Analysis The Policies Balancing Conservation and Community Interests in Maasai Mara

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Abstract. This paper aims to examine what policies are appropriate to balance conservation and community interests in the Maasai Mara. Grey Relational Analysis (GRA) is used to examine the relationship between indicators divided into two categories: wildlife species interests and economic industrial interests. A qualitative analysis is performed to establish a one-to-one linear correlation between the indicators. Multiple objective nonlinear programming and genetic algorithm are then applied to determine an objective function that quantizes the interests. Maximize the number of wildlife species and local community income by simulation. After the analysis of that simulation, an Fuzzy Comprehensive Evaluation (FCE) model combined with the Analytic Hierarchy Process (AHP) are employed to analyze the impact of different policies for different regions by studying the relationships between factors affecting the wildlife reserve, such as migration patterns of wildlife and the impact of human activities. This approach helps to determine the best policy decision based on the scores and pros and cons of each policy.

Keywords: GRA Model, Multiple Objective Nonlinear Programming, Genetic Algorithm, AHP Model, FCE Model.

1. Introduction

Kenya’s wildlife preserves were originally created primarily to protect wildlife and other natural resources. However, the Maasai Mara National Reserve (MMNR), one of Kenya's largest game preserves, is facing significant challenges in balancing conservation and development objectives. The Maasai Mara is home to a diverse range of wildlife, including elephants, lions, and rhinos, and is a popular tourist destination, attracting hundreds of thou-sands of visitors every year. Despite efforts to improve conservation and management of the preserve, the Maasai Mara continues to face several threats, including habitat loss, human wildlife conflicts, and unsustainable tourism practices. Therefore, there is a critical need to develop effective policies and management strategies that balance the interests of the people who live near the preserve with the need to protect wildlife and other natural resources. The topic requires us to develop policies for wildlife sanctuaries that protect wild-life and promote local development in the Maasai Mara region.

2. Consider policies on multiple objective programming model

2.1. Analysis of relationship between local economic industries and wildlife protection

The paper has found a series of ecological and economic data such as Kenya 's population density, agricultural area, forest area, cumulative number and capacity of camps from the perspective of protecting Kenya 's wildlife and natural resources and safeguarding the economic interests inside and outside the wildlife natural reserve.

This paper collected data on Maasai Mara from 1971 to 2020. The proportion of distinct types of wildlife in Mara, the statistics of the number of attacks on human beings by top ten wildlife, and the property losses caused by wildlife were obtained from Kenya Database[1]. The fig 1 shows the

agricultural, animal husbandry and wildlife reserve geographical distribution in Maasai Mara and surrounding nature reserves below.

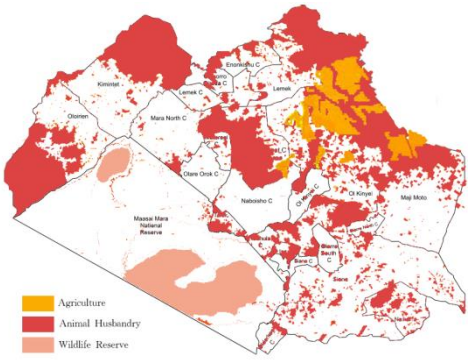


Fig 1: The area distributions

By analyzing the wildlife attack casualty's literature[2], this study obtained the proportion of different wildlife species as shown in the Fig 2 below:

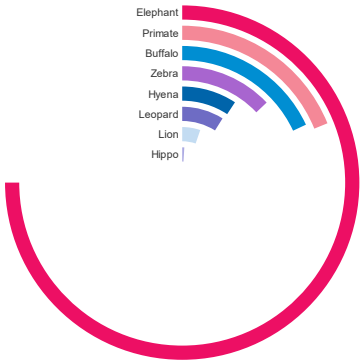


Fig 2: Wildlife attack casualties

As can be seen from the figure above, elephants account for the largest proportion of wildlife, followed by the primate. Elephants do the most harm to humans and the economic industry.

2.2. Determine the indicator correlations

To determine whether there is correlation among all the indicators collected, the gray absolute correlation model is first adopted to calculate the correlation among all indicators in the appendix Table.

