Mechanism of Water Resources Conservation and Recharge of Forest and Its Ecological Function Value Evaluation in Jinyun Mountain,China

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Abstract

Jinyun Mountain, lying in tail end of Three Gorge Reservoir area, China, is a spontaneousness laboratory to study systemly water resources conservation and recharge function of forest because it has integrated coenotype of subtropical broad leaved evergreen forest and reflects natural background of tropical forest ecosystem in central Asia to a certain degree. On the base of fully study on rainfall characteristics of Jinyun Mountain area, four familiar types of forest, namely mixed broadleaf-conifer forest, broad-leaf forest, *Phyllostachys pupescens* forest, and shrub forest had been chosen as subject investigated to study water resources conservation and recharge mechanism of different forest types in Jinyun Mountain and to evaluate its value of ecological function by the means of regression method, shadow price method, break-even cost method□and analogism. Then, evaluating indicator system of forestry water resources conservation and recharge had been established through Analytical Hierarchy Process(AHP) and fuzzing mathematics. The conclusion not only contributes to construction project of ecological environment and Three Gorges project in the Yangtze Valley, but also has of far reaching importance to comprehensive amelioration of ecological environment and sustainable development of social economic in this region. Furthermore, value evaluation of forestry water resources conservation and recharge can offer reference to standardization of ecological compensation policy in this region.
Keywords: forest, water resources conservation and recharge, ecological function, Analytical Hierarchy Process, Jinyun Mountain

1. Introduction

Forest headwater conservation ability means forest ecosystem contribution to precipitation interception and holding which is one mostly ecologic benefit of forest. Previous study paid more attention to mechanism of water resource conservation of forest than headwater conservation ability of different forest style and research results sometimes could not represent wholly forest land and their applicability was not very good for production. Now, through analyzing and comparing each composition element function of headwater conservation system of different forest style its headwater conservation capability can be comprehensively evaluated because reasonable combination of each elemental with more powerful function consequently brings up strong system function. But up to now there is not a suit of perfect means to estimate water resource conservation function of forest impersonalitily and scientifically from whole and systematical angle in the real world so that water resource conservation capability of different kinds of forest can be compared.

China had begun to implement reform experimental unit of forest classification management in the middle of 1990's and forest had been divided into merchandise forest and commonweal forest to manage according to different management philosophy. Establishing compensation system of forestry ecologic benefit is not only core of forest classification management but also key of changing from using forestry ecologic benefit without compensation to using it for value. Economic considerations problem of forestry ecologic benefit is substantially to afford price of ecological product. Accordingly, in the present environment of constructing resource-economical and environmental-friendly society it has important operation significance to study water resource conservation mechanism of forest and afford its quantity of value and establish easy-to-follow and feasible evaluating indicator system which can offer reference to foundation of forest ecologic benefit compensation mechanism.

2. Study area and method

2.1 Natural conditions

Jinyun Mountain lies in west bank of Wentang Gorge of Jialingjiang River, Beibei District,Chungking. Its geographical coordinates is east longitude 106°22′and north latitude 29°49′; area is 400 hm^2, elevation is 350.0~951.5m; average annual temperature is 13.6 □; average annual precipitation is 1143.1 mm; average annual relative humidity is 87 %; annual fog day is 89.8 days; average annual sunshine is 1293.9 h; horizontal zones is representative broad leaved evergreen forest bioclimatic zone of central Asia tropical zone.

Soil of Jinyun Mountain area is mainly acidic jeltozem and paddysoil effloresced from heavy film quartz sandstone, calcrareou shale, and argillaceous shale mother material of Triassic period and is neutral or alkalescent jeltozem-terra voxa developed from purple rammell interlining of Jurassic in piedmont.

In Jinyun Mountain Protected Area of Chungking there are very rich plant resources and vegetation pattern is much; mostly vegetation pattern is evergreen mixed broadleaf-conifer forest, warm evergreen coniferous forest, bamboo grove, brushwood, and cultivated plant; in addition there are subtropics brushwood-hassock and aquatic vegetation. Mostly predominance species of trees is *Pinus massoniana* Lamb, *Cinnamamum camphora Pres,Cunninghamia lanceolata*(Lamb.)Hook, *Pinus armanaii Franch,Lithocarpus glabra,Gordonva Svchuanensvs chang* and so on; about more 20 kinds of bamboo have very wide distribution and are mostly dispersed over conservative slope terra of deep soil; brushwood is sparsity and has fragmentary distribution.

2.2 Study method

Water resource conservation function of forest is important constituent of forest ecosystem service which mostly had been found expression in effect of forest canopy, withered level, and soil horizon on intercepting and holding precipitation. Accordingly, this paper takes summation of storey deposit of moisture, withered layer deposit of moisture, and soil horizon deposit of moisture as water resource conservation quantity of forest.

