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A Solution to Water Allocation and Human-Animal Conflict Reduction in the Masai Mara

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Abstract. The increasing popularity of the Masai Mara reserve, coupled with the end of the global coronavirus pandemic, has intensified conflicts between tourists and wildlife, as well as water scarcity issues. This paper employs the Pareto optimal principle and uses the Cobb-Douglas production function to measure the economic benefits of water resources, taking precipitation into account, and categorizing water demand into three parts: hotel water, residential water, and water evaporation. A multi-objective programming model is established to allocate residential and hotel water in a rational manner, thereby maximizing the economic benefits of water resources. To address conflicts between tourists and wildlife, this paper proposes using hotels to replace the range of tourist activities. The Masai Mara region is rasterized based on longitude and latitude, and update rules for cellular automata are set using MISD (micro land supply distribution). By iterating cellular automata, the change in human activity range can be determined, and the degree of coincidence between human activity areas and wildlife can be used to assess the probability of conflicts between humans and wild animals.

Keywords. Pareto optimal principle, multi-objective programming, MISD, CA

1. Introduction

As an essential wildlife reserve in Kenya and around the world, the Masai Mara is rich in species diversity, rare natural beauty, and countless natural resources. The continuous development of tourism in recent years has also brought huge economic benefits and improved the living standards of residents. However, due to global climate change, the continuous expansion of wildlife and human activities in the reserve, especially tourism, the protection of natural resources in the Masai Mara Reserve, wildlife habitat, and the continuous expansion of conflicts between residents and wild animals, it is necessary to establish a reliable mathematical model to effectively analyze the internal changes.

Ogutu et al. studied the changes in the wild animal population in the Mara region of Kenya from 1977 to 2009 and found that due to land use changes and human activities, the wild animal population continued to decline, so it is very necessary to alleviate the

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contradiction between humans and wild animals. Some studies, such as Dasgupta et al. [1] and Roy et al. [2], show that most human-wildlife conflict occurs as a result of human disturbance in and around wildlife habitats, while others, such as Sangay et al. [3], and Sathyakumar et al. [4], argued that it is a natural phenomenon of ecosystems. To address human-wildlife conflict, Joseph et al. used a zero-bloat count data model and modelled the impact of livestock farming on this conflict by mapping the census distribution of the Masai Mara Reserve and adjacent pastures [5]. In addition, in terms of water resources, they also studied issues such as rainfall and animal drinking preference, to further determine human settlements and animal drinking points and solve conflicts between humans and wildlife [6]. Evelyne et al. used a polynomial logistic regression model to analyze the allocation of competitive land in Kenya [7]. Medani Bhandari has studied the negative impact of tourism development on the Masai Mara and they argued that with the development of tourism, construction of facilities and roads breaks down the boundaries between animal and human activity areas, leading to the loss of natural habitats and wildlife [8]. In general, there are few studies to reduce conflicts between humans and wildlife by considering the allocation of water resources within the reserve, so we completed the research based on this unique perspective.

Aiming at the problem of water shortage and waste caused by scarce precipitation in the Masai Mara Conservation area, we use Pareto optimal principle to further study the optimal allocation ratio of hotel water and domestic water, so that limited water resources can produce higher economic benefits. In view of the conflict between tourists and wild animals in this nature reserve, we use cellular automata to study the activity range of tourists, and then by comparing with the activity area of wild animals, we can judge the probability of conflict in this area, so as to help tourists to take more effective prevention and self-protection. Based on the above research, we can make better use of local natural resources, at the same time ease the conflict between humans and animals, and effectively ensure the real life of wild animals.

