Integrated Prevention and Control System for Soil Erosion in Typical Black Soil Region of Northeast China

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Abstract The black soil region of Northeast China is one of the most important food production bases and commodity grain bases in China. However, the continual loss and degradation of precious black soil resources has led to direct threats to national food security and regional sustainable development. Therefore, it is necessary to summarize integrated prevention and control experience of small watersheds in black soil region of Northeast China. Tongshuang small watershed, a typical watershed in rolling hills of typical black soil areas in Northeast China, is selected as the study area. Based on nearly 50 years' experience in prevention and control of soil and water loss, the structures and overall benefits of an integrated prevention and control system for soil and water loss are investigated. Then, the 'three defense lines' tri – dimensional protection system with reasonable allocation of different types of soil and water control measures from the hill top to gully is systematically analyzed. The first line on the top hill can weaken and block uphill runoff and sediment, hold water resources and improve soil property. The second line on the hill can truncate slope length, slow down the runoff velocity and reduce erosion energy. The third line in the gully is mainly composed of waterfall engineering, which can inhibit soil erosion and restore land resources. The 'three defense lines' system is feasible for soil and water loss control of small watersheds in the typical black soil region of Northeast China. Through the application of the in Tongshuang small watershed, There are effective improvements in ecological conditions in Tongshuang small watershed after the application of 'three defense lines' soil and water control system. Moreover, the integrated treatment paradigm for soil and water loss in typical black soil region is compared with that in loess region. The results of this study could offer references and experiences for other small watersheds in typical black soil region of Northeast China.

Key words Typical black soil region, Small watershed, Soil and water loss, Comprehensive prevention and control system

The black soil region in Northeast China is up to 1 030 000 km^2. The "typical black soil region", approximately 117 800 km^2, is mostly composed of black soil, chernozem and meadow chernozemic soil, and mainly located in the Songnen Plain and its surrounding terrace and low hilly areas[3-5]. The grain production capacity and sustainability of land utilization in this region is of importance to grain security of the whole country in China[3-5]. There are various topographic forms in these areas, including hillocks, rolling hills and flat lands with major characteristics of long and gentle slopes. Under the cultivation conditions on gentle slopes of cultivated slope lands, Soil erosion and ecological degradation has become very serious in cultivated farms of black soil region, due to concentrated rainfalls and irrational cultivation by large scales of migrants since a long time in history[5-7]. Studies indicate that at the current erosion rate, fertile black soil would possibly be lost completely after 40 to 70 years[8]. Compare to other main water erosion regions in China, the special topographic conditions, long and gentle slopes, have brought distinct differences for soil erosion in black soil region. Since the 1980s, great efforts have been made for controls of soil erosion in black soil regions, and great benefits have been obtained[11-13]. However, the experiences are not well summarized to guide practices. To provide theoretical basis for comprehensive control practices of soil erosion in the small watersheds of these areas, a representative small watershed of the typical black soil region in Northeast China, Tongshuang small watershed, has been selected to discuss the comprehensive control pattern.

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1 Introduction

1.1 General Information of Tongshuang Small Watershed

Tongshuang small watershed, at the northern edge of Songnen Plain in front of Lesser Khingan Range, is in Xing'an Village, Xinsheng Town, Baiquan County of the typical black soil region. It belongs to the black soil erosion region with rolling hills in the middle of Heilongjiang Province. Its total drainage area is 21.8 km^2. For a long time, due to influences of natural factors and unreasonable human activities, soil erosion is serious before measures of soil and water conservation are taken. The average annual erosion modulus was 6 600 $t/(km^2 \cdot a)$. The area of soil erosion accounted for 77% of the total area of this watershed. And the area of cultivated slope farm land with serious soil loss was 10.6 km^2, which was 76% of the total cultivated land area. General land conditions Tongshuang small watershed area arelisted in Table 1.

