Forest management based on the TOPSIS model

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Abstract. Forest management strategies that include appropriate harvesting are beneficial compared to the carbon sequestration benefits of no deforestation at all. To develop a sound forest management plan and thus a forest decision model, the article built a TOPSIS model to comprehensively evaluate each forest to obtain the evaluation index. Then, the article regressed the evaluation index with the forest area to obtain the regression equation, and then performed the extreme value operation to obtain the best forest area. This area is used as the basis for judging whether the forest is deforested or not. Also, considering the differences in geographic location of different forests, the article conducted a multiple linear regression of deforestation in some countries with respect to forest area, latitude, and longitude to determine the effect of geographic lo-cation on the percentage of deforestation.

Keywords: TOPSIS Model, Regression Analysis, Proportion of deforestation.

1. Introduction

Forests store carbon dioxide in living plants and products made from trees, including furniture, wood, plywood, paper, and other wood products. Some forest products may live longer than the trees that produce them. The carbon sequestration [1] in these forest products [2] is combined with the carbon sequestration generated by the regeneration of young forests, which is likely to achieve more carbon sequestration in a period compared with the carbon sequestration benefits of no deforestation at all. Therefore, the forest management strategy of appropriate harvesting in the forest management plan is beneficial to carbon sequestration. But at the same time, we should not over harvest.

2. Assumptions

1. The age of trees in the forest always obeys the normal distribution.
2. For a region, its climate and ecological factors remain unchanged for a period.
3. In the future, the forest will not be affected by various serious natural disasters (such as volcanic eruptions).
4. Ignore the additional carbon footprint [3] generated by forest products in the production process.

3. Decision Model of Carbon Sequestration

3.1. Development and solution of a carbon sequestration decision model

3.1.1 Data Collection and Processing

The decision model was determined by analyzing their carbon sequestration using the TOPSIS Model for ten regions that we randomly selected. After reviewing relevant literatures, we intend to take the three-level comprehensive evaluation model to make a comprehensive evaluation [4] of forests in the selected ten regions. As shown in Figure 1.

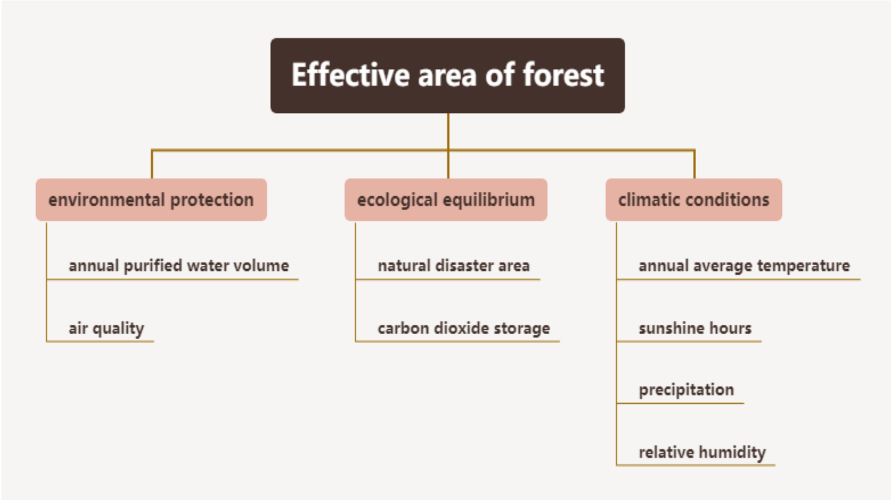

Figure 1. Schematic diagram of index of all three floors

The primary index in the evaluation system is y_{11}: forest area

The secondary index y_{21}, y_{22}, y_{23}: environmental protection, ecological balance, and climatic conditions

The tertiary index:

y_{31}: Annual purified water volume (m^3)
y_{32}: Days when the air quality reaches grade 2 or above (day)
y_{33}: Natural disaster area (khm^2)
y_{34}: Annual purified water volume Carbon dioxide absorption (Tg)
y_{35}: Annual average temperature (degree Celsius)
y_{36}: Sunshine hours (h)
y_{37}: Precipitation (mm)
y_{38}: Relative humidity (%)

The collected data are shown in the Table.1 below:

Table.1. Raw data of index related to ten regions

	y_{31}	y_{32}	y_{33}	y_{34}	y_{35}	y_{36}	y_{37}	y_{38}
Beijing	126.6	285	0.2	0.85	13.1	2420.7	483.9	62
Xinjiang	3516.6	262	16.3	0.96	7.8	2217.6	419.5	61
Yunnan	3459.7	365	80.3	1.33	16.5	2131.1	932.7	67
Shanxi	250.8	296	71.5	0.35	11.5	2528.4	535.4	58
Nei Mongol	1563.9	346	222.8	0.23	8.3	2643.4	261.2	57
Chongqing	1600.3	303	31	0.27	19.2	941.9	1439.2	80
Liaoning	396	328	282.5	0.15	11.8	2377.8	672.3	67
Jilin	1088.9	340	410.8	0.17	7.4	2622.1	534.2	61
Heilongjiang	2586.9	311	3279.7	0.86	5.5	2388.7	444.1	67
Guizhou	2397.7	347	125.8	0.23	17.3	1057.9	884.9	75

Normalize all the data in the above table with the following steps:
1) Collect the data to obtain the original data matrix in the above table.
2) Forward (maximize) all values to form a forward matrix.
3) From the following formula

$$z_{ij} = y_{ij} / \sqrt{\sum_{i=1}^{n} y_{ij}^2} \tag{1}$$

Normalize the data to obtain the non-negative matrix Z, and convert it into a line chart, as shown in Figure 2.

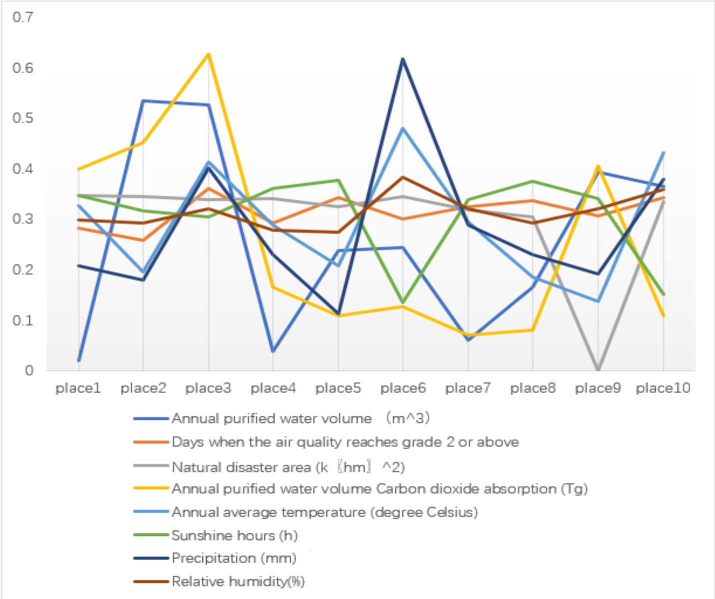

Figure 2. Line chart after standardization of each index data

3.1.2 Weight determination and regression analysis

By the following formula:

$$p_{ij} = \frac{z_{ij}}{\sum_{i=1}^{n} z_{ij}} \tag{2}$$

Calculate the probability matrix P and verify it:

$$\sum_{i=1}^{n} p_{ij=1} \tag{3}$$

That is, the probability sum corresponding to each index is guaranteed to be 1. For the j-th index, the calculation formula of information entropy [5] is:

$$e_j = -\frac{1}{ln\,n}\sum_{i=1}^{n} p_{ij}\, ln\,(p_{ij})(j = 1,2,\dots,m) \tag{4}$$

The information utility value is normalized to obtain the entropy weight [6] of each index:

$$h_j = 1 - e_j \tag{5}$$

$$W_j = {h_j}\Big/{\sum_{j=1}^{m} h_j}(j = 1,2,\dots,m) \tag{6}$$

The entropy weight method is used to calculate the weight of each index in the three-level index, as shown in Table2.

Table.2. Weight of index at the third level

	y_{31}	y_{32}	y_{33}	y_{34}	y_{35}	y_{36}	y_{37}	y_{38}
Weight	0.3062	0.0053	0.1196	0.2953	0.0795	0.0499	0.1236	0.0063

Therefore, the corresponding value of index 2 can be obtained from the following formula $Y_{21}=\sum_{j=0}^{3} W_{3j} * Y_{3j}$

$$Y_{22}=\sum_{j=4}^{6} W_{3j} * Y_{3j} \tag{7}$$

$$Y_{23}=\sum_{j=7}^{9} W_{3j} * Y_{3j}$$

Of these, the values for each indicator at level 2 are shown in the Table.3 below