2. A Way of Maximizing Economic Benefits of Water Resources

2.1. Multi-objective Programming Based on Pareto Optimality

Water is an inseparable precious resource for most living things in the world, and it plays a fundamental role in promoting economic and social development. Different development fields, such as industrial production, ecological protection, and community building, have different demands on water resources. Thus the utilization methods, distribution structure, and efficiency of water resources will also change accordingly [9]. The Masai Mara region has a savannah climate, with high temperatures, drought, and little rainfall throughout the year. Our model comprehensively considers the various flow directions of water resources in the Masai Mara region (tourist hotel water, residential water, water evaporation) and the influence of precipitation factors, and based on the Pareto optimal principle, establish a multi-objective programming model. The structure of water resource allocation maximizes the economic benefits of water resources and saves water resources as much as possible.

2.2. The Allocation of Water Resources and Optimization of Economic Benefits

With the development and progress of society, the value of water resources as a scarce resource is also gradually increasing, so it is imperative to consider the economic benefits brought by the scarcity of water resources. Therefore, we combine the Cobb-Douglas production function to calculate P^i.

$$P^i = A \cdot {W^i_{hotel}}^{\lambda} \tag{1}$$

where A represents an economic benefit coefficient, W^i_{hotel} represents the hotel's water consumption in the i-th year, and λ represents water elasticity.

As shown in Figure 1, we considered the supplementary effect of precipitation W^i_{pre} on local water resources, and divided the flow of water resources into three parts: hotel water consumption W^i_{hotel}, evaporated water W^i_{eva}, and residents' water consumption W^i_{local}, and obtained the following expression:

$$W^i_{total} - W^{i+1}_{tatal} = W^i_{local} + W^i_{eva} + W^i_{hotel} - W^i_{pre} \tag{2}$$

where W^i_{total} indicates the total water consumption in the i-th year.

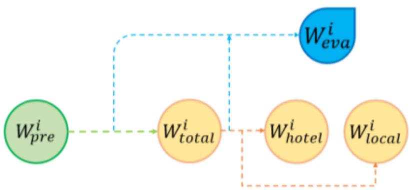

Figure 1. Water resources allocation relationship.

We use the empirical relationship between the precipitable water in the whole layer of the atmosphere and the surface water vapor pressure established [10]:

$$W^i_{pre} = \alpha'_0 + \alpha'_1 e \tag{3}$$

where W^i_{pre} represents total atmospheric precipitable water (unit: cm), e represents ground water vapor pressure, α'_0 and α'_1 represents empirical coefficient [10], and empirical coefficients outside the Tibetan Plateau are:

$$\alpha'_0 = \begin{cases} 0.03\exp\left(-1.39H^2 + 2.74H + 0.15\right) & \left(\varphi \geq 33^\circ\right) \\ 0.04\exp\left(0.6H\right) - d_1 + d_2 & \left(\varphi < 30\right) \end{cases} \tag{4}$$

$$\alpha'_1 = \begin{cases} 0.17 + D_3 & \left(\varphi \geq 33^\circ\right) \\ \left(0.20 - d_3\right)d & \left(\varphi < 33^\circ\right) \end{cases} \tag{5}$$

where

$$d_1 = 0.05 / \left[(\varphi - 25.0)^2 + 0.25 \right]$$

$$d_2 = \begin{cases} 0 & (\varphi > 20^\circ) \\ -0.9 & (\varphi \le 20^\circ) \end{cases}$$

$$d_3 = -0.66 / \left[(\varphi - 33.0)^2 + 4.41 \right]$$

$$d_4 = 1.0$$

where φ indicates the geographic latitude, and H indicates the altitude of the station.