Soil parent material is quaternary alluvial-diluvial loess shaped loam in Tongshuang watershed[14]. Geomorphic feature types are mainly piedmont gradient pluvial-alluvial terraces (upland plain, also known as land of rolling hills), at latitudes ran-

ging from 260 to 326 m. The topographic forms are rolling hills. With slope gradients mainly ranging from 4° to 6°and the slope length mainly ranging from 500 to 1 000 m. Soil is mainly composed of black soil and meadow soil in this watershed. Vegetation is mainly includeing artificial forests, most of which are poplars, pinus sylvestris and willows, and farmland plants generally include soybeans, corns, beets and oil plants. This watershed has mesothermal tropical continental monsoon climate features with distinct four seasons. Spring turns warm soon, with little rainfalls and dry weather, and many strong winds; summer is hotwith concentrated rainfalls and an average annual rainfall of about 500 mm. The precipitation of summer, from July to September, accounts for more than 70% of the total precipitation of the whole year.

Table 1 General land conditions in Tongshuang small watershed (Data source[22])

Geomorphic features	Large flat piece	Large gentle slope piece	Small gentle slope piece	Large steep slope piece	Scattered abrupt slope pieces	Land unable to be used
Land gradient	<1.5°	1.5° to 3°	3° to 5°	5° to 8°	8° to 15°	>15°
Erosion intensity	Slight	Light	Medium	Deep	Extremely deep	Extremely deep
Soil thickness(cm)	>200	150 to 200	50 to 150	30 to 50	15 to 30	<15
Soil texture	Light-medium soil	Light-medium soil	Light-medium soil	Medium-heavy soil	Heavy soil-coarse sand	Heavy clay, coarse sand, parent material
Organic matter content (%)	>4	3 to 4	2 to 3	1.5 to 2	1 to 1.5	<1
Gravel content (%)	<2	2 to 5	5 to 15	15 to 30	30 to 50	>50
pH	6.5 to 7.5	6.5 to 7.5	6.5 to 7.5	>7.5, <5.5	>7.5, <5.5	>7.5, <5.5
Irrigation condition	Yes	No	No	No	No	No

1.2 Representativeness of Tongshuang Small Watershed

Tongshuang small watershed is typical for the black soil region in Northeast China in terms of natural features as well as the characteristics and control history of soil erosion.

(i) Typicalness of the erosion type area. Tongshuang small watershed is located in one of the 32 counties of typical black soil region in Northeast China, where the soil is mainly composed of black soil and meadow soil with parental material of grits and clays. The black soil layer is loose, while its parental material is sticky and heavy. The differences between them can easily cause 'perchedwater' phenomena and lead to surface runoff and easy soil erosion.

(ii) Typicalness of erosion type. Tongshuang small watershed has geomorphic features of piedmont pluvial-alluvial terraces (upland plain, also known as land of rolling hills) with long and gentle slopes. Thus the cultivated farmlands here have large rain collection areas. In summer, there are concentrated rainfall and runoff with strong erosive force of, leading to severe land erosion and gully erosion. Generally, it is in the typical water erosion areas of Northeast China.

(iii) Typicalness of land utilization. Tongshuang small watershed is characterized by traditional agriculturewith main production of soybeans, corns, beets and oil plants and main vegetation of artificial forests, which are typical type of land utilization of black soil regions in Northeast China.

(iv) Typicalness of soil erosion. Water erosion is the main force of soil erosion in Tongshuang small watershed, where surface erosion and gully erosion are common and lead to serious destroy to land resources. Before measurements of soil and water control were taken, , surface black soil layer is peeled off by soil erosion, leading to thinner black soil from 1 m to about 20 to 30 cm[15]. All these characteristics are typical in in black soil regions of Northeast China.

(v) Typicalness of comprehensive controls on soil erosion. Tongshuang small watershed has a long history and rich experiences on soil erosion control. Measures of soil and water loss were started from the early 1950s, in Tongshang small watershed, and became demonstration Engineering in 1999. About 16.7 km^2 of soil erosion area has been controlled accumulatively, which accounts for 90% of areas that need to be controlled. Meanwhile, good benefits have been achieved. Therefore, Tongshuang small watershed is typical area in terms of study on the comprehensive control pattern of soil erosion in black soil regions of Northeast China.

2 Structure and functions of comprehensive control system on soil erosion in Tongshuang small watershed

Tongshuang small watershed locates in the typical water erosion region of rolling hills in Northeast China. It is obviously characterized by long and gentle slopes on the cultivated slope lands with vertical distribution of surface erosion from top hill to bottom hill[9,16]. Flow velocity and sediment transport capacity of runoff change with slope length. On the one hand, increase of velocity would facilitate increase of runoff erosion capacity, while increase of sediment transport would impair the erosion force and thus reduces the erosion capacity of the runoff. The dynamic balance between them always changes along slope length, leading to alternate of erosion and deposition of sediment and resulting in the vertical distribution of strong and weak erosions along from top hills to bottom hills. Although most slopes are gentle in rolling hills of black soil regions, the slope-gradient still has great impacts on slope soil erosion process in black soil regions. With the increase of gradient, soil steady infiltration rate decreases, infiltration volume reduces, and runoff amount increases[17].