The method measures the reciprocal sum of distance between the normalized sub vector and the parent vector of each dimension and maps it to the interval of 0~1 as a strategy to measure the correlation between the sub vector and the parent vector.

Reference sequence:

$$Y = Y(k), k = 1,2 \dots n \tag{1}$$

Comparative sequence:

$$X_i = X_i(k), k = 1,2 \dots n; i = 1,2 \tag{2}$$

Initialize the sequence:

$$x_i(k) = \frac{x_i(k)}{x_i(1)}, k = 1,2 \dots n; i = 0,1,2 \tag{3}$$

Averaging sequence:

$$x_i(k) = \frac{x_i(k)}{\bar{x}_i}, k = 1,2 \dots n; i = 0,1,2 \tag{4}$$

Where $x_i(k)$ is the mean value of the i^{th} factor sequence. From (1) to (4), then calculate the grey absolute correlation degree of $\zeta_i(k)$:

$$\zeta_i(k) = \frac{\min_i \min_k |X_0(k) - X_i(k)| + \rho \max_i \max_k |X_0(k) - X_i(k)|}{|X_0(k) - X_i(k)| + \rho \max_i \max_k |X_0(k) - X_i(k)|} \quad (5)$$

The grey absolute correlation between population density, agricultural area, forest area, number of casualties caused by elephants and number of casualties caused by predators, number of deaths caused by predators, cumulative number and accommodation in camps, percentage of rhino habitat and percentage of livestock expansion is shown below Fig 3.

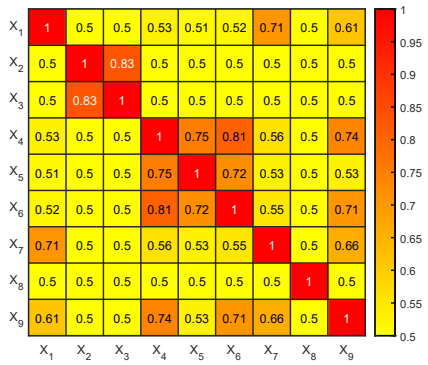


Fig 3: Grey Absolute Correlation heat map of 9 indexes

As can be seen from the Fig 3, there are 7 groups of indicators with high correlation (>0.7), among which agricultural area and forest area have the greatest correlation (x_2 and x_3). There may be a restrictive relationship between the natural resources of the forest and the local agricultural area resources.

Rhino habitat is not strongly correlated with other variables, so further analysis of the relationship between wild rhinos and local economic industries is needed.

The number of human casualties caused by elephants is related to the number of human casualties caused by herbivores, the number of human casualties caused by carnivores, the cumulative number of camps and accommodation (x_4 and x_5, x_6, x_7, x_9). As mentioned before, the number of local wildlife, elephant population is the largest, and the incidents that hurt tourists are also the most. It shows that there is a close relationship between the distribution of elephants and local tourism.

Since the conflicts of human and wildlife interests mainly occur in the agricultural area, the grazing areas and the tourist area, this part focuses on the analysis of these three areas. There may be a restrictive relationship between the natural resources of forest and the local agricultural land resources.

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2.3. Linear regression to the object indicators

Since the conflicts of human and wildlife interests mainly occur in agricultural area, grazing area and tourist area, this study focuses on the analysis of these three comparisons using linear regression to provide valuable insights into how human activities and wildlife conservation efforts can be better balanced in areas where conflict is common:

2.3.1 Consider the agricultural land and the forest land

Since humans are constantly cutting down trees to obtain more land, there is a strong correlation between the two. Since the two are in a state of reciprocal correlation, this part considers using the exponential polynomial regression analysis to solve the functional relationship between the

agricultural area and the forest area. The area of agricultural land as $f(x)$ and the area of forest as x. And expressed them as the determinant of $AX = b$:

$$f(x) = a_0 + a_1 x + \cdots + a_n x^n \tag{6}$$

$$A = \begin{pmatrix} a_n \\ a_{n-1} \\ \vdots \\ a_0 \end{pmatrix}, X = \begin{pmatrix} x(1)^n & x(1)^{n-1} & \cdots & x & 1 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ x(m)^n & x(m)^{n-1} & \cdots & x & 1 \end{pmatrix}, b = \begin{pmatrix} f(1) \\ \vdots \\ f(m) \end{pmatrix} \tag{7}$$