Table.3. Values of each index of the second level

	y_{21}	y_{22}	y_{23}
Beijing	0.007669	0.159834	0.070875
Xinjiang	0.172895	0.174934	0.055438
Yunnan	0.170659	0.225599	0.099541
Shanxi	0.013784	0.089368	0.071074
Nei Mongol	0.078092	0.070754	0.050948
Chongqing	0.079642	0.078751	0.123703
Liaoning	0.021034	0.058867	0.078134
Jilin	0.054893	0.060023	0.063616
Heilongjiang	0.127806	0.119648	0.053572
Guizhou	0.118766	0.071984	0.091182

The corresponding weight of each secondary index can be calculated by entropy weight method. As shown in Table.4.

Table.4. Weight of index at the second level

	y_{21}	y_{22}	y_{23}
Weight	0.6427	0.2631	0.0942

Therefore, the evaluation of primary index forest area can be obtained through TOPSIS, the combined assessment values for each region are shown in the Table.5 below

Table.5. Value of comprehensive evaluation of each region

	Forest Area	**Forest evaluation coefficient**
Beijing	107.1	0.149495
Xinjiang	802.23	0.480607
Yunnan	2106.16	0.526933
Shanxi	321.09	0.114237
Nei Mongol	2614.85	0.221298
Chongqing	354.97	0.257206
Liaoning	571.83	0.110712
Jilin	784.87	0.172974
Heilongjiang	1990.46	0.353517
Guizhou	771.03	0.317754

Assuming that the forest area is x and the forest evaluation coefficient is Z, the regression equation of the evaluation coefficient Z of the forest area can be obtained by quadratic regression of the above data.

$$Z = -1.43 * 10^{-7}x^2 + 4.697 * 10^{-4}x \tag{8}$$

Using the software Stata [7] to analyze the error of the result data, we can find that the p value is less than 0.13, that is, at the 87% confidence level, the two regression coefficients are significantly different from 0. The error analysis Table.6 and Table.7and Table.8 are as follows:

Table.6. Error analysis of regression prediction(a)

Source	**SS**	**df**	**MS**
Model	0.0896775	2	0.0448387
Residual	0.1091225	7	0.0155889
Total	0.1988	9	0.0220889

Table.7. Error analysis of regression prediction(b)

Number of obs=10
F(2, 7)=2.88
Prob > F=0.1225
R-squared=0.4511
Adj R-squared=0.2943
Root MSE=0.12486

Table.8. Error analysis of regression prediction(c)

Comprehensive evaluation	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
z	-1.43E-07	8E-08	-1.72	0.13	-3E-0	5.43E-08
Area	0.0004697	2E-04	2.02	0.083	-0	0.0010183
_cons	0.0337078	0.109	0.31	0.767	-0.22	0.2923429

The regression curve fitted by ordinary least square method is shown in Figure 3 as follows:

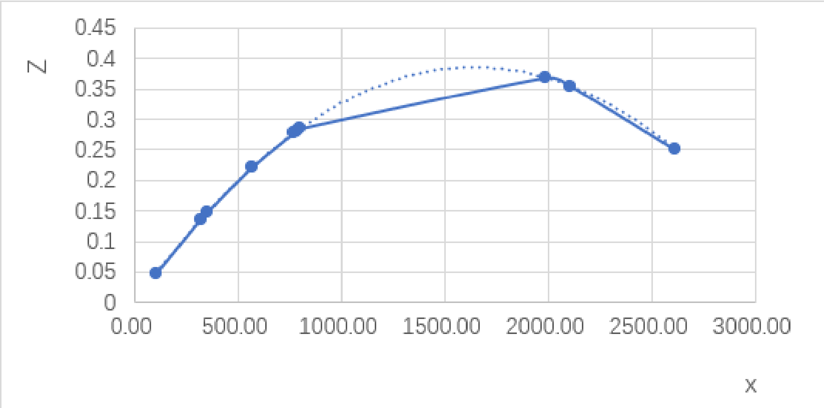

Figure 3. Fitting curve of regression equation

From the regression equation, it can be concluded that x, which makes Z take the maximum value, is 1642.3.