We use the simplified Penman formula [11] to calculate the evaporation loss of water resources, the equation is as follows:

$$W_{eva}^{i} = \frac{700T_m / (100 - A) + 15(T - T_d)}{(80 - T)} \left(mm\ day^{-1} \right) \tag{6}$$

where $T_m = T + 0.006h$, h indicates the elevation (meters), T indicates the mean temperature, A indicates the latitude (degrees), and T_d indicates the mean dew-point. The deviation between the value given by this formula and the measured value is 0.3 mm day^{-1} for the year, 0.5 mm day^{-1} for the month, 0.9 mm day^{-1} for the week, and 1.7 mm day^{-1} for the day. This formula applies to a wide range of climates. The monthly mean of this item $(T - T_d)$ can be obtained from the experience table or the following empirical relationships, provided that precipitation is at least 5 mm and $(T - T_d)$ is at least 4°C [12]:

$$(T - T_d) = 0.0023h + 0.37T + 0.53R + 0.35R_{ann} - 10.9^\circ C \tag{7}$$

where R represents the mean daily range of temperature and R_{ann} represents the difference between the mean temperatures of the hottest and coldest months. Therefore, the evaporation rate can be estimated simply from the values of the elevation, latitude, and daily maximum and minimum temperatures [12].

Next, respectively, hotel water consumption W_{hotel}^{i} can be calculated as:

$$W_{hotel}^{i} = \zeta_1^i \cdot W_{total}^{i} \tag{8}$$

where ζ_1^i indicates the proportion of hotel water consumption in the *i*-th year to the total water consumption. And other water consumption in the same year can be calculated as:

$$W_{local}^{i} + W_{eva}^{i} = \zeta_2^i \cdot W_{total}^{i} \tag{9}$$

where it indicates the amount of evaporated water in the year *i* and the water consumption of residents in the total water consumption of the year.

Because water resources are no longer regarded as a resource for free use, it has both economic benefits and scarcity that cannot be ignored, so we use multi-objective programming to formulate the objective function. On the one hand, to maximize the economic benefits of water resources, and on the other hand, to minimize the expenditure of water resources and achieve the greatest degree of conservation. The two objectives can be coordinated to maximize effectiveness. In economics, we call this result Pareto optimal.

$$\max_{\zeta_1^i,\zeta_2^i} A\left(\zeta_1^i W_{total}^i\right)^{\lambda} \cdot \zeta_2^i W_{total}^i \tag{10}$$

$$\min_{\zeta_1^i,\zeta_2^i} \zeta_1^i + \zeta_2^i \tag{11}$$

We use the multiplication rule to combine and maximize the two factors effectively. At the same time, it is impossible to use up all or none of the water resources in a specific year, so we define such a constraint: $s.t.\ \ 0 < \zeta_1^i + \zeta_2^i < 1$.

Through this method, the optimal proportion of water consumption for hotels and other water consumption in total water consumption can be obtained. Since the annual evaporation of water can be calculated by the above empirical formula, the proportion of water consumption for hotels and other water consumption can be approximately the distribution proportion of water consumption for hotels and domestic water consumption. The government can consider water distribution according to this proportion, so as to maximize the economic benefits of water resources in Masai Mara.

3. A Way to Simulate the Range of Tourists in the Masai Mara

3.1. Cellular Automata Based on Land Allocation

Humans directly or indirectly affect wild animals through their daily activities [13], such as increasing population, unreasonable tourism development, and large-scale hunting. According to current research, due to the cumulative impact of ecological and human factors, human-wildlife conflicts are on the rise all over the world [14]. Therefore, to alleviate the conflicts between humans and wild animals, it is necessary to further clearly plan the changes in the range of human activities. Our model first rasterizes the Masai Mara protected area and then simulates the changes in the range of human activities based on the cellular automaton update rules. Finally, we can obtain the conflicts between the range of human activities and wild animals through comparison and analysis.

3.2. Rasterization of the Preserve

To solve the range of human activities, it is first necessary to determine its spatial model. At the same time, rasterization can intuitively and effectively convert the actual geographical environment into a mathematical representation model, facilitating computer processing and analysis. Therefore, we choose to use the grid method for the geographical conditions and physical environment to solve this problem where the grid label N of any point can be expressed as:

$$N = INT\left(\frac{x}{G_s}\right) + M \times INT\left(\frac{y}{G_s}\right) \tag{12}$$

where (x, y) is the coordinate of a potential place, the abscissa x represents the longitude and the ordinate y represents the latitude, G_s is the gird size, $M = x_{\max}/G_s$, and is the maximum length of the horizontal axis.