Based on the characteristics of soil erosion, topographic features, land utilization conditions and in the water erosion re-

gion of rolling hills, and productivity development level, Control experiences on soil and water loss of small watershed control in Baiquan County were drawn to arrange various control measures for Tongshuang small watershed. The basic principles are as follows: (i) considering adaptation to local conditions and defense against damages; (ii) considering soil erosion control as the focus; (iii) considering protection and reasonable utilization of water and soil resources as the goal. Generally, water, farmlands, forests and roads and simultaneous implementation of engineering, plantation and ecology restoration are arranged coordinately based on above experiences and principles. With a global perspective, properly allocate technical measures with combination of biology, engineering and agriculture are properly allocated in Tongshuang small watershed. And 'three defense lines' from top to bottom (see Fig. 1) are established to form a comprehensive soil erosion prevention and control system with comprehensive controls on specific water, farmlands, forests and roads in the rolling hill regions.

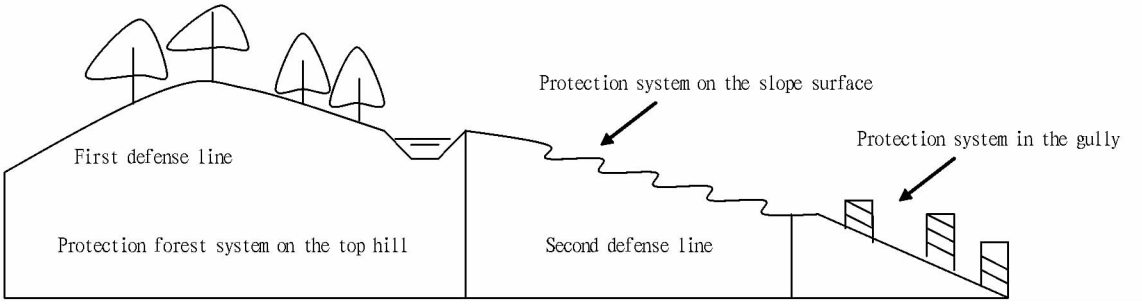

Fig. 1 Schematic of comprehensive control measures of small watershed in the black soil region of Northeast China

The 'first defense line' is the protection system on the hill top and ridge. Due to over-cultivation for a long time, before soil and water conservation, there were no or just sparse vegetation covers on most hill tops. In this case, surface runoff directly flows to the downstream slope, wash out surface soil and make the soil layer thinner and threat seriously to the cultivation land. Therefore, 'in the first defense line', protection forests are planted on the hill top, and on the boundary between the forest and cultivated lands, gullies are dig to stop the runoff. Hill top protection forest has formed a combination of networks with multiple species, arbors, bushes, grasses, and timber production forests. Arbors mainly include poplars, larches and pinus sylvestris, while bushes mainly include bicolor lespedeza. Hill top protection forest, with combination of arbors and bushes, can withhold rainfall with its crown canopy, and change the underlying surface with its litters. And thus hill top protection forest can reduce rain drop splash erosion force and the amount of surface runoff. Meanwhile, organic debris and roots of plants have penetrability facilitate the development and maturation of the soil ecological system, conserve water resources, and improve soil quality. In addition, hill top protection forest has interleaving roots and improve its soil conservation capacity[18-19].