With four digits reserved, the function relationship between the agricultural area and forest area can be obtained by importing data using $n = 2$:

$$f(x) = 7.283 \times 10^{-6} x^2 - 1.395x + 9271 \tag{8}$$

2.3.2 Consider the rhino habitat and grazing area

As grazing ratios in the Maasai Mara and surrounding areas continue to expand, and wildlife ranges overlap with human grazing ranges, it is important to balance the proportion of wildlife habitat and local grazing area. To explore the relationship between the two, it is important to study the relationship between the rhino habitat area and the area of the grazing industry. Here, polynomial linear regression analysis describes the relationship between these indicators. Similarly, let the rhino habitat area be x and the grazing area be $g(x)$. With four digits reserved, the function relationship between rhino habitat area and grazing area can be obtained by importing data using $n = 2$:

$$g(x) = 0.0228x^2 - 1.6567\,x + 39.2919 \tag{9}$$

2.3.3 Consider the elephant wounding and the tourism

Due to the high overlap between the activity range of wildlife and the agricultural area of humans, there are many wildlife deaths. Wildlife deaths are mainly divided into elephant deaths and carnivore deaths, which are also obviously related to the development and continuous expansion of local human beings. Here is a regression analysis of the relationship between elephant casualties and local tourism hotels and camps and uses the multiple linear regression to describe the relationship between these indicators. Use the unitary linear regression analysis to solve the functional relationship between elephants and tourism hotels and camps. Suppose the number of tourism hotels and camps is x, then the elephant hurts people are $h(x)$, and the relationship between the two can be satisfied:

$$h(x) = a_0 + a_1 x \tag{10}$$

Similarly, the functional relationship between the final elephant injury and the number of tourism hotels and camps can be written as follows:

$$h(x) = 3.6993x + 6.2509 \tag{11}$$

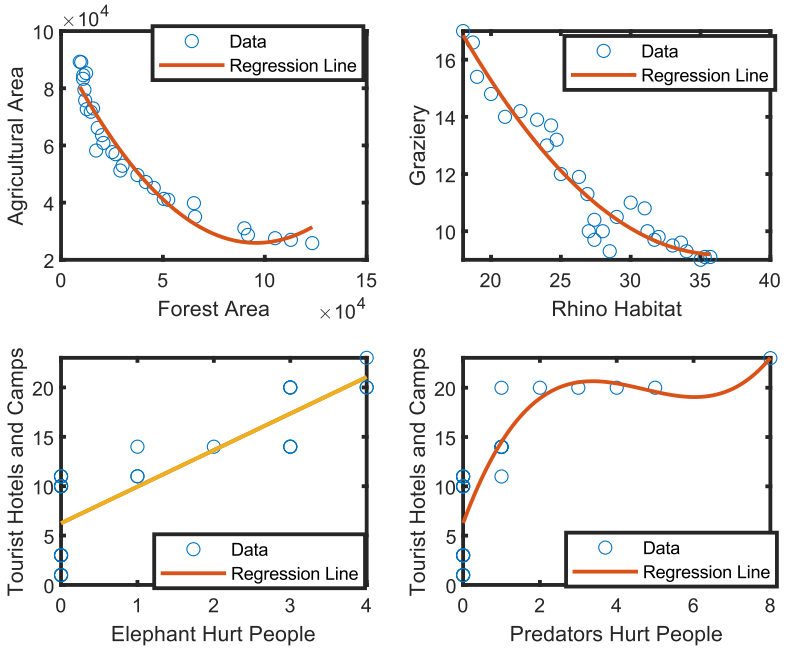


Fig 4: Regressions of wildlife versus economic activities

2.4. Optimize the policy of the corresponding area for maximum benefit

The Multi-Objective Non-Linear Programming Model is a mathematical method to optimize the solution among multi-objective functions. Maximize the benefits of both conservation and economic in MMNR, determine the coefficient parameters to calculate the wildlife species number and the economic industries interests of different districts in different policies.