Secondly, we can obtain the coordinates position of the gird center, which can be calculated by:

$$\begin{cases} x_G = (N\%M)\cdot G_s + \dfrac{G_s}{2} \\ y_G = INT(N/M)\cdot G_s + \dfrac{G_s}{2} \end{cases} \tag{13}$$

We portray three types of girds, which represent hill, plain, and human activity areas respectively. According to the actual physical and geographical conditions of the reserve, we use light yellow and dark yellow to represent the reserve's distribution of hills and plains. To simplify the problem, we use the green grid to denote areas with a high concentration of visitors. These girds can be clearly visualized in Figure 2.

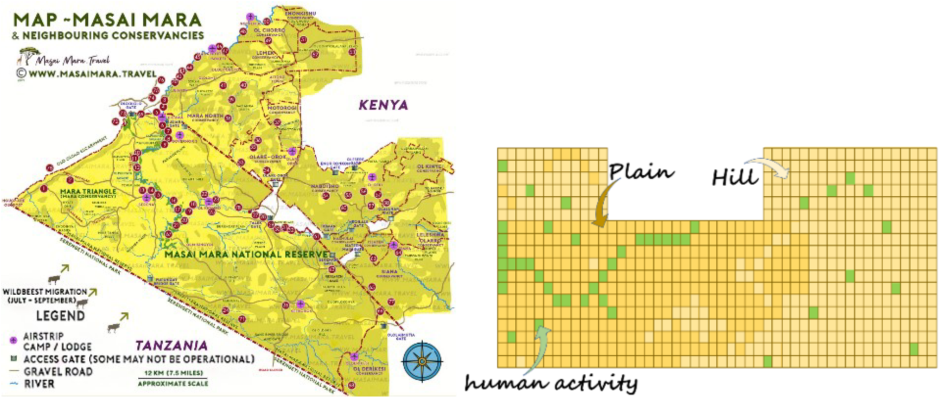

Figure 2. Rasterization of the Masai Mara.

3.3. The Cellular Automata Update Rules Based on Microscopic Land Location

According to the raster image drawn above and the powerful ability of the cellular automata model in simulating the dynamic evolution of complex space-time [15], we regard each grid as a unit. Since its time, space, and state are all discrete, we consider the automatic change of the state of each unit from the inertia, suitability, and surrounding influence of the local land, and then formulate a series of cellular automaton update rules to simulate the changes in the range of human activities in the protected area.

We can't accurately determine the state of possession of a cell (x,y) at a given moment, so it is necessary to indicate $P^t_{K,x,y}$, which represents the probability that the unit (x,y) is occupied by a certain land use type *K* at time *t*, and can be measured by:

$$P^t_{K,x,y} = f\left(S^t_{K,x,y}, N^t_{K,x,y}, I^t_{K,x,y}, \nu\right) \tag{14}$$

$$P^t_{K,x,y} = \left(\left(1+S^t_{K,x,y}\right)\times\left(1+N^t_{K,x,y}\right)+I^t_{K,x,y}\times\left(1-L_{x,y}\right)\times D_{x,y}\right)\nu^t \tag{15}$$

where $S^t_{K,x,y}$ means the suitability of unit (x,y) to land use type *K* at time *t*, $N^t_{K,x,y}$ means the influence of surrounding land units on the unit (x,y) transforming into land use type *K* at time *t*, $I^t_{K,x,y}$ means the inertia (inheritance) of the unit (x,y) maintaining the land use type *K* at time *t*, and ν means the random disturbance factor [16].