The 'second defense line' is the protection system on the slope surface. Multiple measures are adopted for slopes with different gradients, including cultivation measures of contour ploughing, terrace engineering measures and hedgerows, with the consideration of soil erosion characteristics of long and gentle slopes in the rolling hill areas. The 'second defense line' can reduce slope length, slope gradient and water collection area, and thus intercepts runoff and conserves water for soils[18]. In the black soil region of Northeast China, it is easy to form concentrated flow due to large slope length. In addition, the black soil is loose and thus its resistance against erosion is weak. Cultivation measures for the black lands include cross ridge, ridge tillage and pitting field, less or no tillage, deep tillage and mole drain type cultivation etc. The furrows of traditional tillage by longitudinal ridge have caused surface runoff to concentrate flows and intensified soil erosion. With cross ridge, runoff held by conserved temporarily by furrows and mitigated surface runoff erosion force. Also cross ridge can reduce gradients, shorten slope length, reduce water collection area, facilitate crops to get enough water and improve crop yield. It has become one of the most important measures of soil erosion control for the cultivated slope lands with black soil[17,18]. However, the effects of water and soil conservation measures are greatly influenced by slope gradients[17,20,22], The 'second defense line' is applied with full consideration of the effects by slope gradients: (i) for cultivated slope lands $>3°$, counter planting is necessary; (ii) for 3° to 5° slopes, hedgerows are applied mainly with Bicolor lespedeza; (iii) for 5° to 7° slopes, terrace engineering is mainly adopted; (iv) for $>7°$ slopes, cultivation is forbidden and cropland is conversed to forest and grassland. Under the same fertilization conditions, terraces with bicolor lespedeza hedgerows, grew for three years, can increase organic matter by 1.37%, and achieve economic benefits by 3 000 yuan/hm^2[21].

The 'third defense line' is the protection system in the gully. For control of gully erosion, engineering and plantation measures are combined. At the head of the gully, waterfalls, made of willow, are built to reduce erosion force of strong water flow. At the bottom of the gully, check dams are built by weaving wickers into meshes to slow down water flow. At the side of the gully, willows are planted, so as to form the artificial forest and cover the gully to control water and conserve soil. Willows grow vigorously. In the cold regions of Northeast China, waterfall effects by growing willow are far more effective than the waterfall projects made of cements. Except for reducing soil erosion, they can increase vegetation cover and improve ecological benefits.

3 Comprehensive benefits of water and soil conservation in Tongshuang small watershed

After 50 years of comprehensive control, Tongshuang small watershed has achieved great social, economic and ecological benefits. Table 2 compares the conditions before and after the 'three defense lines' control system are applied for soil and water conservation in Tongshuang small watershed in Baiquan County from 1979 – 1995. It shows that in 1995 the percentage of soil erosion control in Tongshang small watershed has reached 90%, with erosion modulus reducing from 6 600 t/(km^2·a) to 300 t/(km^2·a) about 4.5% of that before control system application. Therefore, soil erosion has been effectively controlled. Forest coverage has increased from 4% to 30% and forest and grass coverage increased from 10% to 45%. Controlled cultivated slope lands and barren hills and slopes can withhold rainfall, conserve water and reduce runoff. Their water hold capacity for them is up to 80% (see Table 3). Each measure has made contribution to the improvement of soil properties, and soil nutrients are improved year by year (see Table 4). For example, content of organic matter has increased by 3.90 mg/kg. Total nitrogen and total potassium have increased by 0.41 mg/kg and 0.90 mg/kg respectively, while total phosphorus has no big change. Content of available nitrogen has increased by 13.0 mg/kg, available phosphorus by 1.96 mg/kg, available potassium by 79 mg/kg. Accordingly, grain production has increased from 1,200 kg/hm^2 to 3 465 kg/hm^2, with an increase rate of 188.8% (see Table 2). Table 5 lists the parameters of direction economic benefits of soil erosion control in Tongshuang small watershed. Take building 713 hm^2 terraces for example, it can increase income by 535 thousand yuan for 3 years. So the economic benefit of water and soil conservation is rather considerable. Fig.2 is the curve diagram about the changes of annual per capita income in Tongshuang small watershed. It can be seen that the per capita income in Tongshuang small watershed has increased obviously from 1 100 Yuan in 1985 to 2 700 in 2005 (increased by 145.5%) after the integrated soil and water conservation is applied. Therefore, the integrated prevention and control system for soil and water control in Tongshuang watershed can effectively facilitate the economic development in this area.

4 Discussion on comprehensive prevention and control system for soil and water control in Tongshuang small watershed

To sum up, the characteristics and specialty of soil erosion characteristics in water erosion area of the black soil region of rolling hills are as follow:

(i) Long and gentle slope, concentrated rainfall. Long and gentle slope is typical topographic conditions of this region. Water collection area is large. This leads to soil erosion under concentrated rainfall conditions. In addition, runoff energy, sediment detachment and transport are dynamically balanced along the length of slope. This results in strong and weak erosion zones alternately distributed along slope length. Although the slope is gentle, gradient still has great impacts on the soil erosion intensity and its changes.

