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Study on the Influence of Land Use Patterns on the Comprehensive Harnessing Effects of Soil and Water Erosion

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ABSTRACT

Comprehensive harnessing of soil and water erosion can change the regional surface environment, improve ecological conditions, and promote regional social and economic development, which can also achieve good ecological, social, and economic benefits for the purpose of preventing and controlling soil erosion. Scientific evaluation of soil erosion comprehensive harnessing benefits is presented, and analysis of influencing factors is adopted, which is an important basis for further understanding of work effectiveness and optimization of governance measures. The research selects Taihang Mountain Area of Hebei Province as the research area. This paper evaluates the comprehensive treatment benefits of 16 typical small watersheds by multi-level fuzzy evaluation method, and uses the exponential, linear, logarithmic, power function and polynomial as the model. The correlation between land use type area and comprehensive treatment benefit was studied, and the corresponding improvement of management efficiency has been proposed in order to provide a reference for optimizing the comprehensive management mode of small watersheds in Taihang Mountain area and improving the efficiency of comprehensive management.

INTRODUCTION

The comprehensive harnessing of soil and water erosion refers to the soil and water conservation activities based on the laws of soil erosion, economic and social development, and ecological security, because of comprehensive planning, rational arrangement of land use structure, arrangement of various soil and water conservation measures, and formation of comprehensive prevention and control measures system (Zhang 1989). It is of great significance to protect the balance of the ecosystem and develop the social economy (Fang & Sun 2017, Tian et al. 2012). As long as there are soil and water conservation activities, people will evaluate and judge the effect of soil and water conservation to determine whether the measure has achieved its intended purpose and whether the input and output efficiency of soil and water conservation is satisfactory (Wang 2016).

The comprehensive harnessing of soil and water erosion in small watersheds is a systematic project involving a wide comprehensive area (Bai & Liu 2013). Significant achievements have been made in reducing sedimentation in rivers and lakes, improving agricultural production conditions, adjusting industrial structure, and promoting social and economic development. The initial research on the benefits of soil and water conservation in the academic community focused on areas such as controlling soil erosion, improving the environment, and increasing agricultural production. Judging from the relationship between the benefits and influencing factors of water and soil conservation measures in the basin, previous studies are generally coarser, and qualitative research is more than quantitative research (Tang 2004). In particular, research has rarely involved the area of benefits and soil and water conservation measures, and the proportion of allocation (Ran et al. 2010).

Based on the characteristics of soil erosion, natural and socio-economic conditions and the requirements of national economic development in Taihang Mountain, this study constructs an evaluation index system for comprehensive management benefits of Taihang Mountain. This paper evaluates the comprehensive benefits of soil and water conservation obtained from the comprehensive management of water and soil conservation in small watersheds implemented in different types of areas in Taihang Mountain, and analyses the impact of land use patterns on comprehensive benefits. Exploring the ecological and economic win-win model of Taihang Mountain from the perspective of ecology, economy, and society has important social and economic significance and can provide scientific guidance for the sustainable development of Taihang Mountain.

RESEARCH AREA OVERVIEW

Taihang Mountain is located in the western part of Hebei Province. It is a barrier to the Hebei Plain and an important protection area of water source. It is also an old revolutionary area. Due to historical reasons and the unreasonable production activities of human beings, the Taihang Mountain area has serious soil erosion, the ecological environment is bad, and the agricultural production system is overall functional decline. The total land area is 27,498.62 km^2, which belongs to the warm temperate continental monsoon climate in Taihang Mountain. The average altitude is more than 1000 m, which gradually decreases to 500 m or less in the east and south. The regional soil-forming parent rock is mainly granitic gneiss and limestone, and the soil is dominated by brown soil and cinnamon soil. Soil and water loss in the Taihang Mountains is relatively serious. According to the results of the first national water survey, the soil erosion area of Taihang Mountain is 12252.97 km^2, which is accounting for 39.64% of the total land area. It is the key prevention and control area for national soil and water conservation. In addition, from 2003 to 2017, it will be divided into three stages to carry out comprehensive management of soil erosion (Wang et al. 2014).

COMPREHENSIVE BENEFIT EVALUATION

Type area division: The small watershed is a special complex including a variety of natural factors such as geology, geomorphology, climate, hydrology, soil, vegetation, and which is also including human factors such as population and labour. It depends on the comprehensive characteristics of all natural factors and human factors, and it is not subordinate in any of these separate factors (Cleaves 1970). The surface morphology is closely related to soil erosion. In this study, the Taihangshan small watershed has been divided into two categories, which are the middle and low mountain areas of Taihang Mountain and the low mountain hills of Taihang Mountain. In addition, 16 typical small watersheds are selected for specific research.

Indicator selection: The comprehensive management benefits of soil erosion have fully manifested in various fields of ecology, economy, and society, including soil and water conservation economic benefits, ecological benefits and social benefits. At present, the evaluation of the comprehensive benefits of soil and water conservation uses a combination of quantitative and qualitative methods (Li et al. 2016, Zhao et al. 2013). The evaluation indicators should reflect the ecological-society-economic harmony and unity. Based on the theory of soil and water conservation, this study screens the evaluation indicators according to the ecological, economic, and social benefits (Yu 2013, Wen 2010).