Additionally, $L_{x,y}$ represents the overall scarcity of water resources within the cell (x,y), which can be calculated as:

$$L_{x,y} = \frac{L_{distance}}{d} \tag{16}$$

where $L_{distance}$ indicates the straight-line distance from the central area of the unit (x,y) to its nearest water resource location, and the smaller $L_{x,y}$, the lower the scarcity of water.

$S_{K,x,y}^{t}$ represents the suitability factor of the piece of land, which can be affected by factors such as terrain, traffic, and particular geological structure, and can be calculated as:

$$S_{K,x,y}^{t} = \left(\sum_{i=1}^{m} W_{i,K,x,y} \times S_{i,K,x,y}\right)\prod_{r=1}^{n} C_{r,K,x,y} \tag{17}$$

where $\sum_{i=1}^{m} W_{i,K,x,y}$ means the weight of the general suitability factors and $\prod_{r=1}^{n} C_{r,K,x,y}$ represents the mandatory suitability factor [10].

Because the surrounding environment can affect the thing itself, the effect of the surrounding land on the cell (x,y), $N_{K,x,y}^{t}$ can be calculated by

$$N_{K,x,y}^{t} = \sum_{c}\sum_{l} W_{K,L,C} \cdot G_{c,l}^{t} = \sum_{c}\sum_{l} \frac{W_{K,L} G_{c,l}^{t}}{c} \tag{18}$$

where $W_{K,L,C}$ represents the weight parameter of the interaction strength between the unit whose land use type is *K* and the unit whose land use type is *L* in the neighborhood in distance *C* and $G_{c,l}^{t}$ indicates whether the land type of a certain unit c is 1, and its value is 0 or 1 [16].

We use this equation to measure the random disturbance factor:

$$v = 1 + [-\ln(rand)]^{a} \tag{19}$$

where rand is a stochastic number between 0 and 1, and α is a constant for the size of the disturbance.

According to this rule, in order to reduce errors brought by simulation, we set 10 independent iterations of 100 steps, and the result after average processing is shown in Figure 3.

The red squares in the figure indicate the areas where the range of human activity overlaps with that of animal activity, and it represents the areas of high probability of conflict. As can be seen from the figure, most places prone to conflicts are places with dense tourist activity range. Meanwhile, due to the increasing mobility and expansion of wild animals, the scope of conflict areas will be further expanded, and the tourist activity range is usually clustered, which will also increase the probability of conflicts.

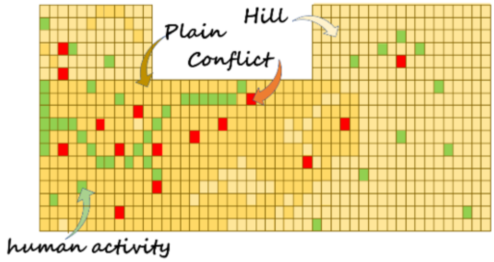

Figure 3. Conflict relationship distribution.

4. Conclusion

Aiming at the shortage and waste of water resources in the Masai Mara Nature Reserve due to the scarcity of precipitation, this paper proposes a solution, which uses the Cobb-Douglas production function to measure the economic benefits of water shortage and is based on the Pareto optimal principle to build a multi-objective programming model. The results show that the economic benefits of the limited water resources in this area are related to the distribution ratio of hotel water and domestic water. The local government or relevant departments can obtain the optimal value of the distribution ratio of the two through this model, and then make the economic benefits of water resources maximize and make fuller and more rational use of natural resources.

In response to the conflicts between tourists and wild animals in this nature reserve, this paper sets updated rules based on the microscopic land allocation theory, uses cellular automata to simulate the range of activities of tourists, and then compares it with the active areas of wild animals to judge the extent of conflicts in this area. The results show that the places prone to conflict are mostly places with high tourist activity, that is, places where people gather. Therefore, the manager of the protected area should reasonably restrict the gathering of tourists, and set up warning signs around areas with a high probability of conflict to remind tourists. This has certain practical significance and value for the management of the protected area.

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