(ii) The black soil layer is greatly different from its parent material layer. It has generally a structure of particles or lumps, so it is porous and loose. Its pores are large and control a large amount of water. Before large scale of soil erosion, the black soil layer is 1 m in this region. While after soil erosion, it has only 20 to 30 cm left, and even yellow soil has appeared in some areas after peel off the black soil. This is absolutely different from the soil layer up to 100 m thick in Loess Plateau, and makes it of significance to reduce soil erosion in the typical black soil region. When the soil layer gets thinner, the water held by black soil would reduce obviously and facilitate water flow on the ground surface, leading to heavier soil erosion.

(iii) Gully erosion develops quickly. The black soil layer is loose and commonly exists in shallow ridges and gully erosion zones in the middle or downstream. It would easily cause gully erosion in rolling hills with black soil. To make things worse, once gullies are formed, many lands would be destroyed or even abandoned[5]. The 'three defense lines' formed with decades of experience in Tongshuang small watershed can slow down and control soil erosion effectively and could be extensively applied in rolling hills of black soil regions, due to its reasonable allocation of various water conservation measures with good consideration of characteristics of soil erosion on long and gentle slopes.

Table 2 Comparison of conditions before and after comprehensive prevention and control system from 1979 – 1995 in Tongshuang small watershed

Index	1979 (before control)	1995 (after control)
Erosion area/km^2	16.82	1.82
Controlled percentage/%	–	90
Erosion modulus/(t·km^{-2}·a^{-1})	6600	300
Water retention capacity/0,000 m^3	–	53.2
Forest coverage/%	4	30
Forest and grass coverage/%	10	45
Ratio among agricultural, forestry and husbandry lands	60:15:25	52:19:29
Per capita grain/kg	1 055	2 321
Per capita arable land/hm^2	0.44	0.39
Per capita forestry land/hm^2	0.08	0.15
Per capita grass land/hm^2	0.2	0.3
Grain output/kg	1200	3465
Land utilization/%	22.7	89

Data source: *Special Report*, *Water Conservation and Soil Amelioration in the Black Soil Region in Northeast China*, 2004.

(i) Moreover, this paper compares 'the three defense lines' in Tongshuang small watershed in rolling hills of black soil region of with those 'three defense lines' in Nanxiaohegou small watershed in Loess Plateau. There are similarities and obvious differences meanwhile. The similarity is that they are arranged with good consideration of soil erosion characteristics and purposed to promote the sustainable development in the watersheds. However, there are obvious differences in func-

tions of these two kinds of 'three defense lines' soil and water protection and control system. The key problem of water and soil loss in rolling hills of black soil region is the reduction of land productivity under the peeling off of black soil. Therefore, the key functions of the 'three defense lines' in the rolling hills region is to preserve soil moisture and fertility to recover soil productivity. While the leading problem of the soil and water loss in Loess Plateau is the sedimentation in lower reaches. So the key function of the 'three defense lines' in Loess Plateau is reducing sediment amounts that enter into the Yellow River.

Table 3 Comprehensive benefits of water and soil conservation in Tongshuang small watershed

Measures	Area hm^2	Water conserved 10,000 $m^3 \cdot a^{-1}$	Water conservation ration/%	Water conservation rate/%
Terraces	713	31.1	95.0	86.30
Ridges change	107	3.5	70.2	
Forests for soil and water conservation	658	24.2	80.0	
Gully treatment	52	1.9	80.0	
Total	1530	60.7		

Data source: *General Report on the Scientific Investigation in the Black Soil Region in Northeast China*, 2006.