According to the comprehensive management characteristics and construction goals of the Taihang Mountain small watershed, through the existing achievements and current laws, regulations and technical standards, an evaluation index system that reflects the sustainable, efficient, and cyclical basic characteristics of ecological, economic and social benefits is constructed (Table 1).

1. Degree of harnessing (%) = area of soil erosion controlled/need to control soil erosion area × 100%
2. Forest and grass coverage (%) = sum of forest and grassland area / total area × 100%
3. Sand interception rate (%) = sediment difference before and after treatment/sediment value generated before treatment × 100%
4. Carbon sequestration (t/hm^2·a): This study used a biomass inventory method based on the relationship between biomass and stocks. Annual carbon sequestration = area ratio weighted average of net productivity of each land use type × 0.4448
5. Purification of the atmospheric environment (kg/hm^2·a): Purification of atmospheric environment value = area ratio weighted average of the dust-retaining capacity of each land use type.
6. Protection of species diversity: The ecosystem formed by soil and water conservation and forestry measures provides a place for survival and reproduction of biological species restoration and succession, which changes the composition of the community and significantly increases the number of species. This study uses a species conservation indicator to reflect the role of forest conservation in biodiversity. Species diversity conservation value = area-weighted average of the Shannon-Weiner index for forest and grassland use.
7. Land productivity: Only the agricultural and forestry of the project area is calculated. Agricultural land productivity is an important indicator of agricultural production. Land productivity = product quantity or value/ land area.
8. Capital production ratio = total agricultural output value/ total agricultural cost.
9. Reducing the drought hazard: In the case of drought, the unit area yield of soil and water conservation measures is compared with the unit area output of the anhy-

Table 1: Evaluation index system for comprehensive management of soil erosion in small watershed.

Target layer A	Criteria layer C	Indicator layer M
Comprehensive benefits of soil and water conservation	C1 ecological benefits	M11 governance
		M12 forest grass coverage
		M13 sand retention rate
		M14 carbon sequestration
		M15 species diversity protection
		M16 purifies the atmosphere
	C2 economic benefits	M21 land productivity
		M22 capital production ratio
	C3 social benefits	M31 mitigates drought damage
		M32 mitigates flood hazards
		M33 agricultural product commodity rate
		M34 per capita grain production

Table 2: Target layer and indicator layer weights.

Target layer	Ecological benefit C_1(0.6363)	Economic Benefit C_2 (0.2046)	Social Benefit C_3(0.1591)	Weight
Degree of governance	0.2817			0.1792
Forest and grass coverage	0.2254			0.1434
Sand retention rate	0.2817			0.1792
Carbon fixation	0.0704			0.0448
Biodiversity conservation	0.0704			0.0448
Purify the atmosphere	0.0704			0.0448
Land productivity		0.5000		0.1023
Capital production ratio		0.5000		0.1023
Mitigating drought hazards			0.2943	0.0468
Reduce flood hazards			0.2943	0.0468
Agricultural product rate			0.1789	0.0285
Per capita grain production			0.2324	0.0370

drous soil maintenance measures. The study is based on the quantity, location, and quality of the engineering measures implemented score.

10. Mitigation of flood hazard: Under the condition of heavy rain, the unit area output of soil and water conservation measures is compared with the unit area output of the anhydrous soil maintenance measures. The number, location, and quality of the engineering measures implemented in this study are scores.
11. Commodity rate: Reflects the contribution of the production system of the project area to the outside and the degree of commercialization. Commodity rate = the sum of the output value of various agricultural products and the annual output value of various agricultural products × 100%.
12. Per capita grain production (kg/person): Per capita grain production can reflect the per capita food possession level. Per capita grain production = total grain output/ total agricultural population

EVALUATION METHOD

Method selection: The method of comprehensive river basin comprehensive management benefit evaluation is divided into the qualitative evaluation and quantitative evaluation. In the actual application process, both of them are often combined for comprehensive benefit evaluation (Kang et al. 2004). In this study, the multi-level fuzzy evaluation method was used to evaluate the comprehensive management benefits of typical small watersheds.

The multi-level fuzzy comprehensive evaluation method is a mathematical method, which evaluates the research object based on the given evaluation criteria and measured values, and then it evaluates the research object (Wang & Mo 2007), which is a combination of qualitative and quantitative evaluation models. The first step is to construct a reasonable membership function according to the nature of the research object, and transform the actual value of the original evaluation index into the [0, 1] interval by the fuzzy transformation of the membership function, and form the fuzzy transformation matrix. The second step is to determine the weight of each index involved by the analytic hierarchy process; in the third step, weight set and the fuzzy transformation matrix obtain the final evaluation value through fuzzy operation (Ding & Wu 2005).

Determination of weight coefficient and consistency test: According to the different sources of the original data, the method of determining the weight of the index has been divided into two methods, which are the subjective weighting method and the objective weighting method (Pang et al. 2001). At present, methods for determining the weight of benefit evaluation indicators mainly include the analytic hierarchy process, DELPH method (expert investigation method) and other methods. According to the reality of operability and simplicity, this study uses the analytic hierarchy process (Sun et al. 2009, Wei et al. 2009) to determine the weight of indicators for the evaluation of small river basin comprehensive management benefits.