3.2. Impact of deforestation rates on different regions

3.2.1 Programs to prevent deforestation

The best effective area X1 can be calculated by regression equation. Therefore, the cutting amount can be obtained from the following formula

$$S1=S0*\int_{0}^{t1}\frac{1}{\sqrt{2\pi}\sigma}e^{-\frac{(t-\mu)^2}{2\sigma^2}}ds\text{-}x1 \tag{9}$$

(Calculated by subtracting the optimal area from the original growth area)

The planting amount can be obtained by the following formula

$$S2=S0*\int_{T}^{t1}\frac{1}{\sqrt{2\pi}\sigma}e^{-\frac{(t-\mu)^2}{2\sigma^2}}ds \tag{10}$$

Discuss the following:

When S0* $\int_{0}^{t1}\frac{1}{\sqrt{2\pi}\sigma}e^{-\frac{(t-\mu)^2}{2\sigma^2}}ds$<= x1, S1<=0, forests cannot be cut down;

When S0* $\int_{0}^{t1} \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(t-\mu)^2}{2\sigma^2}} ds$> x1 , S1>0, the amount of logging should be S1.

Our explanation is as follows:

If the amount of carbon sequestration is very small, that is, the actual amount of carbon dioxide to be sequestered is less than the storage capacity (the effective area is more than the optimal area for carbon sequestration at present), it will cause a large amount of tree surplus. In order to balance the value of the forest [8], it can be cut down appropriately without causing ecological and environmental impact. Another situation is that the carbon sequestration stock is about to be saturated (that is, the effective area is about to reach the optimal value or less than the optimal value), so trees cannot be cut down at will.

3.2.2 Transition Point Determination and Management Plan

We analyzed the forest location, cutting rate and forest area in each country, formed the following Table.9, and developed a regression analysis model to explore the relationship between forest management plan and forest area and the proportion of wood products [9].

Table.9. Raw data of index related to nine regions

	felling rate (k)	Forest area(m)	longitude(a)	latitude(b)
Canada	0.010809076	347115710	-106.35	56.13
Spain	0.020160443	18545340	-3.75	40.46
Italy	0.040872659	9028040	12.57	41.87
Norway	0.047936743	12102000	8.47	60.47
Finland	0.05567916	21875330	25.75	61.92
Germany	0.06130134	11419000	10.45	51.17
New Zealand	0.066825029	9848120	174.89	-40.9
South Korea	0.137430513	6476000	127.98	37.66
Austria	0.149696356	133094500	133.78	-25.27

Assuming K is the felling proportion, M is the forest area, a is the longitude and B is the latitude, the linear regression model [10] is established by Using the software Stata and the relationship between the felling proportion and forest area, longitude and latitude is as follows

$$k = 2.7 * 10^{-10} * m + 0.0009709*a + 0.001077*b \tag{11}$$

Through the error analysis of the data, we can find that the p value is less than 0.096, that is, at the 90% confidence level, the three regression coefficients are significantly different from 0. The error analysis Table.10 and Table.11 and Table.12 are as follows:

Table.10. Error analysis of regression prediction (a)

Source	SS	df	MS
Model	0.014823	3	0.000704
Residual	0.00	5	0.000704
Total	0.01834	8	0.002293

Table.11. Error analysis of regression prediction(b)

Number of obs=9
F(3,5)=7.02
Prob > F=0.0305
R-squared=0.8082
Adj R-squared=0.6931
Root MSE=0.02652

Table.12. Error analysis of regression prediction(c)

Comprehensive evaluation	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
area	2.70E-10	1.25E-10	2.16	0.083	0.00E+00	5.92E-10
longitude	0.000971	0.000264	3.68	0.014	0.000293	0.001649
latitude	0.001077	0.000525	2.05	0.096	-0.00027	0.002428

Therefore, after determining the longitude and latitude of the forest to be planned, the felling proportion K can be determined through the location characteristics and forest area.
If $S1<S2$, then there is a transition point. If $S1\geq S2$, then there is no transition point.

When there are transition points, the management plan is described as follows: It is necessary to cut down the part with the largest age distribution as much as possible, and the planting area is the corresponding position of the deforested trees, so as to realize the transition.

4. Conclusions

The management plan for forests should include cutting down. Our emphasis is on sus-tainable forest management, where trees are replanted as they are cut down, so that carbon can be permanently fixed in the wood that is cut down - the spirit of sustainable legal timber. This paper identifies multi-level indicators for forest value assessment and constructs a TOPSIS model to evaluate each forest in a comprehensive manner. A linear regression model is used to calculate the optimal forest area, which is used as a basis for determining whether a forest should be deforested. The objective is to incorporate harvesting into forest manage-ment plans and to determine the forest decision model and apply it.

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