The 'three defense lines' in rolling hills of black soil regions prevents the slope soil erosion through decreasing the slope length and concentrate water flow area to retain runoff. For gully erosion, soil is and for gully erosion by the plant waterfall program. While the 'three defense lines' in Loess Plateau mainly decrease the sediment yield by increase the infiltration of runoff and reduction of runoff erosion force. For gully erosion, check dams are mostly applied to reduce the amounts of sediment that may flow into the Yellow River. Generally speaking, Tongshuang small watershed adopted the comprehensive prevention and control system for soil and water conservation, *i. e.* the 'three defense lines', to realize the combination of land utilization and regional sustainable development. Thus good comprehensive benefits, including economic, environmental and soil benefits, are achieved. Meanwhile, various factors, such as technical system, service support system, regional layout are coordinated for the comprehensive prevention and control system. After the application of the comprehensive prevention and control system for soil and water conservation, the ecological conditions are much better with reduction of natural hazards. It also drives the good benefits for the development ofagriculture and forestry related industries, revealing the huge benefits of water and soil conservation.

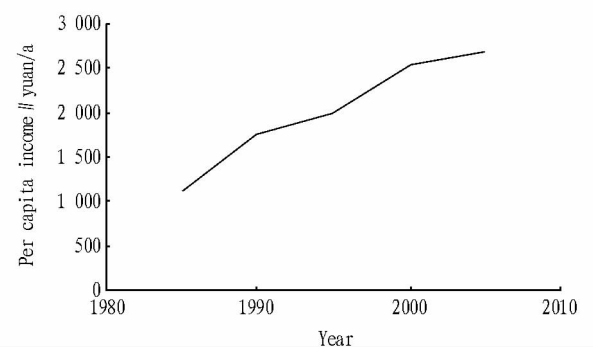

Fig. 2 Changes of Annual Per Capita Income in Tongshuang Small Watershed

Table 4 Nutrients Change in the 0 – 10 cm thick soil layer before and after comprehensive prevention and control system applied mg/kg

Nutrient	Before control (1980)	After control (1995)	Increase
Organic matter	34.8	38.7	+3.90
Total nitrogen	1.51	1.92	+0.41
Total phosphorus	0.50	0.56	+0.06
Total potassium	21.2	22.1	+0.90
Available nitrogen	139	152	+13.0
Available phosphorus	4.04	6.00	+1.96
Available potassium	198	277	+79

Data source: *General Report on the Scientific Investigation in the Black Soil Region in Northeast China*, 2006.

Table 5 Parameters of direction economic benefits of water and soil conservation in Tongshuang small watershed

Production Increase benefits	Items	Terraces	Cross ridges	Hedgerows		Forests	Grass	Ponds	
		Grain	Grain	Grain	Wattles	Standing forest stock	Forage grass	Paddy field	Fish farming
	Units	kg/hm^2	kg/hm^2	kg/hm^2	kg/hm^2	m^3/hm^2	kg/hm^2	kg/hm^2	kg/hm^2
	Increase of production & benefits/a	3	2	2	4	5	2	2	2
	Production increase	750	100.5	225	375	2.25	15000	6000	2200
	Items	Grain	Grain	Grain	Wattles	Standing forest stock	Forage grass	Paddy rice	Fish
	Units	Yuan/kg	Yuan/kg	Yuan /kg	Yuan /kg	Yuan $/m^3$	Yuan /kg	Yuan /kg	Yuan /kg
	Unit price	1.0	1.0	1.0	0.2	400	0.15	1.2	6

Data source[22].

5 Conclusions

With good consideration of soil erosion characteristics in water erosion regions of rolling hills with black soil, comprehensive prevention and control system for soil and water conservation applied in Tongshaung small watershed are summarized as 'three defense lines' prevention system. 'The first line' on

the hill top weakens and blocks uphill runoff and sediment, increases soil water content and improves soil property. 'The second line' on the hill truncates slope length, slows down runoff velocity and reduces erosion kinetic energy. 'The third line' in the gully is mainly composed of waterfall engineering, which can inhibit soil erosion and restore land resources. With this 'three defense lines', soil erosion control measures are properly allocated based on local conditions from hill top to gully bottom, which can effectively prevent and control the slope surface erosion and gully erosion in rolling hills of black soil regions. And this 'three defense lines' is different from 'three defense lines' in Loess Plateau in terms of functions, mechanisms and measures configurations. After decades of control of soil erosion, at present the forest coverage in Tongshuang small watershed has been obviously increased, and the ecological environment effectively improved. Grain production and economic benefits is increased with the improvement of soil productivity. Generally, this comprehensive prevention and control system on soil and water control can properly utilize water and land resources, greatly promote social and economic development in Tongshuang small watershed, and can be extensively applied in rolling hills regions with black soil in Northeast China.

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