1. Calculate the product of each row of the judgment matrix M_i, $W_i=\sqrt[n]{M_i}$ and then find , W_1, W_2,...W_n.

2. Pairs of vectors $W=(W_1,W_2...,W_n)$ are normalized, that is, $\bar{W}=W_i/\sum W_i$, the number of weights calculated.

3. Consistency test, the formula is $CR=CI/RI$.

Through the above method, the number of weights corresponding to each indicator in the criterion layer and the indicator layer can be calculated, and then the combined weight of each indicator can be determined. Let the weight of each indicator in the criterion layer be the weight $\bar{W}_i$, each indicator in the indicator layer is $\bar{W}_{ij}$, then the combined weight of each indicator is $\bar{W}_i \times \bar{W}_{ij}$ (*i* is 1, 2, 3, *j* is the number of criteria, 1, 2, 3...k, which is the number of indicators).

According to the hierarchical analysis model structure, because of expert consultation, the weight of benefit evaluation is determined. The results are given in Table 2.

INDICATOR QUANTIFICATION AND STANDARDIZATION

Standardization of quantitative indicators: In this study, using the benchmark values, passing values and ideal values of the evaluation indicators, the fuzzy mathematics membership function is established to standardize the indicators, so that the data of different dimensions and orders of magnitude can be compared. According to the value range and variation law of each indicator, the membership function model is determined as follows:

$$U(x)=\begin{cases} 0 & 0 \le x_{ij} < x_{ia} \\ (x_{ij}-x_{ia})/(x_{ib}-x_{ia})\cdot 0.6 & x_{ia} \le x_{ij} < x_{ib} \\ (x_{ij}-x_{ib})/(x_{ic}-x_{ib})\cdot 0.4+0.6 & x_{ib} \le x_{ij} < x_{ic} \\ 1 & x_{ij} \ge x_{ic} \end{cases} \quad ...(1)$$

Combined with the survey data, according to expert consultation, national standards (GB/T15773-2008), existing research results (Sun 2011) and other data, to determine the standard values of this study indicators are as shown in Table 3.

Standardization of qualitative indicators: To mitigate drought hazards and mitigate flood hazards, refer to the following functional model.

$$U(x)=\begin{cases} 0.4 & \text{Poor} \\ 0.6 & \text{General} \\ 0.8 & \text{Good} \\ 1 & \text{Well} \end{cases} \quad ...(2)$$

BENEFIT SCORE CALCULATION AND GRADING STANDARDS

Calculation of benefit score value: The target layer benefit and the criterion layer benefit are calculated by the "weighted sum" method. The calculation formula is as follows.

$$B_i=\sum_{i=1}^{n}\omega_{xi}x_i \quad ...(3)$$

Where,

B_i - the benefits of the target layer and the criteria layer;
ω_{xi} - the weight of the target layer and the criteria layer;
x_i - standardized values or calculated scores for the target layer, the criteria layer.

Small watershed comprehensive management efficiency grading standards: The comprehensive benefits of water and soil conservation in small watersheds are graded using numbers between 0-1. The grading standards and evaluations are shown in Table 4.

EVALUATION RESULTS AND ANALYSIS

Analysis of the benefits of low and medium mountainous areas: The middle and low mountain areas of Taihang Mountain include 10 typical small watersheds such as Dongjing Small Watershed and Xinzhuang Small Watershed. The benefit value and evaluation results are given in Table 5. Significant results are achieved in soil erosion control, and 12 indicators have shown positive changes, such as increased vegetation coverage, reduced soil erosion, improved water and fertilizer capacity, improved land produc-

Table 3: Benchmark value, pass value and ideal value of benefit evaluation index.

Project	Benchmark value	Pass value	Ideal value
Degree of governance (%)	50	70	90
Forest and grass coverage (%)	20	40	80
Sand interception rate (%)	30	70	90
Carbon fixation ($t/(hm^2 \cdot a)$)	0.00	2.20	4.00
Species diversity protection	0.30	0.70	1.50
Purify the atmospheric environment ($kg/(hm^2 \cdot a)$)	3000	10000	20000
Land productivity ($yuan/hm^2$)	1500	6000	15000
Capital production ratio	0.3	0.60	1.50
Agricultural product rate	0	0.50	0.95
Per capita grain production (kg/person)	0	400	800

Table 4: Classification criteria for comprehensive benefits of soil and water conservation in small watersheds.

No.	Evaluation total score range	Evaluation	Remarks
1	$B_i \leq 0.6$	Difference	The comprehensive management benefits are not up to standard, and the system is in a non-virtuous cycle.
2	$0.6 < B_i \leq 0.7$	Medium	The comprehensive management benefits have reached the primary standard, and the system is in a primary virtuous circle.
3	$0.70 < B_i \leq 0.80$	Good	The comprehensive management benefits have reached the intermedi ate standard, and the system is in the intermediate virtuous cycle.
4	$B_i > 0.80$	Excellent	The comprehensive management benefits have reached the advanced standards, and the system is in an efficient, continuous, stable and coordinated development.

tivity and household living standards, improvement of basin climate and biology diversity, reduction of natural disaster hazards, and so on.