In the previous preparation, this study obtained correlated data, so in the multi-objective programming, considering the economic development of the area, forest area loss increases agricultural area exponentially, rhino habitat area loss is accompanied by a power level increase in grazing land, and tourist tent increase is accompanied by a linear increase in elephant harm to humans.

2.4.1 Determine the objective function

The objective function is the optimal strategy for optimizing the three regions. Agricultural area maximizes the sum of forest area and agricultural area. Grazing area maximizes the total area of cattle grazing and the wild rhino habitat. Tourist areas maximize the number of tourist camps and reduce the number of elephant attacks.

Multiple objective nonlinear programming has two or more objective functions, and all objective functions and not all the constraints are linear functions, they can be nonlinear. Its mathematical model can be expressed as:

$$max\begin{cases} z_1 = p_1 + p_2 + p_3 \\ z_2 = p_4 + p_5 - p_6 \end{cases} \tag{12}$$

Where the area of agricultural land is p_1, the area of grazing p_2, the number of tourist camps is p_3, the area of forest land is p_4, the area of rhino habitat is p_5, and the number of elephants hurting people that should be minimized is p_6. The first three take the impacts of nearby people interests into consideration, and the last three parts minimize the negative interactions from wildlife and protect the MMNR resources.

- Constraints

Using the non-linear programming formulas to construct the constraints by:

$$s.t.\begin{cases} p_1 - f(p_4) \leqslant 0 \\ p_2 - g(p_5) \leqslant 0 \\ p_3 - h(p_6) \leqslant 0 \\ p_1 + p_4 \leqslant \xi_0 A_0 \\ p_1, p_2 \cdots p_6 \geqslant 0 \end{cases} \tag{13}$$

In the previous part, this paper talked about the relationship among these three indicators and added them into the constraints. agricultural area restrictions: Set the upper and lower limits of these variables, the upper limits ξ_0 are the parameters of the MMNR area A_0.

The total area of forest area and agricultural land area cannot exceed a certain proportion of the total area of the reserve, about 450 km^2. The number of tourist Tents cannot exceed the maximum capacity of the tourist area.

Restrictions on grazing area: The total area of cattle grazing area and wild rhino habitat area shall not exceed a certain proportion of the reserve's total area.

To deal with multiple indexes, this study wants to give a linear weighting sum method, so the multiple objective vector problem is transformed into a scalar problem of weighted summation of all objectives. Based on this reality, the following evaluation function is constructed:

$$\max_{p \in D} Z(p) = \sum_{i=1}^{3} z_i(p) = \sum_{j=1}^{6} \omega_{ij} p_j \tag{14}$$

Its optimal solution $p^*$is regarded as the "optimal solution" of the above formula in the sense of linear weighted sum ω_i as the weighting factor.

2.4.2 Simulate the corresponding benefit of the area with policy

In the regression analysis part, this paper analysis the connection between elephant hurt human and number of tourism hotels and camps, forest land and agricultural land areas, rhino habitat area and grazing area. The process of non-linear programming and genetic algorithm simulates the policy ranking in these three different areas. This table evaluates the total value of each area. After constant adjustment and sum the benefit up, final to get a weighting table and a benefit table 1:

Table 1: The solution of genetic algorithm

	Coefficient						**Value**						**Total benefits**
	p_1	p_2	p_3	p_4	p_5	p_6	p_1	p_2	p_3	p_4	p_5	p_6	$\sum_{i=1}^{6} p_i$
ω_1	0.2	0	0	-0.2	0	0	536.74	7.15	10.57	8827.84	6.49	12.9	87807.4
ω_2	0	250	0	0	-330	0	0	0.18	1.47	9000	0	2.61	90053.56
ω_3	0	0	200	0	0	100	0.02	0.02	2.43	9000	0.1	1.16	90047.24
ω_4	-0.2	0	0	0.2	0	0	0	0.04	0	9000	0.01	0.83	90048.55

The $\omega_1, \omega_2, \omega_3$ and ω_4 in the table respectively represent three policies, which are the agricultural policy represented by ω_1, grazing policy represented by ω_2, tourism policy represented by ω_3, and wildlife conservation policy represented by ω_4.

By adjusting the coefficients of ω_i and continuously optimizing the parameters of the genetic algorithm through analysis, the simulated total benefits for the areas with its policy can be obtained.

