highly suitable for farming. Cultivated land with a slope between 5° and 15° covers 402.2 hm², making up 36.7% of the total. Although this type of land has a certain slope, it is still suitable for cultivation with appropriate measures to prevent soil and water loss. Cultivated land with a slope between 15° and 25° accounts for 20.67 hm², representing approximately 1.9% of the total area. See Table 3 for details.

ISSN 2616-5872 Vol. 7, Issue 1: 37-41, DOI: 10.25236/AJEE.2025.070104

Table 3. Composition of Cultivated Land Slopes in the Tuokan Small Watershed, Tian'e County, Guangxi

Land Type / Total Land Area (hm²)	3165.75		
Cultivated Land	Area (hm²)	1095.41	
	Proportion (%)	34.6	
Cultivated Land Slope Composition	<5°	Area (hm²)	672.54
		Proportion (%)	61.4
	5°~15°	Area (hm²)	402.2
		Proportion (%)	36.7
	15°~25°	15°~25°	20.67
		15°~25°	1.9

4.2 Analysis of Land Use Distribution

The Tuokan small watershed in Tian'e County, Guangxi, features various land use types, including forest land, cultivated land, orchards, and barren land. Forest land comprises shrubland, arbor forests, and sparse young forests, as shown in Table 1. In the process of soil and water conservation, the effective development and utilization of local soil and water resources have maintained a stable area for forest land, cultivated land, and orchards. Specifically, arbor forests cover an area of 852.62 hm², terraced fields occupy 614.47 hm², and sloped cultivated land spans 422.87 hm². Detailed land use statistics are provided in Table 4.

Table 4. Current Land Use in the Tuokan Small Watershed, Tian'e County, Guangxi (hm²)

Land Type / Total Land Area	3165.75	
Forest Land	Shrubland	14.46
	Arbor Forest	852.62
	Sparse Young Forest	760.7
Cultivated Land	Terraced Fields	614.47
	Paddy Fields	58.07
	Sloped Cultivated Land	422.87
Orchards	24.20	
Barren Land	356.03	
Other Land	Transportation	11.70
	Urban and Industrial Land	32.16
	Water Bodies	8.87
Unusable Land	9.60	

4.3 Analysis of Slope Runoff Characteristics of Different Land Use Types

The Tuokan small watershed in Tian'e County, Guangxi, covers a total area of 3,165.75 hm², with cultivated land comprising 1,095.41 hm² (34.6% of the total area). Within this cultivated land, paddy fields account for 58.07 hm², terraced fields for 614.47 hm², and sloped cultivated land for 422.87 hm². Forest land occupies 1,627.78 hm², representing 51.42% of the total area. Non-productive land covers 43.86 hm² (1.38%), while rural residents possess an average of 1.08 hm² of land per person, including 0.37 hm² of cultivated land per person. The cultivated land with a slope of less than 5° occupies 672.54 hm² [4]. The monthly runoff characteristics under different land use types are shown in Table 5.

Table 5. Monthly Runoff Volume from Different Land Use Types in the Tuokan Small Watershed, Tian'e County, Guangxi

Month	Runoff Volume / 10,000 m³					Erosive Rainfall (mm)	Total Runoff / 10,000 m³
	Terraced Fields	Water-Conserving Forest	Sloped Cultivated Land	Fruit Orchard	Barren Grassland		
June	1.789	0.681	3.251	0.821	2.300	171.0	8.842
July	2.173	0.947	3.614	1.110	2.169	191.5	10.013
August	0.943	0.353	1.603	0.430	1.136	121.0	4.465
September	2.247	1.065	3.550	1.055	2.643	175.0	10.560
October	1.216	0.460	1.821	0.550	1.332	100.0	5.379
Total	8.368	3.506	13.839	3.966	9.580	758.5	392.59

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4.4 Comprehensive Benefits of Soil and Water Conservation for Different Land Use Types

Construct a comprehensive evaluation function as follows:

$$F(x)=\sum_{i=1}^{n}\alpha_i \times f_i(x) \tag{1}$$

Here: α_i is the weight value of the evaluation index factor, $F(x)$ is the comprehensive evaluation value of soil and water loss conditions, $f_i(x)$ is the quantitative value of the evaluation factor.

The index value for water conservation and source maintenance is 8.4969%, indicating that soil and water conservation efforts have achieved significant success in enhancing the value of water resources. The index values for land productivity and land utilization rate are also relatively high, at 3.5904% and 4.0543%, respectively, demonstrating that conservation measures have effectively improved land use efficiency.However, the index values for Engel's coefficient, per capita basic farmland, economic internal recycling rate, and environmental population carrying capacity are relatively low, suggesting that land management needs to be further strengthened [5].The vegetation coverage rate has reached 17.5157%, reflecting significant success in increasing vegetation coverage through conservation efforts. The index values for improving soil fertility and soil physical and chemical properties are 8.1242% and 3.7876%, respectively, indicating that the measures have effectively improved soil quality, providing a better environment for crop growth. The index value for reducing the soil erosion modulus is 2.2047%, showing that the measures have contributed to reducing soil erosion to a certain extent. However, the labor utilization rate is only 0.6083%, indicating that the efficiency of labor resource utilization needs to be improved during the conservation process. The index value for reducing non-point source pollution output is 3.7103%, showing that the conservation measures have achieved certain results in controlling agricultural non-point source pollution. See Table 6.

Table 6. Benefits of Comprehensive Soil and Water Conservation Management in Tuokan Watershed, Tiandeng County, Guangxi

Evaluation Index (c_{ij})	Quantified Value ($f_i(x)$)	Weight (α_i)	Index Value (F(x)/%)
Land productivity/(kg·hm^{-2})	0.57	0.0618	3.5904
Engel's coefficient/%	0.43	0.0558	2.5154
Per capita basic farmland/(m^2·person^{-1})	0.59	0.0321	1.6421
Value of water conservation and source maintenance (10,000 yuan)	0.61	0.1369	8.4969
Economic internal recycling rate /%	0.52	0.0318	1.6376
Environmental population carrying capacity (person·hm^{-2})	0.41	0.0185	0.8741
Land utilization rate/%	0.51	0.0764	4.0543
Vegetation coverage rate/%	0.73	0.2365	17.5157
Improvement of soil physical and chemical properties/%	0.47	0.0772	3.7876
Reduction of soil erosion modulus/(t·hm^{-2})	0.51	0.0423	2.2047
Labor utilization rate/%	0.37	0.0155	0.6083
Improvement of soil fertility/%	0.56	0.1374	8.1242
Reduction of non-point source pollution output/%	0.47	0.0772	3.7103

5. Conclusion

Ecological environmental protection is as important as economic development. Water and soil are fundamental issues in regional environmental protection and hold long-term significance for the local environment. Currently, there is a certain trend of desertification spreading in the karst areas of Guangxi. Without effective control, this could lead to severe consequences. Therefore, during the process of managing the rocky desertification areas in Guangxi, efforts to actively promote soil and water conservation are essential. In the Tuokan watershed of Tiandeng County, Guangxi, severe rocky desertification has led to ecological degradation [6]. Measures such as artificial afforestation and grazing

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prohibition combined with grassland restoration have been adopted to gradually restore vegetation coverage and improve land-use planning. With the implementation of comprehensive soil and water conservation measures, significant improvements have been achieved. These include an increase in water resource value, land productivity, and land utilization rates. Vegetation coverage has improved, soil quality has been enhanced, and soil erosion has been controlled to some extent, resulting in positive outcomes.

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