The comprehensive benefit of soil and water conservation in the small and medium-sized mountainous areas of Taihang Mountain is between 0.6 and 0.9; all are above the medium level. However, due to the different natural conditions and socio-economic conditions of small watersheds, the difference among small watersheds is relatively large, and the Anhe small watershed and the Liyushan small watershed are good. The evaluation value is between 0.7 and 0.8, and the small well watershed is medium. The evaluation value is 0.629, the other small watersheds are greater than 8.0, and the highest comprehensive benefit value differs from the lowest value by 36%. The comprehensive benefit of soil and water conservation in Baishilinggou small watershed is the highest, the evaluation of ecological benefit and economic benefit is excellent, the evaluation of social benefit is medium, and the construction of ecological economic system in a small watershed is in a virtuous cycle. The comprehensive benefit value of the small wells in the well is the lowest, and the ecological economic system is more general.

The Hongyeshan small watershed has the highest ecological benefit, reaching 0.9545. The ecological benefit of the Anhe small watershed and the small well watershed is the lowest, and the ecological benefit evaluation value of the small well watershed is 40% lower than that of the Hongyashan small watershed. The economic benefit of Beizhuang Small Watershed was the highest, with an evaluation score of 0.929. The economic benefit evaluation score of the small well in the well is the lowest, with an evaluation score of 0.4244. The Anhe small watershed has the highest social benefit evaluation score, with a score of 0.8097. The Dongjing small watershed has the lowest social benefit evaluation, and the highest and lowest value difference is 30%.

Analysis of benefits of governing in a low mountain and hilly areas: The low mountain and hilly areas of Taihang Mountain include six typical small watersheds such as the ferry small watershed and the Heishan small watershed. The benefit values and evaluation results are presented in Table 6. The soil erosion control of each small watershed has achieved remarkable results, and all 12 indicators have shown positive changes.

The comprehensive benefit scores of soil and water conservation in 6 typical small watersheds in the low mountain and hilly area of Taihang Mountain ranged from 0.7 to 0.8, and the comprehensive benefits of typical small watersheds are not much different. The comprehensive benefit of soil

Table 5: Benefits and evaluation results of small watersheds in the middle and low mountain areas of Taihang Mountain.

Index	Dongjing Small Watershed	Xinzhuang Small Watershed	Jicheng Small Watershed	Anhe Small Watershed	Cejing Small Watershed	Shangyue gezhuang Small Watershed	Baishiling gou Small Watershed	Beizhuang Small Watershed	Hongyashan Small Watershed	Aoyushan Small Watershed
	Score value	Score value	Score value	Score value	Score value	Score value	Score value	Score value	Score value	Score value
Degree of governance	0.2817	0.2518	0.2817	0.2817	0.2817	0.2817	0.2817	0.2817	0.2175	0.2817
Forest and grass coverage	0.2057	0.1973	0.1793	0.1354	0.1232	0.2225	0.2241	0.2254	0.1703	0.2254
Sand retention rate	0.2423	0.2213	0.2310	0.1803	0.1789	0.2469	0.2423	0.2423	0.1859	0.2535
Solid carbon	0.0661	0.0629	0.0644	0.0325	0.0317	0.0580	0.0642	0.0581	0.0433	0.0654
Species diversity protection	0.0585	0.0577	0.0563	0.0489	0.0467	0.0616	0.0644	0.0567	0.0613	0.0704
Purify the atmosphere	0.0504	0.0496	0.0501	0.0365	0.0295	0.0516	0.0448	0.0433	0.0421	0.0581
Ecological Benefits	0.9046	0.8406	0.8629	0.7154	0.6917	0.9223	0.9215	0.9073	0.7203	0.9545
Evaluation results	excellent	excellent	excellent	Good	medium	excellent	excellent	excellent	Good	Excellent
Land productivity	0.4662	0.3913	0.3923	0.3892	0.3605	0.3568	0.4323	0.4649	0.4757	0.2853
Capital production ratio	0.3552	0.4452	0.4114	0.3131	0.0639	0.1836	0.4883	0.4642	0.3558	0.4048
Economic benefit	0.8214	0.8365	0.8037	0.7023	0.4244	0.5404	0.9205	0.9290	0.8315	0.6901
Evaluation results	excellent	excellent	excellent	Good	Poor	Poor	excellent	excellent	excellent	Medium
Mitigating drought hazards	0.1766	0.2355	0.2355	0.2355	0.2355	0.2355	0.1766	0.1766	0.2355	0.1766
Reduce flood hazards	0.1766	0.2355	0.2355	0.2355	0.2355	0.2355	0.1766	0.1766	0.2355	0.1766
Agricultural product rate	0.1789	0.1789	0.1794	0.1326	0.1106	0.1789	0.1705	0.1723	0.1725	0.1789
Per capita grain production	0.0316	0.0060	0.0168	0.2061	0.1776	0.0179	0.1711	0.1398	0.1346	0.0214
Social benefit	0.5637	0.6559	0.6670	0.8097	0.7592	0.6678	0.6949	0.6653	0.7780	0.5535
Evaluation results	Poor	medium	medium	excellent	Good	medium	medium	medium	good	Poor
overall benefit	0.8334	0.8103	0.8196	0.7277	0.6290	0.8037	0.8852	0.8733	0.7522	0.8566
Evaluation results	excellent	excellent	excellent	Good	Medium	excellent	excellent	excellent	Good	excellent

Table 6: Benefits of target and criterion layers in small watersheds in the hilly area of Taihang Mountain.