Leaf canopy interception (r_i) and interception rate(r_i%) can be calculated through comparing rainfall amount beside forest (P) with rainfall amount inside forest (P'), namely: leaf canopy interception (r_i)= rainfall amount beside forest -rainfall amount inside forest, leaf canopy interception rate (r_i%)= leaf canopy interception /rainfall amount beside forest. Leaf canopy maximum water-holding capacity measuring method is below: Firstly, standard branch of test tree had been chosen and their fresh quality had been weighed. Secondly, these standard branches had been fully stained with water and taken out to be weighed after gravity water dropping out to calculate maximum water-holding capacity of leaf canopy.

Through baking soil moisture content were measured and core cutter method were adopted to determine soil density, capillary porosity, and total porosity according to lamination. Soil porous waterstorage capacity of different standing forest had been calculated by layer of layer according to lamination measured porosity and soil thickness of each layer. Through core cutter method soil density, noncapillary porosity, capillary porosity, and total porosity had been measured of forest land and cropland. Soil moisture storage had been calculated according to below formulae:

$$Q = 10\ 000\ P\ D$$

In the formulae: Q is soil rainfall storage capacity, t/hm^2; P is noncapillary porosity, %; D is thickness of soil, D= 0.4 m here.

In hillslope top, middle and bottom of different standing forest three litter layer quadrat of 20 cm×25 cm horizontal area had been chosen to measure their gross thickness and thickness of no-decompound layer, half-decompound layer, and decompound layer. Then, their dry qualities were measured through baking adjustment. In the course of collection half-decompound layer and decompound layer had been not collected by lamination because decompound layer and half-decompound layer were not easy to delaminate. Lamination immersion experiment of collective litter layer of different standing forest had been carried out and measured time-interval was 15 min,30 min,1 h,2 h,4 h,6 h,17 h, and 25 h; measured time-interval of litter layer of mixed broadleaf-conifer forest land was 15 min,30 min,1 h,2 h,4 h,6 h,8 h,10 h, and 22 h owing to confine of local experiment circumstances. In each time-interval each specimen had been measured 5 times repeatedly according to 1-min-interval to measure water holding course of litter. Maximum water-holding capacity of litter had been measured by means of immersion and measured time were 24 h.

3. Results and analysis

3.1 Compare of headwater conservation function

For one kind of forest style different stand characteristics and excellent or inferior quality consequently results in difference of woodland soil water-holding capacity. For some kind of forest style knowing its actuality and possible reached potential of standing forest soil storage capacity contributes to adopt virtual measure of exerting forestry water resource conservation to improve standing forest quality and give full play to potential of forestry water resource conservation. Whereas overall water holding capacity of forest are made up of ground water holding capacity and soil horizon water holding capacity. Forest has more overall water-storage capacity shows that its standing forest has stronger water holding ability. Table 1 shows syntheses water-storage capacity of four kinds of forest.

Table 1 Water-storage capacity of different kinds of forest in Jinyun Mountain

Forest style	Leaf canopy interception		Litter water holding		Soil water storage		Total
	t/hm²	%	t/hm²	%	t/hm²	%	t/hm²
Mixed broadleaf-conifer forest	5.23	0.08	47.10	0.73	6397.84	99.19	6450.17
Broad-leaf forest	4.20	0.07	43.20	0.74	5762.93	99.18	5810.33
Phyllostachys pupescens forest	4.14	0.09	33.40	0.71	4697.68	99.21	4735.22
Shrub forest	2.34	0.03	80.60	1.20	6629.02	98.76	6711.96
Average	3.98	0.06	51.07	0.79	6397.84	99.15	6452.89

Table 1 indicates that water-holding capacity of four kinds of forest in Jinyun Mountain can be sorted by size: shrub forest > mixed broadleaf-conifer forest > broad-leaf forest > *Phyllostachys pupescens* forest, and in three level of leaf canopy interception, litter water holding, and soil water storage , soil level had most contribution rate to water-storage capacity and its water-storage capacity occupied more than 98 % of total storage.

3.2 Foundation of evaluating indicator system

According to principle of selecting evaluating indicator forest water resource conservation capacity had been considered in accordance with four aspect of storey, litter layer, soil horizon, and standing forest productivity on the foundation of analyzing mechanism of forest water resource conservation; and each gradation had been divided into some concretion indicator to form a comprehensive evaluation indicator system of four hierarchy (A layer was target stratum, B layer was criterion, C layer was indicator, D layer was forest style) with eleven indicators and draw skeleton layout of hierarchical analytic system of forest water resource conservation function (Figure 1).