3. Decision-making in Kenya's wildlife reserve policy

3.1. Consider policies based on four areas in MMNR

This paper proposes four policies for managing the MMNR in Kenya, each with a corresponding serial number. In the strict reserve area, it should (1) Establish wildlife corridors, (2) Reduce vehicle traffic, (3) Promote responsible tourism practices. In the Agricultural Area, should (4) Encourage sustainable farming practices and (5) Establish buffer zones around protected areas. In the Tourist Area, should (6) Reducing visitors, (7) Encouraging eco-friendly accommodation, (8) Establishing wildlife watching guidelines. In the animal husbandry area, should (9) Encourage sustainable grazing, education, and training to reduce the proportion of pastoralists in tourist area.

3.2. Establish a comprehensive evaluation index system

The combination of Analytic Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation (FCE) can be applied to the decision-making process in Kenya's policy on protecting wildlife, natural resources and promote the economy. Starting from the original intention of balancing the interests of people and wildlife, it is natural to take ecological benefits and human interests as the evaluation criteria of the evaluation system. When selecting the target layer, refer to the ecological evaluation system of mountain area[3], combined with the change data of forest area and wildlife habitat area in Kenya.Expansion of human settlement caused Kenya 's wildlife living space being occupied[4], so it is necessary to include wildlife living space into the evaluation indicators.

The paper will use the collected land situation as a standard to judge the impact of policies on living space. At the same time, because the income composition of Kenya's wildlife reserves is basically composed of agricultural and tourism income, and is dominated by tourism income.[5] There are also wildlife injuries in Kenya[6], which is detrimental to human interests and is not conducive to the harmonious coexistence of people and wildlife. Policies should consider reducing this impact. In summary, the paper sets the evaluation indicators, as shown in Figure 5 below:

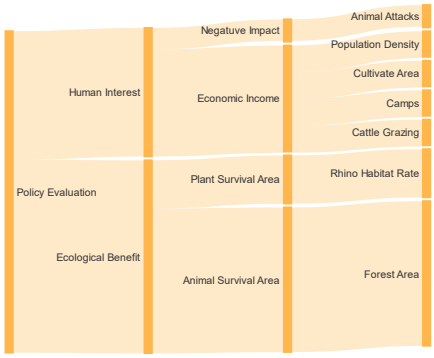


Fig 5: Comprehensive evaluation hierarchical model structure

3.3. Hierarchy gives the weight from analysis method

3.3.1 Establish the factor set

The paper will use the symbol A_1 to represent the target level policy evaluation, the symbols B_1 and B_2 represent the ecological benefits and human interests respectively, and the symbols C_1, C_2, C_3 and C_4 represent the wildlife living space, plant living space, income, and negative effects respectively. Thus, the factor set $A_1 = \{B_1, B_2\}$ and the sub-factor set $B_1 = \{C_1, C_2\}$, $B_2 = \{C_3, C_4\}$ are established.

3.3.2 Establish the index weight

According to the sustainable management system for the MMNR[7], it focuses on the protection of endangered species and habitats. After referring to the adaptive management of biological reserves[8], it is understood that wildlife reserves should give priority to population safety and natural protection.

Therefore, in balancing human and wildlife interests, this model focuses on wildlife protection. According to the literature[9] that similarly constructed, the weight of ecological benefits is set to 0.6, and the weight of human interests is 0.4.

The rest of the index weight will accord to the point of view of psychology and scale 1 ~ 9, analysis of any two indicators a and b in the importance of each level.

Table 2: The importance scale

Scale	The Meaning of the Scale
1	a is as important as b
3	a is slightly more important than b
5	a is more important than b
7	a is more important than the extremes of b
9	a is extremely important than b
2,4,6,8	The median of the two levels
$\frac{1}{C}$	If the importance of a over b is C, then the importance of a over b is $\frac{1}{C}$

Therefore, combined with the Delphi method to determine the judgment matrix, and calculate the maximum eigenvalue of each matrix and its corresponding eigenvalue vector according to the eigenvalue method (EM) for consistency test.

$$B_1 = \begin{pmatrix} 1 & \frac{1}{3} \\ 3 & 1 \end{pmatrix}, B_2 = \begin{pmatrix} 1 & 5 \\ \frac{1}{5} & 1 \end{pmatrix}$$

Matrix B_1 is a judgment matrix of wildlife living space and wild plant living space with ecological interests as the goal. Matrix B_2 is a judgment matrix of income and negative impact with human interests as the goal.