Indicator	Dukou small watershed Score value	Heishan small watershed Score value	Qijiayu small watershed Score value	Chongshan small watershed Score value	Caozhuang small watershed Score value	Bangou small watershed Score value
Degree of governance	0.2817	0.2817	0.2704	0.2817	0.2817	0.2817
Forest and grass coverage	0.1443	0.1823	0.1741	0.1877	0.0429	0.2254
Sand retention rate	0.1864	0.1972	0.1690	0.1905	0.2817	0.2535
Carbon fixation	0.0411	0.0430	0.0463	0.0444	0.0297	0.0542
Species diversity protection	0.0532	0.0518	0.0419	0.0567	0.0704	0.0673
Purify the atmosphere	0.0350	0.0428	0.0395	0.0414	0.0259	0.0480
Ecological Benefits	0.7416	0.7988	0.7413	0.8024	0.7323	0.9300
Evaluation results	Good	Good	Good	Excellent	Good	Excellent
Land productivity	0.4617	0.3767	0.3448	0.4443	0.4925	0.3771
Capital production ratio	0.3599	0.3168	0.4011	0.2603	0.3168	0.2070
Economic benefit	0.8216	0.6934	0.7458	0.7046	0.8093	0.5841
Evaluation results	Excellent	Medium	Good	Good	Excellent	Poor
Mitigating drought hazards	0.1766	0.2355	0.1766	0.1766	0.1766	0.1766
Reduce flood hazards	0.1766	0.1766	0.1766	0.1766	0.1766	0.1766
Agricultural product rate	0.1508	0.1631	0.1523	0.1691	0.1661	0.1789
Per capita grain production	0.2324	0.2324	0.1313	0.2223	0.2324	0.0141
Social benefit	0.7365	0.7976	0.6368	0.7446	0.7517	0.5462
Evaluation results	Good	Good	Medium	Good	Good	Poor
overall benefit	0.7571	0.7786	0.7256	0.7732	0.7511	0.7982
Evaluation results	Good	Good	Good	Good	Good	Good

and water conservation in the small watershed of Heishan is 0.7786, the ecological benefit score is 0.7416, the economic benefit score is 0.6934, and the social benefit score is 0.7976. The relatively low comprehensive benefit of soil and water conservation in the small watershed of Heishan is mainly due to the relatively low proportion of water conservation in forests. Although the proportion of economic forests is reasonable, the allocation of forest species is unreasonable and the output value is relatively low. It is necessary to strengthen post-management and increase the production per unit area.

The ecological benefit evaluation of the semi-ditch small watershed is the highest, and the evaluation score is 0.93. The ecological benefit evaluation of Caozhuang small watershed is the lowest, and the evaluation score is 0.7323, which is 21.25%. Among the economic benefit evaluation results, the evaluation results of the ferry small watershed were the highest, the evaluation score was 0.8216, and the benefit evaluation score of semi-ditch small watershed was the lowest, the evaluation score was 0.5841, which was 28.9% lower than the ferry small watershed evaluation score. The score of social benefit evaluation in Heishan Small watershed is the highest, and the evaluation score is 0.7976. The social benefit evaluation of the semi-ditch small watershed is the lowest, and the highest and lowest value difference is 31.56%.

ANALYSIS OF THE IMPACT OF LAND USE PATTERNS ON COMPREHENSIVE BENEFITS

The effectiveness of soil and water conservation is determined by the land use structure (Zhu et al. 2012). The land use type of small watershed will affect the efficiency of small watershed management. Through the analysis of the comprehensive benefits of small watershed management and the factors related to land use, the corresponding methods to improve its benefits are proposed.

Correlation analysis between forest land ratio and comprehensive benefit: Taking the proportion of land area occupied by forestland as the independent variable, the comprehensive benefit value is the dependent variable, and the index is based on the exponential, linear, logarithmic, power function and polynomial model. The results are provided in Table 7.

The results show that the model with the power function as the model, the model of the forest area and the comprehensive benefit value has the highest correlation coefficient (R^2=0.7446). It can be seen from the fitted curve (Fig. 1) that the comprehensive benefit of small watershed increases with the proportion of forest area.

Correlation analysis between protection forest ratio and comprehensive benefit: Taking the proportion of land area occupied by shelterbelt as the independent variable, the

Table 7: Correlation results of each model of forest land occupation ratio and comprehensive benefit.

Model basis	Result	Correlation (R^2)
Index	$y = 0.6770 \cdot e^{0.4060x}$	0.6451
Linear	$y = 0.3091 \cdot x+0.6748$	0.6459
Logarithm	$y = 0.0996 \cdot \ln(x)+0.8967$	0.7326
Power function	$y = 0.9072 \cdot x^{0.1271}$	0.7446
Polynomial	$y = 1.2178 \cdot x^3-2.0565 \cdot x^2+1.2500 \cdot x+0.5652$	0.7388

Table 8: Correlation between the proportion of shelter forests and comprehensive benefits.