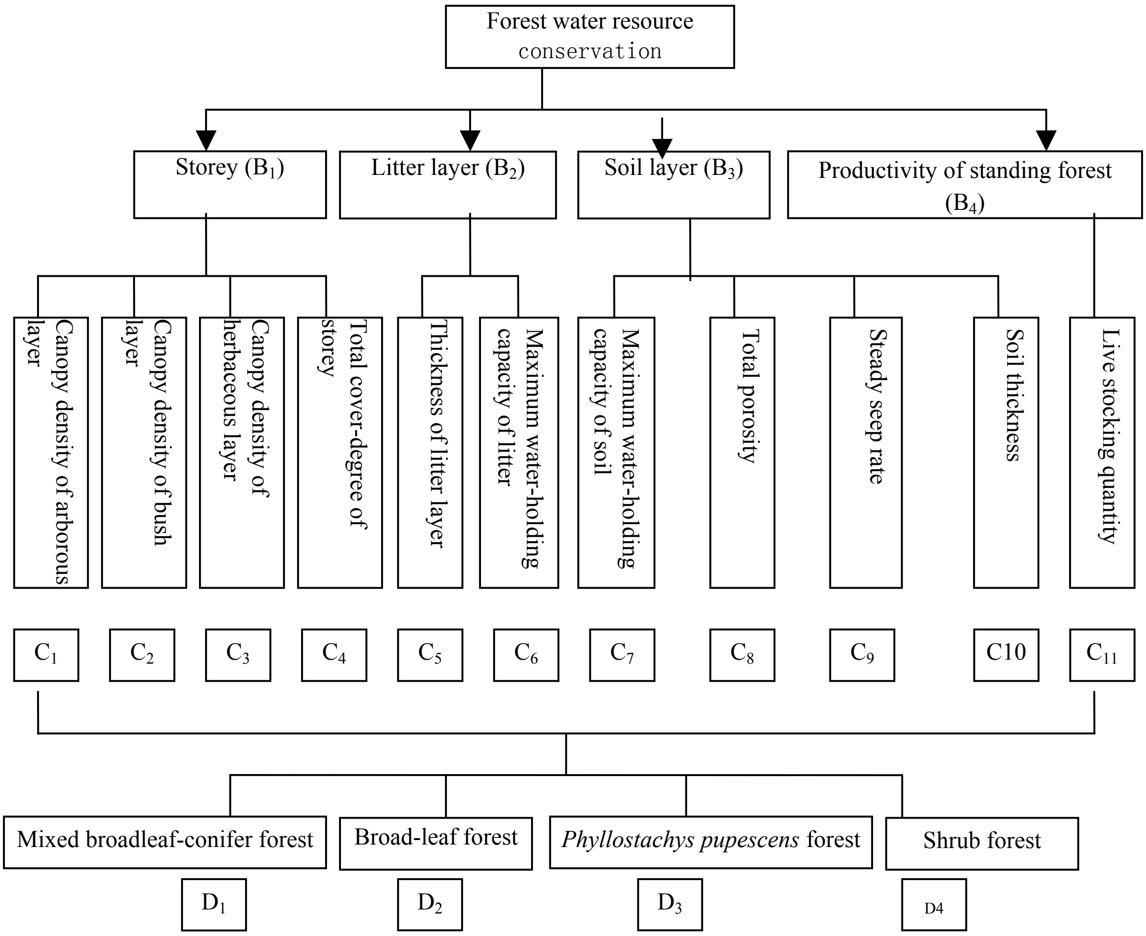

Figure 1 Skeleton layout of hierarchy analytical system of Water Resources conservation function of forest

Each weight of evaluating indicator, namely incidence on forest water resource conservation, was inconsistent. Because it was very difficult to directly analysis effect of multi- indicator on water resource conservation relative importance between per a couple of indicator had been analyzed firstly to found comparing matrices. Then through calculating matrices standardized eigenvector and consistency check effect of each indicator on forest water resource conservation, namely weight, could be obtained. Table 2 is overall weight with reference to general objective, namely synthetic weight.

Table 2 Hierarchy synthetic weight

A	B_1	B_2	B_3	B_4	synthetic weight
	0.0955	0.2045	0.6545	0.0456	
C_1	0.2616	0	0	0	0.0250
C_2	0.0989	0	0	0	0.0094
C_3	0.0434	0	0	0	0.0041
C_4	0.5962	0	0	0	0.0569
C_5	0	0.3660	0	0	0.0748
C_6	0	0.6340	0	0	0.1297
C_7	0	0	0.2010	0	0.1316
C_8	0	0	0.2010	0	0.1316
C_9	0	0	0.5205	0	0.3407
C_{10}	0	0	0.0776	0	0.0508
C_{11}	0	0	0	1	0.0456

Calculating overall weight also need consistency check and result was below:

$$CI = \sum b_k CI_k = 0.0443 \qquad RI = \sum b_k RI_k = 0.6750$$

The result met $CR = \dfrac{CI}{RI}$ =0.0656<0.1 and reached satisfied consistency.