Table 3: Weight vector and consistency check

Element	weight	λ_{max}	CI	RI	CR
B_1	[0.25,0.75]	2	0	0.001	0<0.1
B_2	[0.8333,0.1667]	2	0	0.001	0<01

In the weight vector and consistency check table, the weight vector has been normalized, $\lambda_{\max}$ is the maximum eigenvalue of the judgment matrix, R.I. is selected from the average random consistency index data table according to the dimension of the matrix. When $C.R. < 0.1$, the consistency test passes, the order of the matrix is the dimension of the judgment matrix.

Table 4: Average random consistency index data

Order of matrix	1	2	3	4	5	6
R.I.	0	0	0.52	0.89	1.12	1.26

3.4. Fuzzy Comprehensive Evaluation method to evaluate the policy

3.4.1 Establish the evaluation set

According to the needs of comprehensive fuzzy evaluation, the evaluation set of evaluation policy is established, including five evaluation grades, which are extremely good, good, medium, poor and extremely poor. The symbol A is used to represent the membership degree of fuzzy comprehensive evaluation. In the [0,1] interval, five regions correspond to five grades.

Table 5: Evaluation grade standard score table

Evaluation Level	Extremely Poor	Poor	Medium	Good	Extremely Good
Evaluation Grading	0.2	0.4	0.6	0.8	1

Although the specific value of S varies with the evaluation index, after the data is standardized, it can accurately fall into the required evaluation interval. The specific calculation of the value of *S* will be mentioned in the following introduction of the membership function.

3.4.2 The expected effect and quantification of the policy

There are a total of nine policies and corresponding serial numbers aimed at promoting sustainable practices, reducing human-wildlife conflicts, and protecting Kenyan wildlife and their habitats: In strictly protected area, policies focus on wildlife conservation and habitat protection. This includes controlling the damage caused by elephants, herbivores and carnivores so that everyone is controlled within one; reduce camp accommodation to 20 and reduce population density to below 50 people per square kilometer. In Agricultural Regions, policies aim to promote sustainable agricultural practices that minimize impacts on wildlife and their habitats. This includes reducing the agricultural area to 50,000 or 60,000 hectares. In Wildlife Tourism Zones, the policy aims to promote responsible tourism practices that minimize impacts on wildlife and their habitats. This includes reducing the population density to less than 50 people per square kilometer and limiting the damage caused by elephants, herbivores and carnivores to one per person. In animal husbandry area, the policy aims to improve livestock management practices and reduce conflicts between humans and wildlife. This includes reducing the proportion of pastoralists in tourist area to less than 10% and limiting the harm caused by elephants, herbivores and carnivores to one per person.

After obtaining the expected effect, we can quantify the effect of different strategies. Taking the data of 2020[10] as a reference, we consider the correlation between the indicators in the first question and calculate the corresponding indicators. If the policy impacts the indicator, its value is changed according to its effect. If the policy has no impact on the indicator, the corresponding reference value is filled. Through the above operation, we obtained quantitative data of 9 strategies.

3.4.3 Membership function and establish the evaluation matrix

First, the data should be standardized, and we have:

$$D_{sij} = \frac{D_{ij} - D_{min}}{D_{max} - D_{min}} \tag{15}$$

where D_{ij} is the j^{th} indicator of the i_{th} policy.