Model basis	Result	Correlation(R^2)
Index	$y = 0.7286 \cdot e^{0.3588x}$	0.4099
Linear	$y = 0.2745 \cdot x+0.7304$	0.4163
Logarithm	$y = 0.0292 \cdot \ln(x)+0.8461$	0.3672
Power function	$y = 0.8471 \cdot x^{0.0379}$	0.3568
Polynomial	$y = -0.6391 \cdot x^2+0.5919 \cdot x+0.7057$	0.5030

Table 9: Correlation between economic forest ratio and comprehensive benefit.

Model basis	Result	Correlation(R^2)
Index	$y = 0.7110 \cdot e^{0.5988x}$	0.2424
Linear	$y = 0.4401 \cdot x+0.7147$	0.2261
Logarithm	$y = 0.0777 \cdot \ln(x)+0.9357$	0.375
Power function	$y = 0.9604 \cdot x^{0.1057}$	0.402
Polynomial	$y = 12.206 \cdot x^3-15.814 \cdot x^2+4.4849 \cdot x+0.4674$	0.6616

Table 10: Correlation between the proportion of terraces and comprehensive benefits.

Model basis	Result	Correlation(R^2)
Index	$y = 0.8173 \cdot e^{-0.241x}$	0.3727
Linear	$y = -0.1835 \cdot x+0.8181$	0.3741
Logarithm	$y = -0.0190 \cdot \ln(x)+0.7336$	0.2969
Power function	$y = 0.7310 \cdot x^{-0.025}$	0.2988
Polynomial	$y = 2.2333 \cdot x^3-1.9273 \cdot x^2+0.1506 \cdot x+0.8138$	0.5183

Table 11: Comparative advantages of different land use type areas.

Land use type	Optimal ratio(%)	The maximum benefit value at 98%		The maximum benefit value at 99%	
		Minimum ratio(%)	Maximum ratio(%)	Minimum ratio(%)	Maximum ratio(%)
Shelter forest ratio	46.31	30.57	62.54	34.81	57.80
Economic forest ratio	17.89	13.74	22.25	14.94	20.93
Terraced area	4.22	5	14.99	5	11.64

Table 12: Optimal land occupation ratio of different land use types.

Land use type	Proportion of land	
	Low hilly area	Middle and low mountainous area
Proportion of shelter forest	30%~50%	35%~60%
Economic forest land occupation ratio	16%~23%	12%~18%
Proportion of terraced land	5%~15%	3~10%

comprehensive benefit value is the dependent variable, the exponential, linear, logarithmic, power function and polynomial are used as the model basis, and the results are given in Table 8.

The results show that based on the quadratic polynomial model, the correlation coefficient between the proportion of the shelter forest area and the comprehensive benefit value is the highest (R^2=0.5030). It can be seen from the fitted curve (Fig. 2) that when the proportion of shelter forests is small, the comprehensive benefit of small watersheds increases with the proportion of shelter forests. When the proportion of shelter forests reaches 46.31%, with the increased area ratio of the shelter forests, the comprehensive benefit value will gradually decrease. That is to say, when the protective forest area accounts for 46.31% of the small watershed, the comprehensive benefit value is the largest. It can be seen from Fig. 2 that after the area of the shelterbelt reaches 30~35%, the benefit of the comprehensive benefit changes with the proportion of the shelterbelt, obviously slows down.

When the proportion of shelterbelt area reaches 46.31%, the theoretical value of comprehensive ecological benefit of small watershed is the largest, which is 0.8427. Based on 98% of the maximum theoretical value of comprehensive benefit of a small watershed, it is substituted into the proportion of protective forest area and comprehensive benefit model. When the area is 30.57%~62.54%, the theoretical value of the comprehensive benefit of a small watershed is more than 98% of the maximum value.

Correlation analysis of economic forest ratio and comprehensive benefit: Taking the proportion of land area occupied by economic forest as the independent variable, the comprehensive benefit value is the dependent variable, and the index is based on the exponential, linear, logarithmic, power function and polynomial model. The results are presented in Table 9.

The results show that based on the cubic polynomial model, the correlation coefficient between the proportion of economic forest area and the comprehensive benefit value is the highest (R2=0.6616). It can be seen from the fitted curve (Fig. 3) that when the proportion of economic forests is small, the comprehensive benefits of small watersheds increase with the proportion of economic forests. It can be seen from Fig. 3 that after the economic forest area reaches 15%, the benefit of the comprehensive benefit with the change of the economic forest ratio is slowed down. When the proportion of economic forest area reaches 17.89%, as the proportion of economic forest area increases, the comprehensive benefit value will gradually decrease, but the reduction is small. Due to the selection of 16 small watersheds, the largest proportion of economic forest area is only 28.20% of the small watershed of Aoyu Mountain. Therefore, this result can only show the trend of comprehensive benefits when the proportion of economic forest area is less than this range.

When the proportion of economic forest area reached 17.89%, the theoretical value of comprehensive ecological benefits was the largest at 0.8335. Based on 98% of the maximum value of the comprehensive benefit theory of small watersheds, the economic forest area ratio and comprehensive benefit model are substituted. It is calculated that when the economic forest area is 13.74%~ 22.25%, the theoretical value of the corresponding comprehensive benefit of small watershed is more than 98% of the maximum value.