Fuzzy mapping: numerical value of four kinds of forest in Jinyun Mountain had been substituted in corresponding grade of membership function to determine functional value of grade of membership, namely quantized value (Table 3). On the foundation of quantized evaluating indicator of forest water resource conservation it showed that by size synthetic score order of four kinds of forest in Jinyun Mountain was: shrub forest> mixed broadleaf-conifer forest > broad-leaf forest > *Phyllostachys pupescens* forest. It indicated that in Jinyun Mountain area forestry effect on water resource conservation was different for different forest style; headwater conservation effect of shrub forest were best of all and mixed broadleaf-conifer forest and broad-leaf forest took second place whereas *Phyllostachys pupescens* forest were worst which showed that forest style were important to ameliorate region ecological environment.

Table 3 Grade of membership value of each indicator

Forest style		Mixed broadleaf-conifer forest	Broad-leaf forest	*Phyllostachys pupescens* forest	Shrub forest
Storey	Canopy density of arborous layer	1.00	0.87	0.62	0
	Canopy density of bush layer	0.60	0.60	0	1.00
	Canopy density of herbaceous layer	0.17	0	1.00	0.50
	Total cover-degree of storey	1.00	1.00	0	0
Litter layer	Thickness of litter layer	0.68	0.65	0	1.00
	Maximum water-holding capacity of litter	0.29	0.21	0	1.00
Soil horizon	Maximum water-holding capacity of soil	0.61	0.38	0	1.00
	Total porosity	0.64	0	0	1.00
	Steady seep rate	0.02	0	0.04	1.00
	soil thickness	0.65	0.25	0	1.00
Productivity of standing forest	Live stocking quantity	1.00	0.22	0	0.05
Synthetic score		0.4266	0.2329	0.0332	0.8729

3.3 Value estimate of ecological function

Substantially, forestry stumpages are just part of value of forest. principal value of forest resources should be external economy value for ecological service including water resource conservation, protecting soil, regulating climate, vindicate CO_2 Balance, cleaning atmosphere, etc which are far larger than its stumpage.

From several aspects including value of forestry water resource conservation, erosion protection, increasing soil fertility, grain increase in yield, and cleaning air author generally estimated ecological function quantity of value of forest in Jinyun Mountain (Table 4) which were 25,653.32 Yuan / hm^2 by means of shadow price, break-even cost, and analogism.

Table 4 Economic value evaluation of forestry ecological function in Jinyun Mountain area

Serial number	Estimate indicator	Estimate means	Imputed value□yuan/hm^2□
1	Value of forestry water resource conservation	means of shadow price	2547.28
2	Value of erosion protection	means of shadow price	863.75
3	Value of increasing soil fertility	means of shadow price	5600.00

4	Value of grain increase in yield	means of shadow price	415.00
5	Value of cleaning air	means of shadow price means of break-even cost	16226.29
	Total		25652.32

4. Conclusion and discussion

1) Through comprehensive analysis of water-holding capacity of storey litter layer and soil horizon it concluded that quantity gradation of 4-type forest in Jinyun Mountain was: shrub forest > mixed broadleaf-conifer forest > broad-leaf forest > *Phyllostachys pupescens* forest and soil horizon had maximal contribution to each type of forest storey which water-storage capacity occupied more than 98 % of total storage.

2) With Analytical Hierarchy Process and fuzzing mathematics evaluating indicator system of forestry water resources conservation and recharge in Jinyun Mountain had been established and quantity gradation of integration score of 4 types of forest in Jinyun Mountain had been reached: shrub forest > mixed broadleaf-conifer forest > broad-leaf forest > *Phyllostachys pupescens* forest. It indicated that shrub forest had the best effect on water resources conservation and recharge and mixed broadleaf-conifer forest and broad-leaf forest had better effect and *Phyllostachys pupescens* forest had the worst effect. The outcome had an accord with research result of observation data which showed that established evaluating indicator system of forestry water resources conservation and recharge was creditable.

3) Through the medium of shadow pricing, break-even cost method and analogism, quantity of ecologically functional value was about 25 652.32 yuan/hm^2, and among them value of water resources conservation and recharge of forest was 2 547.28 yuan/hm^2, value of erosion protection was 863.75 yuan/hm^2, value of increasing soil fertility was 5 600.00 yuan/hm^2, value of increasing grain was 415.00 yuan/hm^2, value of cleaner air was 16 226.29 yuan/hm^2.

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