Then, the symbol $s_j(j = 1,2,3,4)$, s_j is used to represent the living space of wild plants, the living space of wildlife and the membership degree set of fuzzy evaluation of regional income and negative impact. Then, use $A_{mn}(m = 1,2,3\cdots,9, n = 1,2,\cdots,5)$, represents the n-level membership degree of the math evaluation basis. The evaluation criteria included forest area, agricultural area, population density, agricultural area, cumulative number of camps, proportion of cattle grazing expansion, number of elephant casualties, number of herbivore casualties, and number of carnivorous casualties. Finally, the appropriate membership functions are as the following (16)-(19):

$$A_{m1} = \begin{cases} 1 & D_{sij} \le 0.2 \\ \frac{0.4 - D_{sij}}{0.4 - 0.2} & 0.2 < D_{sij} < 0.4 \\ 0 & D_{sij} \le 0.2 \end{cases}, A_{m2} = \begin{cases} 0 & D_{sij} \le 0.2 \\ \frac{D_{sij} - 0.2}{0.4 - 0.2} & 0.2 < D_{sij} \leqslant 0.4 \\ \frac{0.6 - D_{sij}}{0.6 - 0.4} & 0.4 < D_{sij} \leqslant 0.6 \\ 0 & D_{sij} > 0.6 \end{cases} \tag{16}$$

$$A_{m3} = \begin{cases} 0 & D_{sij} \le 0.4 \\ \frac{D_{sij} - 0.4}{0.6 - 0.4} & 0.4 < D_{sij} \le 0.6 \\ \frac{0.8 - D_{sij}}{0.8 - 0.6} & 0.6 < D_{sij} \le 0.8 \\ 0 & D_{sij} > 0.8 \end{cases}, A_{m4} = \begin{cases} 0 & D_{sij} \le 0.6 \\ \frac{D_{sij} - 0.6}{0.8 - 0.6} & 0.6 < D_{sij} \le 0.8 \\ \frac{1 - D_{sij}}{1 - 0.8} & 0.8 < D_{sij} \leqslant 1 \\ 0 & D_{sij} > 1 \end{cases} \tag{17}$$

The evaluation basis of wildlife living space and wild plant living space is relatively single. It can simply judge by the percentage of rhino habitat and forest area respectively, but there are many

reference factors for income and negative impact. The income composition of Kenya mainly includes agricultural income, animal husbandry income and tourism income, and mainly tourism income. Obviously, the agricultural area will affect agricultural income, the expansion of cattle grazing will affect animal husbandry income, and tourism income is related to population density and the cumulative number of camps and accommodation. For negative responses, the factors considered mainly include the number of wildlife hurting people. According to the current situation in Kenya and the suggestions of relevant experts, the weight W of each evaluation basis and calculated the set of membership degrees are figured out .

$$\begin{cases} S_1 = A_{1n} \\ S_2 = A_{2n} \\ S_3 = W_1A_{3n} + W_2A_{4n} + W_3A_{5n} + W_4H_{6n} \\ S_4 = 1 - W_5A_{4n} + W_6A_{8n} + W_7A_{2n}) \end{cases} \tag{18}$$

The values of $w_i(i = 1,2,\cdots 9)$ are 0.3, 0.1, 0.4, 0.2, 0.5, 0.2, 0.3, respectively. Since wildlife hurting people is a negative correlation index, it needs to be processed. Then to get the fuzzy evaluation matrix P and the matrix X that evaluates the advantages and disadvantages of each policy, where matrix T is the weight matrix of each level obtained in the analytic hierarchy process. Each vector has been normalized in the calculation process. The policy evaluation value and score.

$$\begin{cases} X = TP = T \cdot \begin{pmatrix} T_1P_1 \\ T_2P_2 \end{pmatrix} \\ T = (0.6,0.4) \\ T_1 = (0.25.0.75) \\ T_2 = (0.8333.0.167) \\ P_1 = \begin{pmatrix} S_1 \\ S_2 \end{pmatrix} \\ P_2 = \begin{pmatrix} S_3 \\ S_4 \end{pmatrix} \end{cases} \tag{19}$$

4. Conclusion

From the above analysis steps, it can get the evaluation value of the corresponding comments of each policy. After giving each comment a proper score, it can score each policy by calculating the weighted sum of each policy score and measure the pros and cons of the policy. It has compiled the calculated data into a table for the evaluator to analyze intuitively.

According to the final score calculation, the highest score of policy (3) in the strictly protected area is 50.8285, the highest score of policy (4) in the planting area is 51.4025, the highest score of policy (6) in the tourist area is 50.24, and the highest score of policy (9) in the animal husbandry area is 51.98. Among all policies, policy (9) has the best adaptation.

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