Correlation analysis between terrace proportion and comprehensive benefit: The proportion of the land occupied by the terraced fields (the terraced area of this study refers only to the terraced area where the grain crops are grown) is the independent variable, and the comprehensive benefit value is the dependent variable. The index is based on the index, linear, logarithmic, power function, and polynomial. It was fitted and the results are shown in Table 10.

The results show that based on the cubic polynomial model, the correlation coefficient between the proportion of terrace area and the comprehensive benefit value is the highest (R^2=0.5183). It can be seen from the fitted curve (Fig. 4) that the comprehensive benefit of small watershed increases first, then decreases and later increases with the proportion of terraced fields. When the proportion of terraced area is 4.22%, the comprehensive benefit of small watershed gets the highest value. It can be seen from Fig. 4 that the proportion of the terraced area is in the range of 0 to 20%, and the change trend is relatively flat.

When the proportion of terraced area reaches 4.22%, the theoretical value of comprehensive ecological benefit is the largest, which is 0.8138. Based on 98% of the maximum theoretical value of comprehensive benefit of small watershed, the proportion of terraced area and comprehensive benefit model are calculated. When the terraced area is 4.22%~14.99%, the theoretical value of the comprehensive benefit of the small watershed is more than 98% of the maximum value.

Efficient allocation technology for land use type area: According to the fitted land use type area ratio and comprehensive benefit relationship model, the proportion of land use types, when the theory reaches the maximum comprehensive benefit value of 98% and 99%, is obtained as given in Table 11.

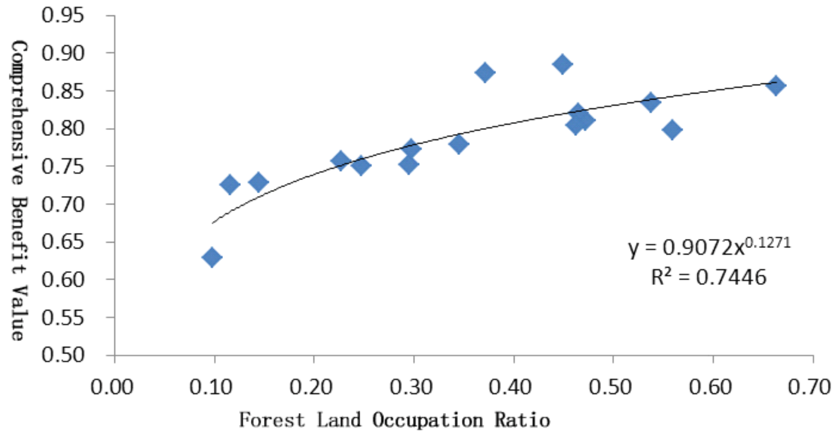

Fig 1: Forest land occupation ratio and comprehensive benefit fitting results.

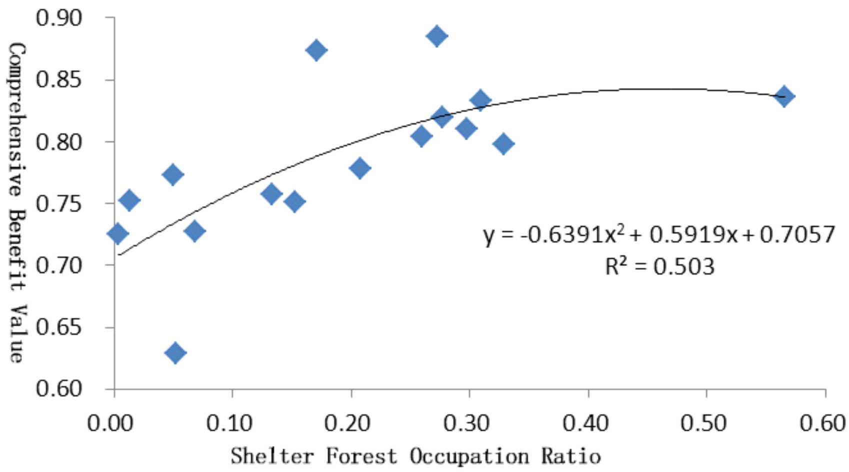

Fig 2: Shelter forest occupation ratio and comprehensive benefit fitting results.

The increase in the proportion of shelter forests has an obvious effect on the improvement of ecological benefits in small watersheds; the increase in the proportion of economic forests and terraced areas is relatively significant for the economic and social benefits of small watersheds. In view of the relatively large population density in low hilly areas, the population density of low and medium mountain areas is generally relatively small. In order to balance economic and social benefits, the proportion of economic forests and terraced areas should be increased in low hilly areas with relatively large population density. In order to increase its economic and social benefits; appropriately increase the area of shelter forests in the middle and low mountain areas where the relative density of population is relatively small, so as to better maintain the water and soil and conserve water sources. This paper proposes the proportion of land use types in low hilly areas and low and medium mountain areas, as given in Table 12.

DISCUSSION AND CONCLUSION

The evaluation of the comprehensive management of soil erosion and its implementation effect analysis is an arduous and complicated study. There are still many problems to have further discussed, such as the further quantification of the weight of comprehensive evaluation indicators of management benefit, the forward-looking indicators and the future practical problems. The non-consistency of multi-method evaluation conclusions need to have further explored the most comprehensive research prospects for exploring the establishment of consistent comprehensive evaluation methods.

For the first time, the research analyses and compares

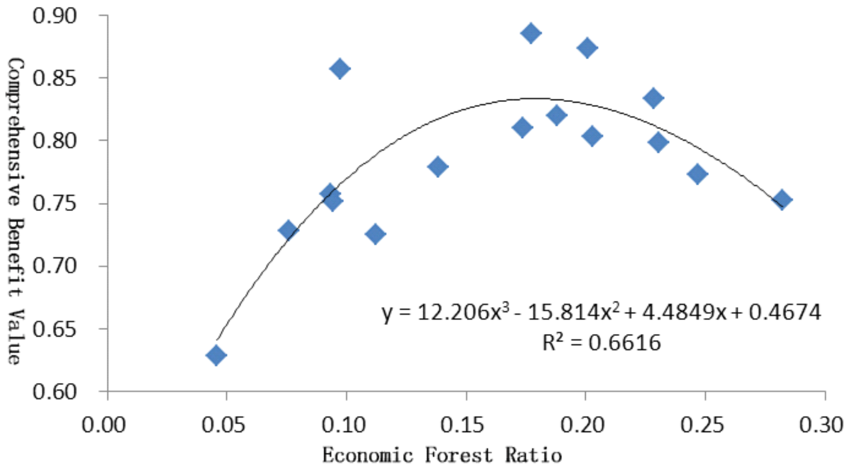

Fig 3: Economic forestland occupation ratio and comprehensive benefit fitting results.

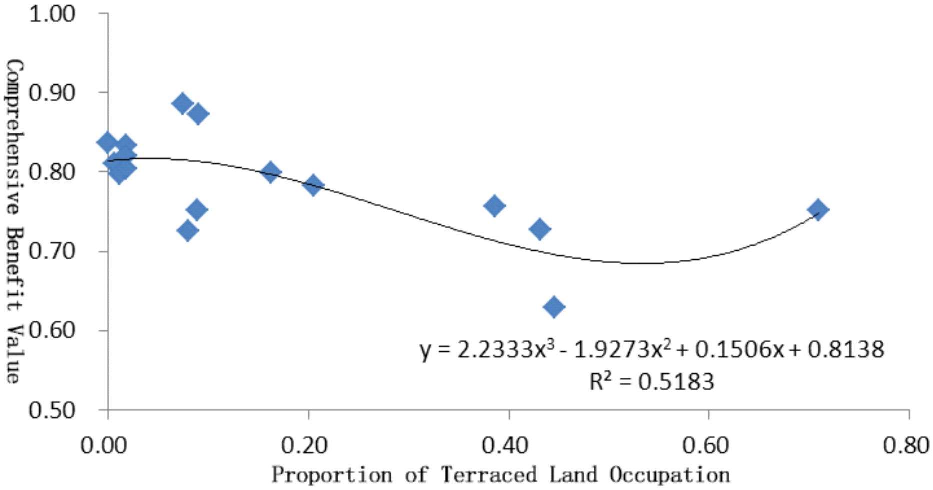

Fig 4: The proportion of terraced land occupation and comprehensive benefits.

the relationship between the proportion of forestland, shelterbelt, economic forest, and terraced area and the comprehensive benefit of small watershed management, and proposes the efficient allocation of land use type area and the best mode of each type of small watershed in the small watershed of Taihang Mountain. Follow-up should be carried out to strengthen the analysis of the impact factors of comprehensive benefits from multiple angles, optimize the comprehensive management model of soil erosion, and improve the efficiency of governance.

According to the surface morphology of the small watershed, the small watershed in the Taihang Mountains is divided into small watersheds in the middle and low mountains of Taihang Mountain and small watersheds in the low hills of Taihang Mountain. The study selected 16 typical small watersheds. In terms of governance degree, sand interception rate, forest and grass cover rate, carbon sequestration, species diversity protection, purification of atmospheric environment, land productivity, capital production and investment ratio, mitigation of drought hazard, mitigation of flood hazard, agricultural product commodity rate, per capita grain production, and so on, which are 12 factors, used as evaluation indicators; they are evaluated by multi-level fuzzy evaluation method. The results showed that the evaluations of 7 small watersheds were excellent, 8 were good and 1 was medium.

The proportion of various land use types in small watersheds and their comprehensive benefit relationships are analysed. The results showed that the comprehensive benefits of small watersheds increase with the proportion of forestland area. When the proportion of shelter forests and economic forests is small, the comprehensive benefits of small watersheds increase with the proportion of shelter forests. When the proportion of shelter forests reaches 46.31% the proportion of economic forests reaches 17.89%. When the proportion increases, the comprehensive benefit value will gradually decrease. The comprehensive benefit of small watershed will increase first, then decrease, and later increase with the proportion of terraced land. When the proportion of terraced area is 4.22%, small watershed comprehensive benefit value is highest.

The proportion of land use types in low hilly areas is 30%~50%, the economic forest is 16%~23%, the terraces are at 5%~15%. The proportion of land use type in the middle and low mountain areas is as follows: the protection forest is 35%~60%, economic forest is 12%~18%, terraced is 3%~10%.

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